RELATIONAL DESCRIPTION OF SHAPES AND FORM GENERATION

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Abstract. The paper describes a relations-based graphic environment for shape delineation and dynamic drawing manipulation that can provide a qualitatively different way to explore shape, dimension, and geometric organization. Relational description of shapes based on the concept of construction or regulating lines is introduced as an explicit formulation of a strategy to form generation and creative discovery. A limited prototype of the relations-based graphic system, called ReDRAW, is briefly described and the implications of its use in conceptual architectural design are discussed.

1. Introduction

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

Using computer-based media to discover and create new form is a different task than drawing or modeling a known, existing, or already conceived form. It requires computer-based design systems which can treat the form or object being created as an entity subject to continuous manipulation and change. For these systems 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, for these computer-based graphic systems to become actual design systems, they should be versatile and thought provoking.

In architectural design much of the creative discovery takes place in the two-dimensional realm of study drawings. An apparent contradiction, however, emerges in closer examination of this process. The act of drawing, as well as other traditional ways of communicating spatial information in architectural design, is inherently static—it produces drawings, snapshots of an evolving
design concept. The act of designing, however, is intrinsically dynamic. Shapes depicting an evolving design concept are seldom static—they change constantly.

The recognition of this disparity between drawing as a static and design as a dynamic activity provided an impetus1 to search for a dynamic design medium. A computer-based graphic context for design conceptualization based on regulating or construction lines and their geometric relations is described, its prototype implementation is presented, and application implications are discussed in this paper.

2. Shape Delineation Based on Construction Lines and Geometric Relations

"The line occupies the absolutely dominating position in all representations of form. It is therefore the starting point of all compositional work."—Iakov Chernikhov (1931)

Shapes, or "figures," as referred to by the Russian Constructivist Iakov Chernikhov, 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. Their role in design is significant—they represent and inform.

![Figure 1. Le Corbusier's "les tracés régulateurs."](image)

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 construction lines. For example, Durand and Sullivan relied heavily on grids (patterns of construction lines) and axes (construction lines of specific

1 Another impetus comes from the inability to adequately represent and manipulate design relationships using traditional media.
importance). Le Corbusier's work from the purist period, both in architecture and painting, was guided by the application of regulating (i.e., construction) lines—"les tracés régulateurs" (Figure 1).

*Figure 2.* "Pencil" construction lines and "inked" line segments. An interpretation and incremental assembly of Peter Eisenman's House II based on the concept of construction lines and their 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).

Regulating or construction lines provide at a basic compositional level an organizing framework for establishing positions and relations of line segments within and between shapes. The construction 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 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. As a consequence, drawings can become semantically charged and can be manipulated in a semantically sophisticated fashion. 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, construction lines\(^2\) define a compositional framework for establishing positions and relations of shapes. Shapes are constructed as combinations of shape primitives—"inked" line segments—delimited by intersecting construction lines (Figure 2). Each "inked" line segment has an underlying construction line as a baseline, and two construction lines that intersect the baseline. This process of delineation is very similar to traditional manual drafting practice, whereby "pencil" (construction) lines are laid out first, followed by "inking" of the selected portions between intersections.

A rather small repertoire of geometric relations\(^3\), which are present or recognizable in any architectural composition, can be used to establish dependencies between construction lines and "inked" line segments:

- CONNECTED AT a point
- INTERSECTED AT a point
- ALIGNED ALONG a curve
- PARALLEL TO a curve
- PERPENDICULAR TO a curve
- ANGLED TO a curve
- SYMMETRICAL (bilaterally) TO a curve

The hypothesis is that a fairly small set of carefully selected relations could provide an appropriate compositional repertoire. New relations could be defined as combinations of already defined relations.\(^4\)

The architectural composition then essentially becomes a process of forming geometric relations between construction lines. Shapes are constructed by delineating underlying and intersecting construction lines. Design begins by first laying out inter-related construction lines—its organizing framework. It proceeds with the designer adding new construction lines, relations and shapes or changing the existing ones. In the process, many different options may be

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\(^2\) The construction lines are not necessarily linear. We can classify construction lines "according to the movement characteristics of the point generating the line" (Chernikov 1931) as straight (linear) or curved. Curved lines can be broken into subclasses: circular, elliptical, parabolic, sinusoidal, etc.

\(^3\) Also, it is important to note that these are not the only geometric relations that can comprise the lexicon. The number of geometric relations is indeed quite large and cannot be determined in advance.

\(^4\) For a detailed discussion of geometric relations and their properties see (Kolarevic 1993).
explored. As design evolves, shapes depicting an evolving design concept are manipulated and changed dynamically.

3. ReDRA W — A Relations-Based Drawing System

ReDRA W (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” construction lines and specifies simultaneously positional relations (none, parallel, perpendicular or angled) and dependency (none, uni-directional or bi-directional) between them. Currently, ReDRA W supports straight (linear) construction 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 ReDRA W’s database representation.⁵

![Figure 3. ReDRA W's drawing window with icon menu.](image)

To construct shapes user “inks” selected portions of construction lines that are bound by intersections with other construction lines. Connectivity and alignment relations between shape segments are implicitly supported through

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⁵ For more information about ReDRA W’s data structures, important algorithms, interface, and usage rules see (Kolarevic 1993, 1994).
the database structure.\footnote{See (Kolarevic 1993, 1994) for a detailed description of the drawing database structure.} The user manipulates created compositions by applying editing operations (erase, move, rotate) to selected construction 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.

As already mentioned, 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). ReDRAW employs an incremental propagation technique, i.e., relations are satisfied sequentially. In its current capacity, ReDRAW does not involve any equations to satisfy geometric relations—relations are simply satisfied by only two actions: translation and rotation. The conflicts in propagation are resolved in two ways. In the inactive mode, ReDRAW simply eliminates invalidated relations. In the "smart" or active mode, it establishes new uni-directional relationships by computing the angle between the two construction lines. This is not a perfect solution, since all of the conflicts which might result from propagating a single transformation through the hierarchy are handled in the same manner. In other words, invalidated relations are either eliminated or new ones are established. This rather simply strategy, however, eliminates extensive user intervention in solving potentially numerous low-level conflicts, which may be too distracting and unimportant in the process of design conceptualization. (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 type of the relationship and the dependency could be changed by using the "magic wand" tool. After new relationship and dependency are selected, user selects a construction line whose parent relationship will be changed, and then selects a new reference, a new parent construction line.\footnote{Changing, or substituting an existing relationship can introduce cyclical dependencies. If ReDRAW recognizes a dependency cycle, it cancels the substitution and informs the user of its action.}

Since hundreds, or even thousand, of geometric relations might be established in an architectural parti, a designer will need some ability to anticipate the consequences of propagating changes after transformation through the composition. The 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 a designer in visualizing the dependencies within a drawing. ReDRAW supports four types of queries regarding the dependencies and relationship established in the
composition. First, user can query the database for a parent relationship of a selected construction line, and request the information about its type, dependency direction, and a reference (i.e., parent) construction line. Second, user can request that direct dependents of a selected construction line be displayed. Since ReDRAW supports both uni- and bi-directional dependencies, transformations can affect construction lines throughout the hierarchy, not just "below" the construction line to which the transformation is directly applied. As a consequence, user can query the database to display all construction lines to be affected by the application of a certain transformation. In addition, user can request the display of all construction lines whose transformation will affect the selected construction line.

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. The existing version of ReDRAW was limited in its features—its primary purpose was to serve as a testbed for the investigation. The next version should overcome the primary deficiency of the first version, a lack of two very important ternary relationships: bilateral symmetry and intersection. Implementing ternary relations will require a slightly different database structure and probably a very different database maintenance mechanism, which will become increasingly more complex, and will probably rely on relaxation to resolve potential conflicts. The next version of ReDRAW should also provide circular construction 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.\(^8\)

Further more, the introduced idea of construction lines and their geometric relations could be extended into three-dimensional modeling. Construction planes would become primary constructs; their intersection would define construction lines whose intersection would define construction points. After all, construction lines are nothing more than intersections of perpendicular construction planes with the "base" construction plane. On a more pragmatic side, a drawing or a 3D model based on geometric relations might have wide application in its post-processing. For example, it could facilitate dimensioning of building structural elements (Richens 1975); in construction robotics it could be used in assembly operations to define fixing operation and transportation path of a component in order to achieve desired spatial relations (Earl 1986, Woodbury 1986).

\(^8\) Tan's ECART prototype for shape recognition (Tan 1991) and ReDRAW share a similar database representation. By incorporating the results of Tan's study, ReDRAW's value as a conceptualization tool could be considerably expanded.
4. Relations-Based Drawing and Design

As a conceptualization “tool,” ReDRAW is seen as an active agent in a design process rather than a passive record of design development. ReDRAW, and the proposed concept of geometric relations as a framework for design conceptualization, are envisioned as means to efficiently and effectively generate new information within the design task through graphic processes, i.e., dynamic manipulation of architectural compositions. ReDRAW’s capability to generate new information 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.

Figure 4. A possible transformation of Peter Eisenman’s House II, based on an interpretation illustrated in figure 2.
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. The choice of relationships applied in a composition (parti) may result in a dramatically different designs even though a small set of possible relations and a few transformations are available. How the composition is assembled, structured, or re-structured, determines its developmental potential. 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."

*Figure 5. Another possible transformation of Peter Eisenman’s House II, based on an interpretation illustrated in figure 2.*
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 explore various alternatives (Figures 4 and 5).

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 are 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. One formal universe might collapse into another, order can turn into chaos.9

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" (Tan 1991). 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.

5. Conclusions

This paper explored a relational description of shapes based on the concept of regulating or construction lines and their geometric relations as an explicit formulation of a strategy to form generation and creative discovery. It demonstrated how interrelated construction lines, as an organizing device in design conceptualization, 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. Designers could structure the behavior of the object being designed under future transformations; drawings could become semantically charged and could be manipulated in a semantically sophisticated fashion. The paper also presented ReDRAW, a limited prototype of a relations-based graphic system, and

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9 As Wojtowicz (1990) demonstrates in his doctoral thesis, poetic invention in design frequently coincides with the discontinuity, rupture and sometimes collapse of the formal design language.
discussed its application in conceptual architectural design as a dynamic, versatile and stimulating medium.

The principal conclusion is not that designing is necessarily done as proposed, but that it might and beneficially be. The proposed relations-based approach to design conceptualization benefits designers by allowing them to efficiently and effectively generate new information within the design task through graphic processes, i.e., by providing graphic means of generating new but always contingent information within the design task through dynamic manipulation of the design object’s relational structure. It expands the designer’s ability to speculate about possibilities. It places value on explicit formulation—its use requires “discipline” and an understanding of the relation-based approach to design as a method. Once the approach is understood, it can be used effectively to “program” the “behavior” of a design object.

References
