Computer Exercises in Architectural Design Theory

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Introduction

This paper discusses how architectural theory may be taught using computer based exercises to explore the practical application of those theories. The particular view of architecture developed is, necessarily, a restricted one but the objectives behind the exercises are slightly different to those that a pure architectural theorist or historian might have 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 he utilised to advantage. In concentrating on computer applications in design eclectic use has been made of a number of architectural examples ranging from Greek temples to the work of modern deconstructionists. Architectural theory since Vitruvius is littered with attempts to define universal theories of design and this paper certainly does not presume to anything so grand: 1 have merely looked at buildings, compared them and noted what they have in common and how that might relate to computer-aided design. 1 have ignored completely any sociological, philosophical or phenomenological questions but would readily agree with the criticism that Cartesian rationality is not. on its own, a sufficient base upon which to build a theory of design. However 1 believe there is merit in articulating design by separating it from other concerns and making it a subject of study in its own right. Work in design research will provide the models and intellectual structures to facilitate discourse about design and might he expected to benefit the development of design skills by providing material that could be formally taught and debated in a way that is removed from the ephemeral -fashionable designer" debate. Of course, some of the ideas discussed here may prove to be equally ephemeral but that does not entirely negate their value. As the Abbé Laugier said, in a similar context:

> It seems to me that in those arts which are not purely mechanical it is not sufficient to know how to work; it is above all important to learn to think. An artist should he able to explain to himself everything he does, and for this he needs firm principles to determine his judgements and justify his choice so that he can tell whether a thing is good or had. not simply by instinct but by reasoning and as a man experienced in the way of beauty.
>
> Laugier, Abbé Marc-Antoine (1753)
> Preface to "Essai sur l'architecture"

Geometry and Grid

Geometry is a fundamental component of design and computers provide a convenient medium to explore it in two or three dimensions. 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 application is the use of basic geometrical figures (circle, square, triangle, etc in two dimensions) to determine the built form configuration. 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 he adjacent to, overlap, or be entirely contained within another figure. These geometrical combinations may themselves then be further combined (figure 1).

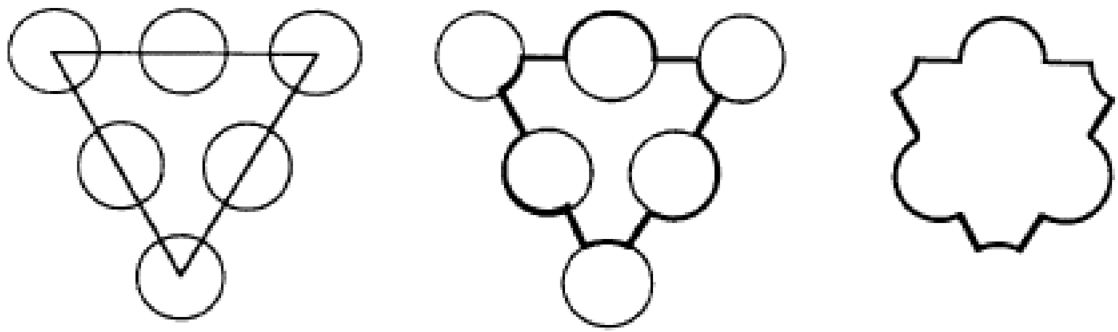

Figure 1. Parties and Diagrammatic Plan of S. Ivo, Rome (1642)

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. 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 (figure 2) and Durand shows a "formule graphique" using *2 x 2, 3 x 3, 4 x 4,* and 5 x 5 square generators (figure *3).* Variations may he made on any of these plans by removing certain component parts, modifying the sizes of component parts or substituting other shapes for the squares.

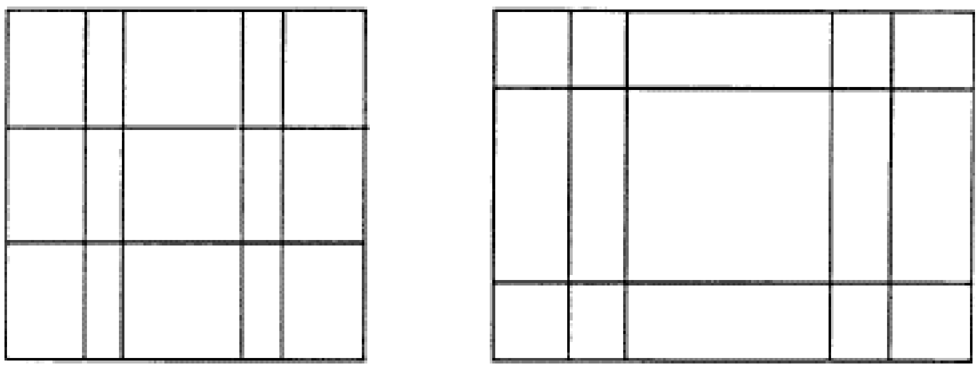

Figure 2. Parti for Palladio's Villas, together with diagrammatic plan of Villa Thiene at Cicogna.

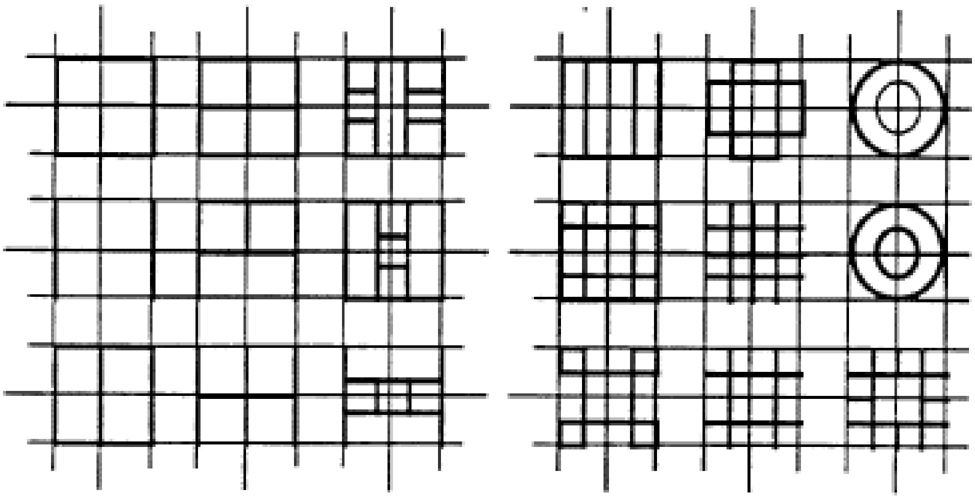

Figure 3. Parties from Durand's "Formule Graphique Applicable aux Edifices Publics Voutés dont les parties sont destinées à des usages différents".

The Palladian Villas all derive from a single partie developed from an analysis of the requirements of an Italian villa: loggias and a large hall in the central axis, two or three livingrooms or bedrooms of various sizes at the sides, and, between them and the hall, space for smaller rooms and staircases. The Villa Thiene at Cicogna, built during the 1550's shows the pattern most clearly (figure 2). 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) follows the same pattern, but with one portico now placed outside the cube of the building (figure 4). The Villa Cornaro at Piombino Dese (1566) (figure 4) is essentially the same scheme inverted with the two small rooms each side of the hall joined to form larger rooms with their axes at right angles to the hall. The staircases are moved to the wings leaving an almost square hall with the same width as the porticos. When the staircases are brought inside alongside the small rooms the hall takes on the cruciform shape of the Villa Foscari at Mira (La Malcontenta, 1560) (figure 5).

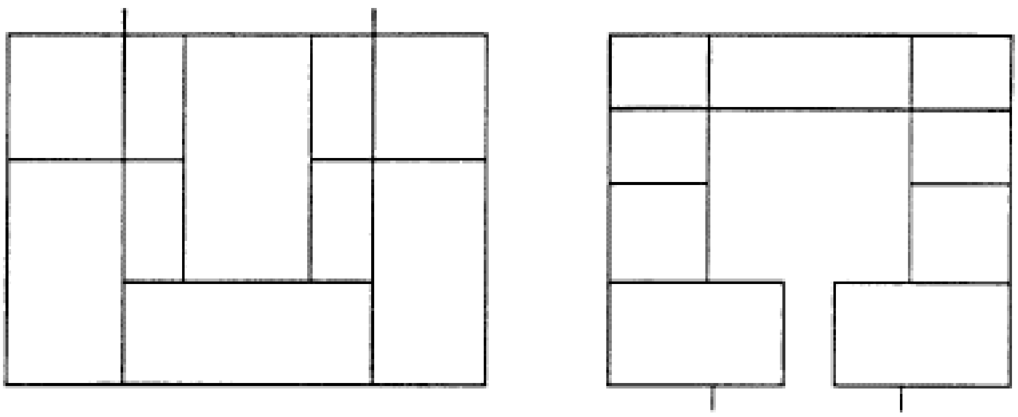

Figure 4. Diagrammatic plans of Palladio's Villas Badoer at Fratta, Polesine and Cornaro at Piombino Dese

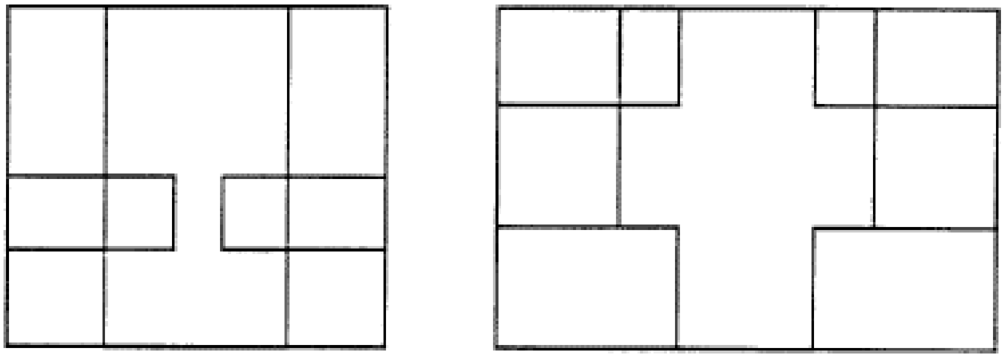

Figure 5. Diagrammatic plans of Palladio's Villas Emo at Fanzola and Foscari (La Malcontenta) at Mira

Topological relationships may be found between apparently quite different buildings such as Palladio's Villa FoscariatMalcontentaofc.1550-60 and the Villa Stein de Monzie at Garches by Le Corbusier (1927). Rowe (1976) shows how both are conceived of as single blocks, and, allowing for variations in the roof treatment, are of similar volume, each measuring 8 units in length, by 5.5 in breadth, by 5 in height (figure 6). Then there is also a comparable bay structure. Each house contains an alternating rhythm of double and single spatial intervals in the form ABABA, with proportions 2:1:2:1:'-. Each house, read from front to back, displays a comparable tripartite distribution of lines of support. Both are built following strict laws of proportion. Le Corbusier carefully indicates his relationships by an apparatus of regulating lines and figures and by placing on the drawings of his elevations the ratio of the golden section, A:B = B:(A+B). But, if Le Corbusier's facades are for him the primary demonstrations of the virtues of a mathematical discipline, with Palladio the main demonstration is in the plan. All the interior spaces of Villa Foscari (except for the stairs and the length of the main hall) are integrated according to the proportions 12:3A. Wittkower (1952) also shows how this same proportional integration applies to the portico as well. The layout is basically two suites of 3 rooms each and 2 staircases arranged on opposing sides of a main hall. The basic module is a square of 16 foot side: the larger rooms in each suite are 16 ft x 24 ft (i.e. proportions of 23) and the smaller rooms 16 ft x 12 ft (i.e. 14). The height of the rooms are determined (in accordance with the -first rule- in Palladio's Primo Libro, chapter 23) by adding the length and breadth and dividing the total by two.

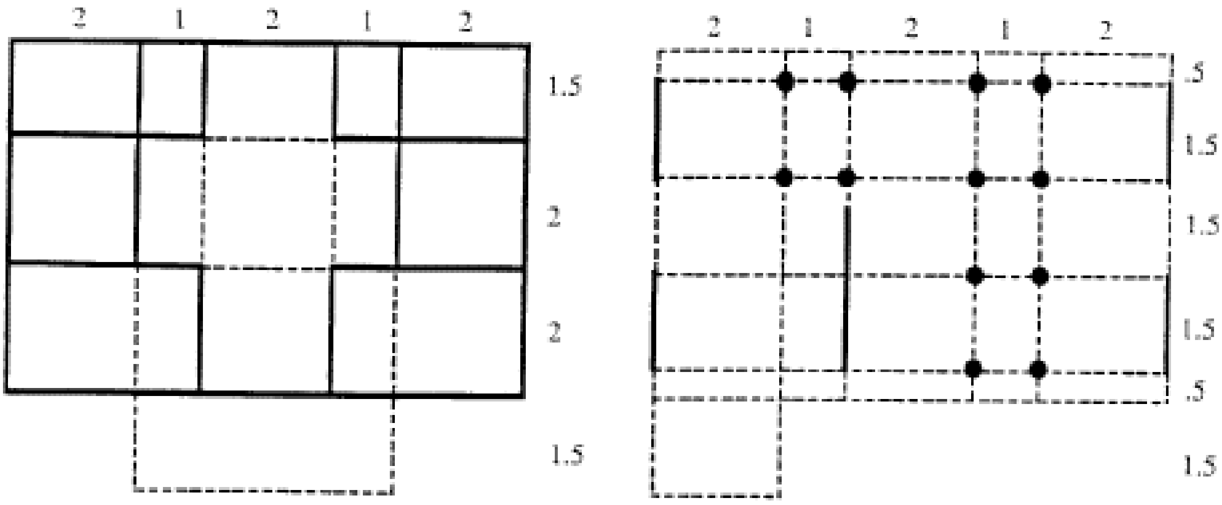

Figure 6. Diagrammatic plans of Villa Foscari at Malcontenta and Villa Stein de Monzie at Garches

Another series of configurations may he developed through the manipulation of geometries by simple translations and rotations, Translations which result in overlaps create a third figure from the combining of the two other figures. The development of apparent complexity through these simple operations is well illustrated in the work of Peter Eisenman (figure 7).

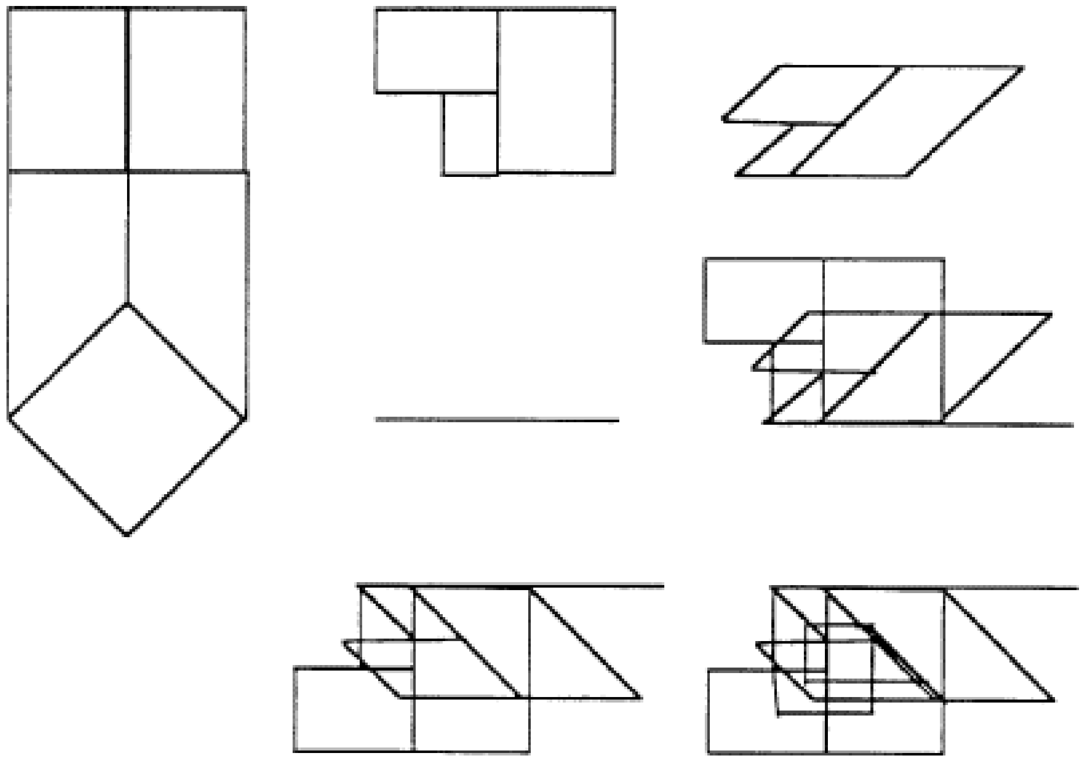

Figure 7. Analysis Diagrams of Peter Eisenman's House El Even Odd. Elevation of a cube; the cube with a smaller cube removed; axonometric; superimposition; inversion; transformation.

Grids are developed from the repetition of basic geometries. Multiplication, combination and subdivision of elements all produce relative complexity from simple basic elements. Grids may be irregular, with the spatial divisions differentiated by size, proportion or location. Another aspect of grids is the relationship between the generating series (which may or may not he orthogonal to each other). For example, if the relationship is orthogonal with all intervals in both series equal a square grid results, whereas two orthogonal series each with more than one equal interval will create a rectangular tartan arid. Like basic geometric figures grids can he combined or manipulated by rotation. translation and overlapping. Figure 8 shows SOM's "field theory grid" used at the Architecture and Arts Building, University of Illinois Chicago Circus Campus. In this design the major module was produced by placing an 80'0" square over an 85'0" square at a 45 degree angle. Each of these star-shaped modules houses one studio. Grids may he further transformed by disrupting their continuity (maybe to define a major space) or part maybe dislocated and rotated. Grids need not even be made up of straight lines (figure 9).

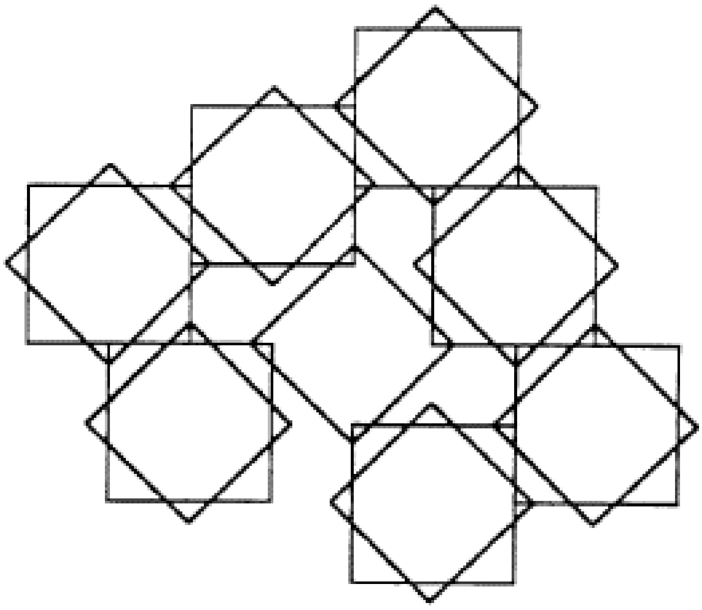

Figure 8. SOM Field Theory Grid

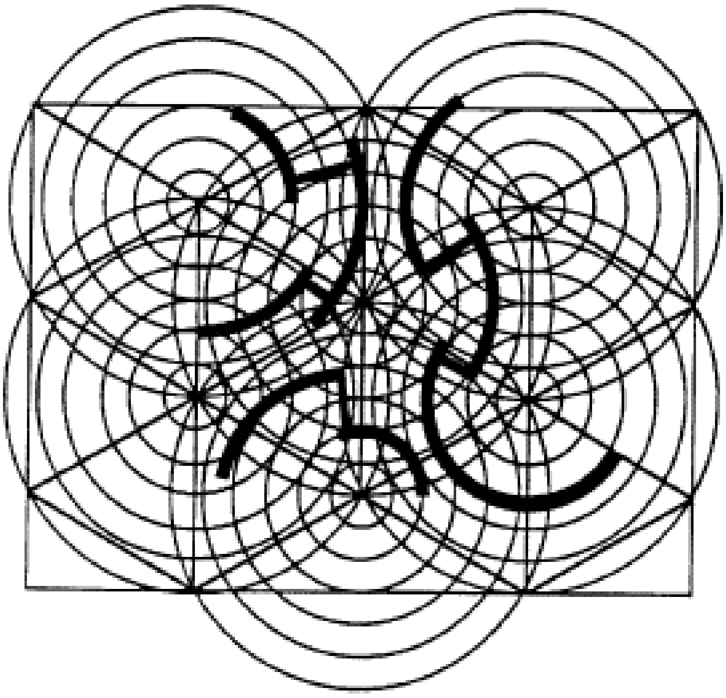

Figure 9. After a drawing by Paolo Portoghesi

Precedents from Architectural Theory

The tripartition seen in Garches and Malcontenta is a classical division of space: it may be seen as marking the difference between the internal and external sections of a work. It divides a building into three parts, two border parts and one enclosed. The "whole", states Aristotle, is tripartite: it has "a beginning, a middle and an end". Tripartition underlies the Vitruvian classification of temples (De Architectura bk 3 ch 2). The first two types "inantis" and "prostyle" - are similar, both having a front part, usually pilasters or free standing columns, attached to the main unarticulated volume (the "cella"). The third form is "amphiprostyle": this has columns both (amphi) front and back i.e. a portico at each end. Last is the "peripteral" temple with columns all round (peri): this plan is divided in three from every view. These three generic styles may he represented by a formula, each letter standing for an architectural part (figure 10).

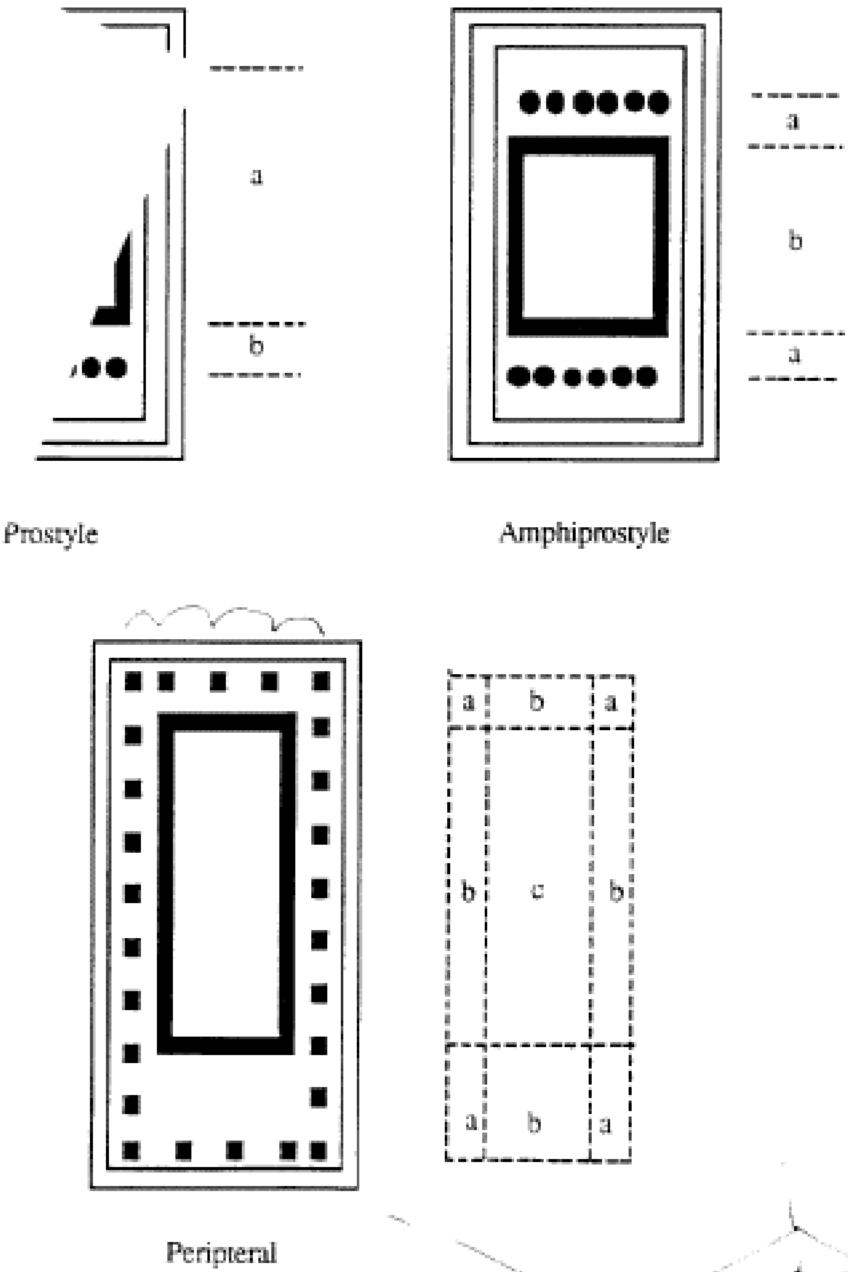

Figure 10. Classification of Greek temples

Vitruvius defined more kinds of temples by adding parts and/or rows of columns (or deleting them). All can be derived from the same formula of tripartition. What is interesting is not so much Vitruvius' typology of buildings but his system of classification which contains an implicit method for generating plans. This is more easily seen if we represent these basic plan types symbolically using the formulae ab, aba, etc. as in figure 10.

This may be seen particularly in Cesariano's 1521 edition of De Architectura - the first translation of Vitruvius into vernacular Italian. This edition contained an extensive commentary and many illustrations. The figures relating to the grid and tripartition may be found in the series of illustrations to Vitruvius' Third Book (see figure 11).

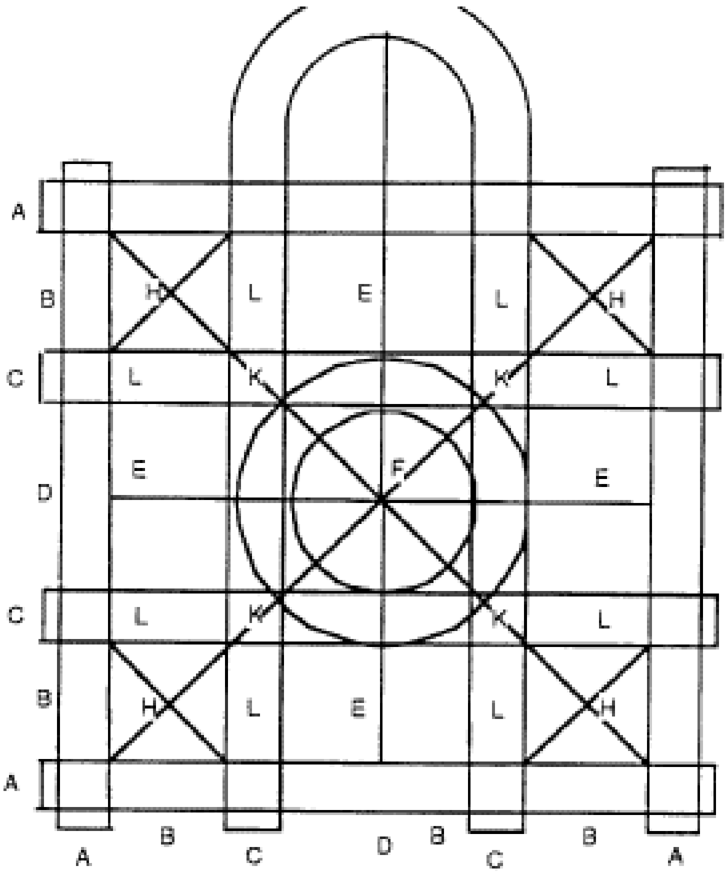

Figure 11. Grid Pattern (after Cesariano, 1521)

The grid is used in a number of ways - generally and specifically - and in regular or irregular units. Referring to the Cesariano plan we see an example of a square grid dividing the plan into seven parts:

A B C D C B A

the middle unit (D) being made up of two identical B units, giving:

A B C B B C B A

which is classically tripartite - a beginning part B between A and C, a middle part BB between C and C, and an end part B identical to the initial part.

The whole may, therefore, be condensed as follows:

```
A B C  B B  C B A
  a     b     a
```

We can transcribe Cesariano's plan in its entirety with his notation only adding an X where no notation is already provided.

```
A B C   D   C B A
B H L   E   L H B
C L K   X   K L C

D E X   F   X E D

C L K   X   K L C
B H L   E   L H B
A B C   D   C B A
```

As a next step we can rewrite the plan pattern, simplifying it to demonstrate, as before, its tripartite pattern:

```
a b a
b c b
a b a
```

Here we find the Aristotelian tripartite schema expressed in the most elementary way. We also find the Vitruvian temple formula. This -square and cross- pattern is one of the most predominant formal patterns of classical architecture since the Renaissance and is often referred to as the -mother taxis formula---.

The formula may be expanded by inserting an intermediary part between the end and middle sections. This permits us to demonstrate the workings of the -production rules- of classical architecture and to relate the formula more easily to specific buildings.

```
a b   c   b a
b c   d   c b

c d   f   d c

b c   d   c b
a b   c   b a
```

It is possible to apply further productions such as deletion of parts, fusion of parts, addition of parts and substitution of parts (by hierarchically embedding other parts). Further, we may translate the rectangular grid into a polar grid and apply similar productions. Some possible results of these operations may be briefly listed.

1. Deletion of Parts

```
   c          b c b          a b c b a        a b c b a
 c d c       b  d  b         b       b        b       b
c d f d c   c d f d c        c       c        c   f   c
 c d c       b  d  b         b       b        b       b
   c          b c b          a b c b a        a b c b a
```

2. Fusion of Parts

```
 a  b  a             a   B
|b  |c |b    into
|a  |b |a            B C B

 a b |a              B   B
|b c |b      into      c
|a b  a              B   B

a |b a               a C a
b |c b       into    b   b
a  b a               a b a
```

3. Addition or Repetition of Parts

```
a b c b a
b c d c b
c d f d c
c d f d c
b c d c b
a b c b a
```

4. Embedding of Parts

```
                     d e d      d e d
                     e f e   b   e f e
                     d e d      d e d
a b a
b c b        into       b     c     b
a b a

                        a     b     a
```

5. Translation to Polar Grid

```
                         b c b
                       a     a
 a b c b a            b    d    b
 b c d c b               c  c
 c d f d c         into    c  d  f  d  c
 b c d c b               c  c
 a b c b a            b    d    b
                       a     a
                         b c b
```

A number of plans of classical architecture follow these kinds of pattems., for example, Bramante's plans for S. Pietro inRome and hisTempietto(S. Pietro in Montorio) bring together rectangular and polar formulae to create hybr-id formal pattems integrating grids and tripariition schema. From the Renaissance on, taxis and its normative schemata have controlled an architectural composition by setting up contours, regulatory lines or planes, that plot limits defining the parts within which the architectural elements lie. Towards the end of the eighteenth century another way of specifying the divisions of a work became dominant: specification by an axis rather than by an outline. It is presupposed here that the architectural members of the section indicated by the axis are laid out -balanced -around the axis in bilateral symmetry. Acomparison of the Cesaiiano diagrams (1521) with figures from Durand's Prdcis (1819) is revealing. This shift from contour to axis marks a step towards abstraction and facilitates the application of multiple taxis formulae on the same object, one laid over the other.

Guadet (1894) introduced the nofion of axial drawing and proposes a "mdthode h suivre" (echoing Durand's marche 5 suivre). The famous Durand plate shows an analysis of a Grand Prix project of Charles Percier annotated by Durand to show a method of design by composing elements on grid sections directed and organised by axes. Elements of -design by prototype refinemenC may also he found in Durand's work. He typically adapted other architects' designs, tailoring traditional arrangements to accord with his own ideals, reducing all composifions to standardised, elementary forms, such as circles and squares, made up of a repetitive pattern of basic units. Durand not only -corrected- originals, but also reduced plans to abstract diagrams and very rarely acknowledged either the original author or the buildings original function. The Marche à Suivre illustrates all these aspects. Percier's -Monument destind à rassembler les diffdrents acaddmies" of 1786 was one of the most famous academic designs of the late eighteenth century.

Durand published Percier's project in 1805 as a prototype for an Institute, systematising the proportions of the plan and omitting the platfonn and obelisks. He extended the steps the full length of the wings and made three smaller entrances in place of one small one. The entrance hall is subdivided to mirror those of the other three wings; the corridors are aligned, and the doorways reduced in size. The elevation was also modified. In 1813. in the revised edition of his lecture course, the Nouveau Prdcis, this simplified project becomes the model for the Marché Suivre dans la Composifion d'un Projet Quelconque- where no specific function is designated.

Durand taught his students the mdcanisme de la composition, which involved the use of a grid to order the fundamental disposition of elements in the plan. Columns were to be placed at intersections, walls on axes, and openings at module centres. Durand showed how to apply this method to all parts of the building and how those parts may be combined in a specific project. Although the solution of the plan was always the primary concern, the application of combinations to facades, general volumetric studies. roofing, and parti generation was also taught. Combinations provided the solution to any architectural problem.

The use of the grid in design was not, of course, Durand's invention. The first signs of this shift may also he traced back to Cesariano's 1521 edition of Vitruvius where the famous Vitruvian man is superimposed on a grid!

Conclusion

I do not wish to give the impression that grids dominate architectural design entirely. It is simply that, within the confines of this short paper, they provide a convenient example. My main objective is to demonstrate that computers provide a convenient medium within which to explore design ideas. Our use of the computer follows the traditional processes of the design studio - learning by doing - but the flexibility of the medium and the possibility to easily manipulate designs (without destroying intermediary solutions) extends the possibilities far beyond the traditional studio. The computer techniques used are elementary: the simplest elements of a drawing system as a "drawing processor" analogous to a word processor. There are, of course, examples that overlap with topics which may just as easily he discussed under the heading of "Shape Grammars" in a Computing Theory course, but this particular course, the introductory part of which is described here, is taught as an Architectural Theory course. This is significant as it is not timetabled as a "computing option": the computing elements are subsidiary to (though an essential part of) the main design theme of the course.

The Architectural Theory Course is taught to second year undergraduates at Strathclyde and slightly more senior students at Delft. The format of teaching is usually a fortyfive 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 as briefly described in this paper. 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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