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Designing with regulating lines and geometric relations

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Abstract

This paper introduces regulating lines and geometric relations as a framework for shape delineation and dynamic drawing manipulation. It describes a relation - based graphic environment that can provide a qualitatively different way to explore shape, dimension, and geometric organisation in design. It also presents ReDraw, a limited prototype of the relations-based graphic system, and discusses some implications of its use in conceptual architectural design.

1. Introduction

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 the intertwined acts of drawing and designing. The act of drawing 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 change constantly, i.e., they are seldom static.

The recognition of this disparity between drawing as a static and design as a dynamic activity, and the inability to adequately represent and manipulate design relationships using traditional means, provided an impetus to search for a computer-based drawing and design medium that can provide a qualitatively different way to explore shape, dimension, and geometric organisation. The result of that search, a computer-based graphic context for shape delineation based on regulating 'pencil' lines and their geometric relations, is described in this paper, its prototype implementation presented, and application implications discussed.

2. Regulating lines, geometric relations, and shapes

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. Their role 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 organisational 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 traces regulateurs" (Figure 1).

Regulating "pencil" lines therefore often provide, at a basic compositional level, an organising framework for establishing positions and relations of "inked" line segments within and between shapes. Those "pencil" 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 behaviour of a drawing and to maintain its essential structure as its parts are manipulated. In other words, by allowing some "pencil" lines to control positions and orientations of other lines through their geometric relations and dependencies, we can structure the behaviour of the object being designed under transformations. A computer based design "assistant" can record and maintain once established relationships, recognise the

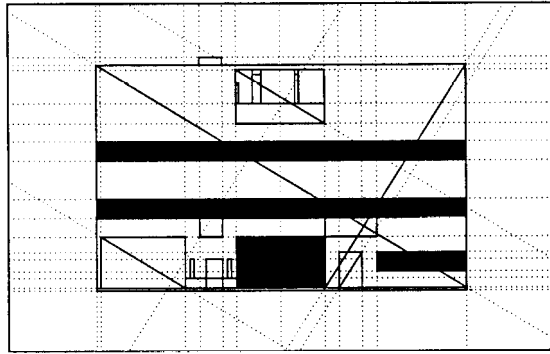


Figure 1. Le Corbusier's "les traces regulateurs."

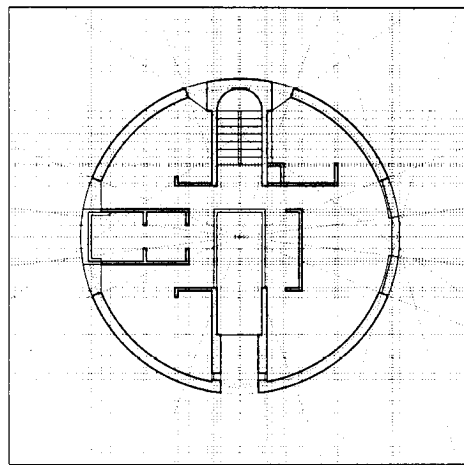


Figure 2. "Pencil" (regulating) lines and "inked" line segments. An interpretation of Mario Botta's Casa Rotunda based on regulating lines and their geometric relationships. Geometric shapes and relations are abstracted and translated into a relational drawing. New designs can be created by applying the transformations of translation and rotation (figures 4 and 5).

emergent ones, and compute the consequences of design transformations while preserving the semantic integrity of the drawing.

In this scenario, regulating "pencil" lines¹ (See Notes) 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 regulating lines (Figure 2). Each "inked" 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.

A rather small repertoire of geometric relations², which are present or recognisable in any architectural composition, can be used to establish dependencies between "pencil" 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

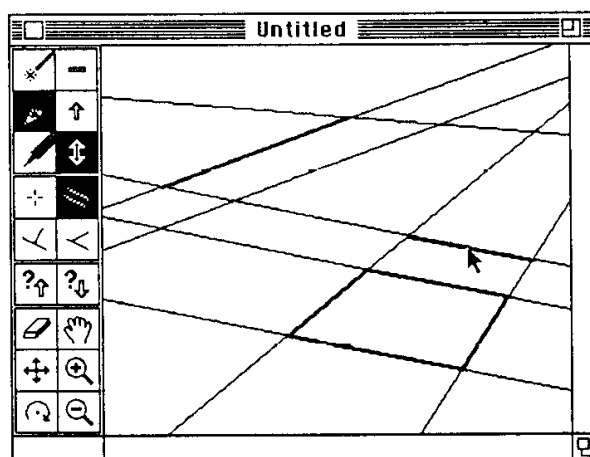


Figure 3. ReDRAW's drawing window with icon menu.

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

3. 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 modelled 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.³

To construct shapes, user "inks" selected portions of "pencil" lines that are bound by intersections with other regulating lines.⁴ 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).⁵ 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.⁶

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 visualising 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 will affect a selected line.⁷

The existing version of ReDRAW is limited in its features. The next version should add two very important ternary relationships: bilateral symmetry and intersection⁸. 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.⁹

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 introduced concept of shape delineation based on regulating lines and their geometric relations can be extended into three-dimensional modelling. Regulating planes can become primary constructs - their intersections can define regulating lines.

4. Drawing and designing using relations

After all, nothing is more fundamental in design than formation and discovery of

relationships among parts of a composition. W. Mitchell and M. 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. The choice of relationships applied in a composition (parti) may result in a dramatically different design 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:

The choice of modelling conventions and organisational 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 explore various alternatives (Figures 4 and 5). Relationships and dependencies determine the behaviour of the model. A

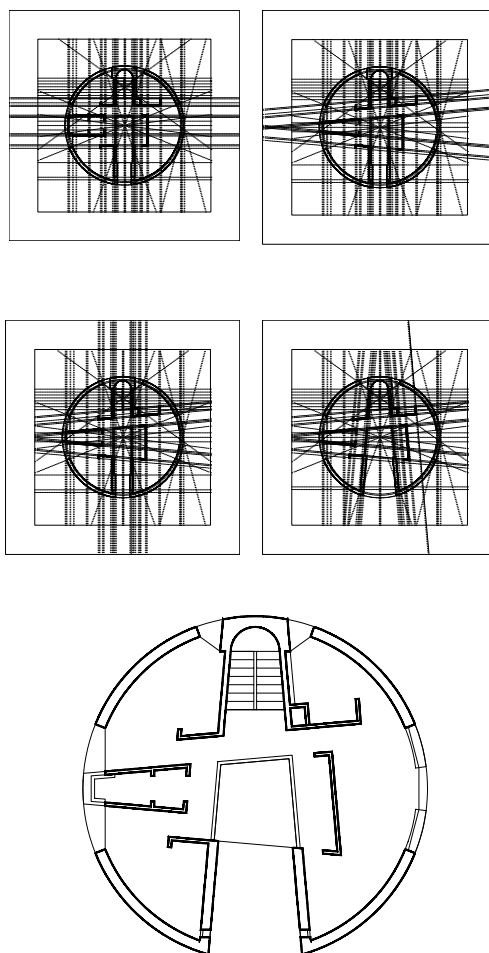


Figure 4. A possible transformation of Mario Botta's Casa Rotunda, based on an interpretation illustrated in figure 2.

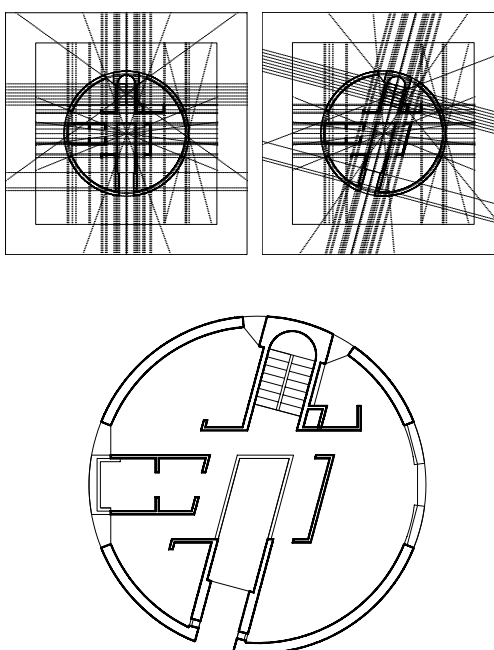


Figure 5. Another possible transformation of Mario Botta's Casa Rotunda, based on an interpretation illustrated in figure 2.

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 envisage. 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.

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 reframing” (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 presented a relational description of shapes based on regulating lines and their geometric relations. It demonstrated how interrelated regulating lines, as an organising device in design conceptualisation, could become much more useful and interesting when they are used not just as a rigid skeleton, but to regulate the behaviour of a drawing and to maintain its essential structure as its parts are manipulated. Designers could structure the behaviour 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 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 conceptualisation 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. The proposed approach 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 “behaviour” of a design object.

Notes

- 1 The regulating lines are not necessarily linear. We can classify regulating lines as straight (linear) or curved. Curved lines can be broken into subclasses: circular, elliptical, parabolic, sinusoidal, etc.
- 2 It is important to note that the number of geometric relations is indeed quite large and cannot be determined in advance. 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. For a detailed discussion of geometric relations and their properties see (Kolarevic 1993).
- 3 Currently, 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. For more information about ReDRAW’s data structures, important algorithms, interface, and usage rules see (Kolarevic 1993, 1994).

- 4 Connectivity and alignment relations between shape segments are implicitly supported through the database structure. See (Kolarevic 1993, 1994) for a detailed description of the drawing database structure.
- 5 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.
- 6 Changing, or substituting an existing relationship can introduce cyclical dependencies. If ReDRAW recognises a dependency cycle, it cancels the substitution and informs the user of its action.
- 7 See (Kolarevic 1993) for more information about database queries in ReDRAW.
- 8 Implementing ternary relations will require a slightly different database structure and probably a very different database maintenance mechanism, which will become increasingly more complex. It will probably rely on relaxation to resolve potential conflicts.
- 9 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 design tool can be considerably expanded.

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