

Department of Architecture,
Faculty of Architecture
Middle East Technical
University
Ankara, Turkey 06531
ozkar@metu.edu.tr

Visual Schemas: Pragmatics of Design Learning in Foundations Studios

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Abstract. Visual schemas are prequels to shape rules in formalizing the pedagogical discussions in foundational design studios.

The importance of talking in the foundations studio

It may well be true that if one half of the conduct of a design student in the studio is designing, the other half is talking about designing. The ideal studio environment allows for the students to vocalize to themselves as much as to others, the questions and the possible answers they have regarding their thinking and designing processes. It is important that the students in any design studio discuss what they are doing to improve and impede their learning. This is a way to vocalize the *reflection-in-action* and is even more significant in a foundations studio where the reflection habits are being established for the first time for the purposes of designing.

The view that design is to be talked about, explicitly, is increasingly shared among educators who acknowledge the growing role of process over the product in technologically integrated design processes. Since the beginnings in the early 1900s [Özkar 2005a], the issue of *how to* has been proposed as taking precedence over *what to* in design education. Despite heated debates, the interest and the conviction in explicit design processes accelerated with the Design Methods movement [Broadbent 1979] and continued with the notion of diagrams [Do and Gross 2001]. Increasingly integrated with information technologies, the contemporary paradigm of architectural design calls for open and dynamic processes of design. Today, more design ideas and processes are depicted through various, perhaps unclear but nevertheless seductive and stimulating diagrams and are encouraging for the growing field of inquiry into design methodologies and techniques.

Similarly in a growing number of design studios, methods that enable actions and critical discussions regarding the product are coming to the forefront. There is a good volume and breadth of literature regarding the various technical, social, pedagogical and practical issues surrounding the state of the art in design education, some with a focus on the studio. To mention a few key references, Findeli [2001] provides a comprehensive discussion of multiple aspects of the general topic while Oxman [2008] gives an accurate and extensive account of the impact of digital technologies on design education, and Stiny [2006] introduces a computable connection between *doing* and *talking* in design. Looking from the viewpoint of integrating computer technologies to design curricula as enablers of contemporary design processes, this paper assumes that the studio, particularly the foundations studio, is the medium not only for learning to produce but also for learning to talk about design. The purpose of talking in the foundations studio is twofold: one, understanding and developing design skills, all the while connecting them with the general notions of computation, in order to liberate thinking/reasoning from the

association with quantitative and hierarchic structures alone; two, as part of a holistic view of design and design education where the student (the novice designer) is at the center as the actor of learning.

Beginning architecture students often display discouragement in discussing what is, to them, internal, unclear, and sometimes accidental in the work they produce. They often come with preconceptions of how designers behave based on the common market imagery of the architect and/or architecture, which is lacking in social and rational groundedness. Encouraging students to talk about what they do is a significant step for de-mystifying the notion of design in their eyes. Talking changes the image of the designer into an accessible one and shows that design is to be criticized based on various valid criteria, and is learnt and developed. The first year in architecture education is where the culture and habits of design thinking start to form and where the students are introduced to its tools for the first time. As tools of representation and thinking are constantly revised with the changing technology, it is necessary, for the sustainability of a contemporary design education, that students acquire from early on an awareness of the dynamic nature of design knowledge.

There is a growing literature on the student/learner-centered higher education paradigm, which is quite relevant to any scholar engaged in curricula or course design. Brown [2003] recapitulates the necessary conditions for it and the psychological factors involved. Although well beyond the scope of this paper, some of these factors and conditions, such as active and hands-on learning, student motivation and social development fall in line with what is epitomized here in talking. Talking in the studio involves asking questions, playing different roles, comparing, seeing, and doing something just to try it out as actions of self-reflection in a process of production. The studio environment is often considered as the ideal setting for a learner-centered higher education paradigm, but every studio setting does not by default fit this model. The key is in the attitudes and the discussion environment provided for the student to self-reflect and develop his or her own position in action. Where enabling the student as an active and self-critical subject is a key matter of concern, grounding studio learning on dialogue (through questions, panel discussions, critiques, etc.) is a common starting point. Nevertheless, in addition to just words, formalisms are needed for this conversation to be linked with visual and spatial thought processes in question.

Means for talking, formally, about basic design

In basic design education, a format for foundations studios in architecture schools throughout the world, tasks are often deemed abstract and removed from real design problems. First and foremost, the learning outcome of basic design is the design thinking experience and accordingly, the ability to relate various forms at different levels of complexity. Defining relations (some arrangement of what is conceived as separate parts) is usually a more complex task when there are fewer constraints in how to perceive the parts and wholes visually, as there are multiple levels and alternatives in perception.

Talking in the studio does not have to be formal but, formalisms are handy to follow, repeat and document the talking. The premise here is that basic design exercises are visual/spatial computations [Özkar 2005b]. Ideally, showing that their design works as a visual computation helps the student to observe what they are doing, to accommodate it within one's own sense and to develop it further. Basic design exercises seem especially suitable for observation in shape computation formalism, as they deal with less complex forms and relations. However, as basic design exercises display their own level of

complexity due to their abstract nature, conveying the formalism of visual rules to the beginning student proves to be not as straightforward. This paper intends to draw attention to the practicality of the matter by showing what kinds of formalisms are relevant to the students' discussions in the context of basic design.

Shape grammars have been presented and widely used as devices of talking about design. Many scholars have worked towards integrating the formalism of shape grammars to design education. At various levels of architecture education, the formalism has been valuable for enabling the students to recognize and develop further the systemic, recursive aspects of their design, as well as the generative aspects of rule-based systems and parametric assemblies towards contemporary production processes. Knight [2000] has been one of the key promoters in architecture and has been diligently encouraging architecture students to bring their design processes to terms with visual rules. While Celani [2002] emphasizes recursion in design in her valuable attempts to introduce the shape grammar formalism to her students early on, Sass [2005] incorporates rule-based processes with fabrication. Additionally, there is a wide variety of tools that are developed to provide an interface with the shape grammars formalisms [Chase 2005].

The general idea for integrating the shape grammar formalism in the foundations studio is to incorporate shape rules as well as the knowledge of visual algebras and Boolean operations into the vocabulary of studio talk, in support of the conventional panel discussions. Hypothetically, similar to pointing at the visual composition with a finger and elaborating a visual relation with words, using rules should be an efficient and shared way to talk about design decisions. However, a few attempts quickly show that for any basic design there are too many visual relations to consider for shape rules. The abundance is confusing and futile unless one also talks of some higher-level relations between the shape rules. Then, the design knowledge to be conveyed seems to concern the relations of parts and wholes, not just at one level but at multiple levels. The next sections will be dedicated to expand on this design knowledge and how it can be turned into the matter of formal talk. All the while, the paper proposes that visual schemas come in handy to talk about this particular design knowledge.

What is meant by a schema here is a generalized version of a rule [Stiny 2006, 2009]. Visual schemas are more general ways to understand design decisions, processes and methods, whereas a visual rule can have more specifications. In this paper schemas are sometimes represented in abstract ways such as $x \rightarrow y$ but still refer to visual schemas as they deal with shapes. Drawing from these illustrations, the proposal is that visual schemas provide a more suitable level of discussion than the detailed shape rule formalism for foundations studio talk. As part of a preliminary study for incorporating formal methods in the foundations studio, this paper illustrates some visual schemas in two completed basic design examples based on what the students have explored and identified in their work without the knowledge of visual schemas.

Recurrence, emergence and visual schemas: foundational design knowledge?

In the keynote lecture at the 2009 eCAADe meeting, George Stiny emphasized once again the indispensable connection between recursion and embedding in the context of design computing. In addition to the usual coupling of recursion with the identity relation in symbolic computation, Stiny proposes that in design computation, part relations, specifically embedding, are indispensable partners to recursion. Recursion and embedding constitute a significant part of design knowledge in the context of computation and have been playing their parts, in the form of rule-based systems and

emergence, in numerous practices of visual computation in design. Stiny's emphasis was not a mere recursion but also a reminder to see the simultaneity of the two aspects. This paper proposes that these two notions are part of the foundational design knowledge to be primarily conveyed in basic design exercises and that visual schemas are suitable for doing so.

Recursive functions in design computing have been acknowledged before [Stiny and Gips 1972; Stiny 1985; Kirsch and Kirsch 1986]. Existing examples of shape grammar applications in education since have mostly explored the recursive aspects of design via additive approaches, starting out with initial shapes set in some spatial relation which are iterated in space as relevant addition rules of the type $x \rightarrow x+t(x)$ are applied. Basic design exercises, as abstract compositions, are not unlike these processes. They inevitably rely on recursion – or rhythm, to use a more designerly term – as it establishes links of similarity or variance between the parts, which in turn help the eye in reading what makes up the unity in a composition.

It is useful to identify the two common ways, one additive, another subtractive, of setting up basic design problems. An example of the additive approach would be something along the lines of “organize the given shapes in space,” while an example of the subtractive approach would be something along the lines of “carve shapes out of a solid material.” If the goal of a unified whole is also given, both approaches are usually treated as composition. However they differ greatly in the level of plasticity they provide. Compositions with primitives mostly tend to be orthographic (easily measured, geometrized and cut) and carving seems to promote free hand movements.

Both types of basic design problems encourage embedding and recursion but the emphases are different. One may argue that while additive processes run the risk of limiting one to discrete parts and preset structures, subtractive processes may encourage part embedding. The ice-ray examples [Stiny 1977] are comparable to the second type. Parameterized divisions provide flexibility in changing how the rule is applied similar to the subtractive approach. Rules are applied in changing ways. Özkar [2004] had argued previously that working with an interpretable whole provides for more creative operations than working with conceptually constrained initial shapes. Dividing the whole into consequent parts involves recursion as much as an additive process. But, since each recurrence deals with what is emergently left over from, or has been previously an embedded part of the step before it (rather than a composed new whole as in addition), these subtractive processes might be further explored as a way to convey to the students the emergence of new wholes alongside of recursion.

Oxman [2002] describes emergence as visual cognition and distinguishes between the syntactic and semantic structures involved. The advantage of shape grammars over the symbolic rule-based approaches has been the open door for emergence, enabled by seeing. Semantics are left to the subject and syntax is left to circumstance. Emergence of new shapes in additive shape computations has allowed for dynamic and creative generative processes with indeterminable results and large design spaces. Moreover, the embedding part relation allows for emergence of new parts all the time.

The two examples in the next section follow along the thread of additive schemas and emerging shapes. One of them starts the students with a given additive schema and the other starts the students with an already designed whole asking for what possible schemas may have been used. While inquiring into how formal ways to talk about design can be

introduced to first-year architecture students, this paper draws attention to expansions of these notions with visual evidence from these two basic design examples.

In line with Stiny's conceptualization, a design schema is also described as a visual form of generic design knowledge [Oxman 2000]. In the context of design education, Oxman and Streich [2001] propose that the acquisition of the ability to represent design knowledge and the basic visual schema are part of learning in design. With emphasis on the cognitive aspects of what they imply, a computer model has been developed to support the representation of visual schemas and cognitive processes in design [Oxman 2000]. Additionally, with the purpose of providing a formal description of design exploration with sketches, Prats et al. [2009] show how schemas correspond to design rules in a process and utilize visual schemas to correlate different designers' visual rules. However, the existing literature does not discuss visual schemas with a particular reference to foundational design education.

The discussions below show some schemas and some visual rules they encompass, with illustrations from student works. The works are by Havva Elif Koç in the first exercise, and by İlker Teker and Sabiha Göloğlu consecutively in the second exercise. All three were students in the first-year design studio at the Middle East Technical University Department of Architecture between the years 2004 and 2006.

Before looking at the examples, here is the list of visual schemas that will be discussed:

(Schema 1) $x \rightarrow \Sigma t(x)$

(Schema 2) $x \rightarrow x+t(x)$

(Schema 3) $x \rightarrow x$

(Schema 4) $x \rightarrow x'$

(Schema 5) $x \rightarrow x+x'$

These all have their place in Stiny's specification of rule types [2009: 168] and can be extended to include $b(x)$, $b(t(x))$, $prt(x)$, and $b(prt(x))$ as will be discussed in the examples. Visual rules that are depicted work within these schemas. This paper is limited to only a few of these rules. In the studio environment, the number of rules to be discussed increase and the meticulous representation of each and every one of them loses any practicality. The argument based on these cases is that when different students operate within one schema, rule variations are good to compare and learn from. There are too many visual rules and no grammar that can be finally set whereas schemas are general devices that help compare, group, categorize, associate, contextualize and vary rules. Students do not discuss every single possible rule, but do have the chance to observe and discuss the fact that rules of the same schema are good for doing different things.

Practicing with an additive visual schema

The first example is based on a recursive prescription given by the instructors. This exercise makes it possible to concentrate on a small number of rules and schemas, and introduce the notion of material properties. Using the given visual schema, the student looks for and works with changing form relations of parts and wholes. New parts and wholes as well as other visual schemas constantly emerge. Shapes, weights and labels come into play. The task turns out not to be simply the compositional one prescribed in

the beginning. Here, the student is encouraged to see, within the bounds of a given set of confining rules, and to explore multiple variations. The analysis shows the visual exploration that is possible with an identified formal schema.

In this first example, an additive schema is verbally expressed to the students at the start. Students are expected to work with primitives that they defined (independent from this new problem) in a previous exercise. These primitives, however, consist of parts that they can modify in terms of weights. In the end, the sum of these primitives yield new wholes (more than the sum of parts) because their parts can be configured into new shapes. The task in the assignment is to put together nine square units in a square grid, with the aim of creating a composition. Composition, in the context of the studio, implies a unified whole of parts/elements. The unit is itself a two-dimensional composition done in the previous assignment. Students are allowed to modify some aspects of the composition as necessary and according to how they adapt it to its new environment. Extreme changes are not encouraged.

The end result of one student's work is presented below in fig. 1.

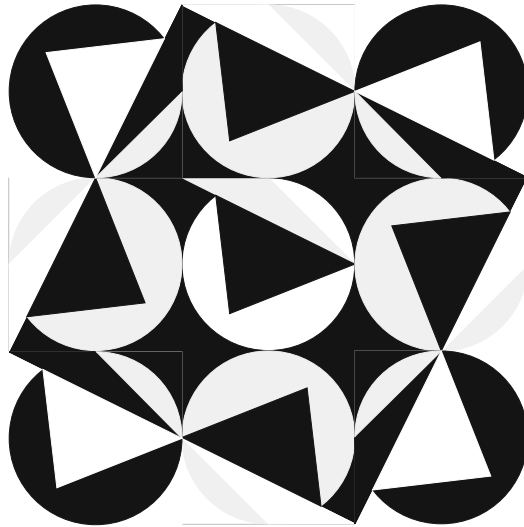


Fig. 1.

When starting this particular composition, the student already had at her disposition a unit shape from a previous assignment. Let us for now only take the boundaries of the maximal planes ignoring the different tones/weights (fig. 2).

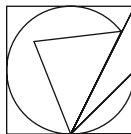
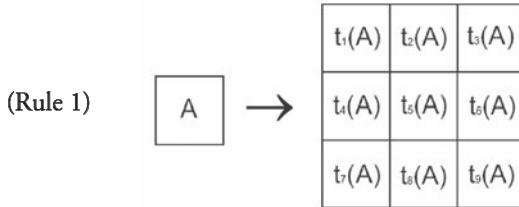


Fig. 2.

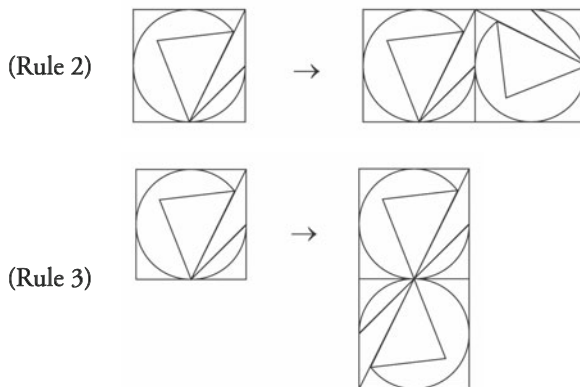
The general schema for the exercise

The student is asked to put together nine of these units to form a square. Euclidean transformations of the unit are allowed. The description of the assignment can be illustrated by the schema $x \rightarrow \Sigma t(x)$ (Schema 1). A visual rule that complies with this schema and describes the problem well is Rule 1. One square is replaced with nine, each some Euclidean transformation of the first.



The schema for experimenting with couplets of units

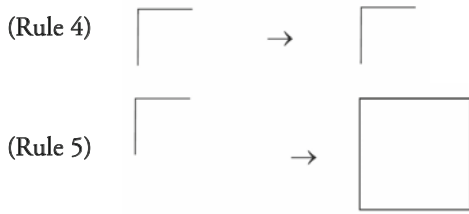
As the task is not necessarily a one-step computation, the student also may choose to use Schema 2, $x \rightarrow x+t(x)$, to start putting units together two at a time. Many rules fit under this schema, one of which is “add one square to any one side of the original square.” The student could have had an alternate spatial relation/rule where the two adjacent units have line parts that align as in Rule 3 rather than meeting perpendicularly as in Rule 2.



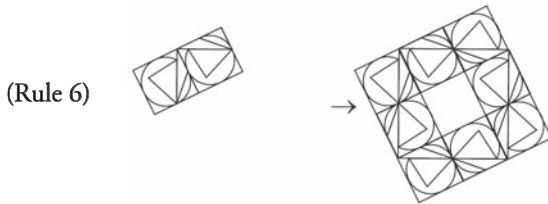
Alternatively the student could have chosen from among many other rules of the kind $x \rightarrow \Sigma t(x)$ (Schema 1) if she wished to try more of the parts together – for example, groups of three or more – at one time.

The schema for seeing new relations between elements

In a further step, the spatial relation formed as a result of Schema 2 above evokes the following Rule 4. In short, the student sees a *corner*. The schema to acknowledge this is the act of seeing $x \rightarrow x$ (Schema 3). Rule 4 serves as the basis for a new rule (Rule 5) within the previous schema $x \rightarrow \Sigma t(x)$ (Schema 1) where the student more or less clarifies the aim to create a new shape with parts of several units.



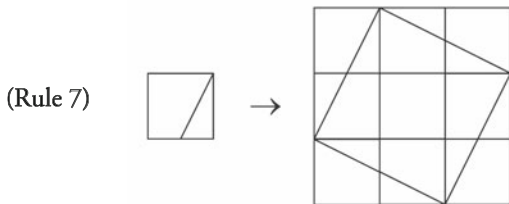
She identifies a shape x within what is given and also establishes that $\Sigma t(x)$ can be a desired shape (in this case a square). This new $\Sigma t(x)$, and its complementary parts can also be produced in other ways, for example with **Rule 6** again within the same schema.



By still keeping in mind the rest of the shape while forming a square with the four corners, **Rule 5** is semantically guiding **Rule 6**. In this case, x and $\text{prt}(x)$ are considered simultaneously and dependently for the creation of a new shape: $\text{prt}(x) \rightarrow \Sigma t(\text{prt}(x))$ is a condition to $x \rightarrow \Sigma t(x)$. One sees and operates on a shape that is a part of another shape, and the operation changes the whole shape at the end. The reason for the student to try out **Rule 6** is because she knows of and wants to apply **Rule 5**.

Simplified version to show the rich compositional variety

To retrace the same computation and to show the abundant variations the student may have or could have tried, let us exclude some of the features to emphasize what is going on with this emergent shape and new schema. The updated and simplified version of **Rule 1** is **Rule 7** from **Schema 1** $x \rightarrow \Sigma t(x)$.



The right side of this rule shows all of the 8 transformations of the initial unit with the symmetry group of 8 (fig. 3).

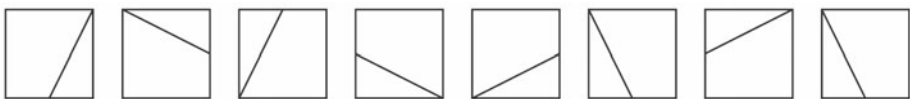


Fig. 3.

Rule 2 can be applied to put two units together in 64 different ways using the symmetries. The outcomes are reduced to 22 after similar ones are omitted (fig. 4).

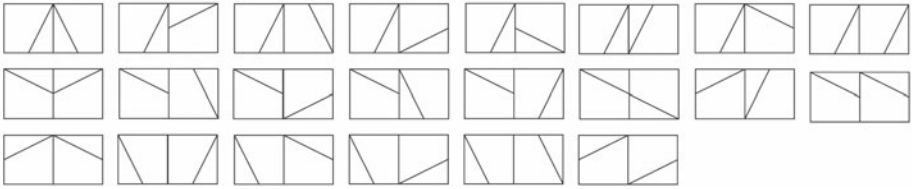


Fig. 4.

Including weights

There are already 22 ways to go at the very beginning of trying out couplets. Moreover, the problem asks the students to work with different tones/weights. If black is assigned to the triangular area and white to the quadrilateral, the 22 pairs appear as shown in fig. 5.

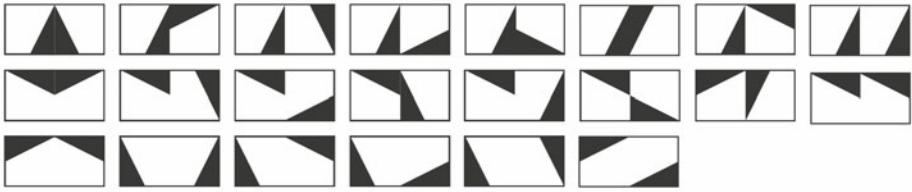
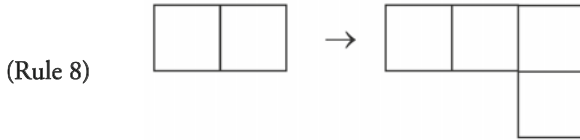


Fig. 5.

Following Schema $2x \rightarrow x + t(x)$ again with some of these pairs, Rule 8 can produce so many various results.



The student can come up with designs like those shown in fig. 6:

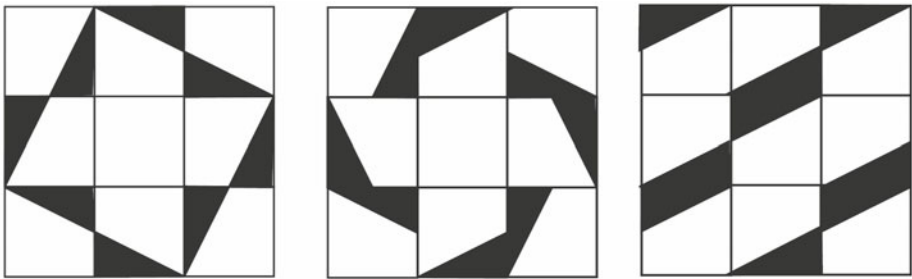


Fig. 6

When, however, the tones interchange between the triangular area and the quadrilateral, the number of alternating pairs rises to 85 (fig. 7) and eventual combinations of nine units multiply. The additive schemas guide the students to try out relations in similar ways but at the same time have them focus on seeing new relations among parts as options multiply due to different transformations and weights.

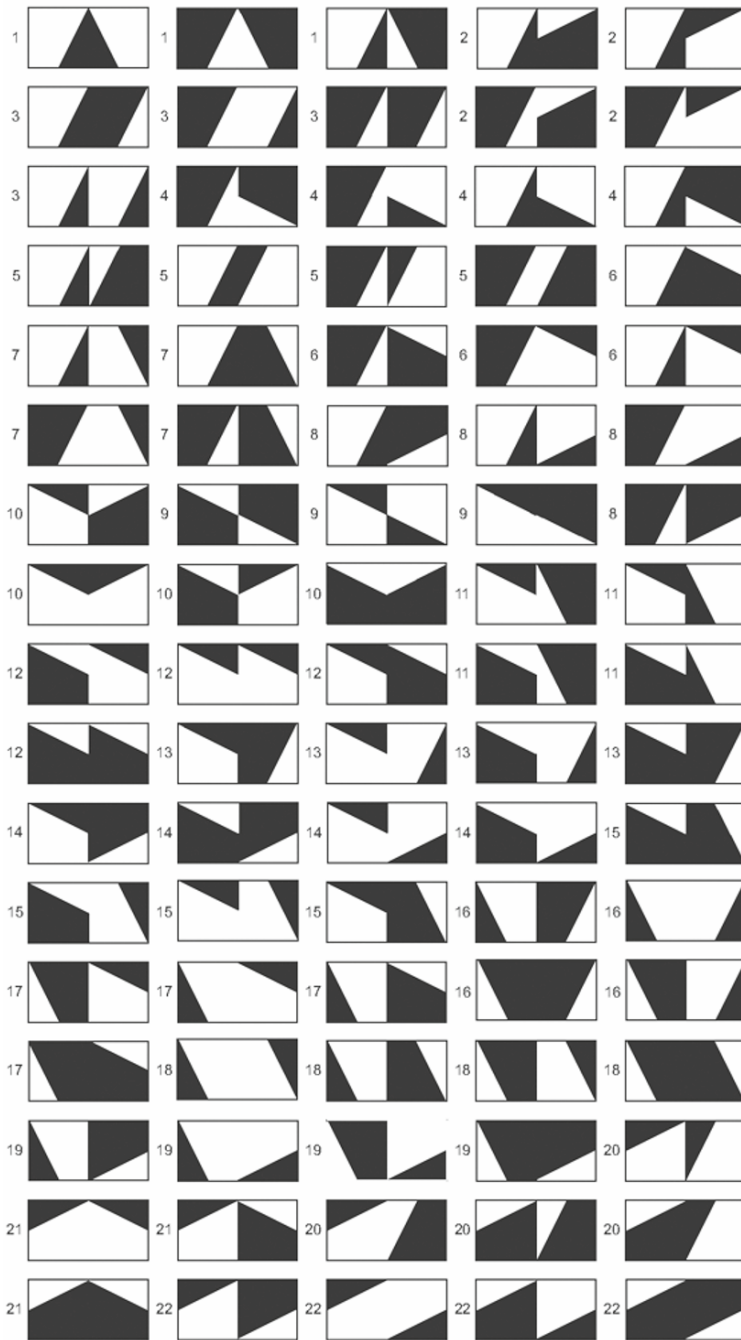


Fig. 7.

In this particular exercise, the student has more areas to assign tones to and more tones to assign than our analysis shows. Moreover she tries different combinations. Figure 8 shows two combinations she has in her final design.



Fig. 8.

Some possible outcomes just with changing the tones could have been those in fig. 9.



Fig. 9.

Overview

This exercise and its analysis demonstrate a few points. Firstly, however simple the shapes are, the students are dealing with large design spaces with multiple relations of parts and wholes at one time. The analysis given here only shows a small portion of it. Any production and discussion in the studio will also be limited to a small portion. Whereas the student is encouraged to enumerate as many possible options as possible, it is not practical and meaningful to talk of ALL the rules and relations as enumeration merely shows the abundance of choices with little clue to how the student is to guide himself or herself through these choices. Secondly, while the number of rules increases quickly, schemas recur, and talking in terms of schemas can be the students' guide to making meaningful choices. The analysis shows the generic schemas used. **Schema 1** ($x \rightarrow \Sigma t(x)$), given in the definition of the exercise, and **Schema 2** ($x \rightarrow x + t(x)$) are additive and promote recursion as a method of pursuing the problem. Within the recursions, students can exercise variation of relations and outcomes. That the rules vary from moment to moment within the same schema might be useful in terms of acknowledging different cognitive steps. **Schema 3** ($x \rightarrow x$) is significant as it indicates moments of discovery or seeing. All three are included in the specification of rule types Stiny presented during his course lecture "Recursion, Identity, Embedding" given at SIGGRAPH [Stiny 2009].

Practicing recognizing various visual schemas

The second example illustrates a reversed relationship between recurrence (with an additive schema) and seeing. The task is reading a fellow student's design work to identify visually recursive patterns, relations, and visual schemas, and to improve on

them. This time, it is the student who identifies some rules or schemas within an existing composition to follow and apply again. Seeing and doing are reversed. Whether the second one is an improvement over the first is not an issue. The example is more for comparison and an opportunity to talk about how to read design rules similar to Habraken and Gross's "silent game" [1987].

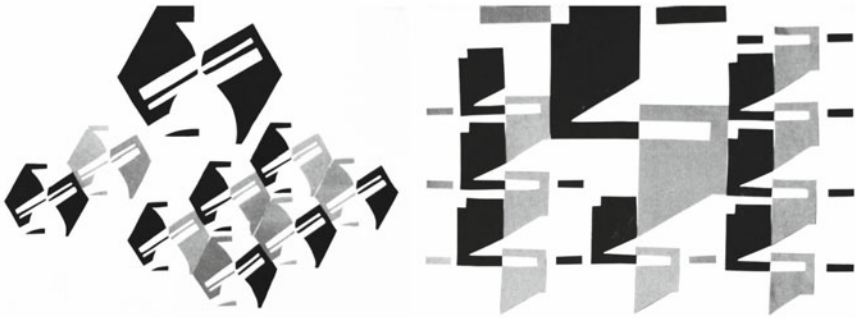


Fig. 10.

The general schema for the exercise

To start with, the general schema from the first student's work to the second's (fig. 10) is $x \rightarrow x'$ (Schema 4) specified for general transformations and parametric variation. Shapes change a little; some parts and relations are maintained. The number of shape groups increases in the second work. There is still one big group more or less centrally located in both. The schema for both the first and the second work individually is $x \rightarrow \Sigma t(x)$ (Schema 2). The only exceptions in the second one are a few shapes in the top row where a few rectangular pieces, or $t(\text{prt}(x))$'s, come into view.

The schema for forming groups of elements

In the second work, the schema to acquire the module that consists of two parts seemingly in rotational symmetry with one another is $x \rightarrow x + x'$ (Schema 5) and is visualized in Rule 9.



If instead the schema had been a more specific schema $x \rightarrow x + t(x)$ (Schema 2), the composition shown in fig. 11 would have resulted.



Fig. 11.

The schema for organizing the layout of the composition

Another schema recognized in the first work is the schema to organize the page. Parts are arranged in alignments and this could be specified in **Rules 10 and 11**. **Rule 10** is employed by itself in the first composition whereas the second student creates a variation of **Rule 10**, namely **Rule 11**, in the same schema and uses both. This is similar to the visual rules discussed in the context of other basic design problems [Özkar 2005b]. It is promising that not only schemas but sometimes rules as general as these are recurrent in various design problems. The two rules are especially significant to showcase the slight variations within a schema and what different outcomes can result. Here, the second student acknowledges the spatial relations, and reapplies them with slight variation with the aim of improving the overall design and how it fits an orthogonal page frame.

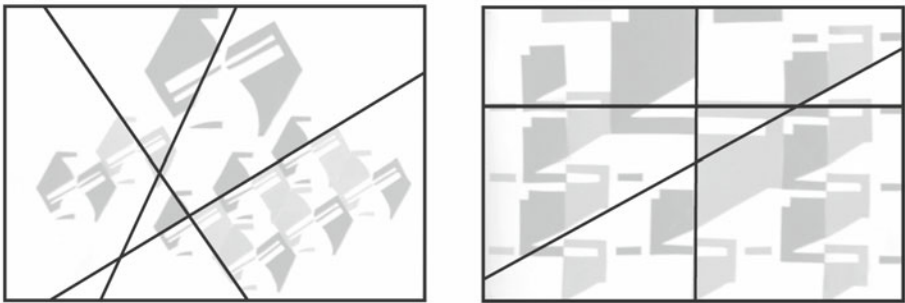
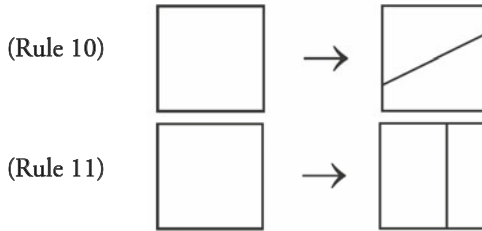


Fig. 12.

As a result of this variation, the axes for shape alignments differ from the first to the second. The second application of the schema takes into consideration the orthogonal frame of the canvas along with the angles of the parts.

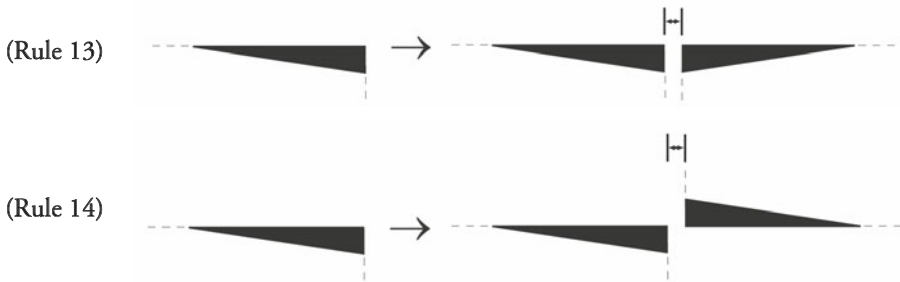
The schema for aligning elements of the composition

Furthermore, if we look at what is aligned, we see that the second student reads in the first work the alignment of boundaries of parts $b(\text{prt}(x))$ and takes care to follow the same criterion. **Rule 12** from **Schema 2**, $x \rightarrow x + t(x)$, can be used to specify this, and the distance in between the two aligned parts can be varied to fit many possibilities.



Continuing to look at aligned parts, we see that since the alignment is of the boundaries and not of the whole shapes, there is variation in which side of the shape they are aligned with. Rules 13 and 14, again from the same schema as above, depict these relations.

Rule 13 aligns the edges of planar shapes on the same side, and Rule 14 aligns them on opposite sides.



Since in most of the alignments one piece seems to be matching the void in the opposing piece as in Rule 15, these planes can also be interpreted as weighted lines. A thick line with assigned W_1 (black) is aligned with a thick line assigned W_2 (white) in Rule 16. In both students' works, as grey and black shapes align, white shapes emerge as parts to be picked out in the same schema. They are just as good to align with as the darker colored shapes.



Overview

There is simply no unique way to look at these compositions. The students read many rules which all fit into only a few schemas. Schemas are general and sharable. Rules are more specific, sometimes comprising weights, labels, or parametric values, and are hence greater in number. Mostly they are alternatives for one another in alternative computations of the same problem. For example Rules 12-16 above are all valid, even towards the same result, but open up different potentials. Also, rules are mostly coincident and may serve similar purposes. Weights can be specified in one way, but the end result of the rule could immediately invoke another way. A rule could be applied to align the black line with the grey line, only to find that the grey line is defined by its neighboring white line so that the black line is also aligned with the white line. If one part aligns, some other parts automatically do as well, and at different levels parts act together to form numerous wholes which correlate in the bigger whole. These changing hierarchies are not very easy for the students to grasp; to unite them in one schema would

help. The important lesson here is that rules are part of a shared schema, which in turn helps the student talk about the rules and their differences.

To illustrate the same richness here is one other observation. The detailed nooks in the first student's work are simplified into singular nooks in the second's. This shows that schemas allow for the use of rules with different specificities. Parts of shapes can be ignored, proportions can be altered.

In this second example, we are looking at the process of the second student rather than the process behind the first composition. The analysis is based on a comparison of the two. It is a good example for showing the schemas identified by the second student. Weights, scale transformations and number of parts change but schemas are common. How rules within the same schema are applied or detailed show us variations of the same theme. Going back and forth between a schema and shape rules helps the student to talk about variations. The second student identifies some rules, speculating on what the first student might have been thinking about. They can be combined or modified, for example simplified, or there are simply different ways to talk about the same thing. There are many options, but schemas generalize them. The second student does not have to understand fully how the first student used a particular rule, but the schema is shared among the two.

There are more opportunities for the student to see different parts to the shapes in this second example because the primitives are not given, but identified in different ways again and again on the spot. She excludes details where she sees fit. She utilizes schemas of seeing: $\text{prt}(x) \rightarrow \text{prt}(x)$, $\text{t}(\text{prt}(x)) \rightarrow \text{t}(\text{prt}(x))$, and $\text{b}(\text{prt}(x)) \rightarrow \text{b}(\text{prt}(x))$. This is the kind of emergence mentioned in the beginning of this paper. Surprises occur in the additive processes, in this case mostly within Schema 5, $x \rightarrow x + x'$, because the wholes are more than the sum of parts. Parameters are not defined and the grammar is not as precise as in the ice-rays, but certainly those can come in more advanced exercises to follow.

Generic schemas work for discussing recurrence, emergence and variation

Formalisms are not a direct way of talking about design in the foundations studio where seeing and doing are emphasized. Formal ways to talk about design actions are conventionally encouraged and so far they have mostly been drawings, or the products themselves in addition to words that are transferred from daily life. A novice designer's vocabulary slowly develops through discussions. It is a worthy idea to include shape grammars to these formal ways, but shape grammars and proper visual rules are external devices that are difficult to incorporate into the already heavy intellectual and physical load at hand. Students are not going to be bothered with abstractions (the notion of computing with shape rules might as well be abstract to them) in an environment where they are constantly being encouraged to think visually and spatially, and the number of potential rules is quite high. Pointing at some relation while trying to come up with a good descriptive word, or at best a concept, is the practice. Nevertheless, rules can be talked of as simple as two shapes connected with an arrow, and to compare and contrast these, visual schemas seem to be relevant. Rather than a seamless mathematics of shapes that do not add up to a sensible grammar, the schema is easier to grasp, and it addresses, with benefits, the need for formalism.

The schemas discussed in relation to the two examples also signify the design knowledge conveyable in the foundations studios. Firstly, emergence is not only the occurrence of a new shape in a linear generative process, but also a recognition of a shape

that was there before but not seen. This is generally what is referred to as the ambiguity in shapes, but can be extended to emergence if one understands it with reference to the changing context. In the examples discussed, shapes are parts of wholes and co-existing parts act in the emergence of new shapes despite the fact that these shapes are already there to begin with. Hence, there is a need to talk about emergence as ambiguity in a general sense. More generic schemas can be devised in future studies, for example to include $b(x)$ or $\text{prt}(x)$, as it is mostly boundaries or parts that the eye sees in a different light.

Similarly, recursion in design is more complex than a linear iteration. In basic design exercises, repetition or rhythm comes forth as an organizing schema and is rarely linear. It develops in multiple dimensions and multiple instances of it coexist. In architecture education, repetition comes forth as a strong schema for making sensible and unified wholes. The two exercises discussed above are good illustrations for rhythm in two dimensions that is more than merely a linear recursion.

Recursion and emergence culminate in variation, which includes not only repetition but also similarity and change all at once. A schema of variation could be:

Rule A ($x \rightarrow x + t(x)$) varies into **Rule B** ($\text{prt}(x) \rightarrow x + t(\text{prt}(x))$).

Variation is a powerful tool for teaching design and is easily talked about with visual rules/schemas. For example, the schema $x \rightarrow x + y$ might help in comparing and contrasting rules where y is varied with one constraint and in understanding, recognizing, discussing organizational decisions. Visual rules help not only in generating alternative solutions but also in creating controlled variations of one solution as a way of trying and erring and retracing. Being able to vary (according to a theme if needed) seems to be an important skill to acquire for beginning design student.

In short, schemas help identify, generalize and convey the key aspects of relational and reflective thinking: recursion, seeing emergent shapes as well as parts, boundaries, and relations, and building up variation, prior to learning proper shape rules and design grammars.

This paper can be taken as a preliminary study to place formalism in the studio. More inquiries are required to develop and test ways to incorporate visual schemas to design studio talk systematically. Interdisciplinary collaborations may come in handy for addressing pedagogical, cognitive and instrumental aspects of the problem in a unified manner. Moreover, there are many more rule types to be explored in conjunction with basic design exercises. Hierarchic relations to be explored between the types may also be helpful for students.

These analyses set up examples for better understanding design computations with visual schemas. They show that visual computations coexist at multiple levels in visual design processes, that parts and wholes are interrelated, and that different wholes are causally related. Both examples show that an intensity of different simultaneous perceptions of parts exists. There is a complexity due to the parallel processing of shapes. Schemas are a way for the beginning students to understand this complexity and how to be active within it. Moreover, visual computations are not just literally limited to the visual. They are coupled with labels (that is, information relevant to the application of the rule), such as assumptions about a certain part (e.g., the Gestalt notion of continuity) and material properties (e.g., properties that weights are assigned to). Schemas encompass all these traits and set up a good prequel to learning about more explicit shape computations in more advanced level design studios.

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About the author

Mine Özkar, an architect by training, holds a Master of Science degree in Architecture Studies and a Ph.D. in design and computation from the Massachusetts Institute of Technology. She has been coordinating and teaching undergraduate and graduate level design studios and computational design courses in the departments of architecture at the Middle East Technical University since 2004 and as an adjunct assistant professor at the Istanbul Technical University since 2009. Pedagogically, she focuses on the integration of computation to architectural design education starting from the first year studios. Some of her collaborative research is on information and computing technologies in design processes, visual computation, and computer implementation of part relations of shapes. She has also published on the history, theory, and practice of foundational design education and its integration with computing, as well as on developing methodology for curriculum changes in architectural education as part of a nationally funded research project.