Design as Formal Language

Leandro Madrazo
Department of Architecture
Swiss Federal Institute of Technology
Zurich, Switzerland

Abstract.

Geometry and language are disciplines with which architecture holds a strong relationship. They have highly structured natures, which make them well-suited for computer implementation. Architecture, on the other hand, lacks such an abstract and hierarchical system. This is one of the main obstacles to the integration of computers in architecture at this point. This paper presents the results of a pedagogic approach based on the association of language, geometry and computers. This association can be successfully used in the education of basic design principles that, although not directly related with architecture, are fundamental to the education of an architect.

Introduction.

Geometry and language are disciplines to which architecture has been traditionally related. Geometric figures allow architecture to exist in the realm of abstraction. They make up the vocabulary that allows an architect to project ideas from the mind to an external medium, that is, to design.

Language, on the other hand, has been taken as a model in the quest to systematize architectural knowledge. J.N.L. Durand, who attempted in his theoretical work to define the fundamental principles of architecture, already compared architecture with language: "Les éléments des édifices sont à l'architecture ce que les mots sont au discours, les notes à la musique". After him, many other architects and educators have turned to language looking for cues when trying to turn architecture into an abstract system of knowledge.

This System, is precisely what architecture has tried to borrow from geometry and language. Both geometry and language are characterized by a highly structured system, each one with its own particular abstractions and methods. The abstractions used by language are characters and words, which are combined into sentences according to the rules of syntax of a particular language. Geometry's abstractions are the points, lines and planes. Similar to language, the basic elements of geometry are organized hierarchically: points define lines, lines and points define planes and planes bound solids.
A highly structured nature is what characterizes both, geometry and language. It is not surprising that both language and geometry have been able to make a natural use of computers, since the logic on which a computer operates is also based on symbols, hierarchical structures and rules. Word processors and drafting systems were among the first computer applications, and the most successful so far. This success is due to the existence in both, language and geometry, of a structured system that was ideal for implementation on the computer. This, however, has not been the case with architecture: it is precisely the lack of a structured and abstract system with which architectural knowledge can be, articulated, that continues to impede the integration of computers in architecture.

Teaching Design with Computers.

For the last two academic years in the Chair for Architecture and CAAD at the ETH, we have been teaching a course which is built around the association of language, geometry and computers. We have strived to create an environment that enable us to use computers in design education in a meaningful way. An integral part of this strategy has been to match a certain design philosophy with appropriate computer tools. An important component in the approach we have adopted has been the creation of simple and interactive tools that support the ideas on which the course is based.

One of the goals of this course is to use computers to teach basic design principles without dealing necessarily with specific architectural issues. The reason for this is both theoretical and practical. From a theoretical standpoint, it is a firmly established method in architectural education to introduce students to the logic of design by working first with abstract forms more related to painting and sculpture than to architecture itself. It was a natural step to introduce computers in this area of architectural education. From a pragmatic point of view, there are other reasons for restricting the application of computers to the generation of abstract forms devoid of architectural significance. Currently, computer modeling programs are better suited to handle geometric forms rather than representations of buildings. Also, dealing with architectural objects means dealing with specific architectural issues which pose important conceptual obstacles to current computer tools. Some of these issues are: the problem of scale, the relationships between a three-dimensional model and two-dimensional representations and the difficulties to get quick and high quality outputs.

Course Implementation.

The course is built around the paradigm of types and instances. A vocabulary of extruded profiles represent the types. This vocabulary can be easily edited and modified by means of interactive tools. The types are instantiated in the objects that the students build in ever-y exercise. Specific functions make it possible to edit the attributes of instances so that formal variations can be quickly explored. The idea of substitution associated with instantiation is one of the central topics in the course. After an object has, been built, its components can be replaced by other types in the vocabulary. The process of substitution is performed graphically and interactively using tools designed for that purpose. Formal variations of an object can be quickly generated by replacing different components. Altogether, the different tools provide students with the means to create and modify forms in a simply and interactive way.
Simple types can be hierarchically combined to create the 'compound objects'. In this way, the hierarchical nature of design language can be explored with a tool, the computer, that also operates with hierarchical structures. At the end of the semester, students are given a final exercise in which they are asked to apply the principles they have learned during the course to an architectural problem.

A more detailed description of the tools and individual exercise can be found in a previous paper (Design Education with Computers, L. Madrazo, CAAD Futures 1991). Some changes have been introduced in the exercises and tools since then, but the basic idea remains the same. The goal of this paper is to present some of the results obtained in the last edition of the course.

Transformations of Two-Dimensional Compositions.

This first exercise in two dimensional composition shows the basic format of the initial exercises of the course. A grid of 16 squares is given to the students and they are asked to create four rows of compositions. The initial composition is made in the first column of the layout. The other variations based on the first composition are created in the next columns.

In the exercise in Figure 1, the vocabulary of types used in the composition is made up of colored rectangles. The first composition, in the upper left corner, is made up of two set's of rectangular stripes, one vertical and the other horizontal. Each set is identified with its own color. The spatial arrangement of those elements on the square characterizes the composition. In the following columns, other alternatives are explored using overlapping and rotational transformations.

Figure 1. Two-dimensional compositions with types and instances. Exercise by Gerd Grohe.
Being able to organize elements and to operate with them in a clear and ordered manner is part of the design process, with or without computers. When using computers in design, however, the systematic component of the design process acquires special relevance. The exercise in Figure 1 shows a clear effort to be systematic and creative with a small repertory of element.

Some of the principles that will be explored further in the course are already present in this exercise in a simplified way. The creation of variations from a given type is one of the recurrent topics in the course. In this first exercise, the variations are created by applying the transformations of rotation, reflection and translation to the rectangles. In the following exercises, other sort of operators are provided.

Transformations of Three-dimensional Objects.

The example in Figure 2 shows a sequence of transformations of three-dimensional objects placed on a horizontal plane. There is an initial object/type (the one at the lower left) which is made up of two sets of prisms, each set having its own color. Each rectangular prism of a set is an instance of a colored cube that is part of the design vocabulary.

Figure 2. Variations of an object/type. Exercise by Gerd Grohe.

In the following variations, the elements of the original object/type are 'activated'. In the second variation, one set of prisms is divided into two parts disclosing a new set of parallel prisms inside the cubic envelope. In the third variation, the set is joined again, this time as a band in the center of the cube. Finally, in the last variation the diamond figure disappears from the center as the result of translating the lighter set of prisms. All of these transformations are achieved.
applying the same basic operations of translation and stretching on the same individual elements that were defined in the initial object/type.

As in the example in Figure 1, a consistency exists between the original object/type and the variations that are derived from it. In this case, the consistency is achieved by using the same vocabulary of elements and maintaining the figure of the cube in all variations.

Working with three-dimensional objects involves the use of axonometric or perspective representations. Axonometric view is properly used in this exercise to show the abstractness of the object. The angle of the axonometric view is crucial for displaying the objects with the right proportions. With most of three-dimensional modeling systems, all kinds of perspective representations can be created in real time. It is important to take advantage of those capabilities to explore the way in which the perception of an object changes as a result of trying out different projections on the screen.

**Compositions in Space.**

In a three-dimensional modeling system the description of an object is stored in a database and the images projected on the screen are just the byproduct of that database. This basic fact implies important differences between traditional representation techniques and those of a computer. In manual drawing, the three-dimensionality of an object only exists in the mind of the person who draws or reads the drawing. In a computer, on the other hand, the three dimensional object actually exists as a mathematical representation. From this representation, all sorts of two-dimensional projections can be created.

Although the mathematical transformations that a computer makes to calculate axonometric and perspective views are similar, there is an important difference for a designer between showing an object or building in axonometric and showing it in perspective. An axonometric view represents the object in its abstractness. The eye is located at the infinite, so that any relationship between observer and object is neglected. Perspectives, on the other hand, imply a link between object and subject.

Consider for example the cubes in Figure 3, which are represented in perspective and compare them with the exercise in Figure 2. The main idea is to express a dynamic interaction of objects in space, and for that purpose a perspective is more appropriate than the axonometric. The same object displayed in axonometric produce a completely different effect.
This connection between the three-dimensional object and its projections is also a main theme of the example in Figure 4. Objects appear to float in a non-gravitational space. The impression of depth in the composition is successfully achieved by an intelligent use of perspective projection. The object and the perspective projection work in conjunction to create a the desired effect in the two-dimensional composition. Effectively, the same object shown in plan or axonometric projection transmits completely different impressions.
Substitution.

In linguistics, the relationship between the components of a sentence determines the structure of a language. The words of a sentence can be replaced by another words without necessarily disturbing the 'correctness' of the sentence. For example, in the sentence 'flies are insects', the word 'flies' can be replaced by 'butterflies'. The sentence 'butterflies are insects' remains meaningful. In each case, the structure of the sentence, that is the order subject-verb-direct object is preserved and independent from the actual word that takes the position of the subject. That means that the structure of the sentence is in itself a distinguishable component of the language.

This linguistic model can also be applied to architecture. In classical architecture there is also a division between visible elements (words, in the language) and hidden structure (syntactic rules). For example, the visible elements of a column are the components that make a column of a particular style. For an Ionic column, these components are the base, the shaft and the capital. The hidden structure of the column is then represented by the relationship that exists between the different parts. To the sequence subject-verb-direct object of the sentence corresponds in the column the sequence base-shaft-capital.

This separation between form and structure, following the linguistic model, is fundamental in the application of computers in design. Understanding how an object or building is structured is an intrinsic component of the activity of design, whether it is done with computers or without. Only after the structure of an object is clearly perceived, can the designer explore variations by modifying or replacing the different parts of the object.

Figure 5. Variations of a 'primitive hut'. Exercise by Gerd Grohe.
To apply the concept of substitution is the goal of the exercise shown in Figure 5. The initial object/type is already a well-structured object made up of a base, a vertical body and a horizontal plate on top. In the following variations, some of these components are replaced by other objects, in much the same way that words can be replaced in a sentence. However, all three object-variations have the same structure, that is, the components and the relationships between them is maintained in all three cases.

The structure of the object is revealed in the exploded view in Figure 6. In this final version the different components of the object are more detailed, but the basic structure remains the same. The hierarchical structure of the object and its components can be seen in the illustration: the component that makes the base is made up of two other elements, a horizontal plate and a stepped pyramid; the central element is a set of interwoven porticos and the top element is a grille made up of separate prisms.

**Figure 6.** Exploded view of a 'primitive hut'. Exercise by Gerd Grohe.

One application of the idea of substitution is the concept of 'level of detail' that is used in the following exercise. Given a particular type, for example a red cube, it is possible to create forms with more elaborated shapes based on the original red cube. In the jargon of the course, these elaborations of the simplest types constitute 'levels of detail'. Altogether, they represent only one type in the vocabulary. That means that a type in the vocabulary has multiple formal representations. After an instance of a type is made in the model, it is possible to replace it automatically with a more elaborate representation, a higher level of detail. In this way, the idea of a separation between hidden structure and form is implicit in the tool itself.
The example in Figure 7 is an application of the concept of 'level of detail'. Two different representations of the same object are shown, each one having a different level of detail. The first one is made up of instances of basic types; in the second, more detailed representation of the types are used. The location of the individual instances remains the same in both objects; only the formal representation of each individual type changes.

![Figure 7](image)

**Figure 7.** Two different representations of the same object. Exercise by Miklos Gyarfas.

It is interesting to note the changes that the replacement of the individual parts produce in the perception of the whole. In the example on the left, the different parts and sub-parts from which the object is built can be easily recognized. In that on the right, however, the overall shape seems to disintegrate as the differences between parts blur.

**Type and Figure.**

A common goal in all of the exercises is to explore the relationship between an object/type and the variations created after it. In some of the exercises shown above an initial object describes a theme which is maintained in all the variations. Type can be understood as the figure that delimits a territory within which formal variants are explored in the process of design.
During this process of transformation and development, the attributes of the type can be preserved or consciously neglected. The exercise in Figure 8 illustrates a process of disintegration. The spatial relationships between the components of original object/type are increasing altered in each variation. The initial objects are simple and regular, then the initial order is degenerated into chaos in a step-by-step transformational process. Figure 9 is a detailed view of a final variation resulting from this transformation.

**Figure 8.** From order to chaos. Exercise by Max Dal’Zotto.

**Figure 9.** The degeneration of a type. Exercise by Max Dal’Zotto.
Systems of Elements.

The objects in Figure 10 are the result of overlapping four different systems of elements. Each system can be isolated from the whole: the horizontal prisms, a set of vertical prisms, the cube placed on the diagonal and the emerging shapes intersecting the horizontal prisms. Transformation operations are applied differently to each system of elements. The interaction between the different systems of elements is a formal device that has been used as a 'generator' for architectural project by architects like Richard Meier. Here we can see the results of this sort of device on a series of abstract compositions.

Figure 10. The interaction of systems of elements. Exercise by Gerd Grohe.

Conclusion.

The teaching project described here is based on a theoretical discourse, which seeks to apply computers in a meaningful way in architectural education. Current computer tools are, for design tasks, limited and unable to grasp the whole complexity of the design process, especially for architectural design. However simple the tools that we have introduced are, they can become useful instruments in the education of designers, because the goals have been tailored to the computer current capabilities. By dealing only with abstract objects, devoid of architectural significance, it is possible to teach basic concepts in design such as type or hierarchical structures. The linguistic model has proven to be a successful strategy for teaching these basic design concepts with computers.
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