Chapter three

Non-discursive technique

'Environments are invisible. Their...ground rules...evade easy perception.' **Marshall McLuhan**

Object artefacts and abstract artefacts

One of the durable intellectual achievements of the twentieth century has been to initiate the scientific study of human artefacts. At first sight, such a study might seem paradoxical. Most artefacts are physical objects that adapt natural laws to human purposes. To make an object for a purpose surely presupposes that we understand it. But twenty-five years ago, Herbert Simon, in his *The Sciences of the Artificial*, showed that this was far from the whole story.[1] Even if the objects we make are not puzzling in themselves, they are so when seen in the context of the ramifying effects of their dispersion throughout our socio-technical ecosystem. He was thinking, amongst other things, of computers. It would be as enlightening, he argued, to have a natural history of computers in our increasingly artificial world, as of any natural phenomenon. Empirical sciences of artefacts were therefore not only a possibility, but a necessity.

But object artefacts are only the lesser aspect of the puzzle of the artificial. There also exists a class of artefacts which are no less dramatic in their impact on human life, but which are also puzzling in themselves precisely because they are not objects, but, on the contrary, seem to take a primarily abstract form. Language is the paradigm case. Language seems to exist in an objective sense, since it lies outside individuals and belongs to a community. But we cannot find language in any region of space-time. Language seems real, but it lacks location. It thus seems both real and abstract at the same time. Other artefacts which share some of the attributes of language, such as cultures, social institutions, and even, some would argue, society itself, all seem to raise this central puzzle of being, it seems, 'abstract artefacts'.

It cannot of course be said that 'abstract artefacts' are not manifested in space-time. They appear in the form of linguistic acts, social behaviours, cultural practices, and so on. But these space-time appearances are not the artefact itself, only its momentary and fragmentary realisations. We apprehend speech, as de Saussure would say, but not language.[2] In the same way, we see social behaviours, but we never see social institutions, and we see cultural events but we never see cultures. Yet in all these cases, the space-time events that we witness seem to be governed in their form by the abstract, unrealisable artefacts that we give a name to. The material world provides the milieu within which the abstract artefact is realised, but these realisations are dispersed and incomplete. The existence of languages, social institutions and cultures can be inferred from space-time events but not seen in them.

In spite of this strange mode of existence, abstract artefacts seem to be the stuff of which society is made. We cannot conceive what a society would be like if deprived of its languages, its characteristic social behaviours, its cultural forms and its institutions. It is not clear that anything would be left which we could reasonably call 'society'. We may conjecture, perhaps, that abstract artefacts are the way they are precisely because their purpose is to generate and govern dispersed events, and through this to convert a dispersed collectivity of speakers, behaviours or social actors into some semblance of a system. The multipositionality of the space-time realisation of abstract artefacts seems to be an essential part of how they work.

However, to say this is to restate the problem, not to solve it. In fact, in spite of their apparent oddity, abstract artefacts pose many of the puzzles which science seeks to explain for natural systems. For example, they seem able both to reproduce themselves over time, and also to undergo morphogenesis, though whether this is by a constant or sudden process is entirely obscure. If abstract artefacts have such properties, then it would seem to follow that they must therefore have some kind of internal principles or laws which give rise to stability and change, as do natural systems.[3] Yet whatever these laws are like, they must also pass through the human mind, since it is only through human mental activity that the self reproduction and morphogenesis of these systems occurs. It seems inconceivable, therefore, that the laws which govern the forms of abstract artefacts are similar to, or even commensurable with, the laws that govern natural systems. At the same time, such laws must be part of nature, since they cannot be otherwise. They must reflect some potentialities within nature.

In view of all these apparent paradoxes, it was the great merit of Lévi-Strauss and other pioneers of the study of abstract artefacts to have both identified the key insight necessary for their study, and to have pointed to a possible methodology for research.[4] The insight was to have seen the dependence of the concrete on the abstract in systems like language and culture, as clearly as Plato once noted it for the natural world.[5] Now, as then, this fundamental insight provides the starting point and initial stance for the setting up of sciences. The methodology was that, as with natural systems, we would expect to find clues to the nature of these organising laws by studying the regularities that abstract artefacts generate in space-time, that is, in speech, behaviour, cultural practices and institutional forms. Accordingly, the movement called structuralism aimed to assign abstract formal models with the structure and variety manifested in the space-time output of such systems - observed speech, social behaviour, organisational dynamics and so on - and through this to account not only for the internal systemness of such phenomena, but also to show how the human mind was capable of holding and creatively transforming such powerfully structured information. In this sense, structuralism was no more or less than orthodox science rewritten for the study of abstract artefacts.[6]

This research strategy reflects the fundamental fact that abstract artefacts manifest themselves to us in two ways: through the space-time events they generate; and through the configurational patterns which seem to support them and which enable us both to generate and interpret them. These two ways in which we experience abstract artefacts are bound together by the fact that in using configurational structures to generate space-time events we also project these configurational structures into space-time and in doing so help to transmit them into the future. This double take between the conscious manipulation of space-time events and the transmission of configurational structure is the defining characteristic of the abstract artefact and the reason it is able to be the stuff of society. By deploying objects and creating space-time events we necessarily transmit structures, and through them the abstract artefacts which hold society together as a communicative system. The object of structuralism is to capture the dynamics of these processes.

Formal methods were therefore critical to structuralism. However, as Heisenberg once remarked: 'Our scientific work in physics consists in asking questions about nature in the language that we possess and trying to get an answer from experiment by the means that are at our disposal.'[7] This is surely true of all scientific enquiry. Unfortunately, it seems to point directly to the failure of structuralism to deliver on its promises. Examining the space-time regularities of the phenomena generated by abstract artefacts, we cannot fail to note one overwhelming consistency; that they seem to be governed by pattern laws of some kind. The words that make up speech and the behaviours that seem social are all manifested in space-time as sequences or dispositions of apparent elements whose interdependencies seem to be multiplex, and irreducible to simple rules of combination. For example, to say, as Chomsky did,[8] that sentences, which appear to be sequences of words, cannot be generated by a left-right grammar, is a configurational proposition. Some degree of syncretic co-presence of many relations is involved whose nature cannot be reduced to an additive list of pairwise relations. This is to say that the laws governing abstract artefacts seem to be *configurational* in something like the sense we have defined it in the previous chapters.

It is in this respect that structuralism seems to have lacked methodology. Its formal techniques did not try to drive straight to the problem of configuration, but confined themselves to the more elementary aspects of logic and set theory, those branches of mathematics, that is, that sought to axiomatise the thinking processes of minds, rather than to model real world complexity.[9] Consequently, just as the 'languages' available for Plato in his time were inadequate for his vision of nature,[10] so the tools picked up in the mid-twentieth century by structuralism were too frail for the vision of artificial phenomena that had initiated their search. The phenomena that structuralist analysis sought to explain were in the main configurational, but the formal techniques through which investigators sought to demonstrate this rarely were.

Built environments as artefacts

The purposes of this digression into abstract artefacts are twofold: first, to draw attention to certain properties of built environments that might otherwise be missed; second, to point to certain advantages of the built environment in providing a platform for taking on the problem of configuration in a new way. First, however, we must understand the very peculiar status of built environments as artefacts.

Built environments appear to us as collections of object artefacts, that is, of buildings, and as such subject to ordinary physical laws, and deserving of Simonian enquiry. But that is not all that they are. As we noted in Chapter 1, in terms of spatial and formal organisation, built environments are also configurational entities, whose forms are not given by natural laws. If we wish to consider built environments as organised systems, then their primary nature is configurational,

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principally because it is through spatial configuration that the social purposes for which the built environment is created are expressed. The collections of object artefacts in space-time that we see, are then a means through which socially meaningful configurational entities are realised. In other words, in spite of appearances, built environments possess a key property of abstract artefacts. Its objects are more durable than, say, the spoken words of a language, or the rule-influenced individual behaviours that make up a social event, but they are of the same kind. They are space-time manifestations of configurational ideas which also have an abstract form. The built environment is only the most durable of the space-time manifestations of the human predilection for configuration. This has an epistemological consequence. We should not expect the built environment merely to be the material backdrop to individual and social behaviour, as it is often taken to be. It is a social behaviour, just as the use of language is a social behaviour and not just a means to social behaviour. We cannot therefore regard the built environment as merely an inert thing, and seek to understand it without understanding the 'social logic' of its generation.

But just as we cannot treat a built environment as a thing, we can no more treat it as though it were no more than a language. The built environment is, apart from society itself, the largest and most complex artefact that human beings make. Its complexity and its scale emerge together, because, like society, a built environment is not so much a thing as a process of spatio-temporal aggregation subject to continual change and carried out by innumerable agencies over a long period of time. Although these processes of aggregation may be locally characterised by the same kind of autonomic rule following as we find for individual acts of building, there are other no less fundamental attributes that make the built environment a special case.

The most obvious, and the most important, is that the spatio-temporal outputs of built environment processes are not ephemeral like those of language or social behaviour. They are long-lasting, and they aggregate by occupying a particular region of space for a long time. This means that over and above thinking of built environments as the products of abstract rule systems, we must also recognise that they have an aggregative dynamic which is to some extent independent of these rule systems, although, as we will see, it is rarely quite out of their control. These aggregative processes have quite distinctive properties. Spatio-temporal additions to a system usually occur locally, but the dynamics of the system tend to work at the more global aggregative levels.[11] Complexity arises in part from the recursive application, in increasingly complex aggregations, of rules which may initially be simple, but themselves may be transformed by the evolving context in which they are applied. A locally driven aggregative process often produces a global state which is not understood[12] but which needs to be understood in order for the locally driven process to be effective. This is the essential nature of the large aggregates of buildings which form most built environments.

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This complex, processual aetiology is the main reason why built environments have proved so resistant to orthodox attempts to model their structure mathematically. Buildings and cities are not crystalline objects, unfolding under the influence only of laws of growth. The elementary spatial gestuaries of humankind and its cultures may construct local elemental configurations, but these then operate as local orderings within growth processes and act as constraints on the 'natural' evolution of global patterns. Architectural and, even more so, urban forms occur at the interface between natural processes and human interventions. Human actions restrict and structure the natural growth processes, so that they cannot be understood without insight into both individually, and into the relations between the two. The intervention of the mind in the evolving complexity must be understood, but so must its limitations.

The built environment may then be the most obvious of objects, and the one that forms our familiar milieu, but at the same time its inner logic and structure is as inaccessible to us as anything in nature. However, it has one great advantage as an object of study. Its very scale, manifestness and slow rate of change offer it up as the paradigm case for configurational investigation. The essence of the problem is to capture the local-to-global dynamics of architectural and urban systems, that is, to show how the elementary generators, which express the human ability to cognise and structure an immediate spatial reality, unfold into the ramified complexities of large-scale systems.

In this, methodological difficulties are central. The aim of a method must be to capture the local or elemental ordering, the emergence of global complexity, and how both relate to the human mind. For any of these, the manifest problem of configuration must be tackled head on, and must be approached first and foremost as an empirical problem. If the space-time products of abstract artefacts are held together by configuration, then configuration can be found by examining them. The corpus of configurations that can be built through the study of real cases must be some indicator of where we might seek for the configurational invariants of built environment processes. For this task, the very scale, relative stability and availability of built environments make them the ideal vehicle for an enquiry. All we need are techniques that permit the extraction of configuration from its space-time embodiments - that is, non-discursive technique.

Simplicity as a means to complexity

The configurational formalisms proposed here as the basis for non-discursive technique are in some ways much simpler than others proposed for the similar classes of phenomena over the last twenty years.[13] Yet they have proved the most powerful in detecting formal and functional regularities in real systems. There are probably three reasons for this. First, the quantitative methods proposed are directed straight at the problem of *configuration*, that is, the problem of understanding the simultaneous effects of a whole complex of entities on each other through their pattern of relationships. Lack of attention to this central problem is the prime reason why past formalism often seemed to offer mathematical sophistication out of proportion to the empirical results achieved. With configurational analysis it is the other way round. Exceedingly simple quantitative techniques have led to a disproportionate success in finding significant formal and form-functional regularities. Configuration, as defined below, seems to be at least one of the things that architectural and urban patterns are about.

Second, in configurational analysis, as much theoretical attention has been given to the *representation* of the spatial or formal system that is to be analysed as to the method of quantification. As we will see, this quite normally gives rise to a whole family of representations of the same spatial system, each one relevant to some aspect of its functioning. It is also normal to combine representations, literally by laying one representation on top of the other and treating the resulting connections as real connections in the system. Through this, we find that pairs or even triples of representations taken together yield formally or functionally informative results. In terms of research strategy, this means trying to represent space in terms of the type of function in which we are interested. For example, simple line structures drawn through spaces, temporarily discounting other properties, have proved sufficient (as we will see in the next chapter) to account for many aspects of movement within buildings and urban areas.

Third, and synthesising the previous two, much attention has been given to the graphic representation of the results of mathematical analysis, so that the formal structures identified in spatial or formal complexes can be intuitively seen and understood without the intermediary of mathematical formalism. This means that much can be understood by those whose temperaments lead them to prefer a graphical rather than a mathematical understanding. By representing mathematical results graphically, a level of communication is possible that permits large numbers of people to be interested and knowledgeable who would otherwise fall at the first fence of mathematical analysis. In parallel to this graphical representation of results, usually drawn by computer, there is a parallel emphasis in the initial stages of investigation to the drawing of spatial or formal ideas by investigators and by students as a constant adjunct to, and check on, formal analysis.

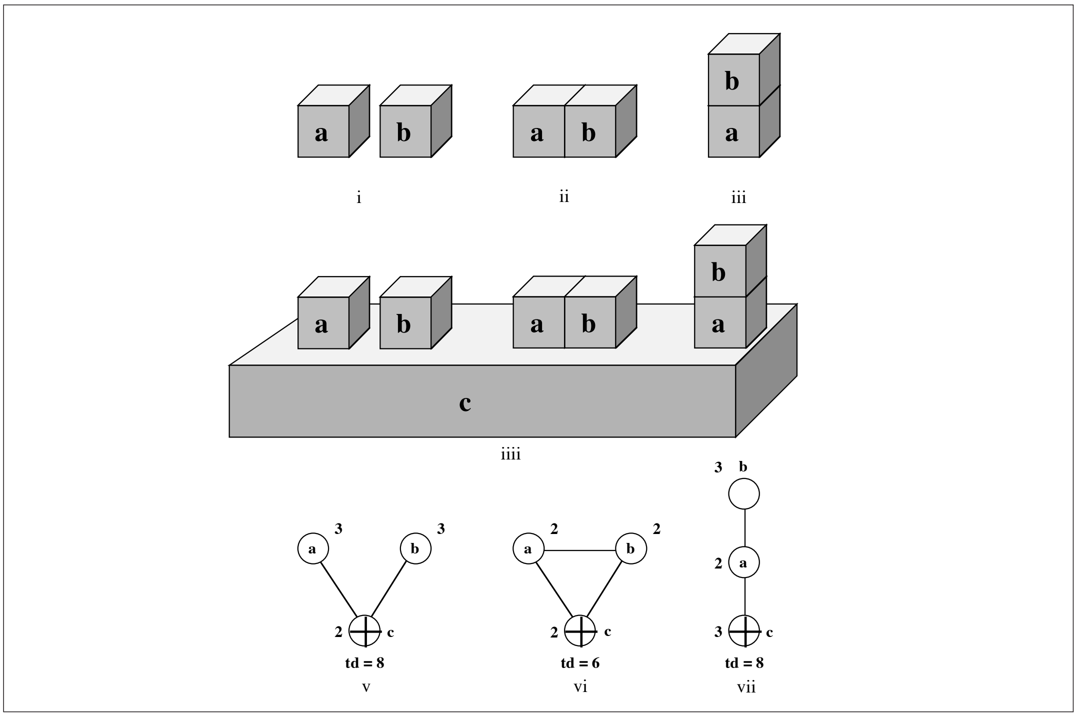
No apology is then offered for the simplicity of some of the notions presented here. Others have discussed some of these properties but have not been minded to explore their full empirical or theoretical relevance, or how they might be fitted into the overall form-function picture. Perhaps one reason for researchers to miss key relations while 'going close', has been what we would see as an overarching and in some ways premature concern with design at the expense of the empirical investigation of buildings. The 'space syntax' research at UCL has been driven by a remark of Lionel March's: 'The only thing you can apply is a good theory.'[14] Another possible reason why formal exploration has missed theoretical insight has been the frequent lack of a close enough relation between mathematical and empirical aspects of the problems posed by real buildings and cities. In contrast, the techniques of spatial representation and quantification proposed here

are essentially survivors of an intensive programme of empirical investigation spread over the best part of two decades in which formal questions have been explored in parallel to the empirical puzzles posed by architectural and urban realities.
We have already discussed the idea of configuration at some length in Chapter 1. Now we need to define it formally, and to show some of its power to say simple things about space and form. It should be noted that what follows is not a methodological cook book, but a theoretical exploration of the idea of configuration. At this stage, the examples given are illustrations of ideas, not worked examples of analysis. Case studies will come in ensuing chapters. The relation of this chapter to those that follow is that of a quarry, which future chapters return to to pick up one of the possibilities set out here, and refine it for the purposes of that chapter. This chapter shows the bases and connection of the whole family of methods.

Defining configuration

Let us begin by defining exactly what we mean by configuration, using an example directly analogous to figure 1.3 in Chapter 1, but taking a slightly different form. We may recall that in Chapter 1, a *simple* relation was defined as a relation - say, adjacency or permeability - between any pair of elements in a complex. A *configurational* relation was then defined as a relation insofar as it is affected

Figure 3.1

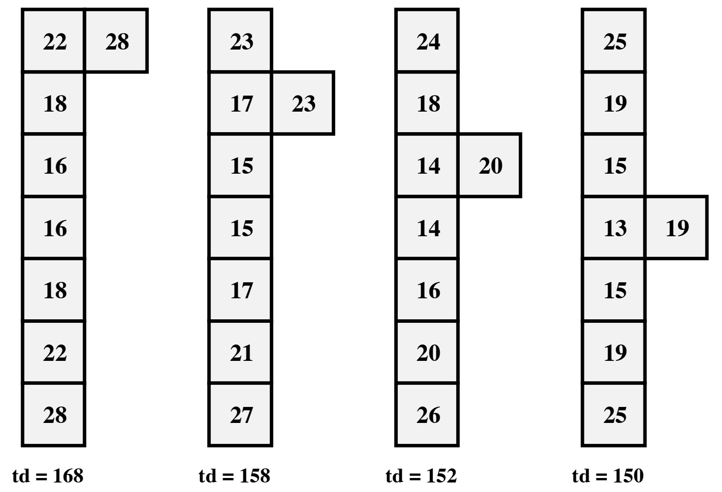


by the simultaneous co-presence of at least a third element, and possibly all other elements, in a complex. In figure 3.1 i, for example, *a* and *b* are two cubes standing on a surface. In 3.1 ii, the cubes are brought together full facewise to make a conjoint object. The relation of *a* and *b* is symmetrical in that *a* being the (contiguous) neighbour of *b* implies that *b* is the (contiguous) neighbour of *a*. One could equally say, though with less obviousness, that in 3.1 i *a* and *b* were non-contiguous neighbours, and were therefore symmetrical in this sense. Either way, the relation of the two remains symmetrical, and in fact this is implicit in the 'neighbour' relation. In 3.1 iii, the conjoint object formed by *a* and *b* in 3.1 ii is taken and rested on one of its ends, without changing the relation of *a* to *b*. But *b* now appears to be 'above' *a*, and the relation of 'being above', unlike that of 'being the neighbour of' is not symmetrical but asymmetrical: *b* being above *a* implies that *a* is not above *b*.

How has this happened? The temptation is to say that relations like 'above' and 'below' depend on an exogenous frame of reference, like 'east' and 'west', or 'up' and 'down'. In fact, what has happened can be said more simply, as shown in 3.1 iiii. The surface on which the cubes stand - say, the surface of the earth - was not referred to in describing the relation between *a* and *b* in 3.1 i and ii. It should have been, had we wanted to foresee the effects of standing the conjoint object on its end. Let us call it *c*. In 3.1 ii, the relation of both *a* and *b*, taken separately, to the third object, *c*, is also symmetrical, as is their relation to each other. So, incidentally, is the relation of the conjoint object formed by *a* and *b* to the third object. These are all simple relations. But we can also say something more complex: that in 3.1 ii, *a* and *b* are symmetrical with respect to *c*, as well as with respect to each other. This is a configurational statement, since it describes a simple spatial relation in terms of at least a third. What happens in 3.1 iii is now clear. Although *a* and *b* remain symmetrical with respect to each other, they are no longer symmetrical with respect to *c*. On the contrary, they are asymmetrical with respect to *c*. The difference between 3.1 ii and iii is then a configurational difference. The relation of *a* and *b* to each other is changed if we add the 'with respect to' clause which embeds the two cubes in a larger complex which includes *c*.

The situation is clarified by the justified graphs (or j-graphs: graphs in which nodes are aligned above a root according to their 'depth' from the root – see

Figure 3.2



Chapter 1) of the configurations shown in 3.1 v, vi and vii. In each, the bottom node is the earth, and is inscribed with a cross to indicate that it is the root. In 3.1 v, *a* and *b* are each independently connected as neighbours to the earth. In 3.1 vi, the relation of neighbour between *a* and *b* is added. In 3.1 vii, the relation between *b* and *c*, the earth, is broken creating a 'two deep' relation between *b* and *c*. One may note that this set-up already exists in 3.1 v between the two non-contiguous cubes with respect to the earth. In this sense, 3.1 vii recreates a graph which already exists in v. This is also shown in the numbers attached to each of the nodes of the graph, which indicate the sum of 'depth' from that node to the other nodes in the system. The total depth of 3.1 v and vii is therefore 8, while that of vi is 6. We might say, then, that the distributions of total depths and their overall sum describe at least some configurational characteristics of these composite objects.

Now let us explore this simple technique a little further by examining figure 3.2, a series of simple figures composed of square cells joined together through their faces (but not their corners) with 'total depths' for each cell to all others inscribed in each cell, and the sums of these total depths for each figure below the figure. The figures are all composed of seven identically related cells, plus an eighth which is joined to the original block of seven initially at the top end in the leftmost figure, then progressively more centrally from left to right. There are two principal effects from changing the position of this single element. First, the total depth values and their distributions all change. Second, the sums of total depth for each figure change, reducing from left to right as the eighth element moves to a more central location. The effects, however, are quite complex. This is not of course surprising, but it illustrates two key principles of configurational analysis. First, changing one element in a configuration can change the configurational properties of many others, and perhaps all others in a complex. Second, the overall characteristics of a complex can be changed by changing a single element, that is, changes do not somehow cancel out their relations to different elements and leave the overall properties invariant. On the contrary, virtually any change to elements that is not simply a symmetrical change, will alter the overall properties of the configuration. We will see in due course that configurational changes of this kind, even small ones, play a vital role in the form and functioning of buildings and built environments.

Shapes as configurations

Another way of saying this, is that different arrangements of the same numbers of elements will have different configurational properties. For example, figure 3.3 is a set of rearrangements of the same eight square cells that we considered in figure 3.2, again with 'total depths' inscribed in each cell, but also with a number of other simple properties, including the total depth, set out close to the figure: *td* is total depth, *d* bar is the average for each cell, *sd* is the standard deviation, *df* is the 'difference factor' indicating the degree of difference between the minimum, maximum and mean depth in each complex (Hillier et al. 1987a), and *t/t* is the number of different depth values over the number of cells.

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In treating shapes as configurations in this sense, that is, as composites made up of standardised elements, we are in effect treating a shape as a graph, that is, as a purely relational complex of some kind in which we temporarily ignore other attributes of the elements and their relations. It is clear that such descriptions are very much less than a full description of the shape. For many shape properties, and for many of the purposes for which we might seek to understand shape, a configurational description of this kind would be quite inadequate or inappropriate. But there is one sense in which the configurational structure of the shape is a uniquely powerful property, and gives insights into properties of spatial and formal shapes which are increasingly manifesting themselves as the most fundamental, especially in studies of architectural and urban objects. This property is that graphs of shapes and spatial layouts are significantly different when seen from different points of view within the graph. This can be demonstrated visually by using the j-graph. By drawing j-graphs from all nodes in a shape, then, we can picture some quite deep properties of shapes.

For example, a highly interesting property of shapes is the number of different j-graphs they have, and how strong the differences are. For example, figure 3.4 shows all different j-graphs for a selection of the shapes in figure 3.3. The number varies from 3 to 6. The reason for this is that if we find that the j-graphs from two nodes are identical, then this means that from these two points of view, the shape has a structural identity, which we intuitively call symmetry. This is why in the shapes in figure 3.4, the smaller the number of different j-graphs as a proportion of the total number of j-graphs (that is, the number of elements in the graph) then the more the shapes appear regular because there are more symmetries in the shape. This is the ratio given as t/t (types over total) in figure 3.3. This aspect of the structure of the graph thus seems to reflect our sense that shapes can be regular or irregular to different degrees.

This analogy can be made more precise. In fact, the symmetry properties of shapes can be exactly translated as configurational properties. Mathematically, symmetry is defined in terms of invariance under transformation. In their book *Fearful Symmetry*, Ian Stewart and Martin Golubitsky illustrates this with singular clarity. ‘To a mathematician’ they argue, ‘an object possesses symmetry if it retains its form after some transformation.’[15] They illustrate this with a diagram showing the symmetries of the square, as in figure 3.5, in which ‘a typical point in the plane is mapped into eight different images by the...eight rigid motions that leave the square invariant’. Thinking of symmetries in terms of points in a shape is useful configurationally, since we may immediately ask what will be the characteristics of j-graphs drawn from each of the points. It is immediately clear that the j-graphs drawn from each of Stewart’s points will be identical, and that this would also be the case for any other comparable set of points which Stewart had selected. It is also clear that once a point has been selected there will only be seven other points in the shape from which j-graphs will be identical. The principle is in fact very simple: in a shape, every symmetry will create exactly one point from which the j-graph is

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Figure 3.3

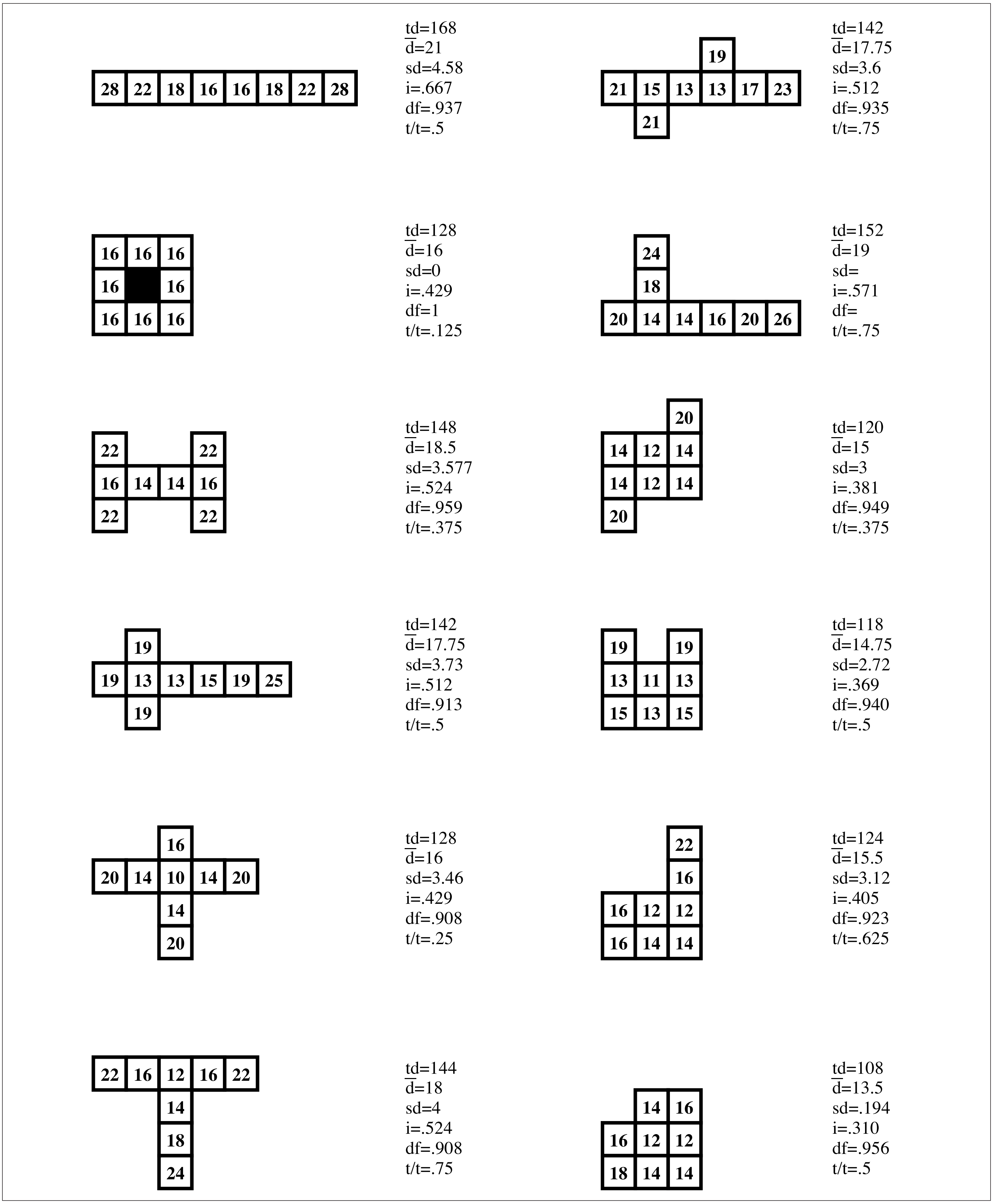

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Figure 3.4

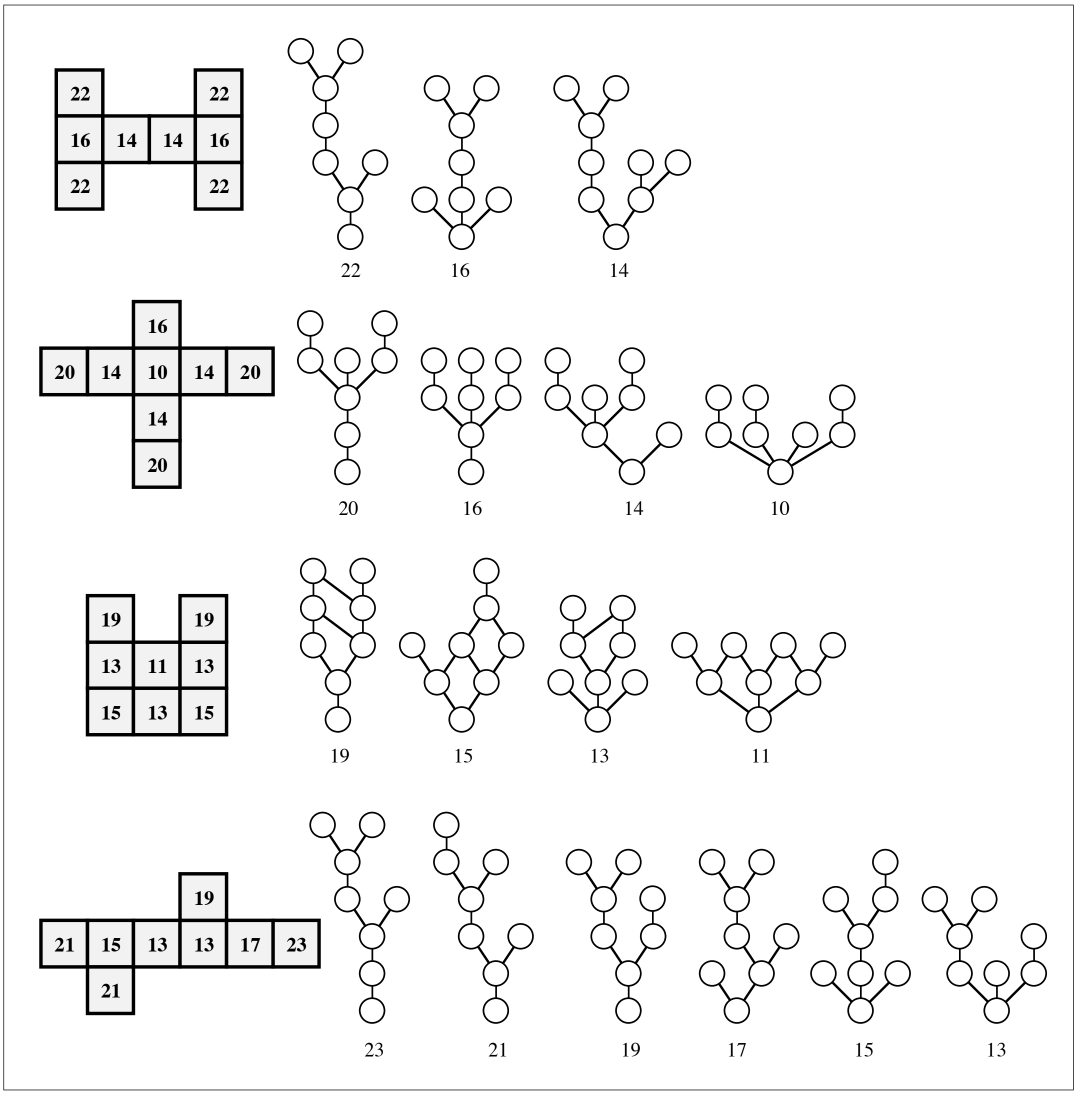
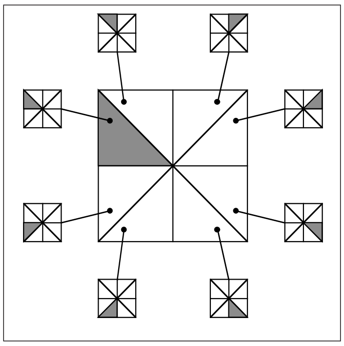


Figure 3.5



isomorphic. In effect, j-graph isomorphism is a test for symmetry. The j-graph allows us to look at symmetry as an internal property, in contrast to the more external view presupposed by the 'invariance under motion' definition. In a sense, the invariance under motion exists because there are different points within the shape from which the shape is identical. We might say that in a shape with symmetry there are points within the shape with identity of positional information in relation to the object as a whole, and this is demonstrated by j-graph isomorphism.

Universal distances

The distributions of depths that are shown through the j-graphs, and which underlie both architectural and geometrical effects - are in fact the most fundamental idea in quantifying the configuration properties of spatial or formal complexes. The idea first made its appearance in the literature of applied graph theory in 1959 when Harary applied it to sociometry under the name of 'status'. 'Status' is defined by Buckley and Harary[16] thus: 'The status s(v) of a node v in

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G (a graph) is the sum of distances from v to each other node in G', distance meaning the fewest number of nodes intervening between one node and another. The problem with status defined in this way as 'total depth' is that the value will be very substantially affected by the number of nodes in the graph. Accordingly, as discussed in Chapter 1, a normalisation formula was proposed in *The Social Logic of Space*[17] which eliminates the bias due to the number of nodes in the graph. With this normalisation, numerical values can be assigned expressing 'total depth' independently of the size of the system. This normalisation formula was discussed and clarified by Steadman in *Architectural Morphology*[18] We will call these normalised values i-values, to express the idea of the degree of 'integration' of an element in a complex, which we believe these values express.

The need for the normalisation formula and the intuition of the form it might take in fact came from using the justified representation of the graph, or j-graph. Simply as a consistently used representation, the j-graph makes the structure of graphs, and more importantly the differences in their structures, extraordinarily clear. However, by representing them in a standard format, it also makes clear the need for comparative numerical analysis and how it might be done. For example, it is immediately clear what graph will be maximally and what minimally deep. It is a simple matter from there to find the normalisation. The fact that no one found this useful expression before, when it opens up whole new vistas for the empirical analysis and comparison of forms, is presumably because no one saw either its necessity or possibility.

However, although the i-value formula allows the theoretical elimination of the effects of the size of the system, it does not deal with the fact that, empirically, architectural and urban spatial complexes use only a small proportion of those theoretically possible, and this proportion shrinks as the size of the system grows. These effects are discussed in full in Chapter 9, and in fact become the basis of a full theory of urban spatial form. A second, empirical normalisation formula was therefore introduced to cope with this empirical fact.[19] The second formula is an empirical approximation with some theoretical justification (that it approximates a normal distribution of depth values from any node in a graph) and as such it lacks elegance. However its robustness has been demonstrated in large numbers of empirical studies over the years, during which time no need has arisen to call it into question.[20] No doubt, as studies advance, it will be possible to eliminate this second normalisation formula and replace it with an expression with more theoretical elegance. In the meantime, 'integration' will refer to the outcomes of both normalisations, unless 'total' depth' (status, with no normalisation) or 'i-value' (status with the first, theoretical normalisation for size) are specified. All these terms are different ways of referring to the same quantity.

Why has this quantity proved so fundamental in the empirical study of spatial and formal configurations? It is possible that its simplicity conceals a very fundamental theoretical property: that it is essentially a generalisation of the idea of distance. Our common concept of distance is that of a specific number of metric

Figure 3.6

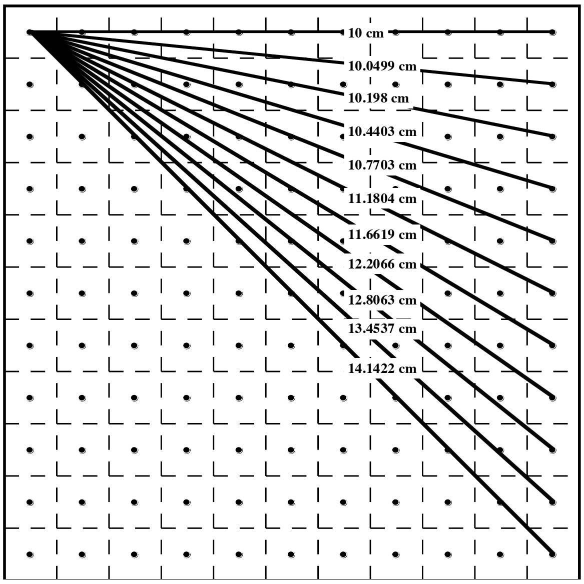
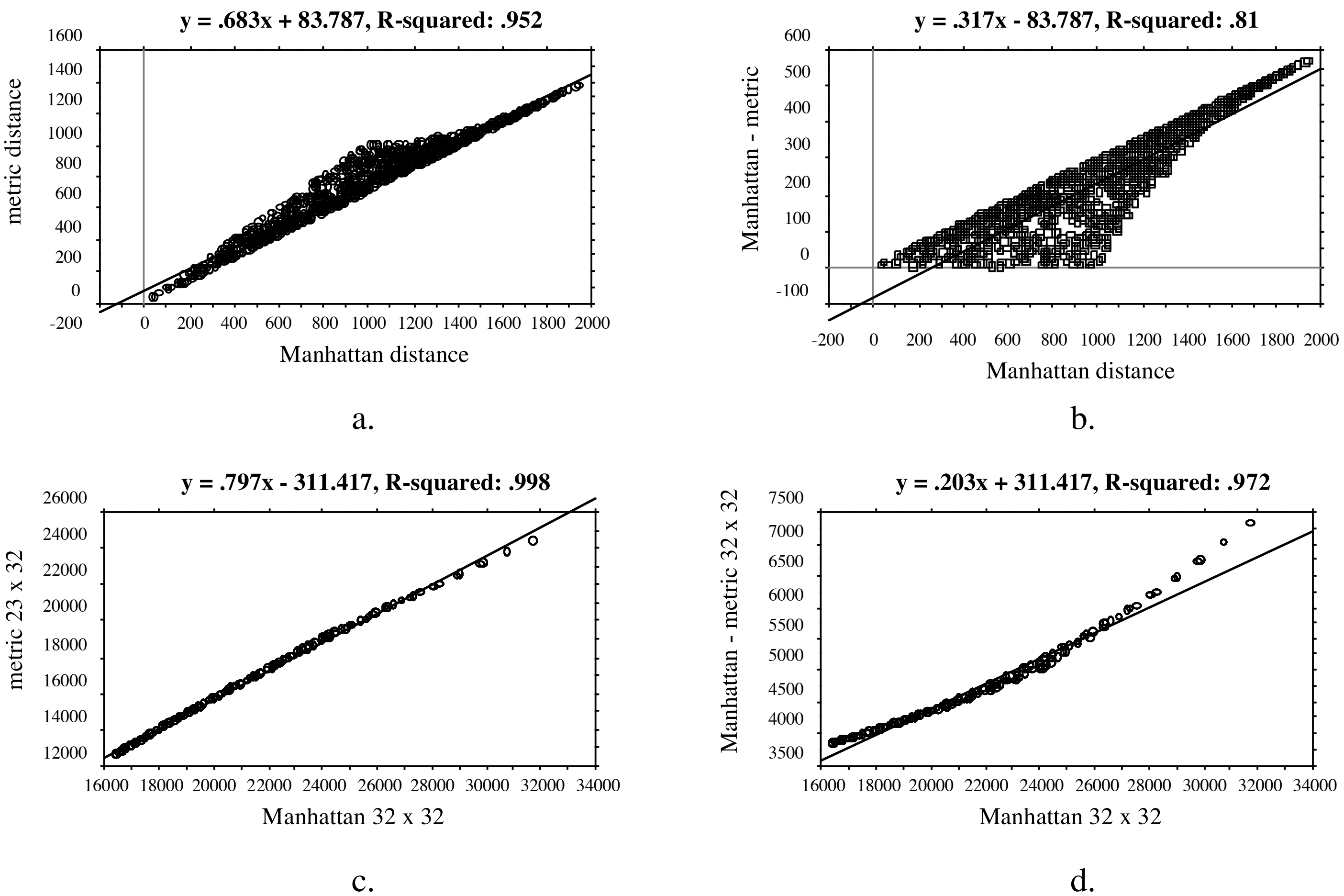


Figure 3.7



units between one point and another within some system of spatial reference. We can call this a specific distance. Total depth sums all specific distances from a node to all others. We may therefore think of it as a 'universal distance' from that node. If specific distance is about the metric properties of shapes and complexes, universal distances seem to be the key to configurational properties. Universal distance seems to be a generalisation of the idea of depth that permits configuration to become the central focus of analysis.

It may be objected that such a concept of universal distance has only been made possible through an unacceptable simplification of the idea of a shape to that of a graph, rather than an infinite set of points. This is a difficulty, but it seems that it might not be as great as it might at first appear. If we consider a square shape made up of square cells, and therefore representable as a graph, as in figure 3.6, and measure distances from and to the centroid of each cell, it is clear that graph distances will approximate metric distances only when they are orthogonally related. On the diagonal, metric distances will be either shorter or longer than graph distances, depending on whether or not we connect the graph diagonally across cell corners, or only allow joins through the faces. If corner links are not allowed, then graph distances will be $n + m$ (or 'Manhattan' distances, by analogy with the Manhattan grid) where m is the horizontal distance and n the vertical distance, while the metric (or 'as the crow flies') distance will be the square root of m squared + n squared. This will be maximal between opposite top and bottom corners. If diagonal links to adjacent nodes are allowed, then the distance between opposite top and bottom corners will be m or n, whichever is the greater, which equally misrepresents the metric distance. If we plot graph distance against metric specific distances in such a system we will find that not only are the differences substantial, but also that they vary in different parts of the system. In other words, graph and metric specific distances are not linearly related, so we cannot use one as a proxy for the other. Figure 3.7a is a plot of metric specific distance against graph (Manhattan) specific distance for 1000 randomly selected pair of points in a 100×100 square cell arrangement of the type shown in the previous figure, and figure 3.7b plots the difference between metric and graph specific distance on the vertical axis for increasing graph distance on the horizontal axis.

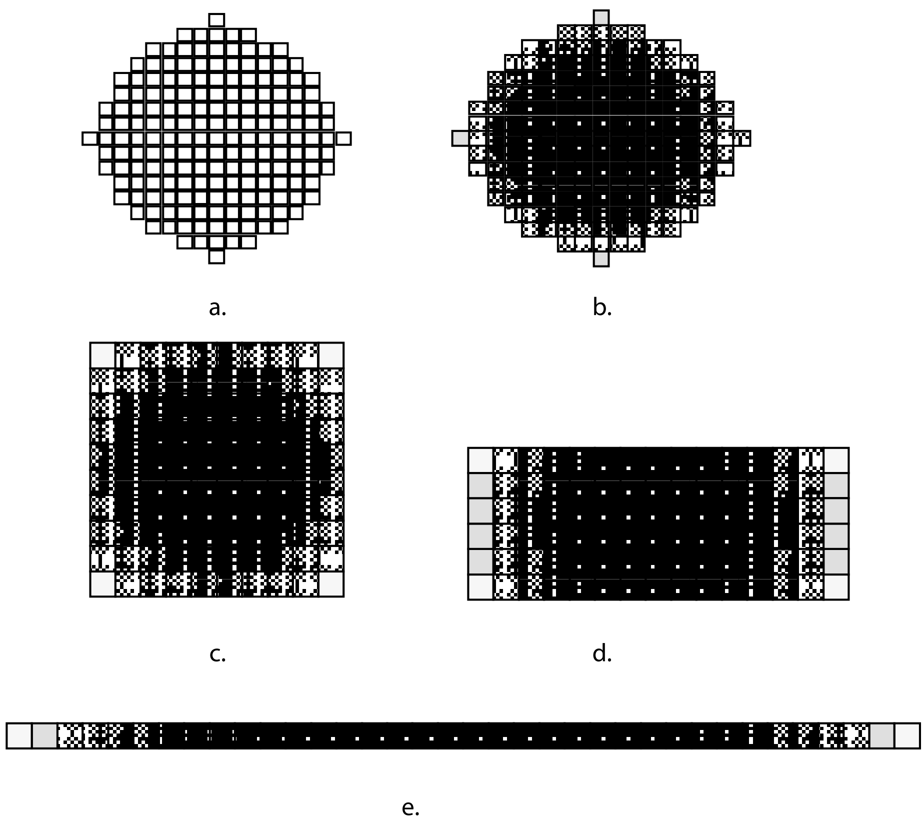
However, if we substitute universal for specific distances, and carry out the same analysis, this problem is significantly diminished. Figure 3.7c shows graph (Manhattan) against metric universal distances for all nodes in a 32×32 (i.e. 1024 cells) square cell complex, and figure 3.7d plots graph distance against the difference between metric and graph distances. Although the values are still exactly as different overall, they are now more or less linearly related, so that it is much more reasonable to use one as a proxy for the other. This fortunate fact permits a far more flexible use of graph based measure of configuration than would otherwise be the case. As we will see, such matters as shape and scale, area and distance can all be brought, as approximations at least, within the scope of the configurational method. All will be in some sense the outcome of seeing a complex of related elements as a set of j-graphs. The j-graph in effect redefines the element of a complex in terms of its relation to all other elements in the complex. Summing the properties of j-graphs to express properties of the whole complex means summing the different points of view from which the complex can be seen internally. The eventual justification of this formalism is that architectural and urban systems are exactly this kind of complex. They are global systems whose structure, functioning and growth dynamics are manufactured out of the innumerable different points of view from which they can be seen.

Regular shapes as configurations

Now let us take the idea a little further, and closer to everyday experience. It is clear that any shape can be represented as a regularly constructed mesh of cellular elements, or tessellation, provided we can scale the mesh as finely as we need. This can then be treated as a graph, and thus expressed as a pattern of universal graph distances. By describing simple everyday shapes in this way, it turns out that we can capture important aspects of how they fit into everyday living patterns.

Suppose, for example, we create an (approximately) circular tessellation of arbitrarily small square cells, as in figure 3.8a. We may calculate the mean depth of each cell from all others, and express the results in a distribution of dot densities for the square elements in which the higher densities, or darker colours, stand for greater integration - that is, less depth – graded through to lightest colours for the least

Figure 3.8



integration, or greatest depth. It is clear that the centre has the highest integration, and that integration reduces evenly in concentric rings around the centre. In a perfect circle, all edge locations will have an identical degree of integration.

If we then consider the square tessellation in figure 3.8c we find that the pattern of integration not only runs from centre to edge, but also from the centre of the edge to the corners. The square form is thus more complex than the circular form in a simple, but critical way. We may say that in the square form, the 'central integration' effect occurs twice: once in the global structure from centre to edge, and once more locally on each side of the form. We can also easily calculate that the square form is less integrated - that is, has greater average universal distances per tessellation element - than the circular form.

As we elongate the square into a rectangle, as in figure 3.8d, the overall form is even less integrated, and the properties first found in the square become more exaggerated. The global structure of the form is now a group of integrated central squares, which includes some on or near the periphery of the object, with the two 'ends' substantially less integrated than other parts. Each side has a central distribution of integration, but one in which the long sides have much greater differentiation than the short sides, and correspond increasingly to the global structure of the tessellation as we elongate it. In the limiting rectangular tessellation, the single sequence of squares, then the local and the global structures are all identical, as in figure 3.8e.

We may summarise this by saying that while all these forms are globally structured from centre to edge, in the circular form the local or lateral structure is uniform, in the square form the lateral structure is maximally different from the global structure, while in the rectangular form the local lateral structure tends to become the global structure as we elongate it, until the limiting form of the single sequence is reached when the two structures become identical. The correspondence between these 'structures' of shapes and the ways in which shape is exploited for social purposes in everyday life is intriguing. For example, on square dining tables the centre side is more advantageous than corner locations, because it is a more integrated location. Similarly, the English prime minister sits in the centre of the long side of a broad rectangular table, maximising this advantage in integration. In contrast, where status rather than interaction is the issue, caricature dukes and duchesses sit at opposite ends of a long table, maximising proxemic segregation but also surveillance, while students and monks classically sit on the sides of a long thin 'refectory' table with no one at the ends, thus making all but localised conversations difficult. The politics of landholding knights with a peripatetic king sitting at a round table are equally manifest, as are the endless political debates over the shapes of conference tables and parliament chambers. The ways in which shapes are exploited and used all follow the pattern of integration in some way, though with opposite tendencies depending on whether interactive status or symbolic status is more critical.

Non-discursive technique

Plans as shaped space

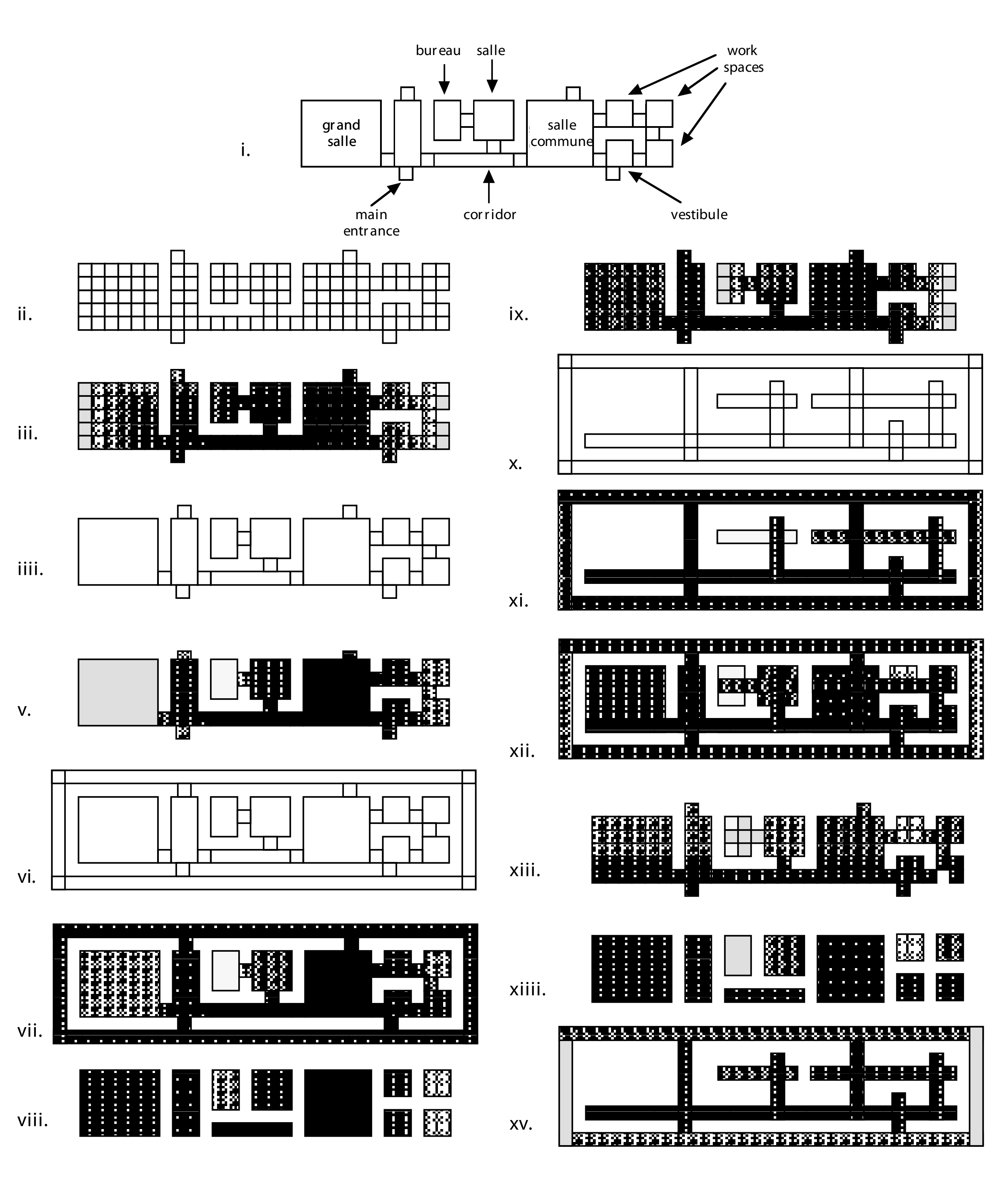
Now let us consider the more complex case of the house plan. In the sequence of plans in figure 3.9i is a slightly simplified version of the plan of one of the farm houses in rural France that were considered in Chapter 1. The salle commune is the everyday space where cooking, eating and the reception of everyday visitors take place. The grande salle is a space for more formal reception of guests. The workspaces to the right are a dairy, washing room and storage, all associated with the female role in the house, the bureau is the office of the principal male occupant, and the salle is an indeterminate space, perhaps functionally associated with the bureau. What does it mean to analyse this plan as a shape?

A plan is, first, a shape, which can be represented as a tessellation, see 3.9ii. For convenience and speed of analysis we use a rather large element, and treat thresholds as single elements. This leads to some unrealism in wall thickness, but this does not affect the analysis. The tessellation may be analysed into a pattern of universal distances. Since this reflects the distribution of centrality in the shape, in this elongated plan the least universal distances - shown darkest - are found in the front corridor between the large space mid-right - the salle commune - and the main entrance mid-left as in 3.9iii.

The metric distribution of universal distances represents the degree to which physical effort must be made to move from one part of the shape to another. If we compare the plan shape to a square shape with the same number of elements we have a simple index of the overall metric integration of the shape. In this case, the mean universal distance of cells in the shape is 10.3 whereas for an equivalent square it would be 4.9. Dividing the former into the latter, we find that our shape has 2.1 times the universal distance of an equivalently sized square, indicating that about twice as much effort must be made to move around this plan as in an equivalent square. We may think of the reciprocal of this number as indexing the degree to which a shape gets towards being a square. In this case the value is .462. The degree and distribution of universal distances thus indexes something like the physical economy of the shape, the human counterpart to which is the amount of physiological effort needed to overcome universal distances. We may perhaps think of this way of looking at the plan as its bodily or physiological structure. It represents the inertia a particular shape offers to the human body occupying it.

However, as we saw in Chapter 1, the plan is also an arrangement of convex elements, that is, rooms, corridors, halls, and so on. We can represent it as such, again, by using single element thresholds, as in 3.9iiii. Again we analyse this for its pattern of integration, this time treating the convex elements as elements, and therefore ignoring actual distances and sizes, giving 3.9v. Now of course, as was shown in Chapter 1, the strongest integrator is the salle commune. Though the colour coding makes it look the same as the corridor, the integration value of the space (.197, using the i-value formula) is a little stronger (that is, has lower universal distance) than the corridor (.205). This means that in terms of convex as opposed to metric organisation, the focus of integration has been displaced from the geometric

Figure 3.9


bureau
salle
work spaces
grand salle
salle commune
i.
main entrance
corridor
vestibule
ii.
iii.
iiii.
v.
vi.
vii.
viii.
ix.
x.
xi.
xii.
xiii.
xiiii.
xv.

centre into one of the function spaces. The distribution survives if we add four linear strips around the plan to represent the outside world (since the relation to the outside is often a critical aspect of domestic space organisation), and reanalyse for integration (3.9vi and vii). The offset salle commune space is still stronger than the central corridor element.

We now overlay the convex elements on the tessellation shape, connecting each to all the tessellation squares that lie immediately under it, and re-analyse the two layers as a single system, so that each convex element is affected by the number of tessellation elements it is directly connected to, and each tessellation element is affected by the links made to other tessellation elements through the pattern of convex elements. Not surprisingly, we find that each layer has affected the distribution of universal distances in the other. Figures 3.9viii and ix show each layer of the two-layer system separately. 3.9viii, the convex layer of the two-level analysis, shows that compared to 3.9v, the large space on the left, the 'best' room, has become relatively more 'integrated' than the work spaces on the right and the office. This is an effect of scale. The fact that the much larger convex area of the ' best' room overlays far more tessellation squares than the small work rooms has the effect of drawing integration towards the 'best' room in direct proportion to its metric scale, and conversely for the small rooms. In effect, the convex layer of the two-level system shows how the pattern of integration of the convex elements is affected by their area, as measured by the number of uniform tessellation elements each overlays. This effect is clarified in figure 3.9ix the tessellation layer of the two-layer system. Comparing this to figure 3.9iii, we see that the overlaying of the larger convex element on the tessellation squares within the 'best' room has the effect of making them more integrated and more uniform. These results show that metric scale, shape, and spatial configuration can all be expressed in the common language of universal distances, or integration, in layered spatial representation considered as unified systems.

We may take this a little further. Another potential 'layer' in the plan is the system of lines of sight linking the convex elements together through the doorways, assuming for this purpose that they are open. We can represent this layer by drawing axial 'strips' corresponding to lines of sight as in figure 3.9x and analyse its pattern of integration, figure 3.9xi. We find that the front 'axis' passing through the salle commune, the salle and the corridor is now the most integrating element but the main entrance front-back line mid-left and the salle commune front-back line mid-right are almost as strong.

We may then superimpose the linear elements on the convex elements and reanalyse these as a single two-level system in which the line elements are all directly connected to the convex elements that lie immediately under them. The effect of this simultaneous analysis of the two layers will be to show how integration is shared between convex and linear elements. We find that the front corridor is still strongest, followed by the front-back line through the salle commune, followed closely by both the front back line through the main entrance and by the convex space of the salle commune itself. These results can be shown by keeping the line and convex system together, as in figure 3.9xii, but also by showing them separately for greater clarity.

Finally we can assemble all three layers into a single system in which both convex and line elements are directly connected to all the tessellation elements that lie immediately under them. We then analyse and print out the three layers separately, first the tessellation layer, figure 3.9xiii, then the convex layer, figure 3.9xiiii, and finally the line layer, figure 3.9xv. The final pattern emerging from the three-layer analysis is that the 'front axis' linking through all the front space is the strongest integrator, followed by the salle commune, the grande salle, the line to the back through the salle commune and the main entrance line and the secondary entrance line.

Compared to the purely convex analysis outlined in Chapter 1, then, a number of new subtleties have been added. For example, it has become clear that the potential line of sight linking rooms through the corridor at the front of the house is a more critical element than appeared in the earlier analysis, and in effect imparts to the house a front-back organisation that had not emerged from the earlier analysis. Also, we can see that the relation between what we might call the 'energy economy' of the house plan, that is, the amount of effort needed to go from one location to another as shown in the metric tessellation, and the higher-level organisation is quite subtle. In effect, convex space integration for the major spaces is displaced from the metric centre of gravity, and the degree of displacement is to some extent compensated by size. Thus the grande salle is more displaced than the salle commune, but compensates for this greater displacement by its greater size. Multi-layered analysis suggests then that we should not see a system of space as one thing. A spatial layout is a shape which contains many configurational potentials, each of which seems to relate to a different aspect of function. These potentials may be treated as independent systems of space by choosing to analyse the layout on the basis of one particular representation rather than another, or they may be treated in selective combinations, or even altogether. It all depends on what we are trying to find out.

Façades as configurations

If the distribution of the various layers of integration in a shape relates to the ways in which we use shapes, then an intriguing possibility might be that it could also be implicated in how we understand shapes. For example, building façades seen as shapes seem capable of being 'understood' as communicators of information in some sense. Could configuration be involved in this type of apparent communication?

Consider in a very elementary way how we recognise objects. The top row of figure 3.10 shows three figures which are constructed by arranging thirty square elements in different ways. Recognising these figures seems to happen in two stages. In the first stage, we identify a distinct shape, different from others. In the second we assign that shape to a category by giving it a name. In figure 3.10a and b, we see two shapes. We easily recognise the difference between the two shapes, that is, we readily make a pure configurational distinction between the two objects. But we have no category to which we can assign either object. The process of object recognition is therefore ended at the first stage. In figure 3.10c we also see a shape, but this time we conjecture a category: the shape looks like an over-regularised humanoid, so we conjecture it is meant to be either a robot, a caricature human, or perhaps a toy. Of course, the figure does not really bear much resemblance to a human being or humanoid. The evidence on which our category conjecture is based is, to say the least, flimsy. However the nature of the evidence is interesting. It seems to be configurational. Figures 3.10a, b and c are no more than outlines produced by rearranging 30 square cells into different configurations. We have, it seems, a clear ability to distinguish pure shapes or configuration from each other, prior to any intuition of the category of thing to which the configuration might belong.

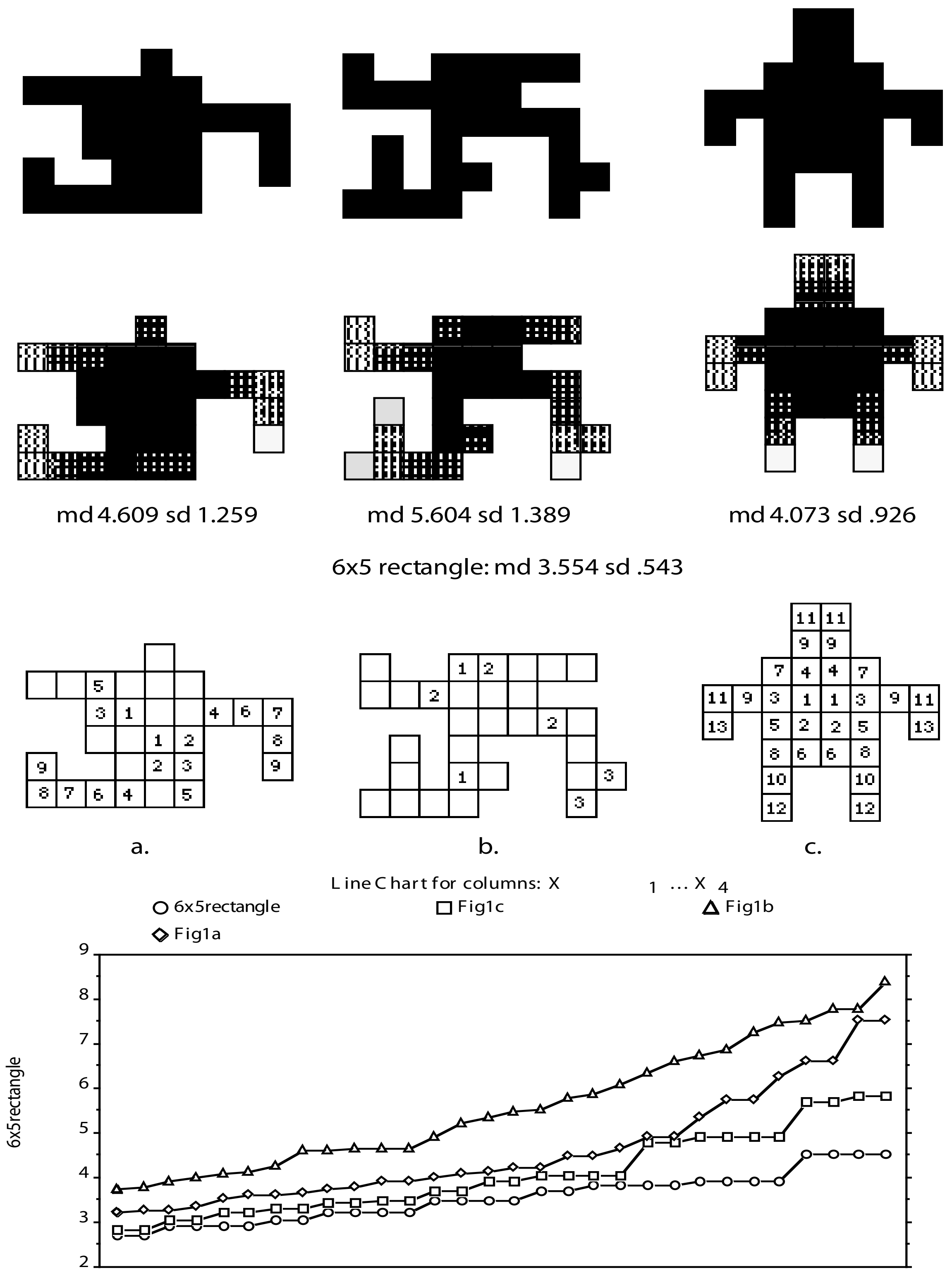
We can call the first the syntactic stage of object recognition, and the second the semantic stage. The second stage has been extensively dealt with by philosophers and others, but what about the first, 'syntactic' stage, only now being investigated by cognitive psychologists?[21] What does it mean to recognise a configuration? One approach to this is to reverse the question and ask what properties configurations have that might allow them to be recognised. Suppose, for example, we analyse the configurations as distributions of total depth values as in the second row of figure 3.10.

This gives us several kinds of useful information about the configuration. First, there is the distribution of integration in each form, as shown by the dark-to-light pattern. This can be thought of as a structure within the shape. Second, there are the integration characteristics of the form as a whole, as indexed by the mean depth (md) values and their standard deviation (sd) as shown beneath each form. For comparison, the mean depth and standard deviation for a six by five rectangle (that is, a regular form with the same number of elements and approximating a square as closely as possible) is also noted. We see that 3.10c is more integrated than 3.10a, which is more integrated than 3.10b, and that all are less integrated than the six by five rectangle. Standard deviations follow a similar pattern. These depth values seem to correspond to certain intuitions we have about the forms, as do the standard deviations, which shows that 3.10b has greater variation in the mean depths of individual elements than 3.10a, which has more than 3.10c, and all have more than the six by five rectangle.

However, there is another intuition which is not expressed in these measures. It is obvious that 3.10c is more 'symmetric' than either 3.10a or 3.10b, since it has the property of bilateral symmetry, one of the commonest and most easily recognisable types of symmetry found in artefacts or in nature. However, while figures 3.10a and 3.10b both lack formal symmetries, they do not seem to be entirely equivalent from this point of view. In some sense, figure 3.10a seems to be closer to symmetric organisation than 3.10b. There is a possible quantification for this property. To explain

Non-discursive technique

Figure 3.10



Non-discursive technique

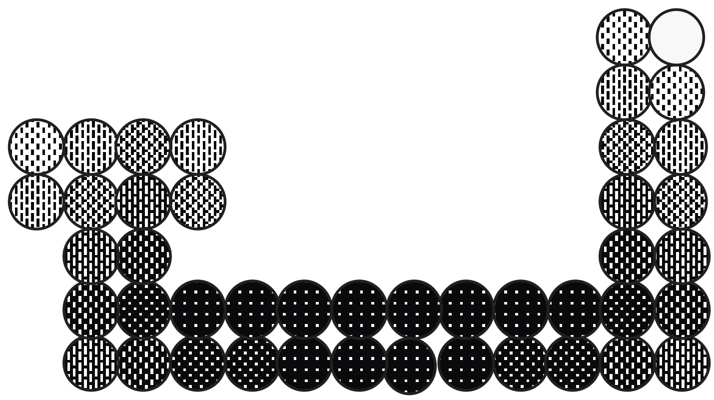
it, we must consider the whole idea of symmetry from a configurational point of view. We have already seen that pure symmetries in shapes could be interpreted as configurational properties, namely j-graph isomorphisms. From an architectural point of view, it is very useful to formulate properties of symmetry in this way, since, unlike the normal 'invariance under motion' definitions of symmetry, it opens the way to weaker definitions of symmetry, and permits an account of intuitively important architectural properties which approach symmetry but cannot be so formally defined. For example, we can specify identity of positional information with respect not to the whole object but to a region within the object, that is, local rather than global j-graph isomorphism, and discuss the relation between local and global j-graph isomorphism. Buildings are full of local symmetries – the form of a window, or of a particular mass within a complex – which sometimes are and sometimes are not reflected in a global symmetry. The relation between local and global symmetry seems a natural way to express this.

Most significantly, we can specify similarity, rather than identity, of positional information, and do so in a precise way. For example, j-graph isomorphism means that j-graphs share not only the same number of elements and the same total depth, but also the same number of elements at each level of the j-graph and the same connections between elements. One way of weakening this property would be to maintain all properties except the requirement that the connections be identical. Another would be to vary the number at each level (from which it follows that connections would be different) but to maintain the total depth the same.[22]

The second of these seems particularly interesting, since it offers a possible formalisation of the property of 'balanced' asymmetry often discussed in the literature in the formal properties of architecture.[23] For example, in figure 3.11 we load a simple linear shape with two sets of four by two cells, one horizontal, the other vertical, but each joined to exactly two cells in the basic form. Although the two end shapes created are different, and in themselves have different distributions of total depth values (or i-values), all the values in the bottom two rows are paired in that each cell has exactly one other cell which is 'symmetrically' located and has the same i-value. This i-value equality seems to give a rather precise meaning to the idea of 'balanced asymmetry'.

We may apply this analysis to the three shapes shown in figure 3.10. The third row shows each shape with cells with equal i-values marked with the same number, from the most to the least integrating. We see that 3.10a has far more equal i-values than 3.10b. Also, in 3.10a the equal values reach well into the integration core of the shape, whereas in 3.10b they are distinctly peripheral. Both of these properties, as well as the degree of integration, can be represented through a simple statistical device: the line chart shown in the final row of 3.10. Here each shape is represented by a series of i-values, plotted from most to least integrated (shown as least to most depth), together with a series representing the six by five rectangle (shown as circles) to provide a baseline for comparison: 3.10a

Figure 3.11



is represented as diamonds, 3.10b as triangles, and 3.10c as squares. Evidently, the overall degree of integration is indexed by the location of the series on the vertical axis. Thus the rectangle is the most integrated, 3.10c next, then 3.10a and finally 3.10b. Also, the shapes diverge as they move from integrated to segregated elements, so that the most integrated elements in each shape are much closer together than the least. The line charts also show the degree of 'balanced asymmetry' in the shape by aligning elements with the same i-value next to each other to form a horizontal line. The ratio of the total number of elements to the number of elements that form part of such lines will index the degree of balanced asymmetry in the shape. The simplest index is the number of i-values over the number of elements. Identical i-values will include both those resulting from perfect symmetry as shown by isomorphic j-graphs, and those that only share the same total depth. This summary figure may then be thought of as a broad 'symmetry index'. Si values for 3.10a, b and c are below the line chart.

Integration analysis of shapes, then, permits us to retrieve some useful descriptions of shape properties in a consistent way, though without any pretence that this is a full account of those properties. One area where this approach is useful, however, is in considering buildings as shapes. The key point here is that buildings are not pure shapes, in the geometric sense of free-standing forms in a uniform context, but oriented shapes, in the sense that they are oriented to and away from the ground on which they stand. If we take this simple fact into account in analysing building façades as shapes then we easily find some very suggestive results. This can be demonstrated by simply standing shapes on a line, which we will call the 'earthline'. The three figures of figure 3.12 are the square and rectangular forms shown earlier with earthlines added. In the case of the rectangular form, the earthline is added twice, once to create a shape horizontally aligned to the earth and once to create a shape vertically aligned.

The first effect that must be noted is that in the case of the square, adding the earthline has the effect of reducing the original eight symmetries of the square to a simple bilateral symmetry. This can be seen visually if we compare the shading patterns of the square with an earthline to the original square form. The concentric pattern is still quite marked, but now an additional bilaterally symmetric pattern is detectable. This effect results, of course, from the earthline, as it were, drawing integration down towards itself. This confirms intuition. It is clear that we do not regard a square ç as having the symmetries of a free-standing geometrical square. We see it as a form anchored to the earth and having left-right symmetry, but not top-bottom symmetry. Indeed the language in which we describe the form - top and bottom, left and right, shows which relations we see as symmetrical and which asymmetrical.

The 'bilateral effect' of the earthline is far more marked in a square form than in an elongated form, whether we elongate the form horizontally or vertically. In the vertical form, the effect of the earthline is to make integration run from the bottom of the form to segregation at the top. This obliterates any sense of a bilateral symmetric effect in the shading pattern, and substitutes a differentiation from bottom to top. Adding an earthline to a horizontally elongated form, we again find the bilateral effect is barely noticeable in the shading pattern, and instead there is a tendency to form broad layers in the form, but with much weaker differentiation from bottom to top.

In terms of integration and symmetry index the differences between the

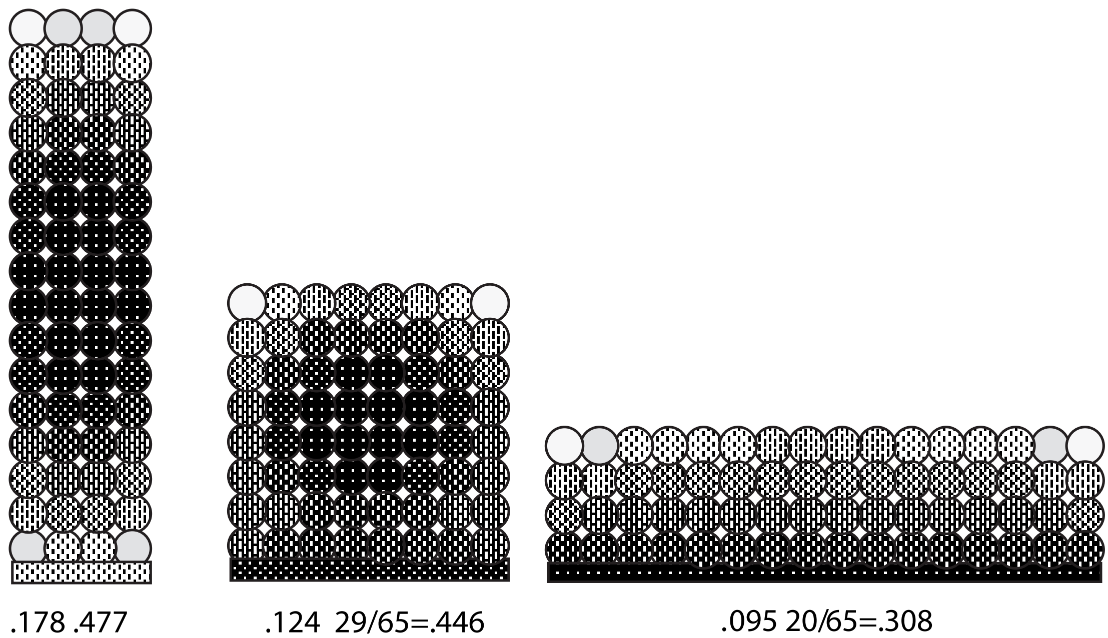


Figure 3.12

vertical and horizontal forms are also striking. The vertical form, because of the greater distance of most elements from the earthline and the fact that far fewer connect directly to it, is almost as segregated as the elongated form without the earth line. In the horizontal form, however, most elements are now closer to the earthline, with many actually touching it, and the effect is that the shape has now become much more integrated than the square form, the opposite of the case without the earthline.

Non-discursive technique

When we consider the symmetry index the effects are no less striking. Whereas in the original shapes, the square form had more 'symmetry' than the elongated form, the addition of the earthline has opposite effects on the vertical and horizontal forms. The vertical form has less symmetry than the square form, because fewer elements are on the same level, while the horizontal form has substantially more, for the contrary reason. Again, there is a common-sense reason for these effects. The addition of an earthline to a vertical form converts a pattern of integration that in the original form went from centre to edge to one that also now goes from the earthline – which, as it were, now anchors the form – upwards through the form, from more integration at the bottom, closest to the earthline, to least at the top, farthest from the earthline. The vertical form in effect now runs vertically from integration to segregation. In the horizontal form, on the other hand, insofar as elements are horizontally related, they will tend to become more similar to each other, by virtue of their closeness to the earthline. This corresponds to the intuition that the more shapes are aligned along a surface, the more equal they become. In contrast, the vertical dimension stresses difference, in that the relations of above and below are asymmetrical. Horizontality, we may say, equalises and integrates, while verticality segregates and differentiates.

The analysis of façades as layers is also suggestive. For example, if we take a simplified representation of a classical façade, we can represent it first as a shape, that is, as a metric tessellation, then, by drawing the dominant elements in the façade, as a pattern of convex elements. By analysing each separately, as in figure 3.13 a and b, we see that the shape, as represented by the tessellation shows a centralised pattern of integration focussed above, and running down into, the central column, giving the distribution a strongly vertical emphasis. In contrast, the convex analysis focusses integration on the frieze, creating a horizontal emphasis. One might conjecture that in looking at a façade we see a shape, and our view of that shape is then modified by the larger-scale organisation of elements imposed on that shape.

These centralised vertical and linear horizontal structures which are revealed by the analysis are, taken separately, among the commonest - perhaps the commonest - formal themes which builders and designers have created in whole classes of building façades across many cultures. The fact that analysis 'discovers' these structures seems, at least, a remarkable confirmation of intuition. The analysis perhaps suggests that one reason why the classical façade has often, from Laugier onwards [24] been argued to constitute a fundamental mode of façade organisation, is exactly because through its shape and convex organisation it both expresses and creates a tension between the two most fundamental modes of façade organisation. If this were the case, then it would suggest that what the human mind 'reads' when it looks at the form of a building is, or at least includes, the pattern of integration at more than one level, and the interrelations between the levels.

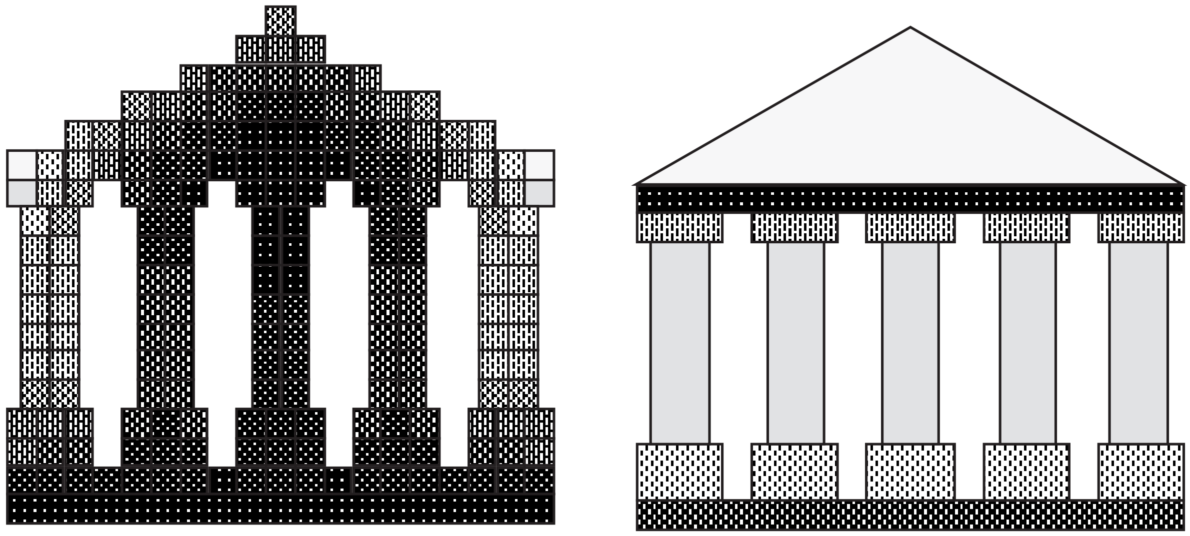


Figure 3.13

Urban space as layers: the problem of intelligibility

Whatever the case with façades, one area where substantial empirical research has established the need to consider layers of configurational potential, and their inter-relations, is urban space. Consider, for example, the two hypothetical urban layouts in figure 3.14a and b. The two layouts are composed of the same 'blocks' or 'islands' of buildings. In the first case, they are arranged in a way which has a certain degree of irregularity, but looks more or less 'urban', in that the pattern of space created by the arrangement of the blocks – and this is all that urban space essentially is – seems to have the right kinds of spaces in the right kinds of relations, and as a result appears 'intelligible' as an 'urban' system. In the second layout, all the 'blocks' are the same but each has been moved slightly with the effect that the system of space seems much less 'urban', and much less easily 'intelligible'. It is clear that any useful analysis of urban space must either capture these intuitions or show why they are illusory. It will turn out that they are not illusory at all, and that they arise from well-defined relations amongst the different spatial potentials that make up the layout.[25]

In one sense, both layouts represent the commonest type of urban space structure. We can call it the 'deformed grid', because while made up of outward facing islands of buildings each surrounded on all sides by continuous space in the manner of a regular grid, the structure of that space is deformed in two ways: it is linearly, or axially deformed, in that lines of sight and access do not continue right through the grid from one side to the other, as they would in a perfectly regular grid, but continually strike the surfaces of the building blocks and change direction as a result; secondly it is convexly deformed in that two-dimensional spaces continuously vary in their dimensions and shape, making a pattern of wider and narrower spaces. The visibility field at any point in the space for someone moving in the grid will be made up of both kinds of element. Wherever the observer is, there will always be a local convex element of some kind, in which every point is visible from every other point, plus the shape made by all lines of sight and access passing through the point. The easiest way to describe the differences between the two layouts intuitively is to say that a moving observer in either layout would experience continuous changes in the visibility field, but that the kinds of visibility field experienced in the first are quite different to those in the second. The apparent differences in intelligibility in the two layouts will turn out to be related to these formal differences in the succession of visibility fields.

We can build up an analysis of the two layouts by investigating these different potentials. First, we will consider the 'overlapping' convex elements that are defined by the surface of this block.[26] Here convex elements are defined by reference to the surface of each block, each of which defines its maximal convex field. These fields will inevitably overlap, and where they do, the area of overlap will itself form a smaller convex element from which both overlapping convex spaces will be fully visible, that is, will be convex, although these spaces are not convex to each other. The same will be true when further overlapping spaces are added. Certain small spaces will indeed be convex to a substantial number of convex spaces because all those spaces overlap in that area. Such areas will as a result have large visibility fields, whereas areas where there is no overlap will tend to have much smaller visibility fields. Overlapping convex elements are virtually impossible to intuit, because the overlapping is so difficult to represent. Computer analysis is therefore required.

Let us look first at the pattern of overlapping convex spaces generated in our two layouts. Figures 3.14c and d, are the result of the analysis of the open-space structure of the two layouts. The computer has first drawn all the overlapping convex elements defined by the faces of each 'block' and then carried out an 'integration' analysis of the pattern, with integration to segregation shown from dark-to-light, as before. In the first 'urban' layout, the darkest spaces of the resulting 'integration core' (the shape made by the darkest areas) cross each other in the informal 'market square', and dark spaces link the market square towards the edge of the 'town'. In the second, there is no longer a strong focus of integration linking a 'square' to the edges of the system and, in effect, the integration core has become diffused. In fact, the most integrating spaces are now found at the edge, and no longer get to the heart of the system. On average, the layout as a whole is much less 'integrated' than the first, that is, it has much greater total depth from all spaces to all others.

In other words, the marginal rearrangement of the urban blocks from the first to the second layout resulting in a spatial structure which is quite different both in the distribution and in the degree of integration. Intuitively, we might suspect that the edge-to-centre integration core structure of the first layout has much to do with the overall sense of urban intelligibility, and its loss in the second layout. Intelligibility is a challenging property in an urban system. Since by definition urban space at ground level cannot be seen and experienced all at once, but requires the observer to move around the system building up a picture of it piece by piece, we might suspect that intelligibility has something to do with the way in which a picture of the whole urban system can be built up from its parts, and more specifically, from moving around from one part to another.

There is in fact a simple and powerful way in which we can represent exactly this property. It is illustrated in the two 'scattergrams' in figures 3.14e and f, corresponding to the two layouts. Each point in the scatter represents one of the overlapping convex spaces in the figure above. The location of the point on the vertical axis is given by the number of other convex spaces that space overlaps with, that is, the 'connectivity' of the space with other spaces, and on the horizontal axis by the 'integration' value of the space, that is, its 'depth' from all others. Now 'connectivity' is clearly a property that can be seen from each space, in that wherever one is in the space one can see how many neighbouring spaces it connects to. Integration, on the other hand, cannot be seen from a space, since it sums up the depth of that space from all others, most of which cannot be seen from that space. The property of 'intelligibility' in a deformed grid means the degree to which what we can see from the spaces that make up the system - that is, how many other spaces are connected to - is a good guide to what we cannot see, that is, the integration of each space into the system as a whole. An intelligible system is one in which well-connected spaces also tend to be well-integrated spaces. An unintelligible system is one where well-connected spaces are not well integrated, so that what we can see of their connections misleads us about the status of that space in the system as a whole.

We can read the degree of intelligibility by looking at the shape of the scatter. If the points (representing the spaces) form a straight line rising at 45 per cent from bottom left to top right, then it would mean that every time a space was a little more connected, then it would also become a little more integrated - that is to say, there would be a perfect 'correlation' between what you can see and what you can't see. The system would then be perfectly intelligible. In figure 3.14e, the points do not form a perfect line, but they do form a tight scatter around the 'regression line', which is evidence of a strong degree of correlation, and therefore good intelligibility. In figure 3.14f we find that the points have become diffused well away from any line, and no longer form a tight fit about the 'regression line'. This means that connectivity is no longer a good guide to integration and therefore as we move around the system we will get very poor information about the layout as a whole from what we see locally. This agrees remarkably well with our intuition of what it would be like to move around this 'labyrinthian' layout.[27]

Now let us explore the two layouts in more detail. In figure 3.14g and h, we have selected a point in the 'square' in the analysis of the first layout, and drawn all the overlapping convex elements that include this point. The scatter then selects these spaces in the scattergram by making them coloured and larger. We can see that the spaces that overlap at this point are among the best connected and most integrated in the layout and that the points also form a reasonable linear scatter in themselves, meaning that for these spaces more visible connectivity means more

Non-discursive technique

Figure 3.14a

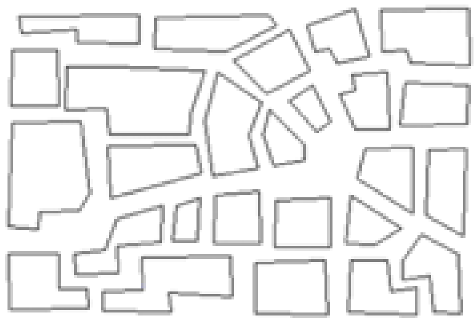


Figure 3.14b

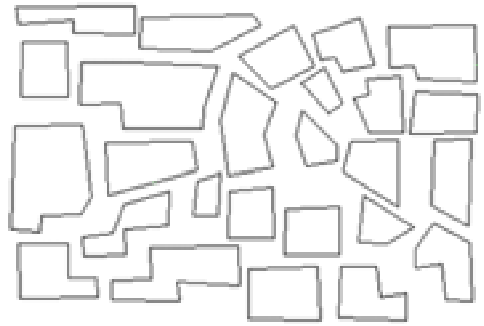


Figure 3.14c

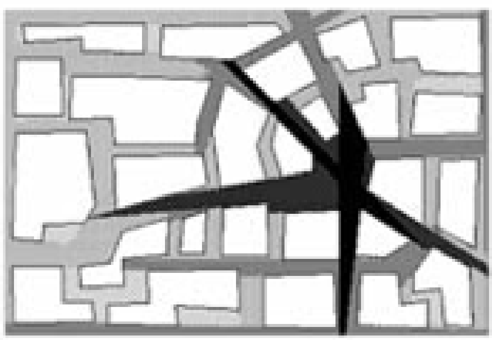


Figure 3.14d

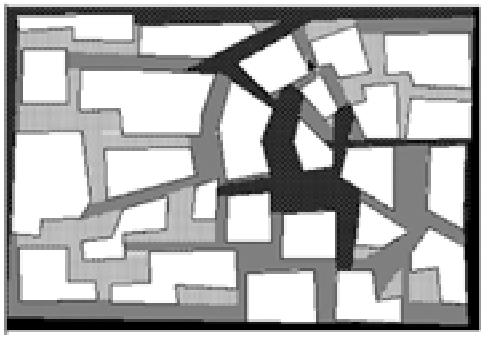


Figure 3.14e

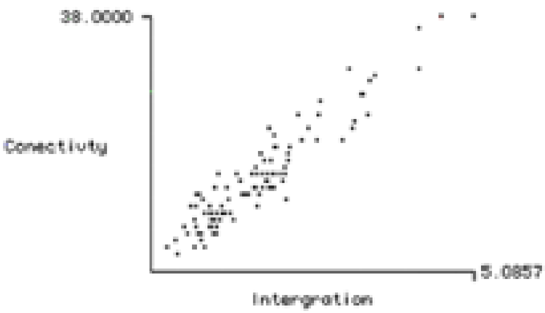
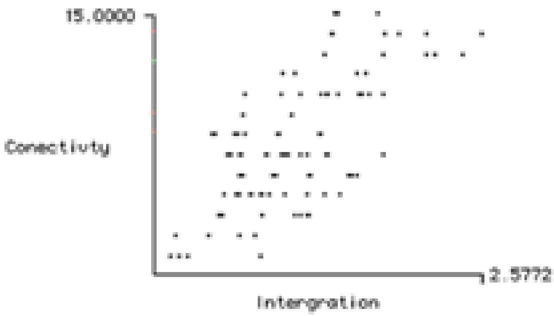


Figure 3.14f



Non-discursive technique

Figure 3.14g

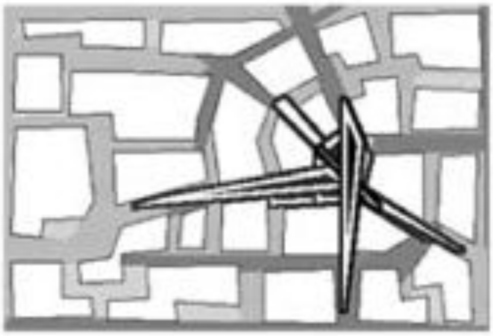


Figure 3.14h

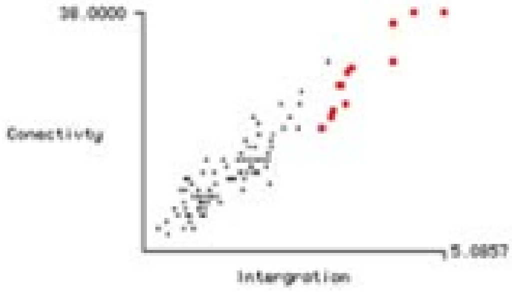


Figure 3.14j

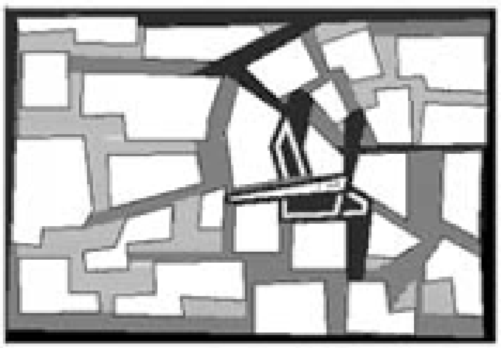


Figure 3.14k

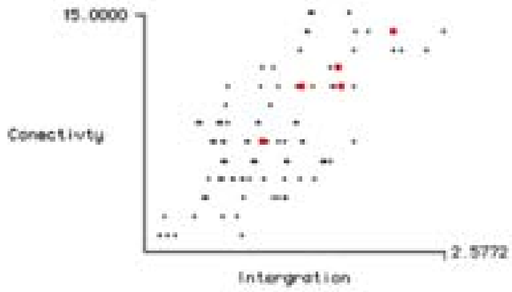


Figure 3.14l

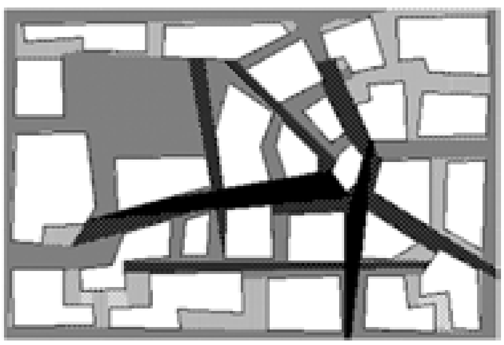
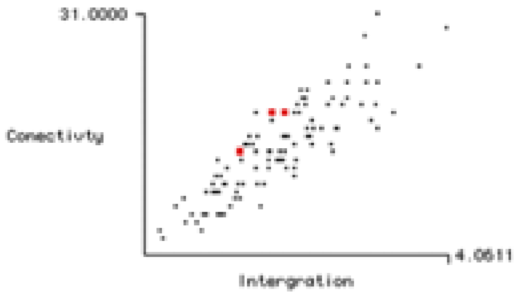


Figure 3.14m



Non-discursive technique

Figure 3.14n

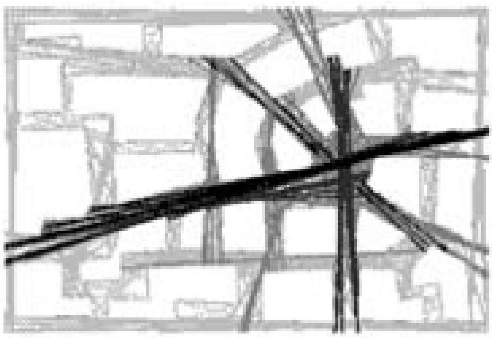


Figure 3.14p

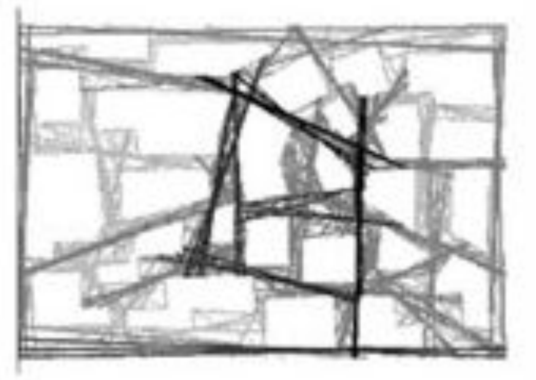


Figure 3.14q

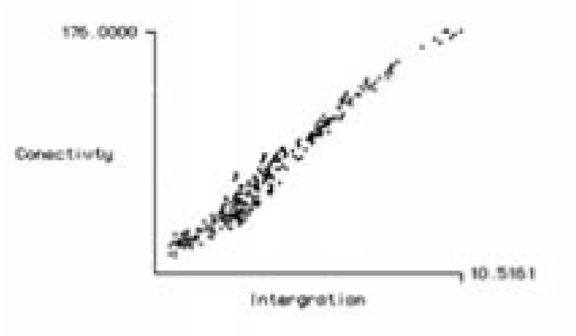
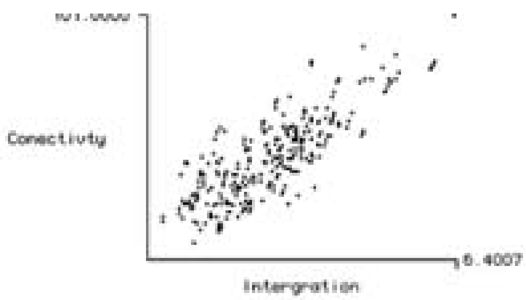


Figure 3.14r



integration. Both the shape made by the set of spaces, reaching out from the square in several directions towards the edge of the system, and the scattergram properties confirm that this point in the 'square' space has a high 'strategic' value in the layout as a whole. If we try to do the same for points in the second layout, as in figure 3.14j and k, we find that the points are buried in the scatter and have no special strategic value. By experimentally clicking on a series of points, and checking both the visual fields and the scattergrams, one can establish that there are no comparable strategic points from which a series of key spatial elements in the layout can be seen.

We may also experiment with the effects of changes to the layout. Suppose, for example, we decide that the current 'market square', although strategically placed, is too small and that it should therefore be moved elsewhere in order to enlarge it. In figure 3.14l and m, the old market square has been built over and a new, larger square has been created towards the top left of the layout. The layout has been analysed and the convex elements overlapping in the new square picked out. In spite of its size, the new square has poor integration, and its overlapping spaces occupy a poor position in the scatter. The most integrated spaces remain those pointing into the old market square. In other words, the spatial configuration as a whole continues to ‘point to’ the old square. An important conclusion from this, amply confirmed by the examination of real town plans, is that a square is more than a local element. How it is embedded in the configuration as a whole is equally, if not more, important. If we were to seek to exploit this by expanding the old market square by removing adjacent blocks, we would find the square becomes much more dominant, and that the largest space within the square (i.e. as opposed to those entering and leaving which are normally more dominant) is now itself the second most integrated space. In other words, we would begin to shift the emphasis of integration from linear elements to the open space itself. Again, this would distort the essential nature of layout. The size, location, and embedding of major open spaces are all formally confirmed as aspects of what we intuitively read as the urban nature of the layout.

Convex elements are not, of course, the most ‘global’ spatial elements in a layout, and do not exhaust all relationships of visibility and permeability. These limits are found by looking not at two-dimensional convex elements, but at one-dimensional line elements. In a deformed grid, the elements most spatially extended linearly will be the set of straight lines that are tangent to the vertices of blocks of buildings. Relations between pairs of these vertices in effect define the limits of visibility from points within the system. This can be explored through ‘axial’ or ‘all line’ analysis, and in figure 3.14n-r where the computer has found and carried out an integration analysis of all the line elements tangential to block vertices. We find that the intelligibility of the system seen axially is better than seen convexly, because lines are more ‘global’ spatial elements than convex elements, in that they explore the full limits of visibility and permeability within the layout. Lines therefore make the relation between the local spatial element and the global pattern of space look as good as possible. The differences between the two layouts that we found through the overlapping convex analysis are however more or less reproduced in the all-line analysis. This agreement between the two kinds of analysis is itself a significant property of the layouts.

From the point of view of how layouts work, both types of analysis are important. Movement, for example, can be predicted from a stripped down version of the axial analysis in which only the longest and fewest lines needed to cover the whole system form the line matrix. Similarly, many aspects of ‘static’ urban behaviours, especially the informal use of open spaces, exploit the two-dimensional ‘visibility field’ properties of space, with the highest levels of use normally adjacent to the most strategic spaces.

Designing with configurational models

Because these techniques allow us to deal graphically with the numerical properties of spatial layouts, we can also use them creatively in design, bringing in much new knowledge about space and function as we do so. For example, extensive research has shown[28] that patterns of movement in urban areas are strongly predicted by the

Non–discursive technique

distribution of integration in a simple line representation of the street grid. By using configurational analysis techniques in simulation mode, we can exploit both this knowledge, and the potential for configurational analysis to give insight into possible urban patterns that will not be at all clear to intuition. This potential has now been exploited in a large number of urban design projects, often involving the modelling of whole cities in order to simulate the effects of new designs.[29]

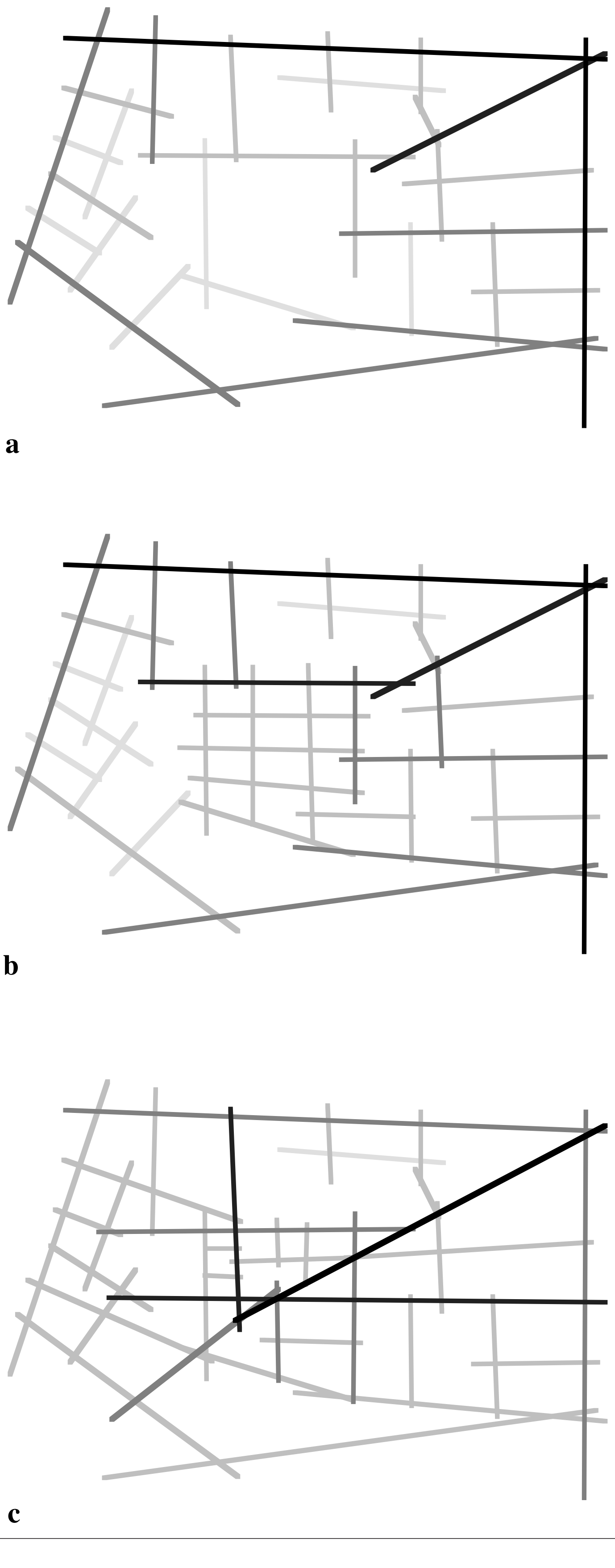
To demonstrate the essentials of the technique, a simplified hypothetical model will suffice. The top left figure of figure 3.15 is an analysed axial map (the longest and fewest lines that cover the street grid) of a small area around a hypothetical redevelopment site, with integration from dark to light as before, with, to its right, the scattergram of its intelligibility, showing a weakly intelligible system. We can experiment by asking, what would happen if, for example, we imposed a regular grid on the site without taking too much account of the surrounding structure, as the second-row figure and scatter. We see that in spite of the geometric regularity, our lack of concern for the global pattern has left us with a rather uniformly segregated space pattern within the site, with too poor a relation to the surrounding areas. As a consequence, we see from the scatter that the area as a whole has become even more unintelligible.

Suppose we then go the other way, and try to design the site by extending strong lines, and linking them to others, as in the third row figure and scatter. The result is an integrating site, and good intelligibility. The spatial structure in the site also has a good range of integrated and segregated space in close proximity to each other. As we will see in later chapters this is an important urban property (see Chapters 4 and 5.) This is a simple example, but it shows the ability of configurational analysis not only to aid the designers' intuition in thinking about patterns, and in particular in trying to understand the pattern consequences of individual design moves, but also its ability to permit the designer to think more effectively about the relation of new and existing patterns, and in general about the relation of parts and wholes in cities.

We may again illustrate this by a simplified simulation. Plate 1 is the axial map of a hypothetical urban system with well-defined sub-areas. Research has shown that the critical thing about urban sub-areas is how their internal structures relate to the larger-scale system in which they are embedded. The best way to bring this out is to analyse the system for its integration at two levels. First we do ordinary integration, which counts how deep or shallow each line in is from every other line. Second we count how deep or shallow each line in is from all lines up to three steps away. The latter we call radius-3 integration, since it looks at each line up to a radius of 3. The former we can call radius-n integration. Radius-3 integration presents a localised picture of integration, and we can therefore think of it also as local integration, while radius-n integration presents a picture of integration at the largest scale, and we can therefore call it global integration.

We will see in due course that local integration in urban systems is the best predictor of smaller-scale movement - that usually means pedestrian movement

Figure 3.15



because pedestrian trips tend to be shorter and read the grid in a relatively localised way - while global integration is the best predictor of larger-scale movement, including some vehicular movement, because people on longer trips will tend to read the grid in a more globalised way. In historical cities, as will be shown, the relationship between these two levels of integration has been a critical determinant of the part-whole structure of cities, because it governs the degree of natural interface there would naturally be between more local, and therefore more internal movement, and more global and therefore more in-out movement and through movement.

Some of the different effects on this relationship that different types of local area design will have can be shown by highlighting the areas in scattergrams of the whole system and examining the scatter of local against global integration. The area shown in the bottom row, for example, is a classically structured area for a European city, with strong lines in all directions from edge to centre, with a less integrated structure of lines related both to this internal core and to the outside. This ensures that those moving in the area will be conscious of both the local and global scales of space as they move around, and there will be a good interface between local and global movement. The scatter formed by the sub-areas is shown to the right. The points of the area form a good linear scatter, showing that local integration is a good predictor of global integration, and cross the regression line for urban area as a whole at a steeper angle, showing that there is a stronger degree of local integration for the degree of global integration. A line on the core of the whole settlement will, in contrast, lie at the top end of the main regression line. This shows how subtly urban areas create a sense of local structure without losing touch with the larger-scale structure of the system. (See Chapter 4 for an examination of real cases).

The area shown immediately above, in the second from bottom row, is typical of the layouts we tend to find in housing estates, with few connections to the edge and little relation between the edge to centre structure and the internal structure of the layout. This type of layout is invariably shown as a series of layers in the red point scatter with virtually no correlation between local and global integration. Such layouts invariably freeze all our natural movement and become structurally segregated lumps in the urban fabric.[30] The areas in the top two rows show other variations on local area structure, one producing effects rather similar to those in the experimental grid in the design experiment of figure 3.16, while the other is a random scatter of lines, showing that in spite of the apparent informality of much good urban design, random lines simply do not work except by chance.

Future urban models: intelligent analogues of cities

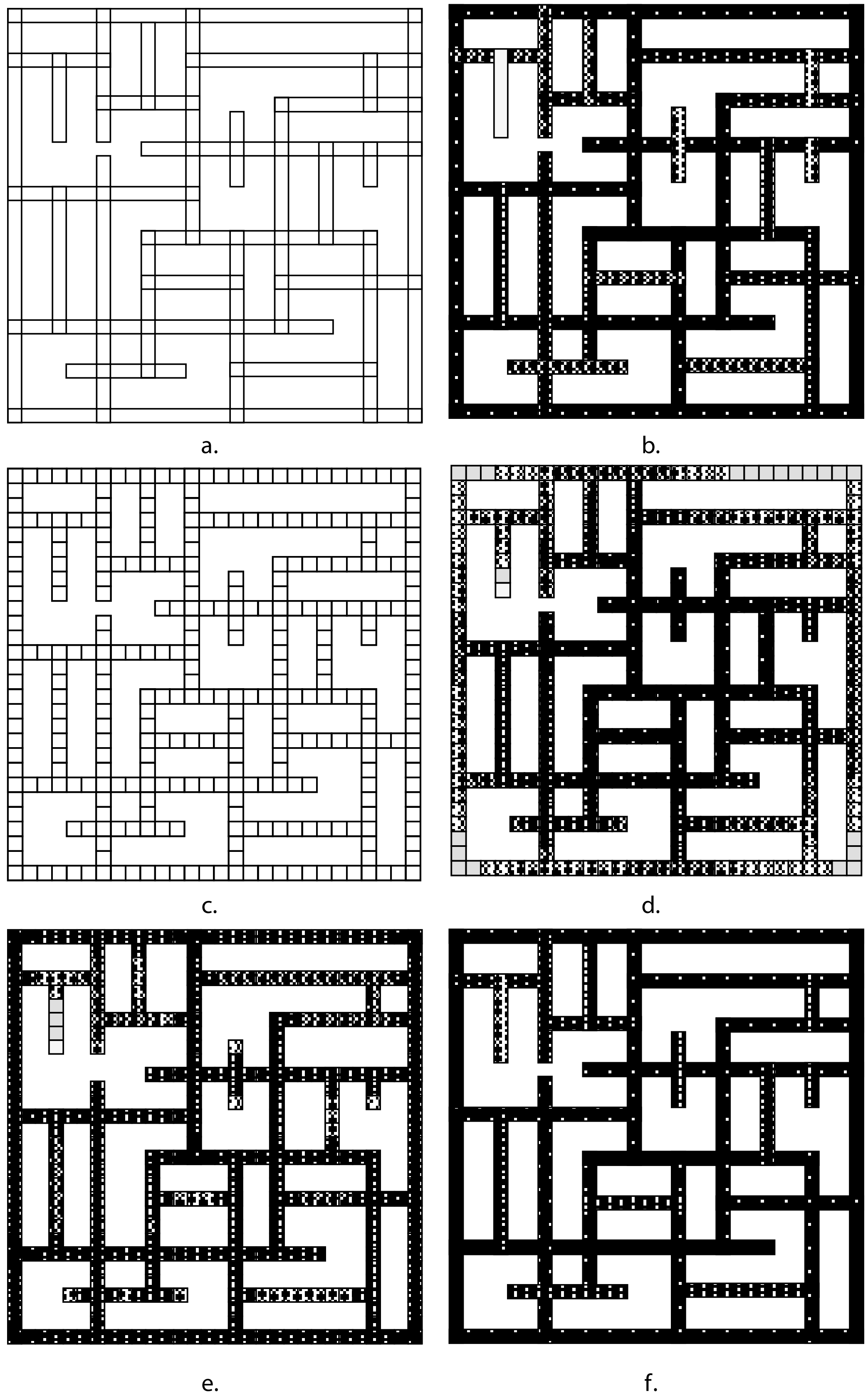
In addition to their role in design, configurational models are now being developed as a basis for researching into the multidimensional dynamics of cities. Consider, for example, one of the broadest and least tractable of issues facing the built environment industry: that of the economic, social and environmental 'sustainability' of cities. Even to monitor effectively and compare cities on sustainability criteria, whatever they might turn out to be, we must bring data on the physical and environmental performance of cities together with data on their economic and social performance, and to relate both to some kind of description of the city. For example, energy consumption and pollution production depend, among other factors, on settlement patterns. Should settlements be dense or sparse, nucleated or dispersed, monocentric or polycentric, or a mix of all types? For research to give an answer, measurement data on environmental performance, and data on the implications of different behavioural assumptions (for example about the distribution of work and home) and 'knock-on' effects such as the economic, social and cultural consequences of spatial aggregation and disaggregation policies, must be related to descriptions of the physical and spatial form of cities which reflect the range of variation found in the real world.

To work towards a theoretical model of how this might be done, we may begin with the purely 'configurational' models we have presented, and show how other key spatial attributes such as metric distance, area, density, plot ratios, shape, political boundaries, and so on can be expressed within the configurational model by using the idea of integrating 'layered' representations of space into a single system. For the purposes of illustration we will again use notional, simplified examples. First, we represent a street network as a series of lines or strips, and analyse their pattern of integration, as in figure 3.16a and b. In this analysis, no account has yet been taken of metric distance. However, in some circumstances at least, this seems likely to be an important variable. We can supply this by selecting an arbitrary module - say a ten-metre square – and linking modules into the pattern of the grid and analysing this as a tessellation shape, as in figure 3.16c. On its own, this is not of great interest, since it inevitably reflects the pattern of metric centrality in the grid, as in figure 3.16d, but if we superimpose the line network onto the metric modular system and analyse the two layers as a single system, then the effect is to weight each line with a number of modules directly related to its length. The outcome of this 'length weighted' integration analysis is shown at both levels of the combined analysis: in terms of the modular units in figure 3.16e, and in terms of the 'line superstructure' of strips in figure 3.16f. The strip level is much the same as previously, but the modular elements show an interesting - and very lifelike - localised structure in which greater integration is concentrated at the 'street intersections', with less integrated modules in the centres of links away from the intersections. This immediately enables us to capture a new and functionally significant aspect of space organisation in a representation.

The relationship between metric area and configuration can be dealt with in an analogous way by underlaying convex elements with a two-dimensional modular layer, as in figure 3.17a-f. In a–c we see how a simple system in which four convex spaces of equal size and shape and the connections between them are represented as a layer of modular elements with four convex elements and four strips for the connection superimposed. The two-layer system is then analysed. Whether we look at the result with the convex layer uppermost or the modular layer, the results will

Non-discursive technique

Figure 3.16



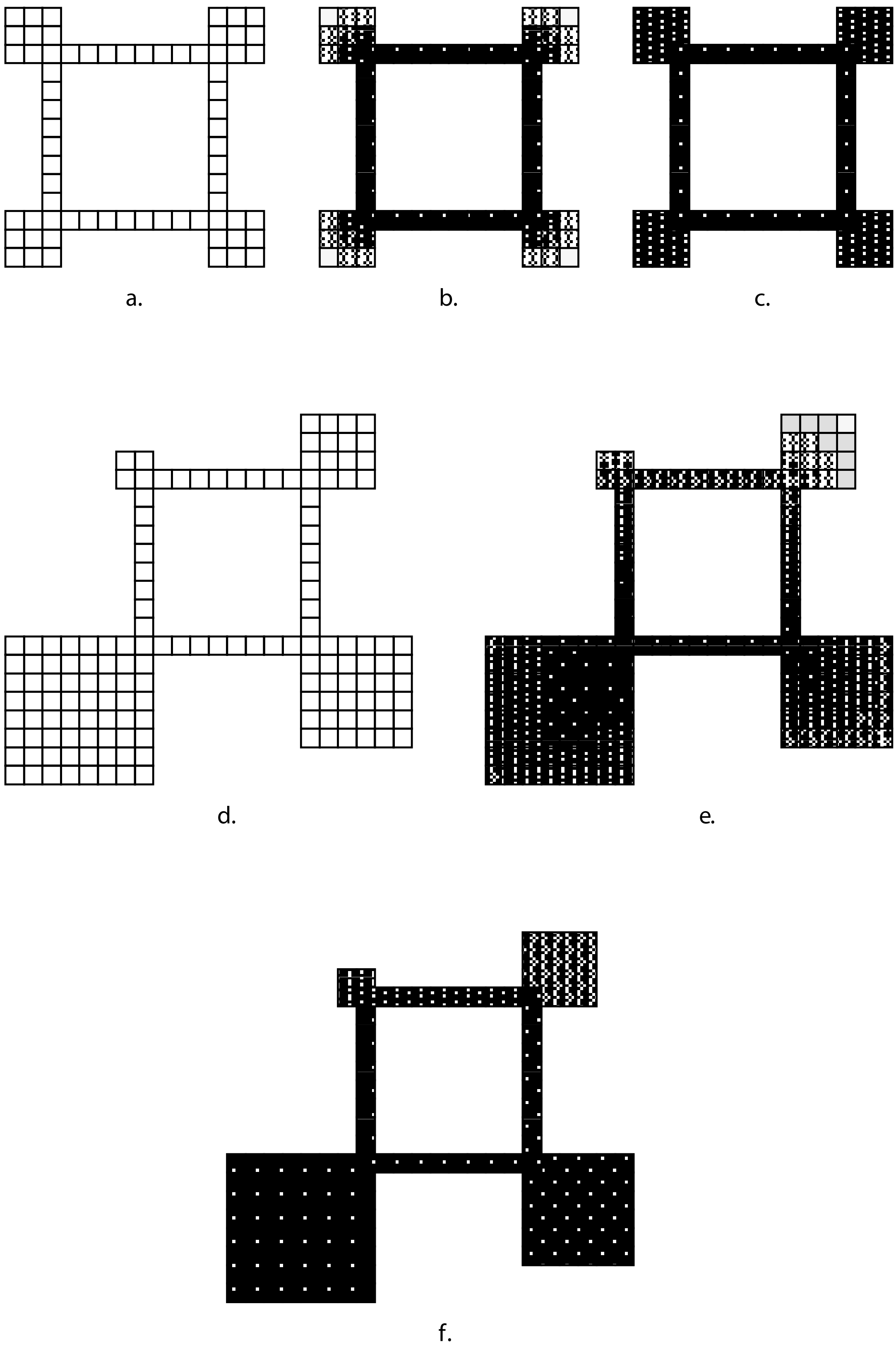
be a symmetrical distribution of integration dominated by the strips. In figure 3.17 d–f we give the convex elements different areas and underlay modular elements accordingly, so that each is now weighted by the number of modular elements it overlays. Analysis separately then together shows that integration is drawn into the convex elements according to their area. Note however that the integration of the two smaller convex areas (on the top) are in the 'wrong' order. This is because the one on the left is closer to the largest-scale convex area (bottom left) and this affects its own integration with respect to the rest of the system. Thus the results show a combination of configurational effects and metric area effects. From this we can see that if we make a large and small square configurationally equivalent in an urban system then the large square will integrate more. Metric area, it turns out is like distance, a property capable of expression as an aspect of configuration.
We may simulate the effect of plot ratios and densities by equally simple means. For example, if we wish to attach a building with a given number of floors to a street network, all we need to do is attach a convex space the size of the ground area of the building to the appropriate position in the street system, then overlay on that a convex element for each floor, making sure that each element above the ground is detached from the street and only connected through the ground layer as it would be in real life. This will not appear visually as a three-dimensional structure, but it will exactly represent the addition of above ground floor space to the urban system.

We may now build a model of an urban system in the following way. First, we divide the city up into an arbitrary number of areas and represent them as non-contiguous polygons. These may be as small or as large as we need, according to the level of resolution required by the research question. The polygons may be based on political boundaries, like wards, administrative boundaries like enumeration districts, segments defined by an arbitrarily fine grid, or they may be defined by objective morphological properties of the built environment. These polygons representing areas are the fundamental units of analysis for the technique.

Figure 3.18a shows our imaginary simplified case in which the street network of the city (or part-city) is superimposed on the patchwork of polygons so that each polygon is linked into the urban system by all the streets or part-streets that pass through it or alongside it. This two-level spatial system is analysed 'configurationally' to find the pattern of integration in the whole system. Evidently, the street pattern will tend to dominate the area polygons simply because the streets are connectors. However, the street system can then be 'peeled off' the polygons, as in figure 3.18b, leaving a pattern of polygons with their spatial characteristics in relation to the city area around them, and to the city system as a whole, recorded as a set of numbers.

This basic process of linking areas together by the street network in a single configurational model is the basis of what we call an 'intelligent urban analogue' model. Once this is established, we can then complicate the model in all the ways we have described previously. For example, we can underlay the street network with metric modules so that the analysis of the street system takes distances into account. We can underlay the polygons with metric modules so that the metric area

Figure 3.17



of a polygon is taken into account. We can also, if we wish, superimpose layers on the polygons representing off the ground floor space.

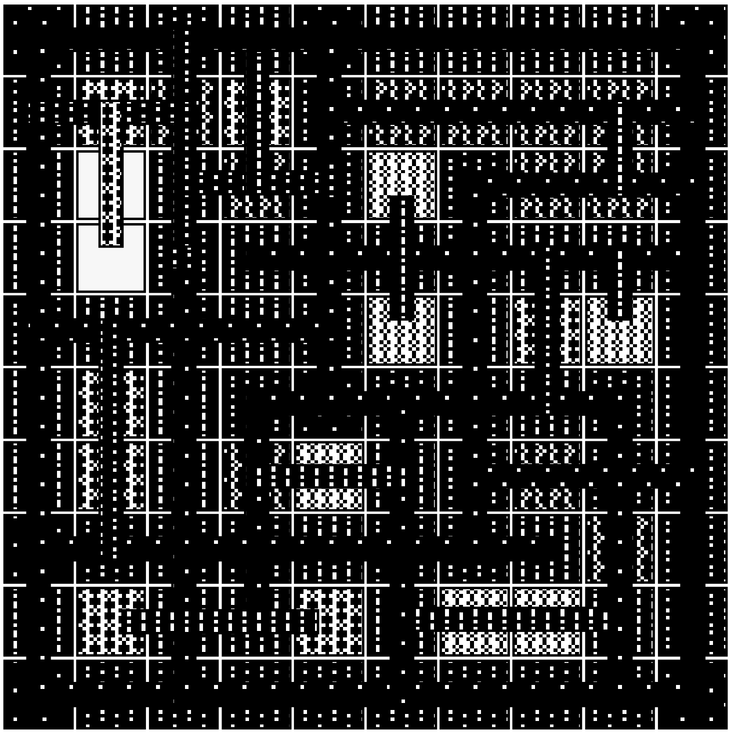
There is also an easy way of further disaggregating any model from the level of resolution originally selected. Each of the original area polygons can be itself subdivided into much smaller polygons and analysed as before. This more localised analysis will give a much richer and denser picture of the detailed characteristics of the area. These may then be fed into a larger-scale model as more detailed environmental descriptors. There is no reason in fact why both levels of the model should not be analysed as a single system. The principal barrier would be computing time. In our experience adding a new level of fine structure to an existing model leaves the larger-scale picture more or less intact provided that the disaggregation is done uniformly and is not confined to particular regions.

At the other end of the scale, we may also derive new measures of the most macro-properties of the city system, such as shape, and shape loaded with different densities in different regions. This can be done by simply linking the area polygons together and analysing the distribution of integration in the system without the superimposed street system. Shape will be indexed by the degree and distribution of integration, and can be shown both by direct graphical representation of the city system, or by statistical representations such as frequency distributions, or simply by numbers. The effects of weighting shapes by loading different regions with higher densities can be explored by simply overlaying the spaces representing the additional densities onto the relevant polygons of the contiguous polygon system, then proceeding as before. By varying the pattern and density of centres we can explore their effects on total distance travelled, other things being equal, in different kinds of three-dimensional urban system. The effects of other nearby settlements can also be investigated by simply adding them as extensions to the model.

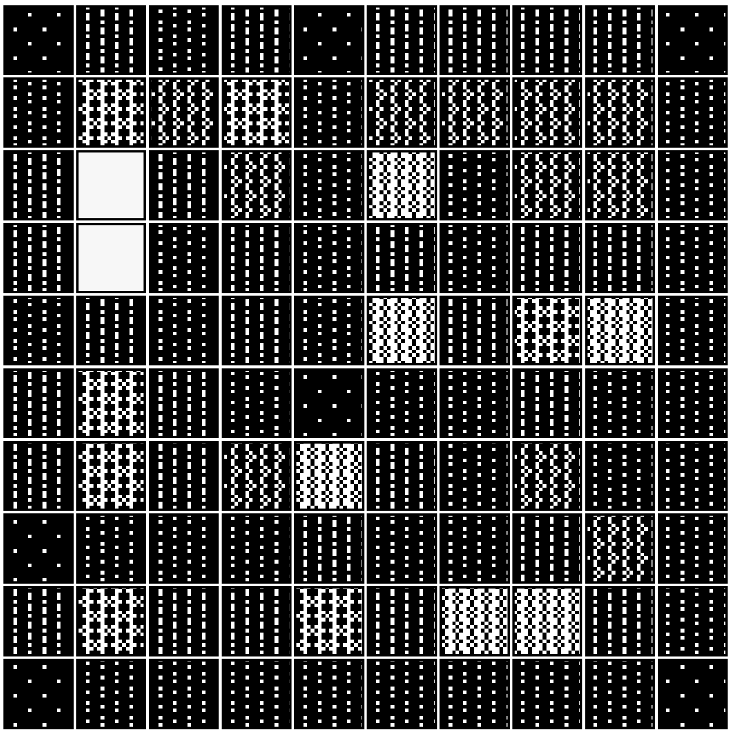
The numerical data resulting from the analysis of the urban system can then be used in a number of ways. First, most obviously, the parametric descriptors for the polygons resulting from analysis, reflecting as they do the position and configuration of each 'finite element' in the city system as a whole, then become the frame for other kinds of data which can be assigned as descriptors to the polygons. This can be done with any functional variable that can be numerically indexed for that area such as population densities, pollution levels, traffic movement, pedestrian movement, unemployment rates, crime rates, council tax banding, and so on. Because spatial and other descriptors are now all in numerical form, simple statistical analyses can begin to reveal patterns. Second, the distribution of any property may be represented graphically in the urban system as a visual distribution of that property in the city system. This means, in practice, that all the visualising and cartographical potentials that have been developed in the past few years through 'geographic information systems' can be interfaced with, and potentially brought within the scope of, an analytic model with proven ability to link morphological and functional properties of built environment systems, hopefully in a more predictive way.

Layered models are the future of configurational modelling of space.

Figure 3.18



a.



b.

These new techniques arise from the results of research over several years in which various types of configurational modelling have been used first to identify non-discursive regularities in the ways in which architectural and urban systems are put together spatially and identify the 'genotypes' of spatial form; second to correlate these non-discursive regularities with aspects of how human beings can be observed to function in space; and third, to begin to build from these regularities a picture of higher generality of how spatial systems in general are put together and function in response to the demands that human beings and their collectivities make of them. In the next chapter we introduce the most fundamental of all correlates with spatial configuration: human movement.

Notes

1 H. Simon H, *The Sciences of the Artificial*, MIT, 1969.

2 F. De Saussure F, *Course in General Linguistics*, McGraw Hill, 1966 translated by C. Bally and A. Sechahaye with A. Riedlinger See pp. 9–15 (originally in French 1915).

3 It has of course become fashionable to follow the later Wittgenstein's *Philosophical Investigations* (Basil Blackwell 1953; Edition used 1968) and deny any systemic properties to such things as languages, and see in them only shifting contingencies. For example: 'Instead of producing something common to all that we call language, I am saying that these phenomena have no one thing in common which makes us use the same word for all, but they are all related to each other in many different ways. And it is because of this relationship, or these relationships, that we call them all "language".' – Wittgenstein, para 65. Or: 'Language is a labyrinth of paths. You approach from one side and know your way about; you approach the same place from another side and no longer know your way about' – Wittgenstein, para 203. The use of the urban analogy is interesting. As we will see in later chapters, this is the one type of artefact where it can be shown quite clearly that Wittgenstein was wrong.

4 The clearest statement is still probably the 'Overture' to Claude Lévi-Strauss's *The Raw and the Cooked*, Jonathon Cape, London 1970, originally in French as *The Cru et le Cuit*, Plon, 1964.

5 Plato, *The Republic*, for example VI, 509–11, pp. 744–7 in Plato, *The Collected Dialogues*, eds. E. Hamilton and H. Cairns H, Princeton University Press, Bollingen Series, 1961. See also ed. F. M. Cornford, *The Republic of Plato*, Oxford University Press, 1941, pp. 216–21.

6 For the clearest formulation, see R. Thom, 'Structuralism and Biology', in ed. C. H. Waddington, *Theoretical Biology 4*, Edinburgh University Press, 1972, pp. 68–82.

7 W. Heisenberg, *Physics and Philosophy* George Allen & Unwin, 1959 p. 57.

8 N. Chomsky, *Syntactic Structures*, Mouton, The Hague, 1957.

9 There are important exceptions to this, for example Lévi-Strauss's attempt, in collaboration with Andre Weil, to model certain marriage systems as Abelian groups. See Lévi-Strauss, *The Elementary Structures of Kinship*, Eyre & Spottiswoode, 1969, pp. 221–9. Originally in French as Les Structures *Elementaire de la Parente*, Mouton, 1949.

10 For example, his ingenious attempt to model the elementary properties of matter through the five regular solids in the *Timaeus*. See Plato, *Timaeus* 33 et seq. p. 1165 in *The Collected Dialogues* (see note 5 above)

11 This process is the subject of Chapter 9.

12 As described, for example, in Chapter 2 of *The Social Logic of Space*.

13 For a lucid summary, see P. Steadman, *Architectural Morphology*, Pion, 1983.

14 L. March, In conversation.

15 I. Stewart and M. Golubitsky, *Fearful Symmetry*, Penguin, 1993, p 229.

16 F. Buckley and F. Harary, *Distance in Graphs*, Addison Wesley,1990, p. 42.

17 B. Hillier and J. Hanson , *The Social Logic of Space*, Cambridge University Press, 1984, p 108. See also note 16 in Chapter 1.

18 Steadman, p. 217.

19 Hillier & Hanson, pp. 109–13.

20 However, see the references in note 16 of Chapter 1.

21 For example, I. Biederman, 'Higher level vision', in eds. D. Osherson et al., *Visual Cognition and Action*, MIT Press, 1990.

22 For a discussion of some of these variations from the point of view of graph theory see Buckley and Harary, *Distance in Graphs*, pp. 179–85.

23 For example, P. Tabor, 'Fearful symmetry', *Architectural Review*, May 1982.

24 Abbe Marc-Antoine Laugier, *Essai sur l'architecture*, Paris 1755.

25 See Hillier & Hanson, *The Logic of Space*, p 90.

26 It should be noted at the outset that these overlapping convex elements are unlike the convex elements described in *The Social Logic of Space*, which were not allowed to overlap. See Hillier & Hanson, pp. 97–8.

27 It is exactly this property that labyrinths exploit. At every point the space you see gives no information – or misleading information – about the structure of the labyrinth as a whole. In general – though not invariably – a good urban form does exactly the opposite.

28 See Chapter 4. Also B. Hillier et al., 'Natural movement: or configuration and attraction in urban pedestrian movement, *Environment & Planning B, Planning & Design*, vol. 20, 1993.

29 As, for example, in the case of the new Shanghai Central Business District on which we collaborated with Sir Richard Rogers and Partners, or the original plan for the Kings' Cross Railways Lands, London with Sir Norman Foster and Partners. See for example B. Hillier, 'Specifically Architectural Theory', Harvard Architectural Review, vol. 9, 1993. Also published as B. Hillier, 'Specifically architectural knowledge', *Nordic Journal of Architectural Research*, 2, 1993.

30 The problems generated by this type of layout are examined in detail in Chapter 5.