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A Computational Framework of Composition

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Abstract. *A computational framework of composition appropriate for the architectural studio is outlined. Rule schemata and rules are put into use for the generation of compositions from scratch.*

Keywords. *Conceptual schema; rule schema; rule based composition.*

Introduction

Computer aided design has a strong influence on contemporary design theory and practice. The nature of this influence depends on the way computational concepts and means are introduced in the design process. But even though CAD systems are considered part of the architectural education, the integration of computation in the architectural curricula remains unsatisfactory. The use of CAD systems is either a peripheral task or it demands the total replacement of the existing studio policies. The students end up using computers for drafting and modeling only, or they entirely abandon the established studio techniques in favor of highly convoluted programming procedures. In the end, computational and studio processes remain segregated.

Beginning from this problem, the paper outlines a computational framework of composition hoping to open a path for better integration of computation in the design studio. The broader aim is to combine conceptual computational devices and digital tools without neglecting the traditional studio practice. The novel aspect of the paper is that it explores synthesis from scratch without analysis of existing designs.

Two projects serve as examples. The first example is based on a design competition for low cost housing. It is an elementary exercise on formal composition that combines analogue and digital tools. Starting from a small number of rooms and spatial relations the objective is to produce house designs. The second example presents the development of the plans for an office building. It captures the design steps of a practicing designer. Starting from a specific site and the building program the designer develops a solution based on an initial hypothesis.

Method

The study was conducted along the lines of shape computation theory. It is based on the assumption that in design, apart from anything else, spatial elements are put together to form spatial compositions (Kotsopoulos 2005). The formalism defined in Stiny (1976, 1980, 1991) within which spatial elements are composed with the aid of production rules, is put into use in the studio. Analogous formal models dealing with the treatment of symbols can be found in Carnap (1912) and Chomsky (1957). Rule based methods for the analysis of architectural styles were first discussed in Stiny and Mitchell (1978) in the production of Palladian villa plans. Numerous papers have followed describing the generation of Frank Lloyd Write's prairie houses (Koning and Eizenberg 1981), Japanese tea-room designs (Knight 1981), Queen Ann houses (Flemming 1987), Taiwanese houses (Chiou and Krishnamurti 1995), Yingzao fashi houses (Li 2000), and Siza's houses (Duarte 2001).

The present approach attempts to capture the exploratory effort of an intuitive design process. It involves selection among possible design actions that fall under a general design concept, or hypothesis. The formal expression of these actions is captured by rule schemata. A rule schema represents an indefinite number of such actions by means of a formal expression containing syntactical variables. The formula g(x)->g(y) denotes the rule schema (∀x) (∀y) (g(x) -> g(y)).

Rule schemata describe the interaction of forms in a general manner without requiring a prefixed vocabulary of shapes. Each rule schema applies to the members of a certain class of shapes to produce other shapes. A rule schema determines a rule each time x and y are substituted by specific shapes belonging to some shape algebra Uij. A rule is a rule schema containing no free variables. The predicate g specifies the attributes of the participating shapes x, y. For simplicity these attributes are denoted verbally. For example, g: "x, y are rectangles".

A rule schema applies on an existing shape C in two steps: First, the transformation t matches some part of C geometrically similar to the shape g(x), which appears on the left side of the rule. Second, the same transformation t is used to subtract g(x) from C and to add the shape g(y), which appears on the right side of the rule, in its place:

$$C' = [C - t(g(x))] + t(g(y))$$

The heuristics of the design process are organized in three levels: First, formation rule schemata produce diagrammatic arrangements (partis). Second, transformation rule schemata produce wall-layouts from selected partis. And, third, refinement rule schemata determine tectonic details (windows, doors, stairs, etc.).

Analogue and digital media coexist in the proposed process. The analogue component involves the description of spatial entities, spatial relationships, and rule schemata with pencil and paper, as parts of a general design hypothesis. The digital component involves their testing. A 2d digital interpreter (Liew 2003) is used to allow the mechanical execution of a large number of tests. The testing reveals whether a particular compilation of spatial entities, spatial relationships, and rule schemata produces any acceptable results. If not, the compilation is modified and re-tested. The translation of rule schemata in digital format requires the specification of the variables of the participating shapes (lengths, widths, heights, etc.). The digital tool is particularly useful in the exploration of 2d partis at the stage of formation, especially in Example I. In transformation and refinement the symbolic expressions of the rules become increasingly complex.

Example I

A low cost housing competition sponsored by Habitat For Humanity (2002) in Boston, Massachusetts served as the first experimental project. The program indicated that the goal was: "the building of simple, decent, affordable houses". It called for adaptable 2, 3 or 4-bedroom houses each including a primary entrance, dining and living areas, bathroom, kitchen, and bedrooms. A minimum space was specified for each house type. Among the possible sites were lots less than 5000 s. f., but also lots larger than 20000 s. f.

In the example, each house is approached as an arrangement of rooms. The rooms are arranged according to parametric spatial relations, which are produced by rule schemata. The selection of spatial relations and rule schemata is based on the resulting room-adjacencies. Initially, a limited number of rule schemata generate partis (formation). From a parti several alternative wall-layouts are developed (transformation). Finally tectonic details, windows, doors, stairs, etc. are added in selected wall-layouts (refinement). Through an iterative process of formation, transformation and refinement the rule schemata and rules are evaluated and redefined according to their compliance to programmatic, intuitive, or other criteria.

In general, two rooms can form four spatial relations: (1) they can share a common boundary, (2) they can be placed so that they do not touch, (3) they can meet in a corner point, or (4) they can share some area, or be placed one inside the other.

The spatial relation 1 (Fig. 1) can be used to depict two adjacent rooms having a common boundary. Each room is represented by a parametric rectangle made out of lines, in the algebra U12, which contains lines that are manipulated on the plane. The relation A (Fig. 2) is an instance of the relation 1 (Fig. 1). Four more parametric spatial relations between the same pair of rectangles (rooms) are distinguished. The produced designs are based on these five spatial relations.

The five parametric spatial relationships A, B, C, D, E can be produced by two rule schemata. The rule schema R1AB produces the relations A and B, where a parametric rectangle is added on the short side of an initial parametric rectangle. The rule schema R1CDE produces the relations C, D and E, where a parametric rectangle is added on the long side of an initial parametric rectangle (Fig. 3).

The two rule schemata can be restricted with labels to produce the preferable room adjacencies. A sample derivation beginning from the living room and continuing with the addition of the kitchen, the auxiliary spaces, and the bedrooms appears next (Fig. 4) in plan and axonometric.

When a parti is selected a variety of transformations and refinements are introduced to it. The following figures present sample partis, wall-layouts and designs. The first three columns of figures correspond to the levels of formation, transformation and refinement respectively. A view of a 3d model is also provided.

Example II

The second example presents the development of the plans for the building of a publishing firm in Los Angeles, California. This time the available site for the project is specific, located at the junction of the freeways 10 and 110. The program

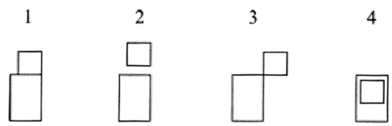

Figure 1. Four generic spatial relations.

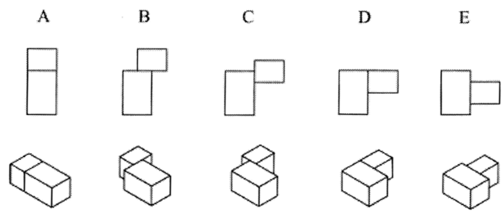

Figure 2. Five parametric spatial relations among rooms.

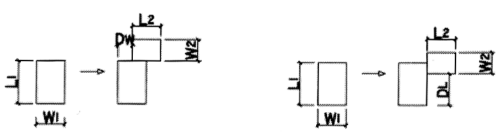

Figure 3. Two rule schemata R1AB (left) and R1CDE (right) produce the relations A,B and C,D,E.

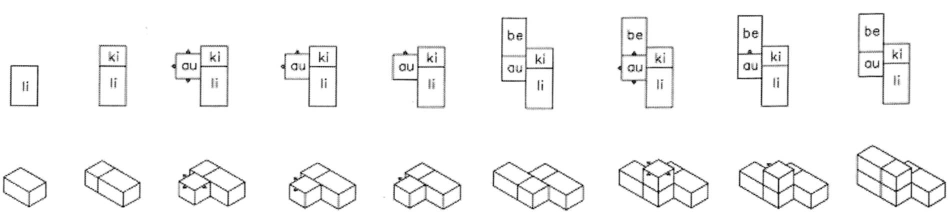

Figure 4. Derivation of a house parti that begins from the living-room.

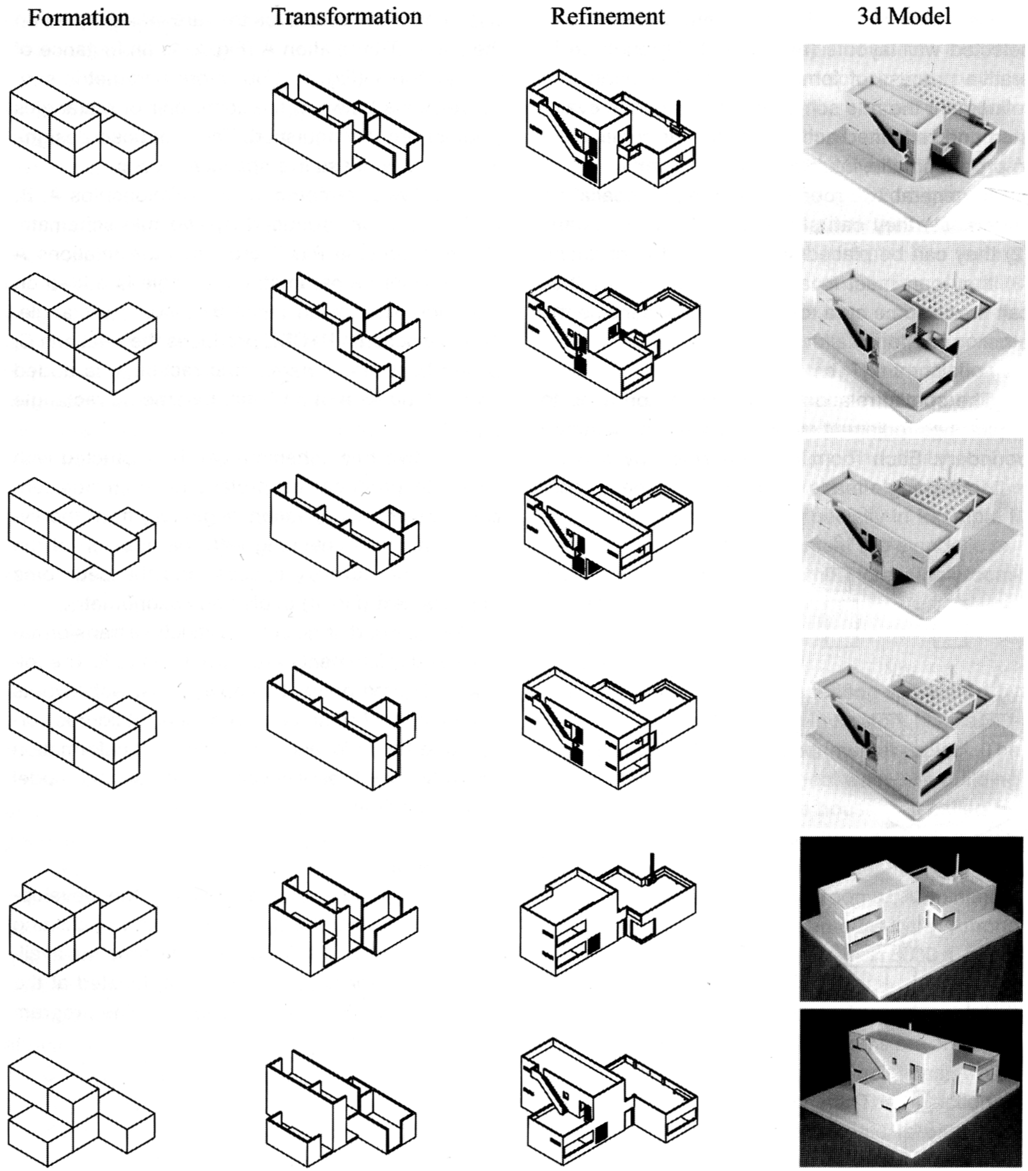

Figure 5. Sample designs at the levels of formation, transformation and refinement.

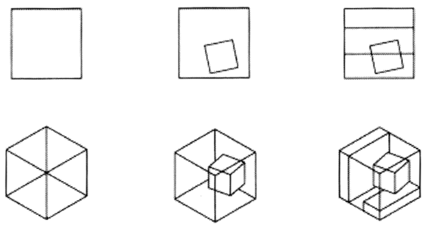

Figure 6. The derivation of the conceptual schema in plan (top) and axonometric (bottom).

Figure 7. Rule schema for placing a room within another (left) and for room division (right).

of the publishing firm includes various private and public spaces. Entrances, exhibition spaces and cafés are open to the public. Private offices, design studios, and study rooms accommodating the working activities of the publishing firm are not open to the public. The square-footage required by the building program fits tightly in the available site area.

The building program and the site are decisive parameters when approaching a design problem. The former determines the functional requirements of the building and the latter the availability of space. It is important to establish a relationship between the two. This relationship is not just the result of analysis of the provided information. It requires judgment and synthesis and takes the role of an initial design hypothesis, or "design concept". A design concept is described through a simple narrative in natural language, it is drawn as a diagram, or it is built as a 3d model (conceptual schema). Example II was based on the following conceptual narrative: "The building is a cubic container occupying the entire usable site-area. A second small cubic container placed within the first accommodates the core creative activities of the firm. Administrative rooms are placed on the perimeter of the exterior cubic container. A public lobby occupies the central, empty ground floor area".

The conceptual schema of spatial organization (parti) is presented next (Fig. 6) in plan and axonometric. The exterior cubic container is represented by its vertices on the left. A smaller cube containing the creative studios of the firm is added within the large cube. The complete conceptual schema with the administrative rooms at the sides of the cubic container appears on the right.

The placement of a room within another is a compositional decision with further implications. And the partitioning of a room is an action that designers perform repeatedly. Both operations are expressed in plan by rule schemata. The first rule schema places one convex shape within another. The second rule schema adds a dividing line to the interior of a convex shape.

The elaboration of the parti is conducted with the aid of additional rule schemata. Rule schemata and rules can be organized to produce specific results. Retrospectively, the systematic ordering of the rules serves to make the information they contain more comprehensive. For example, the rule-systems Grammar I, Grammar II, Grammar III, can be organized to generate the building plans I, II, III respectively (Fig. 8, left). The three plans that derive from the same parti are used to form the entire composition (Fig. 8, right).

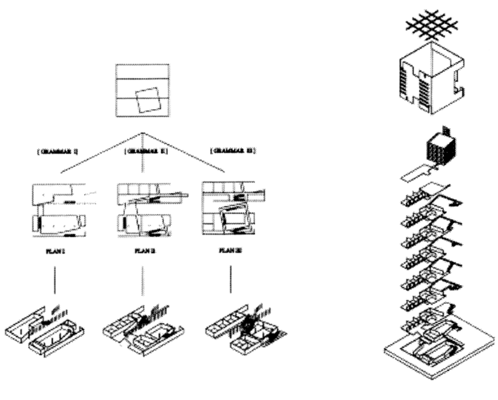

Figure 8. Three plans I, II, III produced by three Grammars I, II, III (left0, form the composition (right)

Discussion

The paper outlines an educational framework of rule based composition. The broader aim of this effort is better integration of computational devices and digital tools in the design studio. Two projects that complement one another are presented as examples. Example I is based on a competition for low cost housing. It is an elementary studio exercise on formal composition. Example II presents the development of the plans for an office building. It is a sample of a systematic design process of a practicing designer.

Example I begins from a simple building program involving a small number of rooms and proceeds to the generation of a variety of houses that may fit in all the available sites. Example II begins from a complex building program involving a large variety of rooms and proceeds to the generation of a building that must fit in a specific, restrictive, site area.

In Example I multiple partis are produced by combining parametric rectangles representing rooms. The resulting partis are gradually developed into house designs. In Example II a single parti is first introduced as a hypothesis. On the basis of this initial arrangement a design solution for the building is developed.

Example I proceeds from the definition of "parts" (rooms) to the definition of possible "wholes" (house arrangements). Example II proceeds from a possible "whole" (parti) to the definition of its "parts" (rooms).

The common aspect of both design examples was the use of rule schemata and rules as abstract expressions of the design decisions. Rule schemata were used to describe the interaction among forms and produce spatial arrangements. In Example I the rooms of a house are represented abstractly by rectangles, and possible arrangements are generated according to rule schemata. In Example II the entire composition is first conceived abstractly as an arrangement of convex shapes where general rule schemata apply.

The heuristics of the design process were organized in three interdependent levels: formation, transformation and refinement. Formation involves the construction of partis, transformation the production of general layouts, and refinement the addition of details. Each level contains rule schemata and rules. The retrospective ordering of the rules can lead to the construction of grammars. A grammar is a formal device able to generate a particular class of designs, which can be metaphorically called design language.

A common objection to the use of rules and grammars in design is that a computational approach of this kind fails to capture the way one acts and thinks. The objection points out that formal representation can represent, at best, only moments of a dynamic network of relations that are constantly changing. Although this objection is reasonable, I think it is missing the point. The issue is not how to mirror "all" the heuristic and pragmatic aspects of a real process, at once, but how to express "some" aspects and features of it. The question is what are the aspects and features that one is interested in, and what is an appropriate formalism to express them.

Winograd and Flores (1987) contrast formal representations with being in the world of human thought by arguing that the projection of human capacities onto computational devices is misleading. Classifications or distinctions caused by formal representation eliminate certain possibilities thus instigating a specific kind of blindness: "Blindness is not something that can be avoided, but it is something that we can be aware. The designer [of a system] is engaged in a conversation of possibilities. Attention to the possibilities being eliminated must be in constant interplay with expectations for the new possibilities being created".

It is true that however ingenious many of the existing formal approaches are, they often have little or no interest from a certain empirical viewpoint. One cannot just pick any formal system and squeeze the empirical content in. The choice of the appropriate computational device becomes an issue of central importance just like choosing the appropriate tool for a specific task.

Computational devices are used in two ways in design: either as prescriptive or as descriptive instruments. A prescriptive system of rules provides a norm for producing results mechanically on the basis of some favored principles (i.e. rules of symmetry). A descriptive system of rules attempts to mirror the behavior of the designer who, on the basis of his finite experience and interaction with a problem, wants to project a particular approach to an indefinite number of future design problems.

An example of the prescriptive approach is the syntactic framework proposed by Eisenman (1982). Eisenman distinguishes between a deep (conceptual) and a surface (perceptual) structure. His approach focuses on the production of form with the aid of syntactic rules. By equalizing deep structure with syntax Eisenman makes syntactic rules the basis for a formal conception of architecture independently from its perceptual meaning. Eisenman's structuralism separates architecture from function and attempts to manipulate form according to laws that are "internal to architecture". It treats architectural elements as symbolic entities and the design process as an investigation into formal structures with no prior empirical justification.

A different prescriptive approach is proposed by Flemming (1990). Flemming defines design languages as corpuses of designs complying with certain compositional principles. The design languages are produced by composing elements that constitute their spatial vocabularies. Flemming distinguishes possible types of such vocabularies: wall architecture, mass architecture, panel architecture, layered architecture, structure/infill architecture, skin architecture etc. Although Flemming's categorization of architectural vocabularies can be debated, his approach is sensibly grounded on experience. After categorizing designs according to their spatial vocabularies Flemming prescribes general compositional rules for each category.

In general, designers consider design rules provisional in contrast to logical or mathematical rules, which are considered permanent. In fact, no formal system can lead to the solution of any problem by itself. Just as a sequence of additions or subtractions can not lead to the discovery of a new mathematical theorem by itself, mechanical rule application can not lead to a design.

In contrast to the prescriptive approach of Eisenman and Flemming the proposed framework of composition is descriptive. Formal rules are not seen as devices that lead mechanically to solutions. Each rule schema, or rule, produces certain effects that a designer aims to create according to a hypothesis. Rule schemata and rules are only a medium for testing the results of one's design decisions. The outcome of the design process is not that some design solution emerges, but that a design hypothesis passes tests.

In design education, a rule based approach need not be distinguished from the ordinary studio policies. They both require good observation and judgment and they are relevant to the education and the preferences of the students. Good observation consists of the ability to identify the parts and the actions that may serve the accomplishment of an objective in a given situation. Good judgment is the ability to decide intelligently among the alternatives. Rule schemata and rules make design decisions clear and allow students to connect them in logical chains and to reason about the results. In this way students can elaborate and test their design hypotheses. Finally, in a time when CAD systems are increasingly involved in the production of architecture, rule schemata provide an excellent medium for conceiving and expressing design thinking in a way that can readily be used in computer implementations.

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