Nexus Netw J (2015) 17:981–1005
DOI 10.1007/s00004-015-0261-9

NEXUS NETWORK JOURNAL
Architecture and Mathematics

DIDACTICS

Schematizing Basic Design in Ilhan Koman's "Embryonic" Approach

Benay Gürsoy[1] · Mine Özkar[2]

Published online: 1 August 2015

Abstract With an outwardly professed interest in mathematics, Ilhan Koman has produced his nonfigurative, abstract sculptures mostly as various series of forms. The difference and similarity between the works in any series is achieved through repetitions and variations of certain relations between parts. This corresponds to creating a relational system and it requires having control over the underlying principles of that system much as basic design students are encouraged to do. In order to substantiate the implications of work such as Koman's in learning about design thinking, we first delineate the mathematical concepts in Koman's "embryonic" approach through visual schemas. These visual schemas are then supplied to first-year design students as guides and design constraints as well as tools to formalize their design thinking. We observe that introducing Koman's schemas to students helps them grasp how they establish relations between parts in their own design processes.

Keywords Ilhan Koman · Design computing · Basic Design · Shape grammars · Visual schemas · Architectural education · Design algebras

✉ Benay Gürsoy
benaygursoy@gmail.com

Mine Özkar
ozkar@itu.edu.tr

1 Mimarlık Fakültesi, Istanbul Bilgi Universitesi, KD-210, Santral Kampüsü, Eyüp, 34060 Istanbul, Turkey

2 Mimarlık Bölümü Taşkışla, Mimarlık Fakültesi, Istanbul Teknik Üniversitesi, Taksim, 34437 Istanbul, Turkey

Birkhäuser

Unity is a criterion habitually sought in design. Learning to unify various design input are among the main objectives of a modernist architectural education. A basic design curriculum, the core of the foundational year in many architecture schools, serves towards this objective. It engages students with various abstract tasks that are detached from real life architectural problems. This way, students find the chance to directly reflect on their reasoning over a simpler and formal vocabulary. Although liberated from the complexity of real world problems, the problem of relating abstract shapes is itself complex under the microscope and so provides a rich material for learning about multiple aspects and the relational nature of design. Unity in a basic design work is achieved through establishing consistent relations between "the elements of a composition in an orderly manner" guided by concepts such as "balance, contrast, harmony, repetition, dominance and hierarchy" (Aytaç-Dural 2012: 117–118). The elements are often two- and three-dimensional shapes, and their features such as size, orientation, position, texture, and color. Using the similarities and differences between the elements to establish relations, students are expected to create perceivable repetitions and their variations in unity.

Creating repetitions and variations constitutes not all but some of the design knowledge conveyed in foundation studios—significantly, a computable part. Previous studies have already dwelt on the possibility of inquiry into design through its visually computational aspects (Stiny 2006) and of "learn[ing] design by visual computation" (Knight 1999; Özkar 2007). A designer's shape rules, as instructions in visual computations—i.e., designs—are tools not only to understand, communicate, and control the relations between shapes but also to learn the know-how. Visual schemas, as more generalized versions of shape rules (Stiny 2011), reflect overarching relations and are even more suitable than rules to the level of beginning design students' formal studio talk (Özkar 2011).

This paper provides a case for guiding entry-level design students with visual schemas that particularly formalize repetitions and variations. The visual schemas that are introduced to the students are developed based on the nonfigurative mathematical art of the Turkish sculptor Ilhan Koman (1921–1986) whose work is characteristically very repetitive. We observe that introducing Koman's schemas to students consequently helps them grasp how they establish relations between parts in their own design processes.

Koman's work provides ideal examples of compositions where elements come together with perceivable repetitions and their variations. With an outwardly professed interest in mathematics and mathematical relations of forms, Ilhan Koman has produced his art mostly as various series of forms. The difference and similarity between the works in any series is achieved through repetitions and variations of certain relations between parts. In (Koman and Ribeyrolles 1979: 1) this approach is called "embryonic in the sense that each series embodies new ideas and the need of different know-how that could be exploited in making further works of the same type". Koman's "embryonic" approach in which he develops a relational system and creates variations in it by controlling the underlying principles of that system is similar to what basic design students are encouraged to do in learning to achieve unity in design.

Below, we first investigate Koman's *Infinity-1 series* using visual schemas and shape rules. Later, in order to substantiate the implications of such works in learning about design thinking and achieving unity, we present a study realized with basic design students where the underlying visual schemas of *Infinity-1 series* serve as guides and design constraints as well as tools to formalize students' design thinking. The analysis uncovers the types and the extent of variations in shape relations. Reflecting on the analysis, our text presents the schemas of the case, a pedagogical proposal, students' processes and a discussion of the outcomes.

Repetition, Variation and Computability in Koman's Work

There is a current and growing interest in Koman's work in the field of computational design, where his approach is deemed digitally and parametrically reproducible (Beşlioğlu 2011). There is also an interest in identifying the mathematical concepts behind the creation of form in Koman's sculptures (Akgün et al. 2006, 2007). Although within the same context of computational design, we present a pedagogical incentive to discuss Koman's work and focus on its systematic shape relations towards a basic design methodology.

Polyhedra and Derivatives, *Hyperforms*, *3D Moebius*, *Pi Series* and *Infinity-1* are some of the sculpture series conceived and produced by Koman. There is often an apparent formal unity between the works in the same series and it is achieved through the repetition of varying formal relations. We claim that what lies beneath this "embryonic" approach is the use of shape rules and their unifying visual schemas in the generation of works in a series. We illustrate this through a comprehensive analysis of the *Infinity-1 series.*

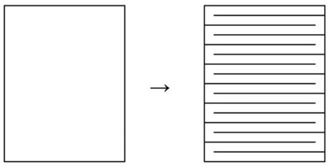
Schematizing Infinity-1

Koman divides either a single sheet of a material such as aluminum, titanium, and wood, or a prismatic block of a material such as wood into connected parts to create the sculptural works of the *Infinity-1* series (Figs. 1, 2, 3). Although repetitive, the connected parts display gradual transformations in space such as rotation or translation, and, hence, produce a variation while still maintaining an unfragmented whole. Repetition of certain relations is perceivable at first sight both in the works themselves and across the body of works in the series. We identify these perceivable shape relations across all the works in the *Infinity-1* series as a set of rules that we have retrospectively categorized under two schemas:

$$x \rightarrow \sum prt(x) \qquad \text{(Schema1)}$$

and

$$x \rightarrow x + t(x) \qquad \text{(Schema2)}$$



Rule 1

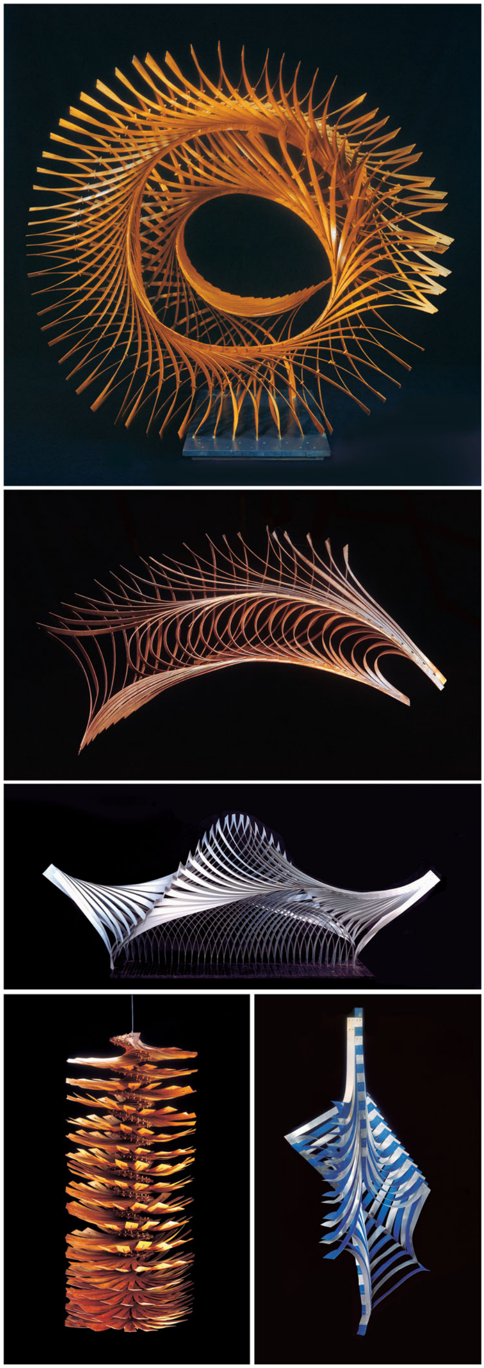


Fig. 1 *Rule 1* and works from Koman's *Infinity-1 series*. From *top* to *bottom*, *left* to *right*: "*Whirlpool"*, "*Untitled 2*", "*To Infinity…*", "*Untitled 1*", "*Untitled 3"*. Photos: Yıldırım Arıcı

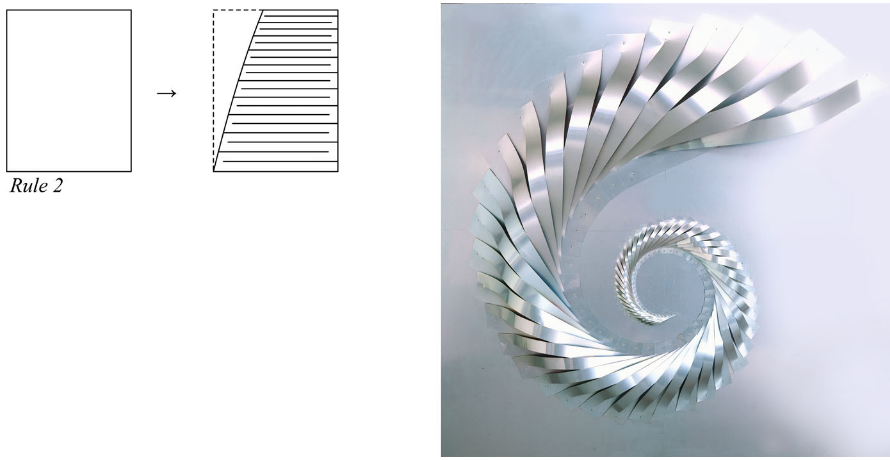


Fig. 2 *Rule 2* and "*Shell*" from Koman's *Infinity-1 series*. Photo: Yıldırım Arıcı

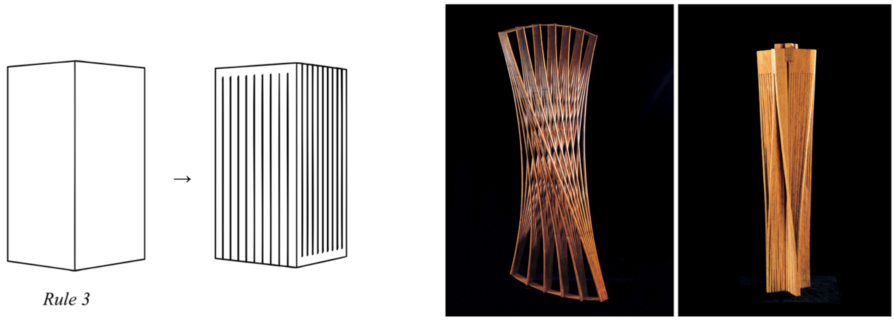


Fig. 3 *Rule 3* and works from *Infinity-1 series*: "Untitled 4", "Untitled 5". Photos: Yıldırım Arıcı

Coincidentally, both schemas are categories defined by Stiny (2011). Schema 1 very generally divides a whole into its parts. A number of rules from Koman's *Infinity-1* works, to be explained below, fall under this schema in algebras U_{12} and U_{23}. Algebras, as introduced to shape computing by Stiny (2006: 180–196) indicate the spatial dimension of a shape in the left index and the spatial dimension of its environment in the right index. The different algebras here correspond to physical operations of dividing either the planar sheet material or the solid block material. The physical parts obtained after this division are subsequently transformed, through rotation and translation in Euclidean space, using Schema 2. The first two shape rules, *Rule 1* (Fig. 1) and *Rule 2* (Fig. 2) under Schema 1, are in algebra U_{12}, as they correspond to line drawings on a planar surface to generate the cut patterns which divide a sheet material into strips. With *Rule 1*, Koman divides a shape into equally sized sub-shapes to obtain a continuous meandering strip of steady width and length from a sheet material (Fig. 1).

Rule 2 divides a shape into sub-shapes in a similar manner but this time sub-shapes sequentially change in size to create an overall trapezoidal shape. In short, Koman applies *Rule 2* to divide a sheet of material into a continuous meandering strip with gradually scaled width and length (Fig. 2).

Although we will mostly focus on shapes in algebra U_{12} from this point onwards, the division rule *Rule 3* under Schema 1 provides a notable and expected exception for a solid. It divides a three-dimensional shape into sub-shapes of equal size in U_{23}. Koman uses this rule to divide a rectangular prismatic block into connected sprouts (Fig. 3) which he later opens up to create various forms.

We create variations of *Rules 1* and *2* to change the number and size of the sub-shapes obtained in the right side of the rule. *Rule 1* is varied as shown in Fig. 4. Length l is kept constant while width w and depth d are changed resulting in different outcomes of the subdivision. These variations of *Rule 1* directly determine the number and the width of the generated sub-shapes as well as the depth of the connection part in between sub-shapes. All variations in this example are purposefully done so that the sheet material is always divided with no leftovers. As seen in the works generated with *Rule 1* in Fig. 1, the width of the strips and the depth of the connection part between strips are of equal length.

We create variations for *Rule 2* as well. A previous study by (Akgün et al. 2007) on the mathematical relations of the *Shell,* the only work Koman produced using *Rule 2*, sets the basis for understanding the parametric variations for this rule. We alter two variables: the sequential scaling of the length l and of the width w of sub-shapes, resulting in different number and sizes of the generated sub-shapes. *Rule 2b* specifies the relation between l's as increments smaller than in *Rule 2a.* This diminishes the number of sub-shapes. These are also longer in average when compared to those in *Rule 2a*. *Rule 2c* specifies values for w higher than in *Rule 2a.* The result is even fewer sub-shapes (Fig. 5).

Rule 2 is also a parametric variation of Rule 1. However, in the context of this paper, we will still be denoting them separately as *Rule 1* and *Rule 2*.

Once the sub-shapes are obtained with the rules under Schema 1, Koman rearranges them by applying three rules under the schema $x \rightarrow x + t(x)$ (Schema 2) repetitively to all the sub-shapes. This schema suggests a spatial relation between a shape and its secondary instance with a transformation—in this case, a Euclidean translation in space—and therefore denotes an additive and repetitive process. In other words, x corresponds to a sub-shape that connects to a second sub-shape, which is its transformed similitude. The three rules we have identified under Schema 2 across the body of works in *Infinity-1* are shown in Fig. 6. It should be noted that the shapes in these rules are abstract representations for the material strips obtained by dividing the sheet material with *Rule 1* or *Rule 2*, and rules themselves represent how the strips are physically aligned in space.

Rule 4 shows how to connect x and $t(x)$ where $t(x)$ is a transformation along the y-axis of the first shape x. The rule indicates the distance of the drift along the y-axis. This distance is the same size as the width of the sub-shapes in *Rule 1*. In the application of this rule, a strip is drifted on top of another strip in one axis only and of the same size as its width. *Rule 5* sets a shape apart from the transformation of that shape so that the two shapes remain detached. Koman uses different types of

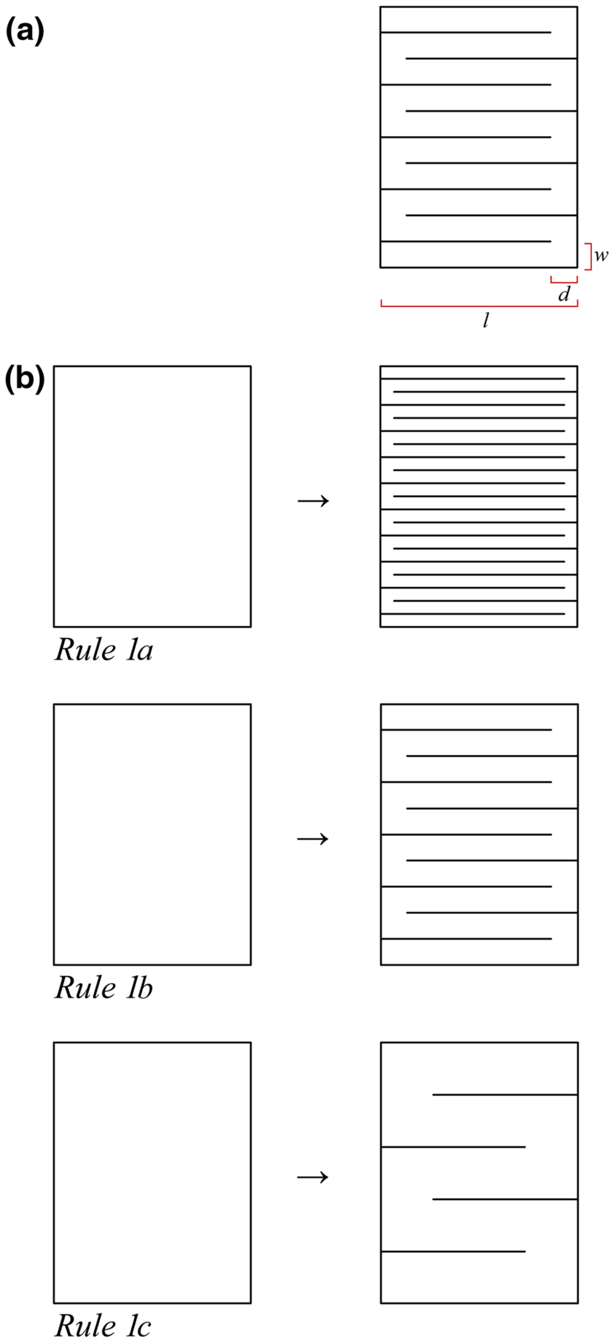
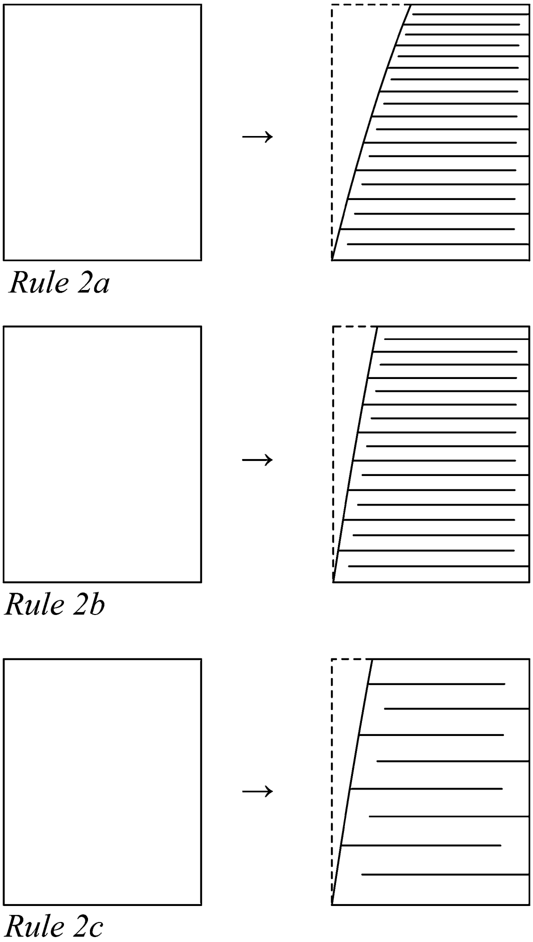


Fig. 4 **a** Legend for how dimensions are named on the sheet, and **b** three variations of *Rule 1*

Fig. 5 Three variations of *Rule 2*



specifications to control their relative position in space. This will be elaborated further below. *Rule 6* shows how to connect *x* and *t*(*x*) where the transformation *t*(*x*) is in both *y* and *x* axes of the first shape *x*. The rule indicates the distance of the drift in both axes. The drift is half the depth of the strip along the *y*-axis and the width of the strip along the *x*-axis.

We claim that the final three-dimensional forms of the sculptural works emerge through the repetitive and hands-on application of the rules under Schema 2 and are not conceived in advance through mathematical calculations as a previous study (Akgün et al. 2007) suggests. What differentiates the works are the choice of the rule or rule set, the sequence of the rules in the chosen rule set, the customized variables in the rules, the total number of repetitions in the application of the rule or rule set (iterations), and the specifications to be introduced to *Rule 5* to indicate the relative positions of the detached parts in space. Table 1 illustrates these factors excluding the specific values for variables.

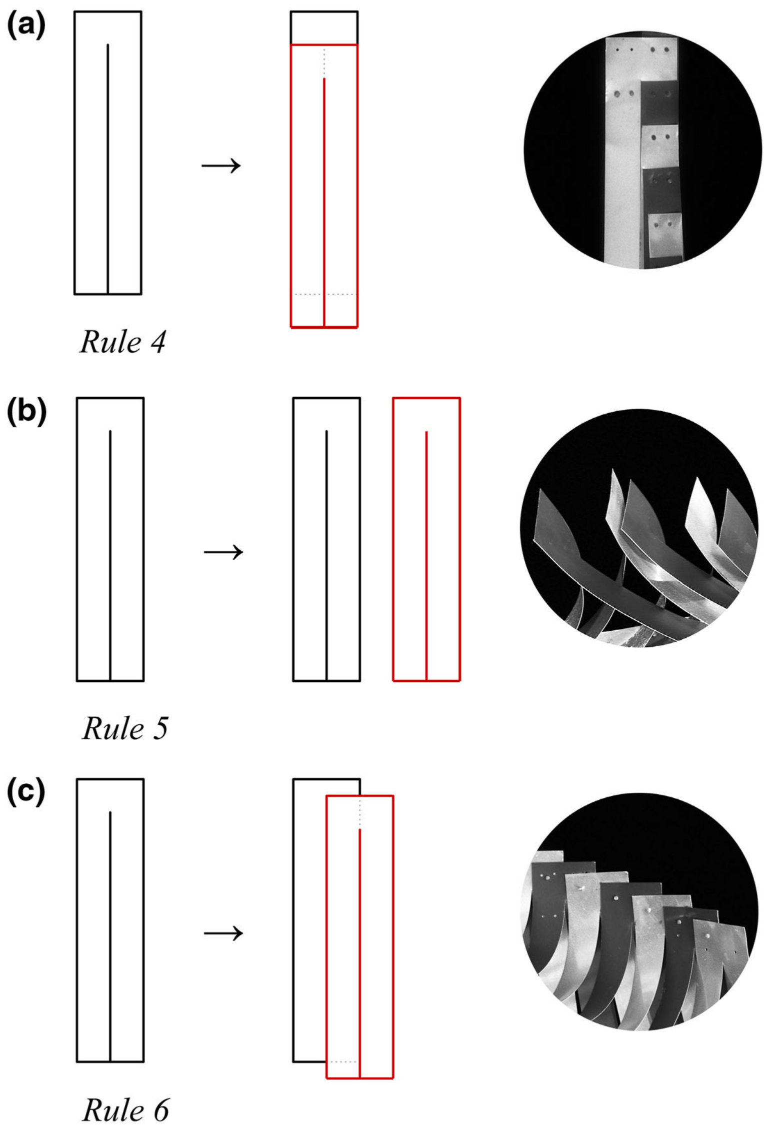


Fig. 6 The three shape rules under Schema 2 and their repetitive physical applications **a** *Rule 4*, **b** *Rule 5*, and **c** *Rule 6*

Specifications that Koman introduces in *Rule 5* control the relative position of spatially detached strip parts in space and can uniquely modify the overall form of the sculptures. In the *Shell,* Koman fixes all the strip edges onto one planar surface applying *Rules 4* and *5*. While applying the rules in an alternating order, Koman keeps every other strip flat on the plane while inevitably curving the rest as he goes along. This gives the overall curved character to the piece. How much Koman

Table 1 Comparison of works in the *Infinity-1 series*

	x →∑ prt(x) (*schema 1*)	x → x + t(x) (*schema 2*)					
		no. of rules in rule set	Rule 4	Rule 5	Rule 6	sequence of rules	total no. of iterations
 *Untitled (1)*	Rule 1	2	x1	x1	-	R4-R5	>200
 *Shell*	Rule 2	2	x1	x1	-	R4-R5	60
 *Whirlpool*	Rule 1	3	x1	x1	x1	R4-R5-R6	105
 *To Infinity...*	Rule 1	2	x2	x2	-	R4-R5-R4-R5	36
 *Untitled (2)*	Rule 1	2	x3	x1	-	R4-R5-R4-R4	20
 *Untitled (3)*	Rule 1	3	x2	x1	x1	R4-R5-R6-R4-R6	16

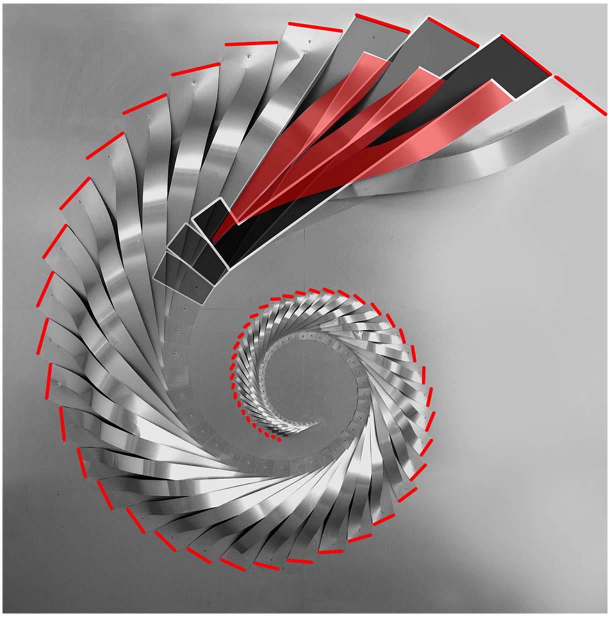


Fig. 7 References of "*Shell*" shown on photograph. Photo: Yıldırım Arıcı

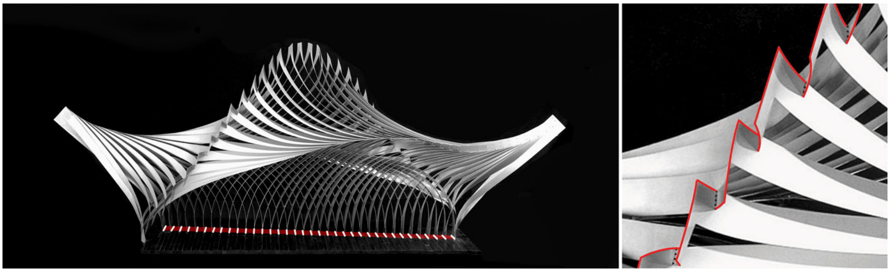


Fig. 8 References of "*To Infinity…*" shown on photograph. Photo: Yıldırım Arıcı

curves each strip is defined by his application of *Rules 4* and *5*. The mean depth of each strip is the point of reference for the translation drift in *Rule 4* while a small rotation angle inevitably emerges (Fig. 7). Accordingly, in the application of *Rule 5*, each flat strip edge (shown as red lines in Fig. 7) is laid next to the previous one as far as it reaches and produces the geometric sequence of spiraling edges.

In *To Infinity…*, *Rule 5* is applied twice with two different specifications (Fig. 8). In its lower part, the sculpture is fixed on a planar surface. Koman creates an axis on this surface and prepares horizontal slits parallel and at equal distances from one another. These slits correspond to where the strip edges are fixed in the every other application of *Rule 5* in the rule sequence. In short, Koman fixes the distances between them in this manner. This is one specification. In the upper part of the sculpture, Koman creates notches near the edge of each strip to interlock another strip to it. In corresponding strips (those that will interlock) these notches appear to be in mirrored but exact locations, at double the depth and half the width of a strip. This is the second specification for *Rule 5* that designates a particular spatial relationship for x and $t(x)$. Both specifications give the sculpture its overall form.

Lastly, the number of rules in a rule sequence, as identified in the table for each sculpture, has an impact on the overall spatial form of the sculptures. Whereas in *Untitled (1)*, the sequence has two alternating rules, resulting in a linear form development around a central axis, in *Whirlpool*, the sequence has three rules resulting in a volumetric development of a triangular cross-section and one that curves onto itself. On the other hand, sculptures such as *To Infinity…* and *Untitled (2)* have four rules in a sequence and produce different volumetric structures. *Untitled (3)* has five rules in a sequence and produces a more complex volume.

Redefining Koman's "Embryonic" Approach

As shown above in the use of rules that specify size parameters, it is possible to discuss parametric variations in Koman's works. However, our analysis of the *Infinity-1* series makes evident that what lies beneath Koman's "embryonic" approach goes beyond numeric specifications and includes rather spatial ones. Spatial specifications are mostly revealed through the process of making and this carries the approach further away from being a top-down mathematical formula. Koman makes visual calculations instead and these lead to the emergence of the final forms.

Still, the mathematical analysis of the *Shell* in (Akgün et al. 2007) has guided us in writing a code in RhinoScript to generate cut-sheets of the strips and the spiral template on which these strips are fixed onto a plane. The code enables us to generate parametric cut-sheets to digitally manufacture works with great precision by modifying the parameters in *Rule 2*. Below are some of the parametrically produced works built with the cut sheets generated using this code and cut in laser cutter (Fig. 9). The variety is endless and is deemed useful pedagogically. These

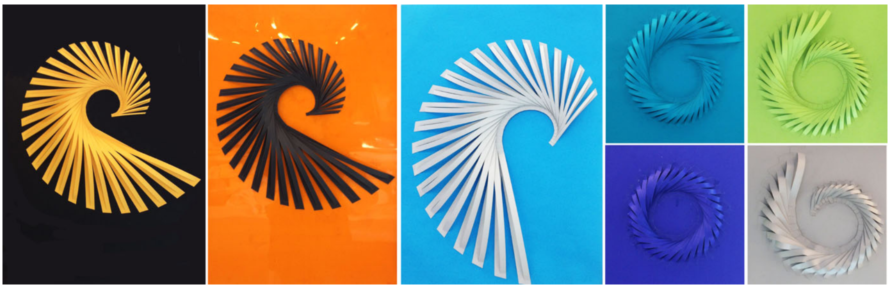


Fig. 9 Parametric *Shell*s produced using the code in RhinoScript

cardboard shells comprise a part of the study realized with the basic design students, presented in the second part of this paper.

Nevertheless, the variations Koman achieved in and across different works in *Infinity-1* series are more than just the parametric variations as we exemplify with the *Shell*s. Koman sets a relational system through certain spatial rules as illustrated in Table 1. Within this relational system, an infinite number of variations can be generated. While trying to uncover the existing relations within the works in *Infinity-1,* we have built several mock-up models and by misinterpreting the set of rules in the original works, we accidentally obtained different, yet similar, "embryonic" *Infinity-1* forms. These mock-ups are illustrated in Table 2. The outcome of the detailed analysis of the *Infinity-1* series therefore might serve not only the reproduction of the existing works but also future experimentation with various materials towards additional *Infinity-1* sculptures at various scales.

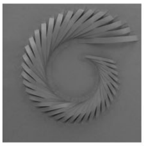
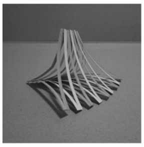
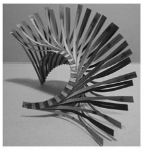
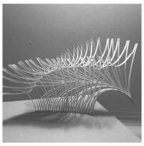
Sculptures in the *Infinity-1 series* also strongly demonstrate how perceived complexity can be achieved through repetition of simple rules. The underlying relations are best understood and conveyed spatially in mock-ups. What we have further discovered through the mock-ups is that the making of these sculptures also necessitate a systematic approach because the connected parts of one meandering strip tend to easily jumble up. We believe that Koman also developed a know-how concerning the making processes behind these sculptures. Differentiating each side of the sheet material with a different color, a trick we made use of while making our models, is previously developed by Koman as in *Untitled (3)* and is helpful in the making process.

The second part of this paper discusses the ways in which Koman's "embryonic" approach relates to basic design and how understanding the visual schemas of perceivable repetitions and their variations in Koman's works can help basic design students to understand and establish a relational system for formal unity.

Koman's "Embryonic" Approach in Basic Design

Basic design students are often encouraged to create variations in a relational system and have control over the underlying principles of that system, much as Koman did with the *Infinity-1* series. However most of the time, entry-level design students struggle in defining a relational system, tend to intuitively seek unity between parts, and mostly fail. Hence, one of the objectives of basic design is to make students aware of the emergent relations they discover intuitively while trying to relate shapes, and to help them in formalizing their discoveries in order to translate them to design decisions. Therefore, showing students their works as visual computations may help them observe what they are doing and develop it further. However, conveying the computable aspects of design through the formalism of visual rules to students already struggling to adapt to the abstract visual language is not an easy task. Visual schemas, as "more general ways to understand design decisions" than visual rules, may be more suitable in making students aware of their design process (Özkar 2011: 115).

Table 2 Paper mock-ups by the authors placed in the *Infinity-1* table

	$x \rightarrow \sum prt(x)$ (*schema 1*)	$x \rightarrow x + t(x)$ (*schema 2*)					
		no. of rules in rule set	Rule 4	Rule 5	Rule 6	sequence of rules	total no. of iterations
	Rule 1	2	x1	x1	-	R4-R5	24
	Rule 2	2	x1	x1	-	R4-R5	39
	Rule 1	2	-	x1	x2	R6-R5-R6	24
	Rule 1	3	-	x1	x1 *+ other rule*	R5-R6-R?	9
	Rule 1	3	x1	x1	x1	R4-R5-R6	27
	Rule 1	2	x2	x2	-	R4-R5-R4-R5	18
	Rule 1	2	x1	x3	-	R4-R5-R5-R5	23
	Rule 1	2	x2	x2	-	R4-R5-R4-R5	23
	Rule 1	3	x2	x1	x1	R4-R5-R6-R4-R6	19

Below we present the outcomes of a basic design exercise where the underlying visual schemas of Koman's *Infinity-1* series are set as guides and design constraints as well as tools to formalize design thinking. The study was realized with fifteen volunteering basic design students at Istanbul Bilgi University, Faculty of Architecture. The volunteers had recently started their design education and had been engaged with basic design exercises for 3 weeks at the time of the study. The exercises they had dealt with so far required two-dimensional compositions by physically cutting and gluing shapes on specifically sized canvases. As part of the broader basic design curriculum at that university, students were especially asked to design systematic wholes where seeking unity between shapes in both the figure and the ground, as well as establishing consistent relations are of the utmost importance. At the same time, they were cautioned to avoid symmetrical arrangements and guided to consider emerging shapes as design elements. The behavioral properties of the materials had not been acknowledged yet as design input.

The study in connection to our paper was realized in two consecutive stages. Students were given the task of designing a two-dimensional composition by cutting and gluing shapes obtained from tangram squares of three different colors on a given canvas area. The task was repeated in the second stage. In between the two stages students were introduced to Koman's works under *Infinity-1* series and were asked to discover the underlying principles (i.e., visual schemas) and to observe similarities and differences in these works. In the second stage, they were asked to focus on two variations of Koman's *Shell* and translate the underlying spatial relations in these works as guides to their own two-dimensional designs. Whereas the students mostly failed in successfully designing a systematic whole in the first stage, there is visible evidence that in the second, they came up with more conscious, consistent and systematic arrangements of tangram shapes that we could retrospectively denote with shape rules. Below, we present the tangram exercise in detail and selectively analyze the design processes of students.

Infinity-1 and Tangram Exercise

Students were given a verbal brief to design a systematic whole. The brief described the task as gluing on a defined canvas some cardboard tangram shapes of specific size but in three different colors. For our notes not shared with the students, the description of the exercise included visual rules that fall under Schema 1 and Schema 3:

$$x \rightarrow \sum prt(x) \qquad \text{(Schema1)}$$

and

$$prt(x) \rightarrow \sum t(prt(x)) \qquad \text{(Schema3)}$$

The first shape rule under Schema 1 divides a square into seven tangram sub-shapes (Fig. 10). This corresponds to physically cutting the cardboards. The sub-shapes obtained through this division are of three different geometries. The square

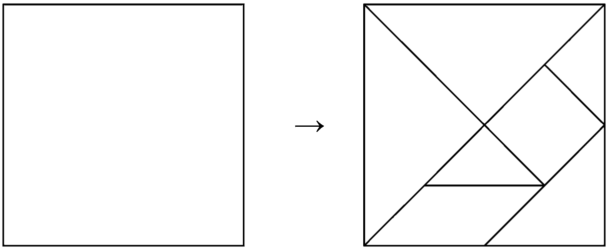


Fig. 10 Shape rule which generates a tangram square

and the parallelogram are unique but the triangles come in three sizes. The shapes already have certain defined relations in that there are inherent similarities of size and geometry between the elements. For instance, the parallelogram and the square can also be constructed using two of the smallest triangles.

The schema $prt(x) \rightarrow \sum t(prt(x))$ (Schema 3) is a summation schema and is consequently used to make Euclidean transformations in U_{22} on the tangram parts obtained to re-design a whole.

In order to test the impact of Koman's visual schemas, the assignment is first given without referring to Koman's works. The majority of the students were not able to define a relational system between different kinds of possible transformations that can be applied to shapes under the Schema 3. Rather, they sought for different possible relations between shapes. Three students' works are redrawn here in Fig. 11, where the left column shows the boundaries of the shapes and the right column shows the shapes with their assigned colors. In these designs, new shapes have emerged in addition to those given in the tangram when shapes with the same colors share boundaries. This does not accord with Schema 3 as the requirement of the assignment but exemplify the potential richness of the exercise.

At the end of this first go, students were introduced to Koman's *Infinity-1* series and provided with a code that generates the parametric cut-sheets of the *Shell* to further investigate the extents of variation within the repetitive system of the series. They produced, in groups of two, the parametric *Shells* shown in Fig. 9. Among the parametric *Shells*, one group chose to generate a circular *Shell*, the rest generated spirally developed *Shells* as Koman did (the former will further be referred to as *the circle*, the latter as *spirals*). They were also asked to verbalize the relations they discovered, as if they were telling them to a friend. One student wrote: "In the *spirals*, a shape is related with its rotated and scaled versions in a successive order, whereas in the *circle*, the same shape is related with its rotated version without difference in scale". This verbal definition corresponds to Koman's visual schema that we identified in the first part of this paper: $x \rightarrow x + t(x)$ (Schema 2). For the *spirals*, the schema denotes a transformation of translation, and scale, whereas in the *circle* it denotes translation only.

Students were then asked to choose one of the two systems for the *spiral* and the *circle* to redo the tangram exercise. This meant changing the more general schema given with the definition of the exercise, $prt(x) \rightarrow \sum t(prt(x))$ (Schema 3), to a

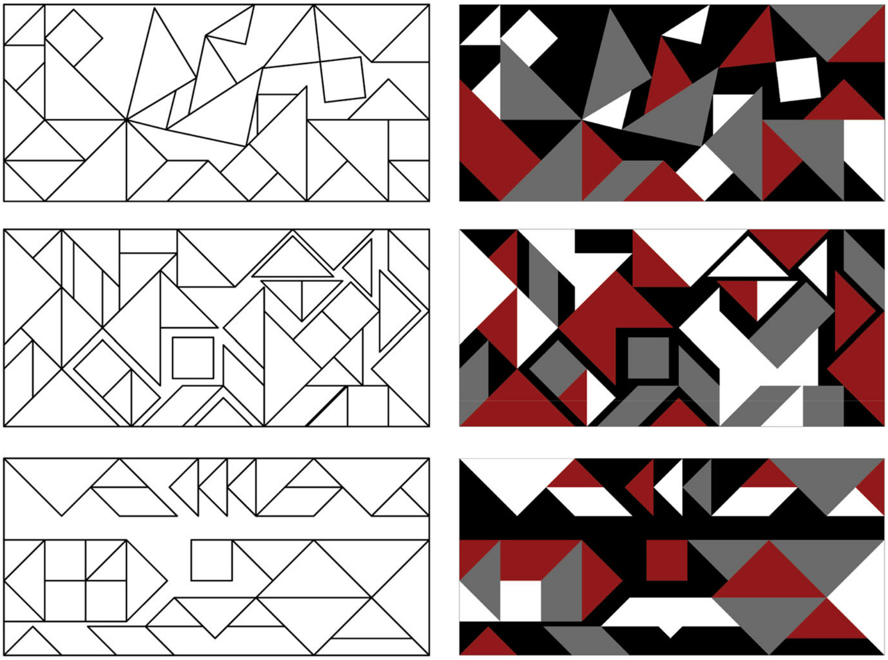


Fig. 11 Studio work by three students before being exposed to Koman's schemas (redrawn on computer)

more specific one, $x \to x + t(x)$ (Schema 2) and applying it to every tangram part separately. Seeing the applications of Schema 2 in Koman's sculptures helped students define consistent spatial relations they had previously had difficulties with. The final works of six students are presented in Fig. 12. The arrangements are much more consciously done when compared to versions prior to Schema 2 (Fig. 11).

The two students who have chosen to work on the relations they discovered through the *circle* (C1 and C2 in Fig. 12a), sustained Koman's $x \to x + t(x)$ (Schema 2) where the only transformation is translation. They both created a unit using discrete parts. Retrospectively, we formally present in Fig. 13 the process to obtain the student work C1 (in Fig. 12a) with shape rules.

The student in C1 defined the total height of the unit in relation to the height of the canvas so that the leftover parts can also relate with the unit (Fig. 13a). Two shape rules (both befitting Schema 2, $x \to x + t(x)$, and shown in Fig. 13b, c) control in parallel the respective relations between the given elements and between the leftover parts on the canvas. Applying both rules recursively for three times, we obtain the compositions in Fig. 13d, e. When the results are combined, the figure-ground distinction disrupts and there is no longer a leftover and unconsidered area (Fig. 13f), with the exception of the thin linear strips between the units which the student seemed to ignore. When the overall composition is placed within the boundary of the canvas, there are leftover areas between the canvas borders and the composition (Fig. 13g). In the final design, the student embedded *tangram* parts, namely a triangle and two parallelograms, in these leftover areas (Fig. 13h). These

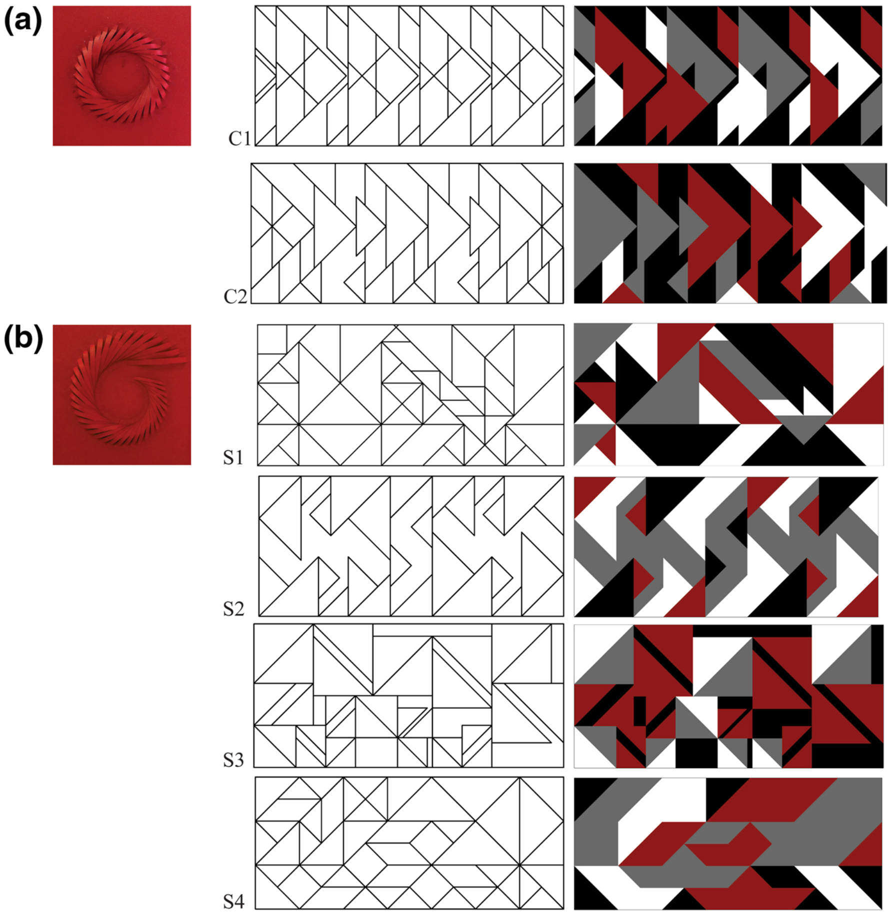


Fig. 12 Workshop results after discussing Koman's schemas **a** from the *circle*, and **b** from the *spirals* (redrawn on computer)

added elements are not only tangram shapes but also parts of the unit the student used earlier. We show the recognition of these shapes in the rules shown in Fig. 13i. These rules fall under a new schema: $x \rightarrow prt(x)$ (Schema 4). After setting these relations between shapes, the student assigned these shapes their colors. For color assignments, no defined set of rules is visible. However, the student seems to have made variations to avoid symmetry within the repetitive order by assigning the same color to adjacent shapes and creating new larger shapes.

The student work C2 (in Fig. 12a) establishes relations that can be denoted by the shape rule in Fig. 14a. While variable a controls the translation on the central axis of x, variable b determines the difference in scale. The significant step that this student takes is in identifying vocabulary shapes in wholes that she creates with other vocabulary shapes. The larger triangles that are a combination of smaller shapes of the same color become the left side of the main rule in more than one

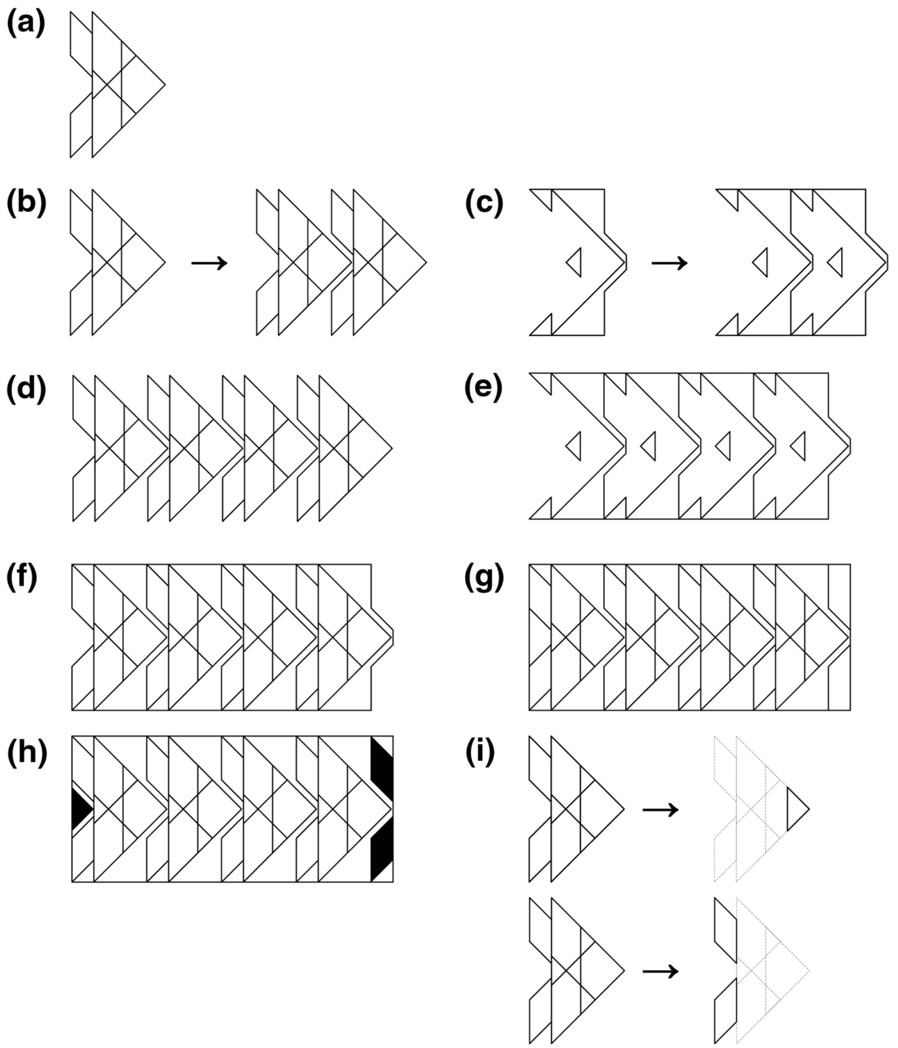


Fig. 13 The process to obtain the student work C1: **a** the repeating unit of the student work C1, **b** shape rule relating the given elements, **c** shape rule relating the leftover parts, **d** first rule applied three times, **e** second rule applied three times, **f** the overall composition as shown with *line drawings* only, **g** the overall composition placed within the boundary of the canvas, **h** the overall composition on canvas with visually embedded shapes shown in *shading*. **i** Student recognizes tangram shapes as parts of the repeating unit

instance (Fig. 14b). This yields a richer variation in how the shape rule in Fig. 14a is applied.

The students who have chosen to work on the relations of the *spiral* made good use of the three different sizes of the tangram triangle. The shape rules we have identified for this comply with the schema $x \rightarrow x + t(x)$ (Schema 2) used in the *spirals* where the transformation denotes "translate, and scale".

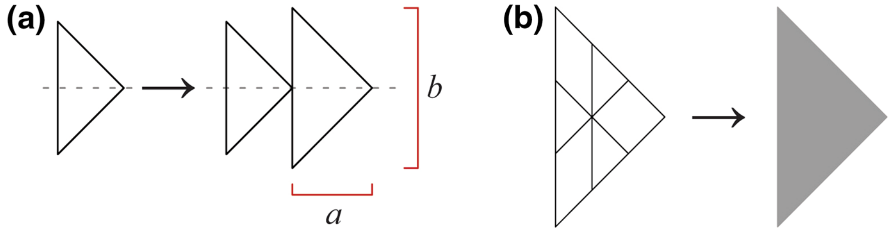


Fig. 14 Rules identified in the student work C2: **a** shape rule with variables *a* and *b*, and **b** rule indicating the identification of larger vocabulary shapes in clusters of smaller vocabulary shapes

The process to obtain the student work S2 (in Fig. 12b) is presented in Fig. 15. The first set of rules establishes relations with scale changes between shapes (Fig. 15a). The rules in each column could be parametrically linked. The rules in the bottom row are in fact similar to the ones in the top row. The size of the added triangle $t(x)$ can be specified. Our analysis with the rules shows the student's conscious decisions in relating the rules to one another. Since the variation in the rules is just this difference in size, for the case of this student, we did not refrain from identifying each rule separately. The second set of rules is similar to the first set of rules already given in Fig. 15a, with the exception of the spatial relation between x and $t(x)$. This relation can be defined by assigning values to variables. We differentiated them as shown in Fig. 15b. The application of the first and second set of rules is highlighted by assigning colors to the shapes in Fig. 15c, d. The student then repeated both sequences to combine in a rotational symmetry on the canvas in a final composition (Fig. 15e). This can be represented with another spatial rule that translates and rotates x, still compliant with Schema 2. It is possible to represent this student's process with entirely different rule sets. The spatial relation between each grey and black triangle couplet (in Fig. 15e) also reveals a repetitive but varied use of yet another rule. The variation in the rule can be specified in terms of the size of each triangle and their relative position to one another within an imaginary rectangular box.

In S3 (Fig. 12b), the student created a unit where the colors are assigned beforehand (Fig. 16a). This unit is used at three different scales. We have identified five shape rules within the schema $x \rightarrow x + t(x)$ (Schema 2). These rules are presented below, in Fig. 16b–f. However, regarding the diversity of the shape rules and noticing that there is no recursion of any rule, except the one illustrated in Fig. 16b, we can say that the student did not define a relational system beyond the similarity due to the repetition of the unit. Instead, he might have sought for alternative transformations within the schema $x \rightarrow x + t(x)$ (Schema 2) to fit within the boundary of the canvas. Nevertheless, by using the same unit at different scales with the same colors and thus acknowledging the corners that emerge in the unit in Fig. 16a, he somehow achieved a unity (Fig. 16g).

In S4, we could not identify the use of any consistent shape rule. However, while working on the composition, the student verbally expressed that he had defined certain relations between different parts that he repeated at different scales. Only

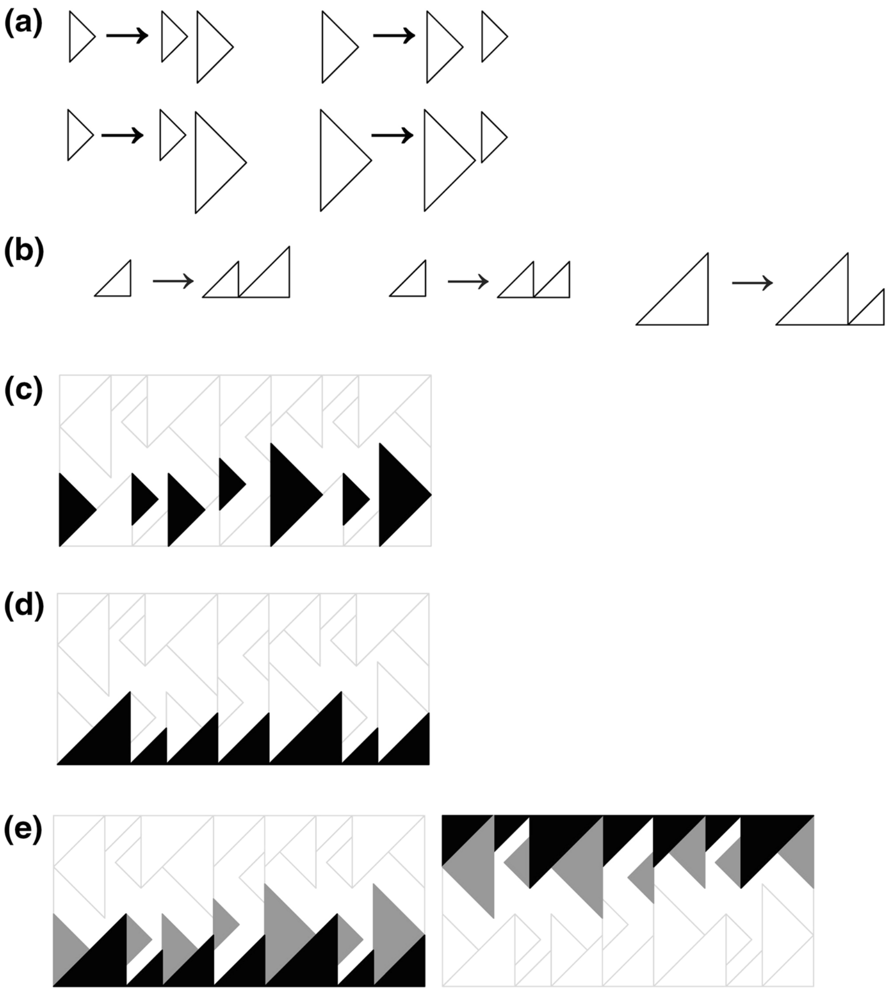
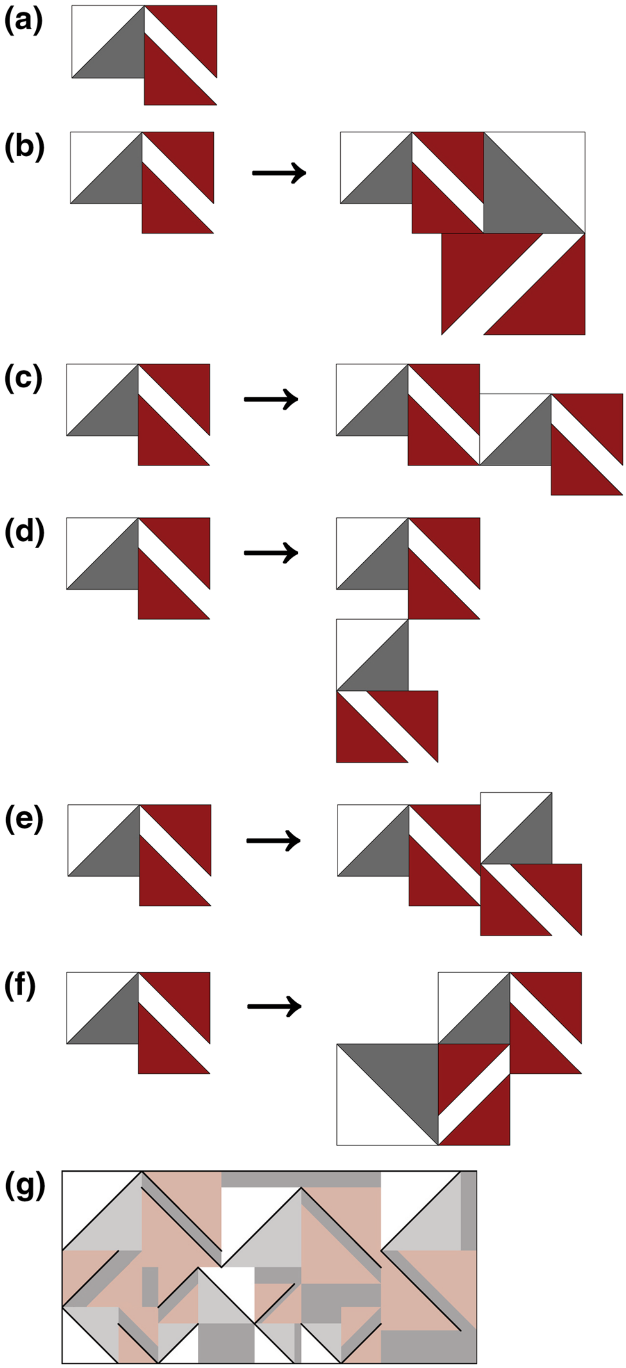


Fig. 15 The process to obtain the student work S2: **a** the first set of rules, **b** the second set of rules, **c** the first set of rules applied with weighted shapes, **d** the second set of rules applied with weighted shapes. **e** The student rotationally mirrors one group of shapes on the opposite edge of the canvas

perceivable in the line drawings, there is a repetition of certain shape relations between squares and parallelograms whether they are original tangram pieces or composed of two triangles. The student had defined spatial relations between different shapes (x and y) but created new shapes while assigning color. Hence, in Fig. 17, in order to make these relations more legible, we assigned new colors to the shapes. This way, a different schema $x \rightarrow x + y$ (Schema 5) in addition to Schema 2 is better exposed.


(a)
(b)
(c)
(d)
(e)
(f)
(g)

◀**Fig. 16** The rules to obtain the student work S3: **a** The basic unit in S3. Right triangles are in a spatial relation that emphasizes a right corner emerging to the eye between the *grey* and *red* ones. **b–f** The rules we have identified. **g** Corners emerge as shapes that repeat in the overall composition (color figure online)

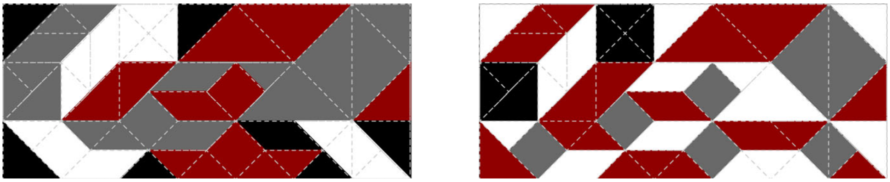


Fig. 17 *Left* S4 with *colors* assigned by student. *Right* S4 with *colors* assigned by the authors

Conclusions and Discussion

Making unified wholes with shapes is often the goal in basic design exercises where abstract organizational concepts such as repetition guide students as they develop a relational system towards creating a whole. Our basic premise is that designs where repetitions and variations are perceivable may reciprocally serve as effective tools in conveying to beginning design students the underlying relational nature of design. We analyzed Ilhan Koman's non-figurative sculpture series, all designs with strongly repetitive features, and illustrated his "embryonic" approach in visual schemas which we then incorporated into a basic design studio exercise to demonstrate students' learning processes. Exposure to the knowledge of Koman's *Infinity-1* series, particularly the *spiral* and the *circle*, visibly helped the students in grasping how the repetition of certain relations enabled the artist to create complex sculptures, and how variations generated different, yet similar outcomes. Our shape computation analysis of students' proposals for the same exercise before and after being exposed to this knowledge shows the apparent progress in the quality of the works in terms of creating a relational system and achieving unity.

The general schema $x \rightarrow x + t(x)$ (Schema 2) of the *Infinity-1 series* denotes an additive process where repetitions and variations are perceivable. The variations in question can be of features such as size, orientation, position, and color. The adoption of this schema by basic design students instead of the more general schema $prt(x) \rightarrow \sum t(prt(x))$ (Schema 3) given with the definition of the exercise, encouraged them to establish relations among shapes and to compute with them without even talking explicitly about individual shape rules. While, within Schema 2, Koman generates his works within a linear iterative process, in basic design works, repetitions are not necessarily linear, and in fact are rarely so. Basic design works are mostly spatial and processes behind them are frequently obstructed through seeing emergent shapes. This is a key aspect that distinguishes basic design works from linear generative processes and provides a richer playground to incorporate perception into a hands-on process.

The schema $prt(x) \rightarrow \sum t(prt(x))$ (Schema 3) which illustrates the description of the exercise given in the studio remains too general for entry-level design students to handle. When asked to design a whole with Schema 3, students mostly concentrated on fitting the shapes at hand within the boundary of the canvas in a way to achieve a unity between figure and ground, which corresponds to a unity between the leftover parts on the canvas and the discrete shapes being used. However, except for this relation, they mostly failed in defining a relational system to organize the whole.

When the general schema is further specified as $x \rightarrow x + t(x)$ (Schema 2) after analyzing Koman, students realized that the repetition of certain relations with a degree of variation could help them achieve unity, as in the *Infinity-1* series. The variations can be of scale, orientation, and position. They also tested the consequences of assigning colors to shapes to create variations within a repetitive system, as exemplified here in what one student did in C1.

In addition to the Koman *Infinity-1* schemas, students' processes present several other schemas: $x \rightarrow x$, $prt(x) \rightarrow prt(x)$, $b(x) \rightarrow b(x)$, $b(prt(x)) \rightarrow b(prt(x))$, etc. Students keep recognizing shapes that they did not see before as they tackle figure-ground, solid-void relations, and relations between discrete shapes in additive schemas. After seeing emergent shapes, they can go back and change their rules to cope with emergence. Going back and forth between the schemas and shape rules in basic design makes it a more complicated task than a linear iteration. A relational system, in this case triggered by the exposure to Koman's "embryonic" approach, helps students to interpret and utilize emergent shapes within a larger whole. Further investigations into the students' interface with visual schema formalisms are required to discuss how students can define visual schemas for their own work towards a computational understanding of design in their curriculum. Finally, processes similar to those seen in Koman's artistic production, in which material properties and behaviors are considered as design input and where material manipulation shapes the design outcome, necessitate extended visual formalisms to represent the feedback from materials. There is potential for future research not only on how visual schemas convey key aspects of relational and reflective thinking to basic design students, but also to elucidate the computational aspects of various art and design work, as was done for an example of Koman's "embryonic" approach in this paper. This will in turn serve to bridge the tacit knowledge of creative processes and contemporary design pedagogy.

Acknowledgments All images are by authors, unless otherwise noted. We thank Yıldırım Arıcı for permission to reproduce the photos that appear here. The tangram exercise is credited to the instructors of the 2013 Basic Design Studio at Istanbul Bilgi University - Faculty of Architecture, including Benay Gürsoy. The student work in Fig. 11 is from the studio. All other student work is from the workshop carried out separately from the studio as part of this study. The rules and schemas that describe the exercise and the student work are retrospective and by the authors.

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Benay Gürsoy is a PhD candidate at Istanbul Technical University, in the Program in Computational Design and a fulltime instructor at Istanbul Bilgi University, Faculty of Architecture where she is teaching Basic Design Studio, Architectural Geometry and Design Computing courses. Her current interests and teaching focuses on foundational design education, material computation, material tectonics, and computational and generative design methodologies.

Mine Ozkar is an associate professor of architecture at Istanbul Technical University, where she is the coordinator of the Program in Computational Design. She teaches graduate level design research methods, a computational design studio, several computational theory courses and an undergraduate architectural design studio. She earned her MS in design inquiry and PhD in design and computation from MIT. In some of her previous work, she has interpreted the history and theory of progressive pedagogy in art and design from a computational perspective. Her current research focuses on shape representation for creative computing, visual/spatial computation, and design methods as well as the integration of foundational design education and computational knowledge. She also publishes on the on-going global and local curriculum reforms in architectural education. She recently co-edited a book entitled *Shaping Design Teaching* and was a Visiting Professor in the MIT Department of Architecture Computation Group during Spring term of 2013.