RELATIONS-BASED DRAWING

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Abstract

Relations-based drawing can offer a qualitatively different way to explore shape and form in design. By allowing some elements to control positions and orientations of other elements through geometric relations and dependencies, designers can structure the behavior of the object being designed under future transformations. As design evolves, shapes depicting an evolving design concept can be manipulated and changed dynamically, thus permitting designers to efficiently explore many different options in a semantically sophisticated fashion.

The paper demonstrates how the proposed relations-based approach to design benefits designers by expanding their ability to speculate about possibilities through dynamic manipulation of the design's underlying relational structure. It introduces the relational description of shapes as an explicit formulation of a strategy to form generation and creative discovery in design. It also describes ReDRAW, a limited prototype of a relations-based graphic environment, and discusses some implications of its use in architectural design.

Introduction

Using digital design media to discover and create a new form is a different task than drawing or modeling a known, existing, or already conceived form. It requires computer-based graphic systems that could enable designers to deal with the form or object being created as a "soft" entity, subject to continuous manipulation and change. Consequently, if such systems were to be effective, they should provide interactive and dynamic creation and manipulation of forms or objects being designed with the level of transparency and fluidity common to traditional techniques. Most importantly, if such systems were to actually become design systems, they should be versatile and thought provoking.

The presently available computer-based graphic systems not only lack this capacity, but are also generally limited in their ability to capture the semantic complexity of architectural compositions and to facilitate their transformation during the course of development. They are essentially representation tools, with a limited role in the design process, due primarily to their semantic deficiency--all the choices made 'elsewhere' during design development about shapes, sizes, and relations are left out. This paper attempts to address this semantic 'impoverishment' by introducing a drawing system that provides means to record and maintain some of the design decisions made at a very basic level of geometric relations. It also presents ReDRAW, a limited prototype of a relations-based drawing system and demonstrates its usefulness in architectural design as a dynamic, versatile and stimulating medium to deal with the design during its "soft" and dynamically tentative states, when the solution is still unknown and under exploration.

Shapes, Regulating Lines, and Geometric Relations

The act of drawing is fundamental to the act of designing. In architectural design much of the creative discovery takes place in the two-dimensional realm of study drawings. Many prominent designers (Robert Stern, Stanley Tigerman, Helmut Jahn) use their study drawings as active participants in design thinking, as a medium that generates new information within the design task (Herbert 1992). According to Michael Graves, there is an "inevitable reciprocity that occurs in the architectural design process between the act of drawing and the thinking associated with it - between 'the image' and 'the mind'" (Graves 1977). Drawings are semantically charged--

they induce circumstantial discoveries and generate information that the designer could not have conceived originally.

Shapes are fundamental to the act of drawing. Through shapes designers express and examine ideas and represent elements of design. Shapes denote edges and boundaries, spaces, building elements, or abstract concepts such as diagrams. The role of shapes in design is significant--they represent and inform.

In architectural design, as in other design disciplines, shapes are frequently constructed within some graphic context, which is at a basic compositional level set by some abstract organizational devices, such as grids, axes, and regulating (or construction) lines. For example, Durand and Sullivan relied heavily on grids (patterns of regulating lines) and axes (regulating lines of specific importance). Le Corbusier's work from the purist period, both in architecture and painting, was guided by the application of regulating lines-"les tracés régulateurs" (Figure 1).

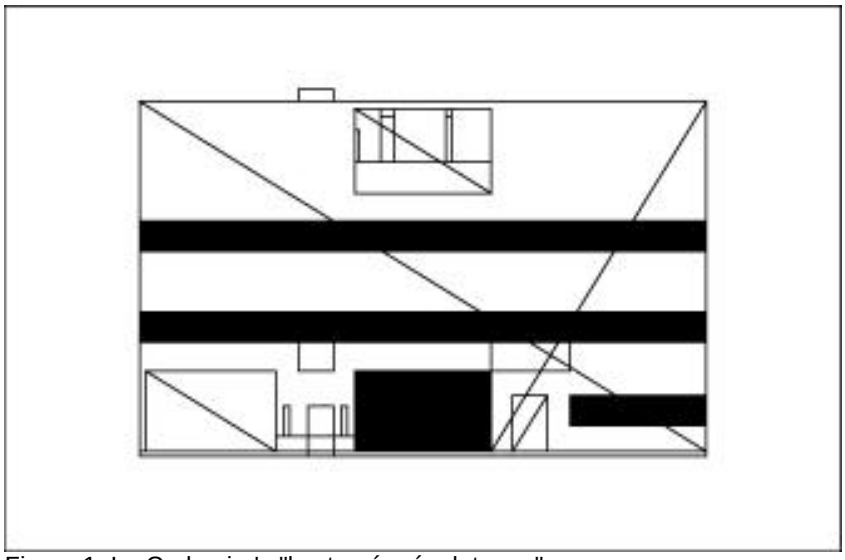

Figure 1. Le Corbusier's "les tracés régulateurs."

Regulating lines can provide, at a basic compositional level, an organizing framework for establishing positions and relations of line segments within and between shapes. The regulating lines, however, can become much more useful and interesting when they are used not just as a rigid skeleton for the delineation of shapes, but to regulate the behavior of a drawing and to maintain its essential structure as its parts are manipulated. In other words, by allowing some regulating lines to control positions and orientations of other lines through their geometric relations and dependencies, we can structure the behavior of the object being designed under transformations. A computer based design "assistant" can record and maintain once established relationships, recognize the emergent ones, and compute the consequences of design transformations while preserving the semantic integrity of the drawing.

In this scenario, regulating lines define a compositional framework for establishing positions and relations of shapes. Shapes are constructed as combinations of shape primitives--line segments--delimited by intersecting regulating lines (Figure 2). Each line segment has an underlying regulating line as a baseline, and two regulating lines that intersect the baseline. This process of delineation is very similar to traditional manual drafting practice, whereby "pencil" (regulating) lines are laid out first, followed by "inking" of the selected portions between intersections.

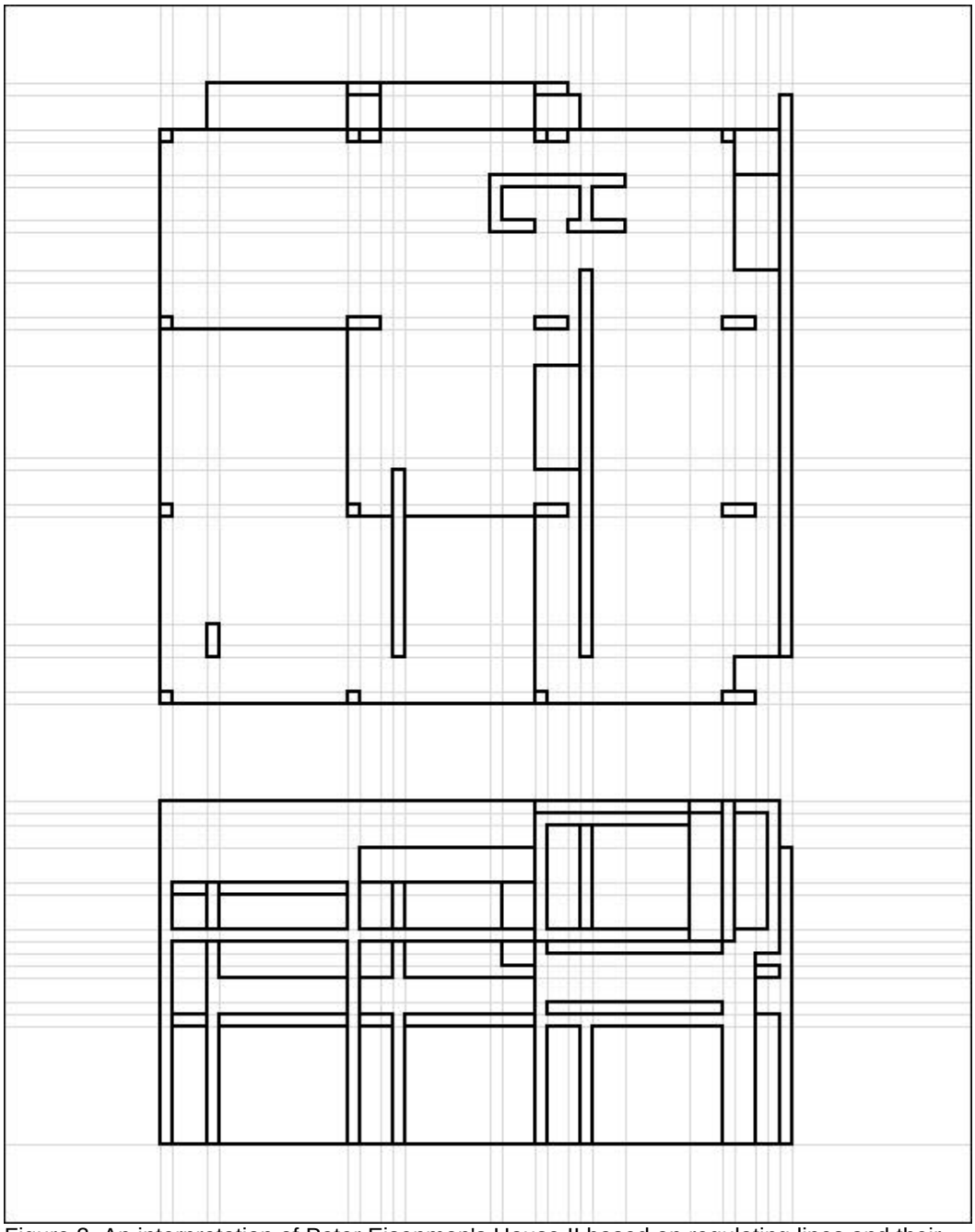

Figure 2. An interpretation of Peter Eisenman's House II based on regulating lines and their geometric relationships. Geometric shapes and relations are abstracted and translated into a relational drawing. New designs can be created by applying the transformations of translation and rotation (figures 4 and 5).

A fairly small repertoire of carefully selected geometric relations, such as

CONNECTED AT a point,
INTERSECTED AT a point,
ALIGNED ALONG a line,
PARALLEL TO a line,
PERPENDICULAR TO a line,
ANGLED TO a line, and
SYMMETRICAL (bilaterally) TO a line,

which are present or recognizable in any architectural composition, can be used to establish dependencies between regulating lines and line segments in shapes. Furthermore, new relations could be defined as combinations of already defined relations (Kolarevic 1993).

The architectural composition then essentially becomes a process of forming geometric relations between regulating lines. Design begins by first laying out inter-related regulating lines--its organizing framework. Shapes are then constructed by delineating underlying and intersecting regulating lines. As design evolves, shapes depicting an evolving design concept can be manipulated and changed dynamically. New regulating lines, relations and shapes can be added or the existing ones changed. In the process, many different options can be explored.

ReDRAW - A Relations-Based Drawing System

ReDRAW (RElational DRAWing), a working, but very limited prototype of a relations-based drawing system (Figure 3), was developed to explore some of the computational and application issues associated with the relational description of shapes (Kolarevic 1993, 1994). It is partly modeled on traditional drawing practice, as previously described. A user lays out infinite "pencil" regulating lines and simultaneously specifies positional relations (none, parallel, perpendicular, or angled) and dependencies (none, uni- or bi-directional) between them.

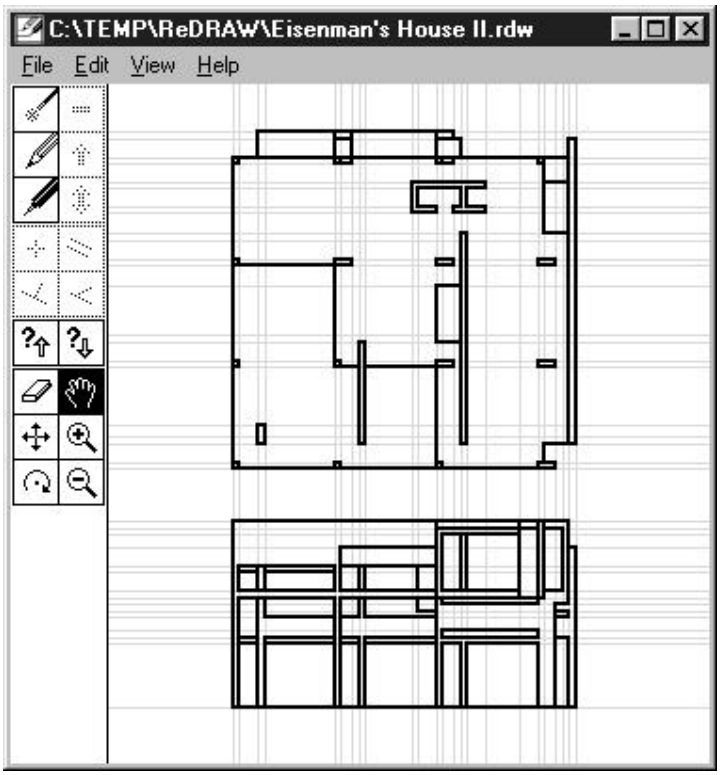

Figure 3. ReDRAW's drawing window with icon menu.

To construct shapes, user "inks" selected portions of "pencil" lines that are bound by intersections with other regulating lines. The user manipulates created compositions by applying editing operations (erase, move, rotate) to selected regulating lines. ReDRAW automatically propagates changes while maintaining previously established relations. If some of the relations cannot be maintained during transformation, it can automatically establish new relations (in the "Smart Mode") or delete them. The user can also change once established relations, either by changing the type of the relationship or dependency.

ReDRAW supports only hierarchical, uni- or bi-directional dependencies. Its maintenance mechanism is based on simple, direct propagation through recursive traversal up and down the tree database structure (because of the bi-directional dependencies). The conflicts in propagation are resolved in two ways, i.e., two modes: inactive and active. In the inactive mode, ReDRAW simply eliminates invalidated relations. In active ("smart") mode, it establishes new uni-directional relationships based on an angle between the two lines. In short, invalidated relations are either eliminated or new relations are established. This simple strategy

eliminates extensive user intervention in solving potentially numerous low-level conflicts, which may be too distracting and unimportant in the design process. (After all, if the results of propagation are unacceptable, user can always use the "undo" command.) ReDRAW also provides for substitution of once established relationships. Both the relationship and dependency can be changed by using the "magic wand" tool. ReDRAW also has a capacity to recognize dependency cycles, which could result from changing, or substituting an existing relationship. If ReDRAW recognizes a dependency cycle, it cancels the substitution and informs the user of its action. (For more information about ReDRAW's data structures, important algorithms, interface, and usage rules see Kolarevic 1993, 1994).

Since hundreds or thousands of geometric relations can be established in a typical architectural parti, a designer will need some ability to anticipate the consequences of propagating changes through the composition after some transformation. The problem is that the compositional complexity, or a number of relations alone, will make the "mental" tracking of dependencies almost impossible. A computer-based graphic context, such as ReDRAW, should therefore aid designers in visualizing dependencies within the drawing. ReDRAW supports four types of queries of dependencies and relationships established in the composition. First, a user can query the database for a parent relationship of a selected "pencil" line-the type, dependency, and reference (i.e., parent) construction line will be graphically displayed. Second, a user can request that direct "dependents" of a selected "pencil" line be displayed. Third, users can query the drawing database to display all regulating lines to be affected by a certain transformation. Lastly, users can request a display of all regulating lines whose transformation would affect a selected line.

In its current version, ReDRAW supports straight (linear) regulating lines only. Its repertoire of positional relations is also purposely limited to only three binary relations-parallel, perpendicular, and angled. Ternary relations, such as symmetry and intersection, are not currently supported, since they can introduce cycles into ReDRAW's database representation. In addition to these two relations, the next version should also provide circular "pencil" lines and parametric definition of relations. By incorporating shape recognition capabilities of Tan's ECART (Tan 1991), it could also support "search and replace" function of shape grammars.

Like most prototype developments, ReDRAW evolved from assumptions and expectations, which would require some change in order for ReDRAW to develop into a more fully-implemented design tool. Furthermore, the introduced concept of shape delineation based on regulating lines and their geometric relations can be extended into three-dimensional modeling. Regulating planes can become primary constructs--their intersections can define regulating lines.

Drawing and Designing Using Relations

"After all, nothing is more fundamental in design than formation and discovery of relationships among parts of a composition."

- William Mitchell and Malcolm McCullough (1991)

As a design "tool," ReDRAW is seen as an active agent in a design process rather than a passive record of the design development. It is envisioned as a tool that can efficiently and effectively generate new information within the design task through graphic processes, i.e., dynamic manipulation of architectural compositions. Its capability to generate new information, however, is highly dependent on designer's perceptual and cognitive abilities. Its generative role is accomplished through the designer's simultaneous interpretation and manipulation of a graphic image in a complex discourse that is continuously reconstituting itself-a 'self-reflexive' discourse in which graphics actively shape the designer's thinking process.

Using geometric relations, a designer can enforce desired spatial configurations of building components and spaces (Figure 2). The established relations constrain the design possibilities--they structure possible manipulations. How the composition is assembled, structured, or re-structured, determines its developmental potential. The choice of relationships applied in a composition (parti) may result in dramatically different designs even though a small set of possible relations and a few transformations are available. As William Mitchell (1989) observes:

"[T]he choice of modeling conventions and organizational devices that will structure the internal symbolic model [...] will determine how the model can be manipulated, and what can be done with it."

The relations, however, do not prescribe a particular form--they bound a space of alternatives without specifying a solution to the design task. "Composition often becomes a game of translating and rotating shapes to vary their spatial relations," writes William Mitchell (1990b). By applying different transformations, such as translation or rotation, to the parts of the composition, designers can explore various alternatives (Figures 4 and 5).

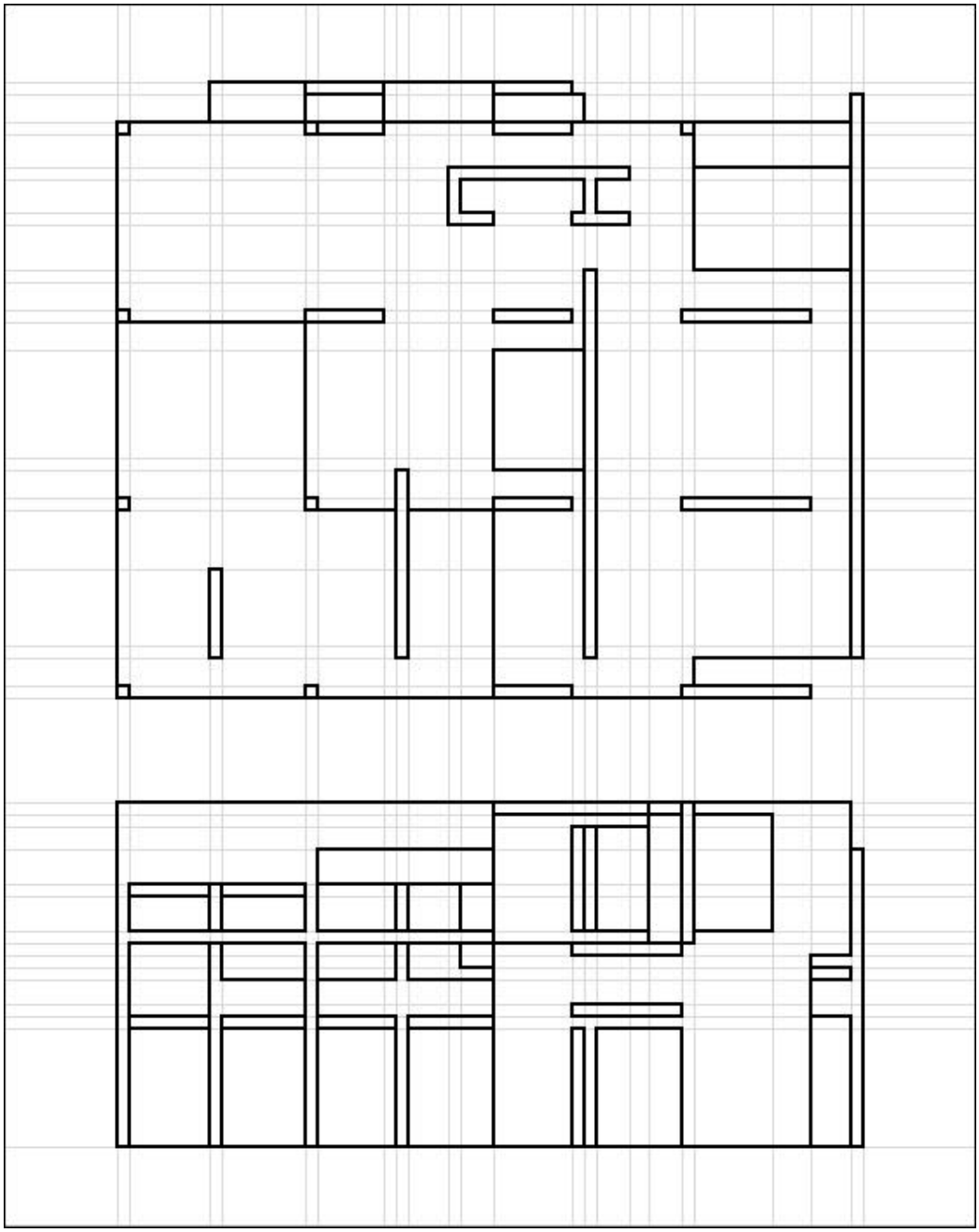

Figure 4. A possible transformation of Peter Eisenman's House II, based on an interpretation illustrated in figure 2.

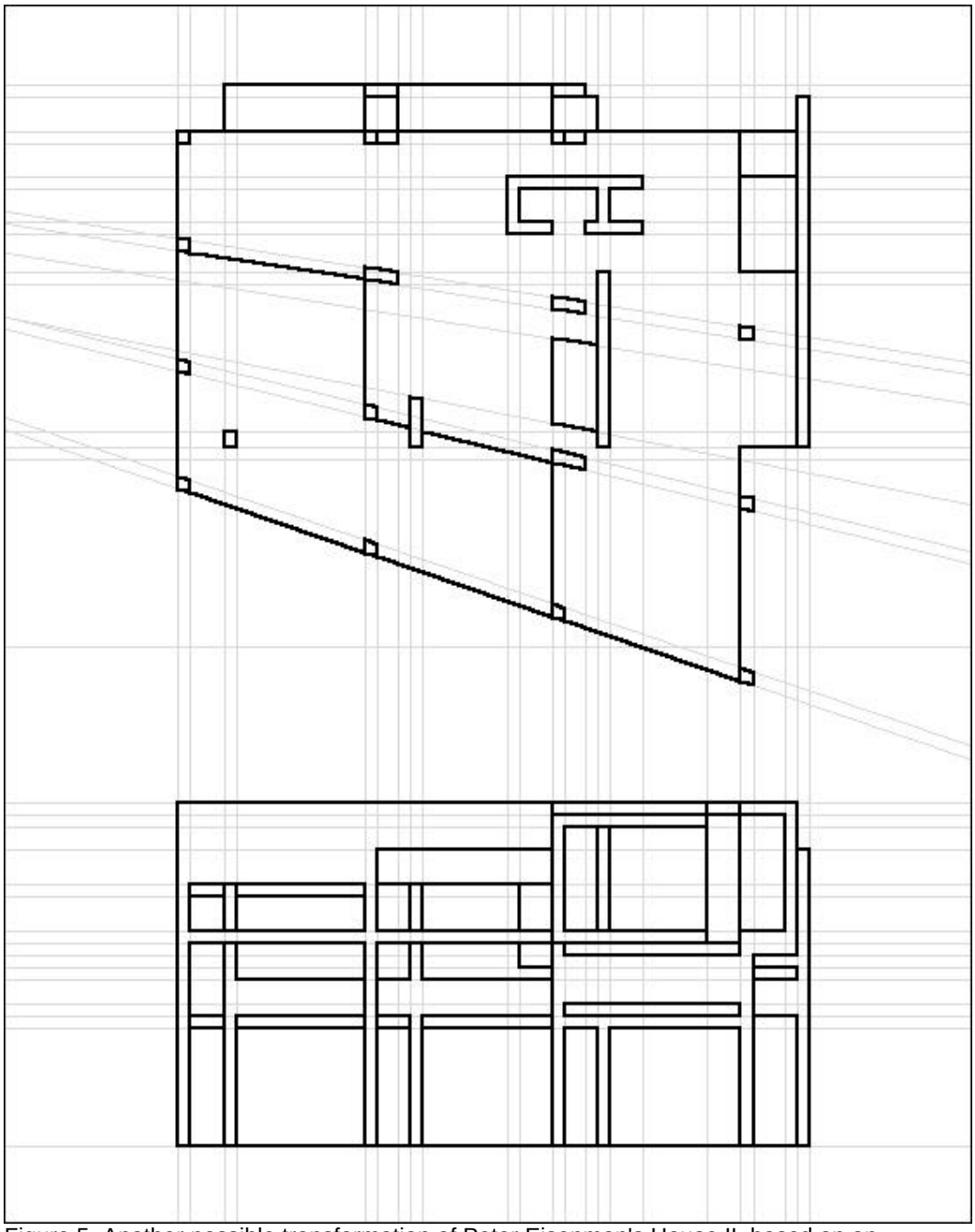

Figure 5. Another possible transformation of Peter Eisenman's House II, based on an interpretation illustrated in figure 2.

Relationships and dependencies determine the behavior of the model. A designer must understand them to operate successfully upon them. This understanding is required on a basic, pragmatic level--if an object is moved, what other objects will move too. However, if a composition is too complex, applying a transformation to it might be difficult to control and envision. In other words, the consequences of propagating changes to the composition after applying a transformation can be very surprising. Resulting configurations can be genuinely new, and, in some instances, might trigger innovation and creativity. If the results of the operations were absolutely predictable, there would be little room left for creative discovery. "Imagination needs something to play with," asserts Mitchell (1990a). A drawing can become a vehicle on a path from known to unknown, from predictable to unpredictable.

As Tan (1991) observed, one of the major features of creativity "is the way in which it pioneers new contents-less in magically 'creating' something out of nothing, than a re-creation or re-framing." It is precisely this re-framing or re-structuring that is in the focal point of this work, which foresees geometric relations and transformations as a vehicle to support it.

Conclusions

The paper described how relations-based approach to drawing could offer a qualitatively different way to explore shape and form in design. It demonstrated how interrelated regulating lines, as an organizing device in design drawing, could become much more useful and interesting when they are used not just as a rigid skeleton, but to regulate the behavior of a drawing and to maintain its essential structure as its parts are manipulated. Drawings could become semantically charged and could be manipulated in a semantically sophisticated fashion. Designers could structure the behavior of the object being designed under future transformations. They could explore design alternatives by simply manipulating the drawing's underlying relational structure.

The paper also presented ReDRAW, a limited prototype of a relations-based graphic system, and discussed some implications of its use in architectural design as a dynamic, versatile and stimulating medium. ReDRAW was presented as an active agent in a design process rather than a passive record of design development.

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