2. Designing with Grammars

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Shape grammars that generate languages of designs have been used widely over the past several years to describe and understand a diversity of architectural and other styles of designs. These grammars have been developed to address two fundamental concerns in design: 1) the analysis of contemporary or historic styles of designs, and 2) the synthesis or creation of completely new and original styles of designs. Most applications of shape grammars so far have been concerned with analysis. The creative use of shape grammars - the use of grammars to invent new architectural or other designs - has not been exploited nearly as well. A new series of exercises for designing with shape grammars, and also with color grammars, is sketched informally here. These exercises are currently being used in classes in the Architecture and Urban Design Program at U.C.L.A.

Introduction

Shape grammars (Stiny 1975, Knight forthcoming) that generate languages of designs have been used widely over the past several years to describe and understand a diversity of architectural and other styles of designs. These grammars have been developed to address two fundamental concerns in design: 1) the analysis or description of contemporary or historic styles of designs, and 2) the synthesis or creation of completely new and original styles of designs. Most applications of shape grammars so far have been concerned with analysis. For example, shape grammars have been defined to understand languages of Chinese ice-ray lattice designs (Stiny 1977), Palladian villas (Stiny and Mitchell 1978), Hepplewhite chairs (Knight 1980), Japanese tearooms (Knight 1981), Frank Lloyd Wright prairie houses (Koning and Eizenberg 1981), and Queen Anne houses (Flemming 1986), among other kinds of designs. However, the creative use of shape grammars - the use of grammars to invent new architectural or other designs - has not been exploited nearly as well as the use of grammars to do analysis. Designers and design students are often intimidated by the formal aspects of grammars and incorrectly assume that the use of grammars requires a technical competency beyond their means or interests. To bring the use of shape grammars into the design studio and into architectural practice where the potential of shape grammars can be fully realized, an appropriate programme for developing new and original grammars is needed. The groundwork for such a programme has been laid by Stiny (1980). Stinys programme is illustrated using the building blocks of the 19th century educator Frederick Froebel. Froebel, the inventor of the kindergarten method of education, is well known among architects through Frank Lloyd Wright's numerous testimonials to his Froebel training as a child, and the impact this training had on his design philosophy and work. Stiny has shown how Froebel's kindergarten
method of education for children, which closely resembles the studio method of architectural education, can be exploited in a sophisticated programme for developing grammars for original languages of designs.

Stiny's programme has recently been reworked and expanded into a series of coordinated design exercises using the Froebel blocks or other 3-dimensional forms. This new programme of exercises is being used in elective classes in the Design Theory and Methods area of the Architecture and Urban Design Program at U.C.L.A. Students in these classes come from the four degree programs in the school (M.Arch. I, M.Arch. II, M.A., and Ph.D.) and have a variety of backgrounds and levels of experience in architectural design and formal methods. Students from the Department of Design frequently participate in these classes as well. The programme of design exercises with grammars is in two parts. One part is comprised of exercises for developing shape grammars; the other part is comprised of exercises for developing color grammars. Color grammars (Knight 1989), an extension of shape grammars, describe qualitative aspects of designs such as color, texture, materials, function, and so on, in addition to spatial aspects of designs. Both series of exercises deal initially with simple, abstract forms. However, the goal of the exercises is to develop these simple forms into more detailed architectural or other designs. An informal and partial overview of both series of exercises is given here. The formal and complete details of these exercises are described elsewhere (Knight forthcoming).

Designing with Shape Grammars

![Figure 1. Froebel's building gifts.](image)

In the first part of the programme, exercises begin with the definition of simple shape grammars that lead to the definition of more complex ones. The development of shape grammars begins by specifying a vocabulary of 3-dimensional forms or shapes. The shapes in a vocabulary are the building blocks for designs. In class demonstrations, vocabularies are
made up of various blocks from the four building gifts of Froebel - cubes, half-cubes, quarter-cubes, oblongs, squares, and pillars (figure 1). In class projects, students are free to use any 3-dimensional shapes in defining their own vocabularies.

A vocabulary of shapes by itself does not determine designs; it merely determines the pieces from which designs may be made. To actually construct designs, the ways that shapes in a vocabulary can be combined with one another must also be specified. These particular ways of combining shapes are given with spatial relations. Figure 2, for example, shows a spatial relation between two oblongs from the Froebel gifts.

![Spatial relation between two oblongs](image)

**Figure 2.** A spatial relation between two oblongs.

Spatial relations, such as the one shown in figure 2, are compositional ideas for making designs. They provide different contexts for either adding shapes in a vocabulary to one another or subtracting these shapes from one another, to create designs. In more traditional terms, they fix the ways that shapes may be either drawn or erased as a design is made. These two basic actions of adding and subtracting shapes are specified more precisely with shape rules.

Given two shapes A and B that are arranged to form a spatial relation, denoted by $A + B$, four different shape rules can be determined. Two of these rules correspond to adding a shape to a design, two correspond to subtracting a shape from a design:

**addition rules:**

1. $A \rightarrow A + B$
2. $B \rightarrow A + B$

**subtraction rules:**

3. $A + B \rightarrow A$
4. $A + B \rightarrow B$

![Shape rules](image)

**Figure 3.** The four shape rules that can be defined from the spatial relation in figure 2.

Once a compositional idea or spatial relation is chosen, a set of simple grammars, called basic grammars, is defined. Basic grammars are defined using one or both of the two addition
rules defined from the chosen spatial relation. If the shapes in a spatial relation are the same - for example, two oblongs - then only one addition rule is necessary to define each basic grammar. (Basic grammars defined from either of the two addition rules determined from a particular spatial relation generate the same designs but in different orientations.) If the shapes in a spatial relation are different - for example, an oblong and a pillar - then both addition rules are necessary to define each basic grammar. A starting or initial shape to begin the construction of designs is also included in each grammar. The initial shape is one of the two shapes in the chosen spatial relation.

![Diagram showing basic grammars and designs](image)

**Figure 4.** The basic grammars determined from the spatial relation in figure 2. (An open circle is used to indicate a label not in view - one which is either on the bottom front face or the back face of the oblong added on the right-side of a rule.)

Basic grammars distinguish all of the simplest, most basic kinds of designs that can be generated with a particular spatial relation. In other words, they allow all of the most basic consequences of a single compositional idea to be explored. Basic grammars are enumerated systematically by labelling the addition rule (or rules) defined from a spatial relation, according to the symmetry properties of the shapes in the rule. Briefly, the symmetry of a shape is determined by the different isometric transformations that keep the position and orientation of the shape invariant. The transformations that determine the symmetry of the shape on the left-side of a rule can be used to identify the different ways (the different transformations under which) the rule can be applied. The application of a rule can then be restricted to each one of these different ways by adding labels to the shapes in the rule. Each different labelling of a rule, according to the symmetries of the shapes in it, determines a different basic grammar. Each different basic grammar generates designs with distinct spatial properties.

Figure 4, for example, shows all of the basic grammars that can be determined from the spatial relation in figure 2. Eight basic grammars are defined, corresponding to the eight possible symmetry transformations of the oblong. The eight basic grammars are identical except for the labelling of the addition rule (rule (1) in figure 3) in each grammar. The position of the label (a dot) on the oblong on the left-side of each rule is the same; however, the
position of the label on the oblong added on the right-side of each rule is different. These different positions of labels correspond to the eight different symmetry transformations of the oblong. Although each basic grammar is based on the same vocabulary, the same spatial relation, and the same rule, each different labelling of the rule produces unique designs. A design generated by each grammar is shown figure 4. (Technically, each basic grammar must also include a rule to erase labels. For simplicity of presentation, these rules are not shown here and in the grammars that follow.)

![Diagram of initial shapes and rules](image)

**Figure 4.** (continued).

Figures 5 and 6 show some student work produced with basic grammars. The designs in figure 5 are generated by basic grammars determined from a spatial relation between two elongated pillars set apart from one another. Sixteen basic grammars can be defined with this spatial relation (the symmetry of the pillar is 16); six designs generated by six of the basic grammars are shown here.
Figure 5. Designs generated by basic grammars determined from a spatial relation between two separated pillars (Djordje Krstic).

The designs in figure 6 are generated by basic grammars determined from a spatial relation between an oblong and a cube. Three-hundred and eighty-four basic grammars can be defined with this spatial relation (the symmetry of the oblong (8) multiplied by the symmetry of the cube (48)); four designs generated by four of the basic grammars are shown.

Figure 6. Designs generated by basic grammars determined from a spatial relation between an oblong arid a cube (Jeng Tay-Sheng).

Once some or all of the most basic designs implied by a particular spatial relation are identified with basic grammars, more elaborate shape grammars are developed. These more
elaborate grammars, called complex grammars, generate more elaborate designs that combine spatial properties of the designs produced by basic grammars. Complex grammars are defined by elaborating the rules and/or elaborating the initial shapes of basic grammars.

Rules are elaborated by combining the rules of basic grammars in various ways. For example, one of the simplest ways of elaborating rules is to combine the rules of two or more basic grammars, determined from the same spatial relation, into a single grammar. The complex grammar so defined will generate designs that are spatial combinations of the designs generated by each of the basic grammars alone. No matter how complex these designs become, however, they are all still based on a single spatial relation. Figure 7, for instance, shows a complex grammar with two rules from two basic grammars - one from basic grammar (a) in figure 4, the other from basic grammar (h).

Still more complex grammars can be developed by combining rules of basic grammars determined from different spatial relations. These grammars allow designs to be created using more than just one or two shapes and more than one compositional idea. For example, figure 8a shows a basic grammar determined from a spatial relation between two oblongs (the same grammar as basic grammar (b) in figure 4); figure 8b shows a basic grammar determined from a spatial relation between an oblong and a pillar. The rules of these two basic grammars are combined to define the complex grammar shown in figure 8c. This new grammar generates designs that combine in various ways the properties of designs generated by each of the two basic grammars from which it was formed.

![Figure 7](image-url) A complex grammar defined from basic grammars (a) and (h) in figure 4.

Another way to elaborate the rules of grammars is to use subtraction rules. Addition rules allow designs to be built up in accordance with particular spatial relations; subtraction rules allow pieces of these designs to be taken away in accordance with particular spatial relations. For instance, figure 9 illustrates a complex grammar that is the same as the grammar of figure 8c, but with one subtraction rule added. The subtraction rule is based on the same spatial relation as the two addition rules above it. It allows a pillar to be extracted from a design only when it is in the specified spatial relation with an oblong.
Figure 8. A complex grammar (c) defined from two basic grammars (a) and (b), each determined from a different spatial relation.

Figure 9. A complex grammar with a subtraction rule.
Complex grammars can be defined not only by elaborating the rules of grammars but also by elaborating the initial shapes of grammars. One simple way of elaborating an initial shape is to elaborate the way it is labelled. Consider, for example, the grammar in figure 10. Except for the initial shape, this grammar is identical to basic grammar (d) in figure 4. The initial shape has two labels allowing the rule to be applied in two different places. Designs generated by this grammar have identical parts that develop from the same initial shape. Compare the design generated by this grammar with the design generated by basic grammar (d) in figure 4.

![Figure 10](image1.png)

**Figure 10.** A complex grammar with an elaborated initial shape.

Ways of elaborating the initial shapes or rules of grammars are limitless. Some of the more obvious and simple ways, a few of which were described above, are structured into a sequence of exercises that students carry out in class. In their own projects, students either duplicate class exercises using their own vocabularies and spatial relations, or invent their own elaborations on the basis of class exercises. In beginning projects, students are encouraged to be experimental and to work abstractly - the purpose and context of designs are not a consideration. Once students become more facile with grammars, more advanced projects that respond to specific architectural programmes are undertaken. Figure 11 shows a more advanced student project for an historical museum in the Italian hilltown of San Gimignano.

![Figure 11](image2.png)

**Figure 11.** A project for a museum in San Gimignano (Randy Brown).
San Gimignano is probably best known for the many tall defensive towers that once stood throughout the town. Only a few of these towers now remain. The long horizontal corridors of the museum are meant to evoke towers that have fallen down the hillside into a seemingly random heap. The overall massing of the corridors, though, was created with one spatial relation. Figure 12a shows this relation. The massing design of the museum was only one of numerous massing designs explored by the student using basic grammars determined from this one spatial relation. Some of these different massing studies are shown in figure 12b.

While the overall massing of the museum was created with one spatial relation, the details of the museum - for example, the sculptural spire in front of the museum, the display panels, window awnings, and roofing structures - were created with another spatial relation. This spatial relation - between a pillar and a curved rectangular plane - is shown in figure 13a. Some of the many designs created with basic grammars determined from this relation are shown in figure 13b. All of these forms were used in the final design of the museum.
Figure 13. A spatial relation (a), and some designs generated with it (b) (Randy Brown).

Designing with Color Grammars

Once the formal details of shape grammars are understood, exercises for developing color grammars are introduced. Color grammars are developed in an analogous way as shape grammars. First, a vocabulary of colored, 3-dimensional shapes is chosen. Next, spatial relations between colored shapes in the vocabulary are defined. Figure 14a, for example, shows a vocabulary consisting of an oblong with red, yellow, and blue faces, and a handed (reflected) version of this oblong. Figure 14b shows a spatial relation between two of these shapes. Except for colors, this spatial relation is the same as the spatial relation shown earlier in figure 2. Addition and subtraction rules can be determined from this or other spatial relations between colored shapes in exactly the same way that they are determined from a spatial relation between uncolored shapes.
Given a spatial relation between colored shapes, a set of *basic color grammars* can be defined. Like basic shape grammars, basic color grammars are defined using one or both of the two addition rules defined from the chosen spatial relation. However, basic color grammars not only distinguish all of the simplest, most basic designs that can be generated with a particular spatial relation between colored shapes; they also distinguish all of the different possible *colorings* of these designs that can be generated with the spatial relation.

Basic color grammars are enumerated systematically by *repositioning* the shapes in the addition rule (or rules) defined from a spatial relation. Shapes are repositioned so that the geometric relationship between shapes remains the same, but color relationships change. Different repositionings of colored shapes in a rule are analogous to different positionings of labels on uncolored shapes in a rule, as discussed earlier for basic shape grammars. Both colors and labels restrict the ways that rules apply and thus lead to designs with distinct formal properties.

Different repositionings of colored shapes in a rule are enumerated according to both the symmetries of the shapes with color and the symmetries of the shapes without color. Each different repositioning of a shape in a rule determines a different basic color grammar. (Depending on the symmetries of the colored shapes in a rule, labels may also be needed to distinguish basic color grammars.) Some of these different color grammars generate different designs in terms of both form and coloring. Some generate the same designs in terms of form but with different colorings. In general, the set of basic color grammars determined from a particular spatial relation can be divided into equivalence classes, where grammars in different classes generate different forms, and grammars in the same class generate the same forms but with different colorings. The number of equivalence classes and the number of grammars in each class can be calculated according to the symmetries of the shapes in the spatial relation (Knight forthcoming).

Figures 15 and 16 illustrate some of the basic color grammars determined from the spatial relation in figure 14b. Sixty-four basic color grammars are possible, corresponding to the eight possible repositionings of one oblong in the spatial relation multiplied by the eight possible repositionings of the other oblong. The sixty-four basic color grammars can be divided into eight equivalence classes with eight grammars in each class. Figure 15a shows a
basic color grammar from each of the eight different equivalence classes. A design generated by each grammar is shown in figure 15b. Notice that in terms of form, these eight designs are the same as the eight designs determined from the uncolored version of the spatial relation used to determine the designs here. (See figures 2 and 4.)

Figure 15. Basic color grammars from different equivalence classes (a), and the different designs generated by them (b).
Figure 16a shows eight basic color grammars from the same equivalence class. A design generated by each grammar is shown in figure 16b.

![Figure 16a](image1)

![Figure 16b](image2)

**Figure 16.** Basic color grammars from the same equivalence class (a), and the designs generated by them (b).

Figure 17a shows a student project using basic color grammars. Each of the designs shown is generated by a different basic color grammar. However, each color grammar is based on the same two vocabulary elements - a pillar and a square, each with beige, copper, and blue faces - put together in the same geometric relationship. This relationship is shown in figure 17b. The two different forms shown in figure 17a and the three alternative colorings of these forms are produced simply by repositioning shapes in the rules of the grammars. Many other forms and colorings of these forms, besides the ones shown here, are possible.
Figure 17. Two different forms and three alternative colorings of these forms (a) generated with the same vocabulary elements in the same geometric relationship (b).

Once some or all of the designs implied by a particular spatial relation between colored shapes are identified with basic color grammars, more complex color grammars can be developed. These are developed using essentially the same techniques discussed previously for complex shape grammars.

Conclusions

Probably the most exciting aspect of the two series of exercises described here is that starting with simple shapes put together in simple relationships - in other words, starting with simple compositional ideas - many of the possible designs and colorings of these designs that can be generated with the starting shapes and relations can be explored in a systematic and straightforward way. Often, the designs generated this way are ones not likely to be imagined or conceived of otherwise, for example, using the conventional trial and error, studio method
of designing. Students are continually surprised not only by the quality of the designs they produce but, just as importantly, by their understanding of these designs.

One difficulty some students experience, though, is the translation of abstract, experimental forms into architectural designs that fit particular contexts or programmes. Often, this results from a student's inability to predict and control the kinds of forms that will be generated from a particular vocabulary and spatial relation. Experience seems to be the best solution to this problem. And, even though grammars are the basis for making designs, aesthetic, functional, and other traditional design decisions must still be made in the usual way. However, since it is now grammars that are being designed, these decisions can be made not at the level of individual designs but at the level of the more fundamental grammars underlying designs.

The work described here is still very new. Continued work and further refinements of the programme promise to lead to interesting, new grammar-based design work.

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**References**


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