4. DAC or Design and Computers

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This paper describes the use of simple computer draughting techniques to explore elements of architectural design theory and suggests that this relatively neglected subject could be liberated by computing to once again play an important part in architectural design education.

Introduction

The question usually posed in relation to computers and the teaching of architectural design is "How can we use computers in the design studio?". Such a question presupposes an existing structure for teaching design and that computers can be made to fit into that structure. A more appropriate question might be "How may we teach design in the computing studio?". To emphasize the precedence of design over computing I have reversed the usual acronym of Computer Aided Design and called this paper DAC or Design And Computers. The full potential of computing in architectural design will only be realized by the creation of new models of the design process appropriate to the new design medium and these new methodologies need to reflect the nature of the design medium being used rather than simply transferring the techniques of the traditional design media to the computer. An analogy with another art - theater - illustrates the point. At the beginning of this century drama was transformed by the introduction of the new technology of the cinema. Actors, directors and producers had to find a way of working in the new medium and, initially, simply carried over theatrical conventions into film. This response to technological change is quite usual; only a few years previously the response to the introduction of the still camera was to imitate painting. Computer aided design is at an equivalent stage of development and programs which automate traditional draughting are well established in practice. However, in the way that we now realize that cinema is not merely theater done with machines, computer aided design is not just architectural design done with computers. This paper describes some explorations of architectural design theory using very simple computing concepts, nothing more than the drawing system as a "design processor" analogous to word processing, showing how design theory can be made live again in a computing environment.

Types of Drawings

Traditional drawings on paper are different to computer based drawings in a number of significant ways. The traditional, Pencil Aided Design (PAD), drawing is, essentially, unstructured - each line is drawn independently of every other line. Thus, if the drawing subsequently requires modification, individual lines have to be erased and redrawn. In a Computer Aided Design (CAD) drawing the elements of the design are represented by a set of "graphic primitives" (such as lines, rectangles, polygons, arcs, circles, etc.) arranged in a two dimensional coordinate system. It is thus possible to globally change a rectangle of one size for a rectangle of a different size (or a quite different shape, say a circle), or make copies of the shape in various ways. The second main difference is the concept of scale. PAD drawings are produced to specific scales, 1:100, 1:50, 1:20, etc. often entailing the redrawing of many elements at a different size with no real difference in their information content. A CAD drawing is stored in the computer at full size and different scale drawings produced by the computer drawing system modifying its fullsize data appropriately.

These two specific features of CAD enable a drawing to be manipulated in a way that relates uniquely to the medium of computing. The ease of modification encourages the exploration of design variation: rather than simply having to accept "preordained" rules from some architectural treatise and being given one or two illustrative examples the student is able to explore unlimited numbers of variations and, equally importantly, contravene the given rule and quickly see the effect. Some of these ideas obviously relate closely to issues being explored with shape grammars and students with a particular interest in computing are able to go on to explore these topics, however, this course is taught as an architectural theory rather than a computing option and the computing element is kept, deliberately, in the background. Only a small section of the course is described here and the examples used are drawn from studios taught at the Faculteit der Bouwkunde, TU Delft and at the Department of Architecture and Building Science, University of Strathclyde.

Shape Definition

As shapes may be made up from graphic primitives we have a choice in the way in which an object is defined. To take a trivial example, a triangle might be seen as a shape consisting of three connected lines or, alternatively, as a three sided instance of the polygon primitive. Mitchell et al (1990) have described the development of a customized CAD system (Topdown) for the exploration of parametric variations building on such concepts and this shell has been used successfully at Delft and Strathclyde as a complementary exercise to the ideas discussed here. This paper simply concentrates on the use of very elementary concepts of computer draughting in the exploration of design theory, making use of the ease of modification of example drawings to investigate topics in architectural theory: as the computing requirements are minimal there is no reason to use sophisticated drawing systems and the class exercises have been carried out using a variety of software. The interest in geometry is a fundamental component of design and computer drawing systems provide a convenient medium for its exploration. Whilst geometry in one form or another exists in all buildings, to use it creatively as a formative generator the student must be aware of a number of underlying principles. The most fundamental level is the use of basic geometrical figures (circle, square, triangle, etc. in two dimensions) to determine the built form configuration. The circle is the most perfect shape and requires "vulgarizing" for use in anything but the most monumental designs. The circle is defined by its center and circumference, but even when the circumference is broken by a number of openings the geometrical identity remains (figure 1). The three dimensional extensions of the circle may be the cylinder (e.g. Botta's Casa Rotonda or Saarinen's MIT Chapel), the sphere (Boulle's Cenotaph for Newton or Ledoux's Maison des Gardes Agricoles for the Château de Maupertuis) or, more commonly, the hemisphere (Pantheon, Rome). All of these shapes emphasize the centrality of the interior space. To make this space usable for anything other than monumental ceremony requires the fragmentation of the space by the insertion of parallel walls (Corbusiers Chancellery for the French Embassy, Brasilia) or the fragmentation of the space (Botta).

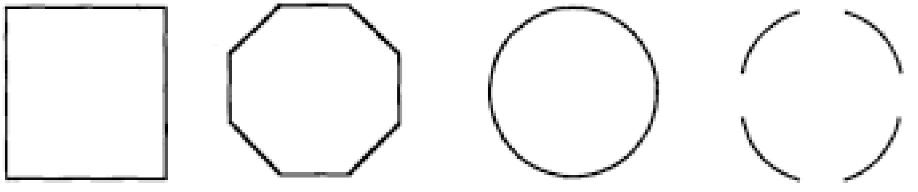

Figure 1. Transformation of Circle into Square and the Problems of Openings in a Circle.

In contrast to the circle the triangle lacks a center as the defining edges have no precise reference. The acute angles between these edges make the triangle an extremely confining space. If openings are made in the sides the center is established by the intersection of the angles and the openings. On the other hand, if the angles are removed the triangle almost disappears; the space is opened up and, depending upon the length of side, may appear to be an implied hexagon (figure 2). The three dimensional equivalents are the prism and pyramid. Examples are rare because of the difficulty of handling space with acute corners: one example is Frank Lloyd Wright's Vigo Sundt House at Madison, Wisconsin, and another, using implied space, is Borromini's San Ivo a la Sapienza in Rome (figure 3).

The square contains strong fields of emphasis at its corners, periphery, diagonals, medians and center. Recognition of these properties allows intervention to reinforce or modify its intrinsic characteristics. The square may be modified with respect to internal subspaces or external space. If parts of the edges are removed (the corners remaining intact) there is an implosion of space. If the corners are removed the space explodes outwards (figure 2). This property was exploited by Frank Lloyd Wright in his house designs where, starting from the nucleus of the hearth space progresses outwards. The three dimensional extensions of the square are the cube and tetrahedron or prism. Perfect cube rooms tend not to be strictly equivalent in all directions, but, nevertheless occur in special rooms in great houses. Square plans are attractive because of their compactness. Transformations of the square may be made to give it orientation by, for example, the insertion of walls. The shape may be eroded' by the placing of openings. In both cases the importance of the center is reduced.

The higher order shapes increasingly move towards the circle, but are important as transitionary forms. Figures such as the octagon are used to form an interface between the square and the circle (figure 1).

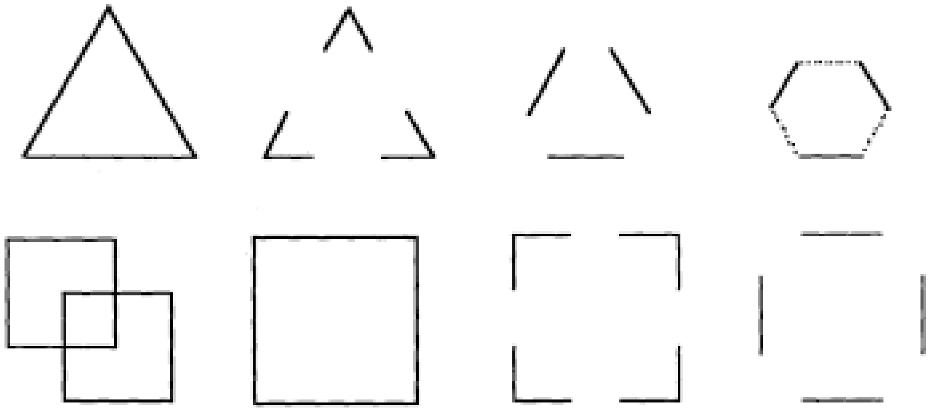

Figure 2. Modifications of the Triangle and Square.

These spatial characteristics of elementary geometric figures are explored, both in two dimensions and in their extensions into three dimensions. Transformations of the basic shapes are investigated: introducing new elements to give orientation or directionality. The different problems and possibilities of forming openings in a square space and a circular space. The "claustrophobic" effects of the acute angles in triangular spaces and the opening up of the triangle by the removal of those corners. Combinations of elements (e.g. a circle and a square) may be used: such figures do not even have to physically exist but may be implied by other figures. Combinations may include different degrees of overlap: one figure may be adjacent to, overlap, or be entirely contained within another figure. These geometrical combinations may themselves then be further combined. Figure 3 shows an example of how an apparently complex plan form is derived from simple combinations of elements and how those elements themselves are modified in the making of the design.

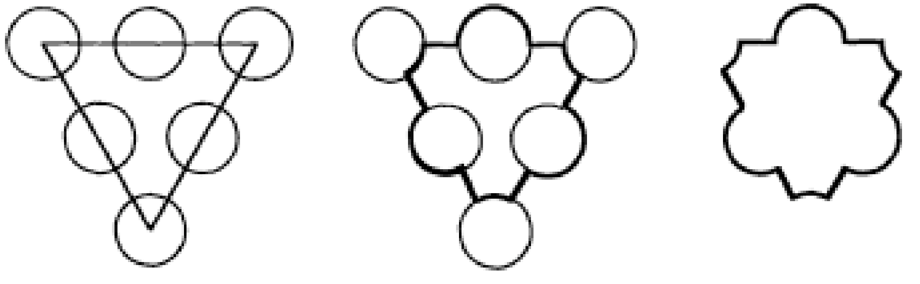

Figure 3. Parties and Diagrammatic Plan of S. Ivo, Rome (1642).

Combinations may be made with similar geometries, for example, two circles, three triangles, etc. of the same or different size. The square is the most commonly used figure, partly because in certain combinations it produces larger versions of itself. The nine-square format assembled from three rows of three squares is one of the classic formative geometries. Durand shows a "formule graphique" using 2 x 2, 3 x 3, 4 x 4, and 5 x 5 square generators.

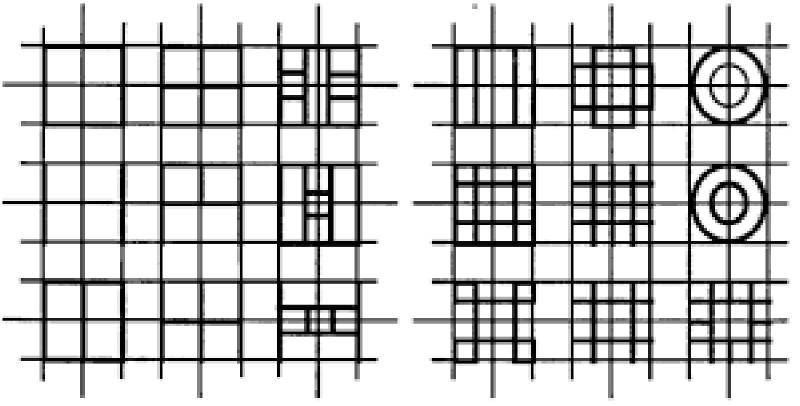

Figure 4. Parties from Durand's "Formule Graphique Applicable aux Edifices Publics Voutés dont les parties sont destinées a des usages différents".

Palladio`s villas are based on a nine-square plan, modified by the insertion of extra divisions to make a non-regular 5 x 3 plan. The Palladian Villas all derive from a single partie developed from an analysis of the requirements of an Italian villa: loggias and a large hail in the central axis, two or three livingrooms or bedrooms of various sizes at the sides, and, between them and the hail, space for smaller rooms and staircases (figure 5). The Villa Thiene at Cicogna, built during the 1550's shows the pattern most clearly. The rooms, together with the porticos, are defined by a rectangle divided by two longitudinal and four transverse lines. The Villa Badoer at Fratta, Polesine (c. 1566) (figure 6) follows the same pattern, but with one portico now placed outside the cube of the building. The Villa Cornaro at Piombino Dese (1566) is essentially the same scheme inverted with the two small rooms each side ,of the hail joined to form larger rooms with their axes at right angles to the hail. The staircases are moved to the wings leaving an almost square hail with the same width as the porticos. When the staircases are brought inside alongside the small rooms the hail takes on the cruciform shape of the Villa Foscari at Mira (La Maicontenta, 1560) (figure 7).

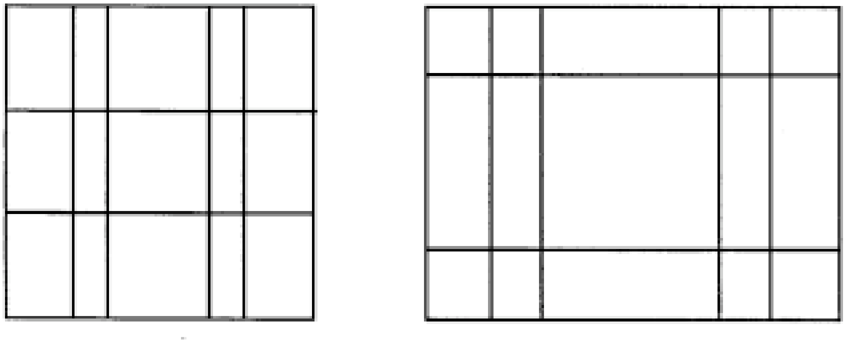

Figure 5. Path for Palladio's Villas, together with diagrammatic plan of Villa Thiene at Cicogna.

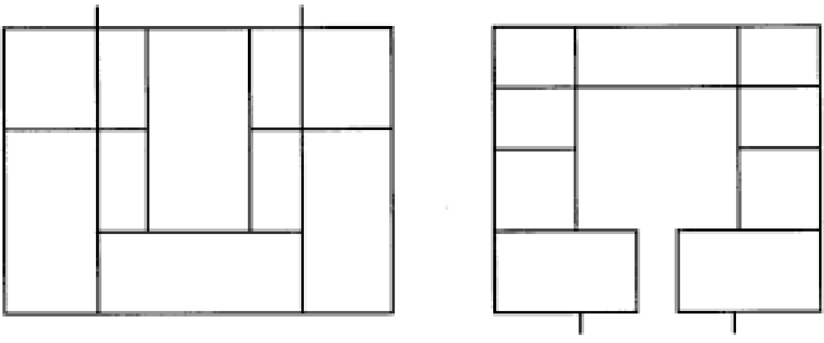

Figure 6. Diagrammatic plans of Palladio's Villa Badoer at Fratta, Polesine and Villa Cornaro at Piombino Dese.

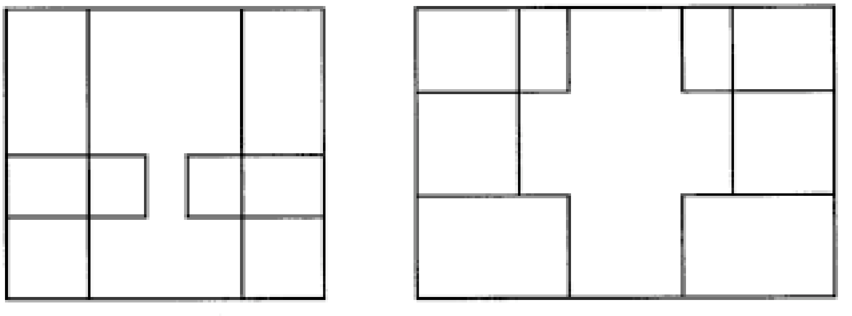

Figure 7. Villa Emo at Fanzola and Villa Foscari (La Malcontenta) at Mira.

Variations may be made on any of these plans by removing certain component parts, modifying the sizes of component parts or substituting other shapes for the squares. Forms may be generated using parts of the basic geometric shape, such as half a circle; or geometries obtained by locating elements at the corners of an implied larger geometric shape. Certain combinations or reductions will result in particular proportions and proportional generating systems may be a subject of study in themselves.

The Readability of Forms

When we draw plans or elevations the forms we are describing are usually defined by their edges. The Platonic Solids are good examples of the importance of edges: simply because they are so familiar the eye almost automatically recognizes the shape and builds the edges, even when they are not explicitly expressed. Several well known optical illusions demonstrate the strong presence of "phantom edges" (figure 8).

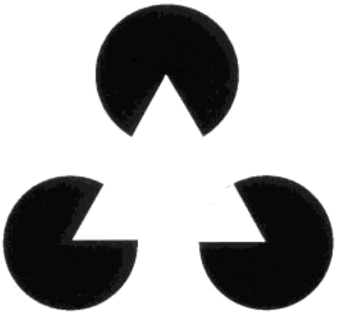

Figure 8. Illusionary triangle.

For other shapes it is common to explicitly emphasize edges in various ways: examples from classical architecture may be referred to show how the base, corners and cornice are accentuated. When we draw a plan we draw the walls (edges of the space) rather than the spaces themselves, but, for designers, it is the space that is important, rather than the defining elements. To emphasize the space instead of the walls a computer paint system can invert figure and ground very simply, but soon the eye simply reads the white lines (which were black before) as a negative plan. An interesting exercise in spatial perception and definition is to "paint" the spaces with tones related to the degree of enclosure of the space or reflecting the relief of the ceiling (figure 9). Axonometric and perspective projections provide other ways of exploring space.

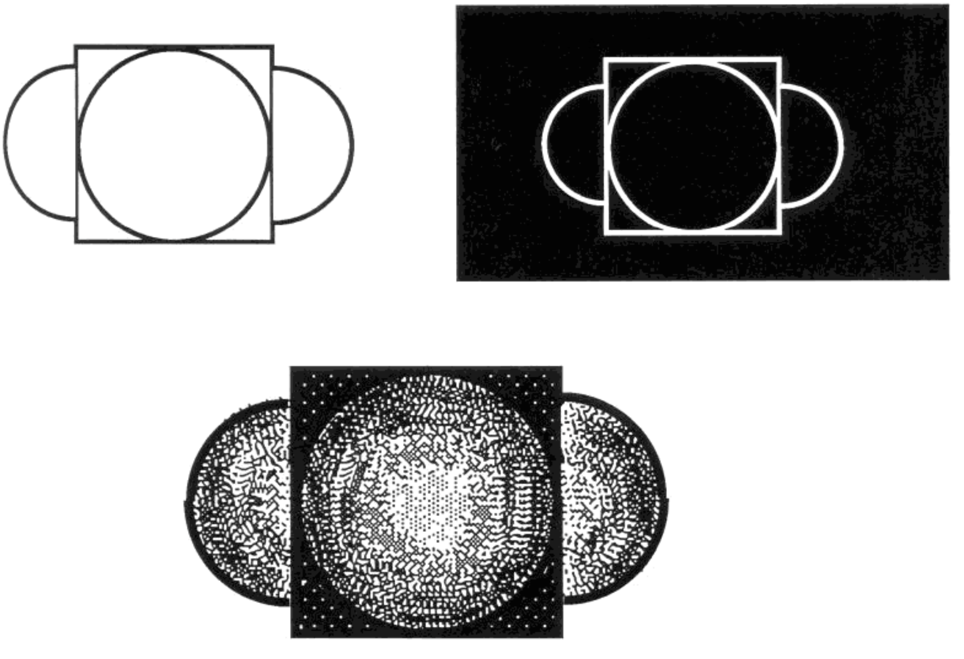

Figure 9. Spatial perception and definition.

Order in Building

The requirements of construction usually restrict designs to fairly simple geometries making use of the repetition of elements that can easily be assembled together. Repetition, alignment and juxtaposition of identical elements impose order regardless, but architectural design acquires its own autonomy by regulating that order in particular ways. Repetition and similarity may be explored, making use of the drawing systems facility to copy and move elements easily. Repetition in design is derived in three different ways: by simply adding similar elements; by dividing the whole; or by making a linked series without a clearly defined form but with elements such as material, scale, proportion, position of windows, etc, in common.

Proximity of elements is important, for elements which are close together are grouped and separated from those that are further away (figure 10). The positioning of windows in facades is used to explore these various "Gestalt Laws" as a means of introducing rhythm and vitality into elevations. The elements of the facade become integrated through common enclosure on a ground and, when the whole is repeated (through alignment and series) linearity and rhythm become important.

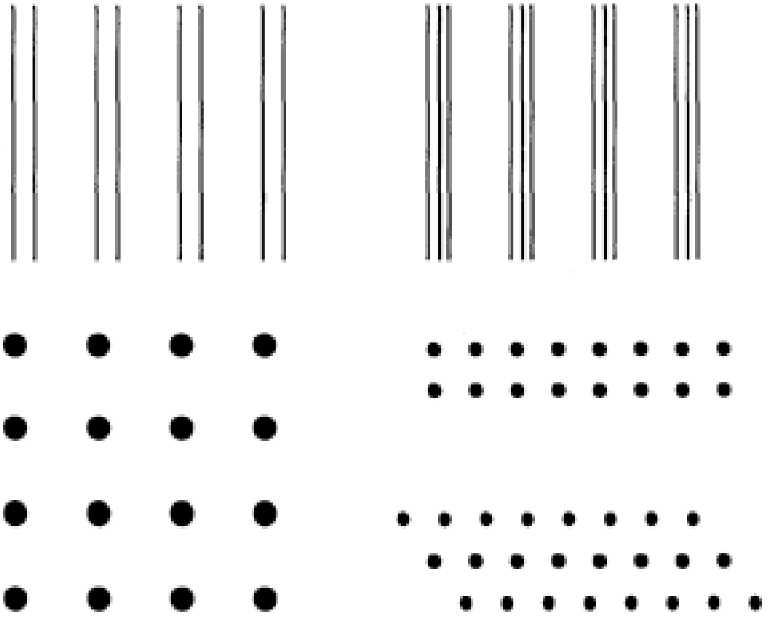

Figure 10. Adjacency and Directional Factors Creating Gestalts.

Individual students may explore the possibilities of the first two phenomena and the combination of their work can demonstrate the third. The importance of the proximity of elements may be explored by manipulating facades, grouping elements in different ways. Street facades may be modified to see how linearity and rhythm are important. The evolution of forms, where the intervals or elements in a repetitive structure gradually change their form, size or orientation are explored. The geometrical properties of centrality, axiality, onentation, etc are used to establish hierarchies of forms. A hierarchy implies primary and secondary elements with one or more forms dominating the others. This implied order can act as a powerful unifying factor in design, making it possible to combine disparate elements in more recognizably ordered designs. Dominant and subordinate elements are recognizable not only in facades or massing, but in architectural space as well. The design of house elevations and the combination of the class work into a street facade makes an interesting project insofar as the resulting street never appears to be such a pot-pourri as might be imagined beforehand.

A simpler exercise is based on the design of a modular exhibition stand which is then analyzed using Arnheim's "energy fields" of forms: this makes the design of the space and the circulation paths very explicit. Arnheim (1977) made the suggestion that architects should replace the notion of figure/ground with one of "energy fields" created by objects. The space would then be defined by vectors modified by distances, expansions and contractions (figure 11). These force fields are plotted on a separate layer over the plan and indicate how the spatial organization works and how junctions between spaces may be resolved.

Definition of Space

Space may be defined implicitly or explicitly. The various ways of defining space each have particular consequences in terms of the "spatial field". Spaces may be closed and introverted or open and extrovert. The way in which Frank Lloyd Wright eliminated corners from the plan and distorted spatial geometry by turning parts of the envelope through 90 degrees may be analyzed by modifying spatial enclosures "in the style of FLW" (figure 12).

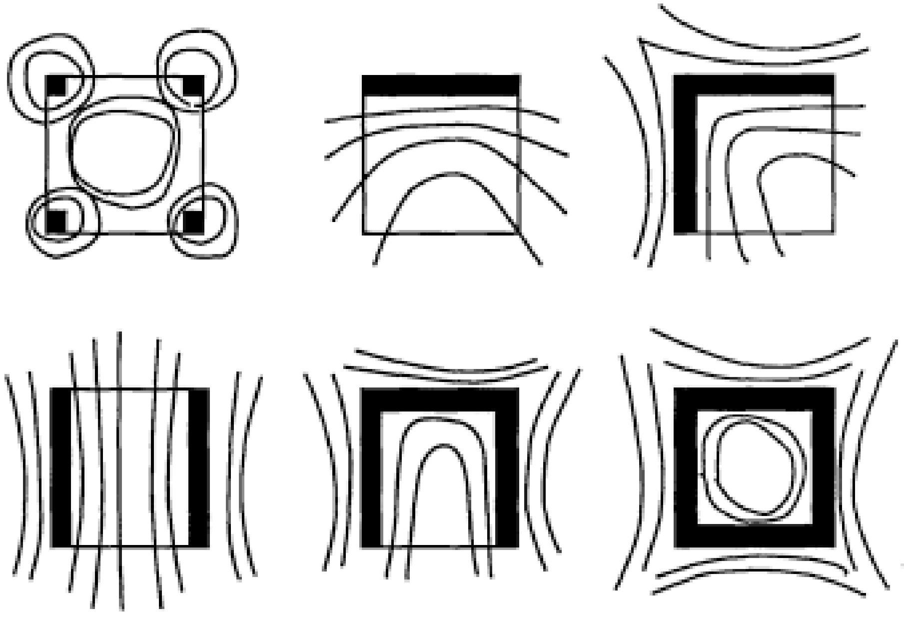

Figure 11. Arnheim's Spatial Fields.

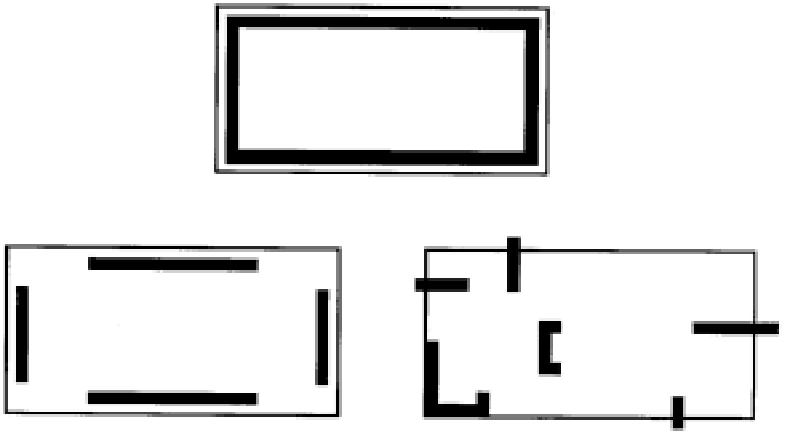

Figure 12. Frank Lloyd Wright's New Spatial Order.

Models are built of famous houses such as the Usonian Houses of Frank Lloyd Wright, Asplund's Villa Sneilman, the Rietveld-Schroeder house, Mario Botta's single family houses, Corbusier's Villa Savoye (see figure 13) and their spatial properties analyzed in plan and through various three-dimensional projections. Mies van de Rohe's Barcelona Pavilion is analyzed to explore the definition of space by different forms of boundaries in the manner described in Oxman et al (1987). Students are encouraged to make their own explorations, developing ideas of spatial juxtaposition and interpenetration (figure 14).

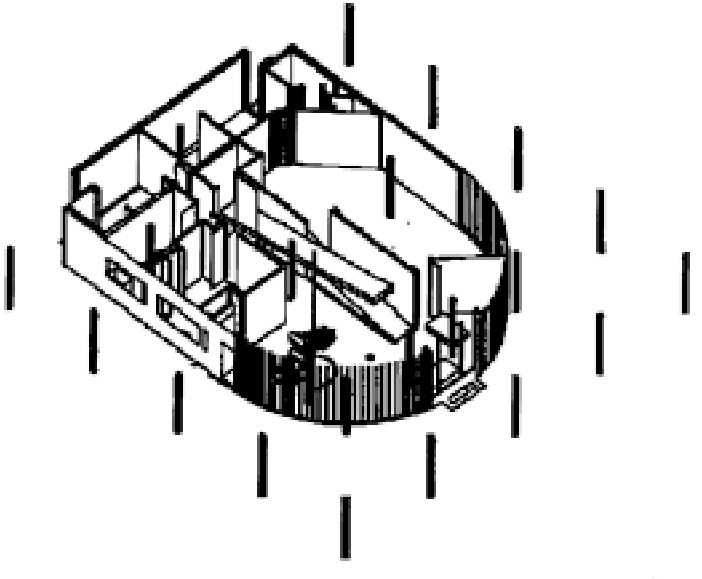

Figure 13. Villa Savoye Analytical Drawing.

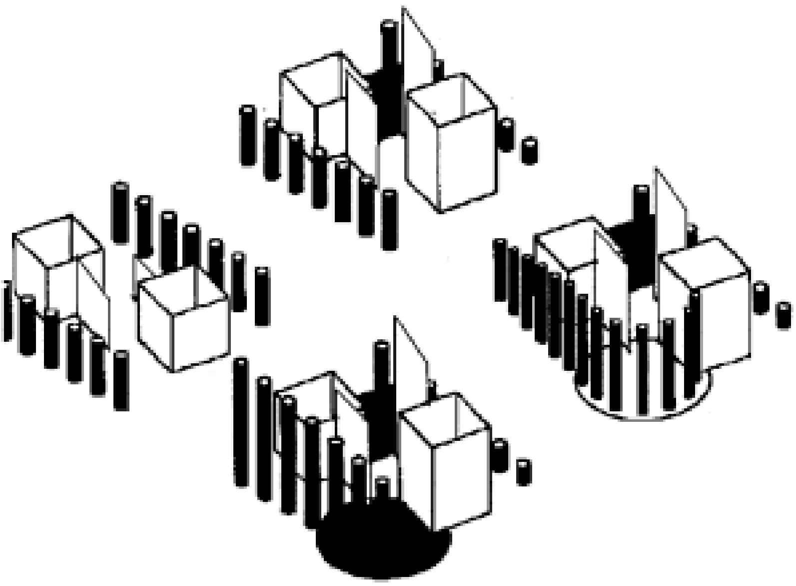

Figure 14. Investigations of Spatial Arrangement.

The Villa Savoye is a disarmingly sophisticated building. The basic organization is so apparently straightforward: regularly spaced pilotis supporting a box within which interior divisions are freely disposed. Le Corbusier formally explores the relationship between organic spatial development and the requirements of external form. A casual reading of the drawings for this house tempts us to see the design in too simple or direct terms without grasping the implications of the formal concepts. The degree of study needed to build the computer model enables some of these points to be appreciated and the attempt to reinterpret those ideas shows the difficulty involved.

Conclusions

The formal teaching of architectural theory and composition has not been very fashionable in Schools of Architecture for several years now. Indeed there is a considerable inbuilt resistance in students to the application of any form of rules or procedures. There is however a general interest in computing and this can be utilized to advantage. The Architectural Theory Course, the introductory part of which is described here, is taught to second year undergraduates at Strathclyde and slightly more senior students at Delft. The format of teaching is usually a forty-five minute lecture followed by a minimum of one hour practical computing. The first lectures cover the basic spatial elements and grids as ordering and generating devices in design. Example illustrations are taken from sources as diverse as Durand, Palladio and Peter Eisenman. Students are then required to make a design arranged on a grid in an explicable way. Everyone works intuitively but some students always begin to make designs which exhibit some internal regularities or structure: symmetry about an axis, repetition with ordered variation, incremental changes of scale, etc. It is then possible to get that student to attempt to explain the rules he or she has in fact used (even if the design was thought to have been developed intuitively). By carrying out the exercise first (after simply showing a number of examples) it is possible to then discuss the resulting designs and show how the best designs tend to have intuitively obeyed the principles we are attempting to teach. Thus an element of learning by discovery is introduced and the student is not simply attempting to apply predefined "rules". Having revealed the formal elements of the design the student is then encouraged to alter those features and discuss the results. The student thus learns by doing rather than by rote. Later classes show how the deliberate breaking of rules or the collision of two or more formal systems can be used as generators of designs. Similarly, other classes illustrate how divergence from the norm, the breaking of symmetry or the distortion of regular patterns may introduce complexity into the design. In all cases it is the ease with which computer based drawings can be modified which makes this form of design exploration possible.

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