
Natural movement: or, configuration and attraction in urban pedestrian movement[†]

B Hillier, A Penn, J Hanson, T Grajewski, J Xu

Unit for Architectural Studies, Bartlett School of Architecture and Planning, University College London, London WC1H 0QB, England

Received 28 September 1989; in revised form 12 February 1992

Abstract. Existing theories relating patterns of pedestrian and vehicular movement to urban form characterise the problem in terms of flows to and from 'attractor' land uses. This paper contains evidence in support of a new 'configurational' paradigm in which a primary property of the form of the urban grid is to privilege certain spaces over others for through movement. In this way it is suggested that the configuration of the urban grid itself is the main generator of patterns of movement. Retail land uses are then located to take advantage of the opportunities offered by the passing trade and may well act as multipliers on the basic pattern of 'natural movement' generated by the grid configuration. The configurational correlates of movement patterns are found to be measures of global properties of the grid with the 'space syntax' measure of 'integration' consistently found to be the most important. This has clear implications for urban design suggesting that if we wish to design for well used urban space, then it is not the local properties of a space that are important in the main but its configurational relations to the larger urban system.

Introduction: attraction and configuration

Quantitative methods for predicting pedestrian movement in urban space have conventionally been adaptations of the models employed in vehicular studies. The trip-generation potential of built forms (buildings or urban blocks) is seen as the key quantity, congestion as the most likely problem, and the scaling of local pedestrian space to match attraction as the main design aim (for example, Pushkarev and Zupan, 1975). We might call this the *attraction* theory of pedestrian movement: movement is seen as being *to and from* built forms with differing degrees of attraction, and design is seen as coping with the local consequences of that attraction.

It follows that attraction theories say little about the spatial *configuration* of the urban grid, that is, about the way in which the spatial elements through which people move—streets, squares, alleys and so on—are linked together to form some kind of global pattern. But it is easy to show that, theoretically at least, configuration can have effects on movement which are independent of attractors. For example, in the simple layout shown in figure 1(a), all journeys from 'sidestreet' origins to

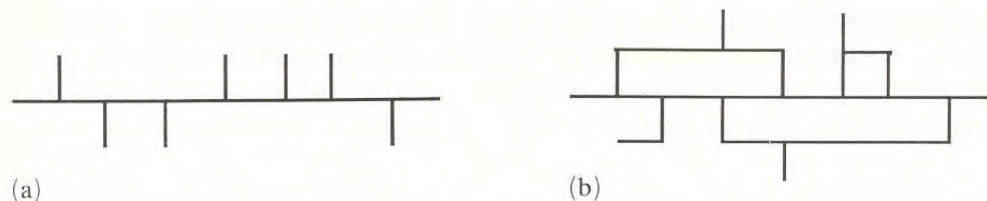


Figure 1. (a) The more central segments of the 'main street' are likely to be the best used, and the peripheral segments the least. (b) The two most central vertical elements, one above and one below the 'main street', would be on more shortest routes than more peripheral vertical elements.

[†] Paper presented at the European Conference on the Representation and Management of Urban Change, University Centre, University of Cambridge, England, 28–29 September 1989.

'sidestreet' destinations must pass through one or more segments of the 'main street', giving a movement pattern in which the more central segments of the 'main street' are likely to be the best used, and the peripheral segments the least. This would remain the case regardless of any metric deformation of the pattern, provided the topology was retained. In the slightly more complicated case shown in figure 1(b) there is a relation between configuration and movement which is less deterministic, in that assumptions about metrically or topologically shortest routes are required, but also more complex in that spaces other than the 'main street' are involved. For example, the two most central vertical elements, one above and one below the 'main street', would be on more shortest routes than more peripheral vertical elements.

These effects are of configuration on *through-movement*, and are seen if we consider the layout as a system of possible routes. But, if we consider layout as a system of origins and destinations, it becomes clear that configuration may also be implicated in *to-movement*. For example, in figure 2(a) the 'central square' offers a metrically or topologically more accessible destination than the other spaces in the layout. This also holds for the more central elements in the improbable layout of figure 2(b). To the extent that accessibility of destinations is a factor in the choice of destinations, we could again expect to find effects of configuration on movement.

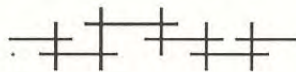
On the face of it, then, configuration may have effects on both through-movement and to-movement in urban grids, which are independent of built-form attractors, and perhaps to some extent also of metric properties. Are such configurational priorities found in real urban grids? And if so, do they matter? Common sense and common practice would surely insist they are and they do. Urban grids are almost invariably conceptualised as some kind of 'spatial hierarchy', in which different kinds of configurational priority are assumed to be associated with different degrees of functional importance. The notion of some kind of configurational structure with functional implications is, it seems, usually present in our notions of urban form, even though its theoretical and formal articulation is unsophisticated.

Let us follow common sense for a moment and suppose that configurational priorities are both present in urban grids and important enough to have significant effects on movement patterns. What would follow from this? It would surely follow that, as an urban system evolved, the distribution of built-form attractors might itself be influenced by these priorities. For example, spaces which the grid configuration prioritised for through-movement might for that reason already have been selected as good locations for 'passing trade' land uses. Other types of land use might equally have sought to minimise the possible interference of through-movement. Similarly, topologically or metrically accessible locations may have been preselected for types of land use where this was a useful asset, and vice versa.

If, then, at any stage of the evolution of the urban system we were to investigate movement patterns and found agreement between movement rates and the presence of attractors it would clearly be unwise to assume that movement could be *explained* by attractors until we were sure that the configuration properties had not influenced both the presence of movement and the presence of attractors. If we



(a)



(b)

Figure 2. The 'central square' (a) and central elements (b) offer a metrically or topologically more accessible destination than the other spaces in the layout.

then found that configurational properties were in agreement both with movement rates and with attractors, how should we proceed? We would seem to have the familiar problem of needing to distinguish the respective 'causal' effects of two variables which are both correlated with a third, and which are also correlated with each other.

The matter may not, however, be as difficult as it looks. In a situation where movement, configuration, and attraction were all in agreement there would be powerful logical reasons for preferring configuration as the primary 'cause' of movement. Logically, the presence of attractors can influence the presence of people, but it cannot influence the fixed configurational parameters which describe its spatial location. Similarly, configuration may affect movement, but configurational parameters cannot be affected by it. If we find a strong degree of agreement among all three, therefore, then it must either be the result of chance or the result of configuration having influenced both the pattern of movement and the distribution of attractors. In other words, if we find all three in agreement then we are compelled to assign causal primacy to configuration. We may clarify this through figure 3.

In real urban situations we may also find that the issue of attraction versus configuration is less of an issue. For example, in many urban areas, attractors tend to be clustered in specific locations—shops in a high street for example—and, given our premises, we might expect the selection of these locations to have been configurationally influenced. In such cases, we would expect the grouped attractors to act as multipliers on a basic movement pattern generated by the configuration. Alternatively, we might find urban areas where the effects of attractors were equalised by their being evenly distributed throughout the system, for example, in a residential area. In such cases, it would be reasonable to expect that configuration would be a more obviously dominant influence on movement. It would only be where the pattern of attractors was both strong, unequal, and distributed without regard for the configurational logic of the urban system that we would expect to find a lack of influence of configuration on movement.

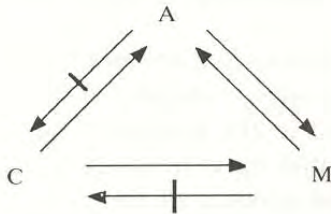


Figure 3. A is attraction, C is configuration, M is movement. Attractors and movement may influence each other, but the other two relations are asymmetric. Configuration may influence the location of attractors, but the location of attractors cannot influence configuration. Likewise, configuration may influence movement but movement cannot influence configuration. If strong correlations are found between movement and both configuration and attractors, the only logically possible lines of influence are from configuration to both movement and attractors, with the latter two influencing each other.

The theory of natural movement

In this paper it is proposed that these theoretical premises describe the real state of affairs. In urban systems configuration is the primary generator of pedestrian movement patterns, and, in general, attractors are either equalisable or work as multipliers on the basic pattern established by configuration. This is not to say that in all situations the greater proportion of movement is generated by configuration. On the contrary, it will often be the case that the multiplier effect of attractors far exceeds the effects of configurations. The argument is that configuration is the

primary generator, and without understanding it we cannot understand either urban pedestrian movement, or the distribution of attractors or indeed the morphology of the urban grid itself.

Because movement generated by the grid configuration is so basic we suggest it should be identified by a special term. We propose the term *natural movement*. Natural movement in a grid is the proportion of urban pedestrian movement determined by the grid configuration itself. Natural movement, although not always quantitatively the largest component of movement in urban spaces, is so much the most pervasive type of movement in urban areas that without it most spaces will be empty for most of the time. It is also the most consistent, so much so that it is difficult to avoid the inference that natural movement is the *raison d'être* of the urban grid itself. Urban grids seem to be structured in order to create, by the generation and channelling of movement, a kind of probabilistic field of potential encounter and avoidance.

This is not to say that natural movement is not a culturally variable phenomenon. On the contrary, it takes different forms in different cultures, reflecting the different spatial logics of the urban grid. Urban grids are cultural products because they create, through natural movement, encounter fields with different structures. These differences are primarily composed of different degrees and types of probabilistic interface between different categories of person: inhabitants and strangers, men and women, adults and children, social classes, and so on.

What is invariant about natural movement is the logic that links spatial configuration to movement. The key element in this relation is that natural movement is a *global* property of a configuration in that it responds to configurational parameters which relate each spatial element to every other element in a system which may be several kilometres in diameter. Natural movement is only secondarily influenced by local spatial properties, such as those which describe the relation of each space to its neighbours, or the neighbours of its neighbours. Where design is overlocalised, as has often been the case in 20th century urban design, then the natural movement pattern will be disrupted, and space will tend to become radically underused (Hillier, 1988; Hillier et al, 1987).

If the theory of natural movement is right, then it would follow that the modern tendency to see the urban grid as a by-product of other processes, even as an epiphenomenon, is misconceived. The grid is itself implicated in the generation of urbanism and its functional logic. Natural movement shows that movement is fundamentally a morphological issue in urbanism, a functional product of the intrinsic nature of the grid, not a specialised aspect of it. As such the question of movement, and of space use in general, cannot be separated from the question of urban form itself.

Space syntax and natural movement

Natural movement has come to light as a formal and empirical phenomenon through the application of new techniques of configurational analysis known as 'space syntax' to the analysis of the local and global structure of the urban grid, and their coupling to simple techniques for observing space use and movement. It is noteworthy that the space-syntax techniques which post-dict⁽¹⁾ natural movement were not originally aimed at modelling movement but at understanding the morphological logic of urban grids, especially their growth. The theory of 'natural movement' is literally a by-product of a research programme with different aims.

⁽¹⁾ That is, techniques which find regularities that form the basis for prediction.

It was only the discovery of the pervasive relation between configuration and movement that alerted us to the possibility that movement might be as fundamental to the morphology of urban grids as we now believe it to be.

Our aim in this paper is to set out the evidence for natural movement, and to argue that even on present evidence configuration models ought to be brought into play alongside attraction models in the analysis and design of urban systems. The paper is in four parts. First, the concepts and techniques of space syntax are introduced, with reference to other texts where they are more fully discussed where necessary. Second, a selection of case studies is presented showing the relation between configuration parameters and movement. Third, some examples of probabilistic interfaces are sketched. Fourth, a number of inferences are drawn for design and for the morphological theory of urban form, with special reference to the question of scale.

The deformed grid

The grid of a town or city may be defined as the system of space of public access created by the way in which buildings are aggregated and aligned. For clarity, we may represent an urban grid by reversing usual conventions and showing the space as black and built 'islands' as white [figure 4(a)]. This has the useful effect of bringing the grid to the foreground as the prime object of analysis. Most urban grids are, and always have been, *deformed* grids, characterised by apparent irregularity [figure 4(a)], rather than *ideal* grids, characterised by geometric regularity [figure 4(b)]. This presents obvious difficulties for analysis, because most of our special concepts are geometric. Urban grids are also by definition *continuous*. This creates a second difficulty. How is the urban grid to be represented as a set of discrete elements to make configurational analysis possible?

The obvious answer is to use the customary topological representation of the grid as a graph in which route intersections are the nodes and route segments the edges. There are two problems with this representation. First, it makes grids look too similar to each other. It is, for example, a simple matter to design a highly irregular arrangement of sixteen urban blocks, but with a node graph isomorphic to that of figure 4(b). Second, few interesting consequences, theoretical or empirical, seem to follow from this representation⁽²⁾. What seems to be needed is a representation

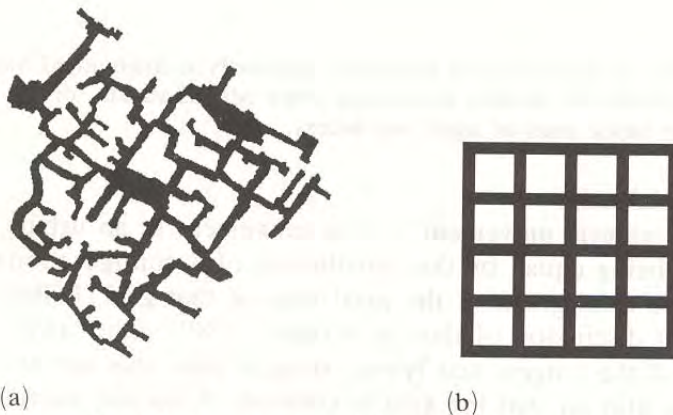


Figure 4. (a) A typical urban deformed grid town is characterised by apparent irregularity. (b) An ideal grid is characterised by geometric regularity.

⁽²⁾ This may at first seem surprising because this representation is commonly used in transport modelling. However, in these applications the form of representation is relatively unimportant. The main factors in the success of these models are the assignment and calibration routines.

less general than the topology of the node graph, yet less precise than the geometry of the form itself.

However, we may usefully approach deformity and continuity in grids by making comparisons to geometric regularity. The ideal orthogonal grid of figure 4(b) is one in which islands of built forms with identical shape and perfect alignment create a grid structure in which all lines of sight and access cross the grid, and pass everywhere through space of uniform width. Spatially, we might say that in the ideal grid one-dimensional, or axial, elements are as extended as they can be, and so are two-dimensional, or convex elements. Every point in space belongs both to lines and convex elements which cross the grid unimpeded from side to side.

The deformed grid is different first in that the shaping and alignment of islands breaks the continuity of lines of sight and access across the grid; and, second, in that spaces vary in width as one passes along lines. More formally, we might say that two types of deformity have been introduced: one-dimensional, or axial, deformity by the breaking up of lines of sight and access; and two-dimensional, or convex, deformity by variations in the width of spaces.

In the example shown in figure 4(a), deformity is clearly associated with the lack of geometric order. But this is not necessarily the case. For example, in the Roman grid shown in figure 5 overall geometric regularity is maintained, but spaces are varied in width, and alignments are broken by making some islands vacant, or partly vacant, and using others to block lines of sight and access. Deformity in both types of grid can be described by comparing the degree of axial and convex break up with a perfectly regular grid.

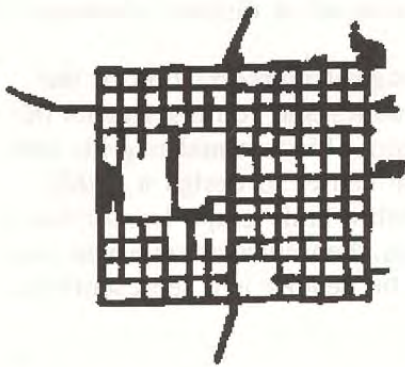


Figure 5. Timgad, a Roman grid town in which overall geometric regularity is maintained but spaces are varied in width and alignments are broken by making some islands vacant, or partly vacant, and others are used to block lines of sight and access.

Axial graphs, node graphs, and axial maps

The fundamental proposition of 'natural movement' is that movement in an urban grid is determined, other things being equal, by the distribution of a configurational quantity called 'integration' in the axial graph of the axial map of that grid (Hillier and Hanson, 1984; for a current discussion of this see Krüger, 1989). The 'axial map' of an urban grid consists of the longest and fewest straight lines that can be drawn through the spaces of the grid so that the grid is covered. 'Covered' means that all rings of circulation are completed and all convex elements passed through. The axial graph is the graph in which the lines of the axial map are the nodes and the intersections of the lines are the edges.

The axial graph is thus a representation of the grid in which the ordering of nodes is lost. All information in the graph is of line-to-line relations, irrespective of the ordering of nodes. The axial map, however, does have information on the

ordering of nodes. The topology—though not of course the geometry—of the axial map can thus be reconstructed by adding the node graph to the axial graph. Practically speaking, the axial graph is sufficient for the post-diction of movement, though this is not to say that a more refined form of analysis in which node-to-node information was also included would not yield even better results.

The 'axial map' can be constructed automatically by computer using a series of rule-based algorithms given the geometric description of the building block forms. It is also practicable to draw the axial map manually by the 'eyeball method'. The map is transformed into a matrix representation, where each axial line is numbered, and an incidence matrix is compiled of connectivities between lines—a line is said to be connected when it crosses or intersects another.

In this way a geometric building block plan is transformed into a matrix or graph representation where each node of the graph is an axial line (a direct line of sight and access) and each link describes the other lines that are visible and accessible from it. Essentially, the basic description already describes something that is perceptually important, and relates to how one might understand and move around a configuration.

There are a number of measures of the graph which can now be used to describe configurational properties of the grid. The simplest are those that describe the local properties of a node in the graph (that is, an axial line): 'connectivity', for example, merely measures how many other nodes are directly accessible from it (in graph theory this is called the 'valency' or 'order' of a vertex); 'control value' (Hillier and Hanson, 1984) measures the degree to which a node 'controls' access to and from its neighbours. It is calculated by summing the reciprocals of connectivities between neighbours as follows: if the line is the only connection to a neighbour it acquires a value of 1 from that neighbour, if it is one of two connections, then it acquires 1/2, if one out of three, then 1/3, and so on. In effect, therefore, control value indexes the amount of choice each line represents for each of its neighbours.

A similar measure taking into account the relations between each space and the whole system is 'global choice', which indexes how often each line is used on topologically shortest paths from all lines to all other lines in the system. It thus also indexes how often each line is visited on random journey simulations through topologically shortest paths in the system. But empirically, by far the most important global measure is called 'integration' which measures the mean depth of every other line in the system from each line in turn, relativised with respect to how deep they could possibly be with that number of lines, then standardised as shown in Hillier and Hanson (1984) and discussed by Krüger (1989). The most integrated lines are those from which all others are shallowest on average, and the most segregated are those from which they are deepest.

A key property of interest is how the various configurational variables are distributed in the urban grid. This can be shown graphically by drawing 'core maps' of, for example, the 10% most integrated lines and the 50% least integrated (most 'segregated') in a system. In most towns or urban areas integration core maps will pick out the main thoroughfares and shopping areas, whereas the least integrating will tend to pick out areas with primarily residential functions, that is integration cores seem to offer a graphic realisation of some morphological 'deep structure' of a town or urban area [for example, see figure 9(a) below]. The reason why this may be so will become clear in the case studies of the relationship between spatial configuration (especially the distribution of 'integration') and movement which now follow.

Case study 1: King's Cross

The first case study will also introduce the method through which configurational properties and movement patterns are examined conjointly. The study is of the King's Cross development site, and was carried out on behalf of the Railway Lands Community Group, with funding from Foster Associates, masterplanners for the site, and the developers, the London Regeneration Consortium. The aim was to analyse the urban configuration of the area around the King's Cross site and how it related to existing patterns of movement and space use, then to advise on the implications of this for the agreed design objective of knitting the new development into the surrounding urban fabric of Camden and Islington. Only the analytic aspects of this study are reviewed here.

The spatial structure of the area

Figure 6 is a map of the area surrounding the King's Cross site, showing the modelling area bounded by Tufnell Park in the north, Upper Street in the east, Regent's Park in the west, and Holborn in the south, covering an area of around 12 km². Figure 7 shows the street network of the area in black, including the internal ground-level spaces of several housing estates in the vicinity of the site. The housing estates are easily picked out by the dramatic reduction of spatial scale and increase in spatial complexity. Figure 8 is an 'axial map' of figure 7, as digitised into the computer. Syntactic analysis was carried out at two levels and in two modes: of the whole area (the 'large area'), and of a smaller area bounded by Camden Road (north), Caledonian Road (east), Euston Road (south), and Eversholt Street (west). The idea of varying the scale of analysis is to check for any analytic effect that might result from the choice of boundary.

The scale of the smaller area is based on a rough estimate of the normal pedestrian catchment area for the site, and the larger area on a rough estimate of 'catchment area of the catchment area'. Previous studies have invariably shown that movement patterns are globally, not locally, determined and that post-diction is only possible from syntactic parameters by setting the area into a reasonably large urban context. It follows that, if we are to predict natural movement within a development site, we must first post-dict movement in the catchment area, and, if we are to post-dict movement patterns within the catchment area, then we must know how the whole of the catchment relates to its own catchment area. A further benefit of the 'catchment area of the catchment area' approach is that it also displaces any 'edge effect' in the spatial analysis into the outer reaches of the larger system, away from the area of prime interest in the more immediate vicinity of the site.

Syntactic analysis of the axial map produces two kinds of output: alphanumeric data in the form of line numbers with spatial parameters assigned to each; and graphic data in the form of 'core' maps in which lines are coloured up in accordance with their value on the various parameters. The latter are of course crude approximations compared with the former, but they do allow the designer an immediate, intuitive grasp of the structure of the spatial pattern of the area.

From the point of view of natural movement, the key result of computation is the distribution of integration in the axial map. Graphically, the most informative strategy is to look at an axial map in which the integration values of lines are represented by the colours of the spectrum from red for the most integrated through to indigo for the most segregated. This allows one to form a picture of how integration spreads through the urban structure. Figure 9(a) shows the distribution of integration in the largest system (though in this case in black and white with the most integrated lines in heavy black through to the most segregated in light grey). Coupling the graphic representation with the alphanumeric output we

can trace the actual *order* in which lines integrate the system, and the degree to which each does so.

It is best if we first consider the area without the interiors of its housing estates, because this will give the truest picture of the fully public space of the area as it has evolved. If we do so, the most integrating line in the area is the section of Euston Road between Tottenham Court Road and King's Cross. The second is the line covering Eversholt Street and the upper part of Southampton Row, and the third is the southernmost section of York Way, up to Copenhagen Street. From there the core moves to Camden High Street, Pentonville Road, Royal College Street, and

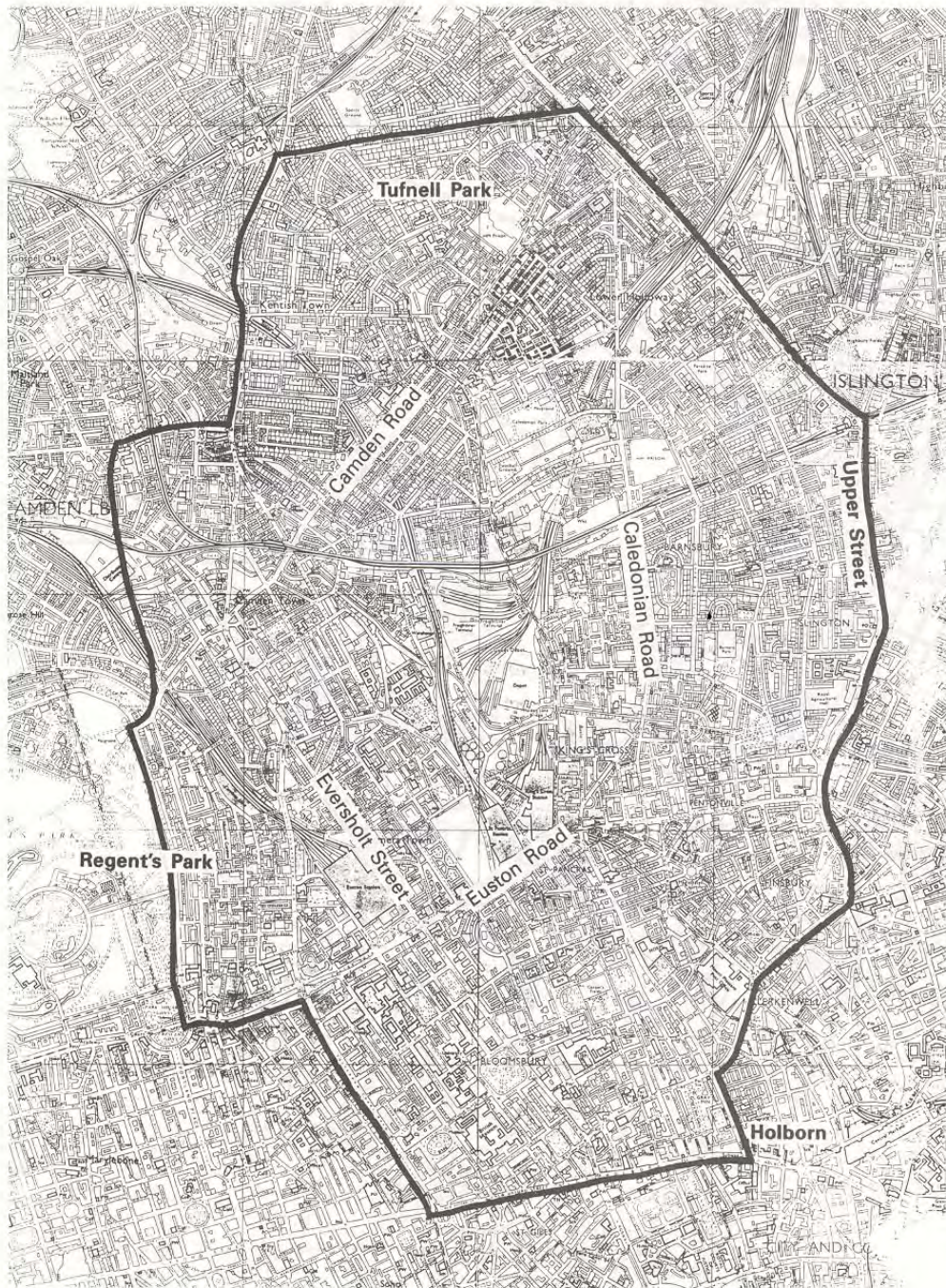


Figure 6. Ordnance survey map showing the King's Cross site and the surrounding areas.

Tottenham Court Road. Five of the top seven lines thus run north-south, with only Euston Road and Pentonville Road running east-west.

The core of the area around the King's Cross site thus has not only a strong north-south bias, but also a bias towards the south and west. Two of the next three lines, Crowndale Road and Copenhagen Street, do run east-west, but then



Figure 7. The street and open space pattern in the larger King's Cross area, including recent housing estates in the vicinity of the site.

the north-south bias takes over again, as does the bias to the south and west. The Barnsbury section of the Caledonian Road and Camden Road are relatively weak for such long lines, coming in fifteenth and eighteenth positions respectively, which emphasises the comparative weakness of the core to the east and north of the site.



Figure 8. Axial map of the larger King's Cross area, including recent housing estates in the vicinity of the site.

Figure 9(a) also shows that the distribution of integration to the west and south of the site has a different character from that found to the east and north. To the east and north, the core is linear: a small number of linearly connected and branching street sections forming major routes, but without lateral development linking these routes into well-structured subareas. To the west and south, the core is more



(a)

Figure 9. Pattern of integration in the larger King's Cross area (a) excluding and (b) including recent housing estates, with the most integrated lines in heavy black through to the most segregated in light grey.

grid-like, defining local area core grids for Camden Town, Somers Town, and the Argyle Square area.

We can thus say that to the east and north of the site the core is sparse and linear, and does not construct subareas, whereas to the west and south the core is denser and more grid like, and creates identifiable subareas. More simply, the west



(b)

Figure 9. (continued).

and south have a property which we might call *grid-integration*, which is a common characteristic of urban centres and subcentres, whereas the east and north have the more restricted *line-integration*, which is often found in areas with a less developed urban character.

If we now add in the housing estates [figure 9(b)], we find a further structural phenomenon: certain estates, especially the two immediately north and northwest of the King's Cross site, form solid blocks of segregated lines, unrelieved by either integrating or intermediate lines. Typically, street-based urban subareas will mix and intersect integrated, segregated, and intermediate lines. The 'structural segregation' which often characterises modern housing estates appears to be very much a 20th-century phenomenon.

Observing movement

The next stage of the study was an extensive firsthand investigation of space use and movement. In space-syntax studies, an observation technique is used in which observers walk at about 3.75 mph (5.5 kph) along selected routes of about twenty or thirty line segments (mixing integration and segregation as far as possible) and count the people they pass who are moving or static on the same line, that is people crossing the line rather than walking along it are discounted. Distinctions are made between men and women, and children, the last being estimated as being 16 years of age or less. Children who are not moving independently are not counted. Routes are observed between twenty and thirty times, taking care to cover all times of the day by gathering approximately equal numbers of observations in each of five standard time periods: 8–10AM, 10–12AM, 12–2PM, 2–4PM, and 4–6PM. In this case, the extreme time pressure on the study meant that observations were conducted in an extraordinary variety of weathers, from hot to cold and from fine weather to fairly heavy rain. Experience shows—and this study confirms—that weather has relatively little effect on natural movement, although it does affect static behaviour considerably.

Routes were selected in ten areas around the site, including three housing estates, and covering a total of 239 street sections. The routes are shown as the dark lines in figure 10. The figure alongside each line is the adult movement rate for that line, that is the average number of adults passed on that line for all observation periods, standardised for length of line observed to a norm of the number of people per hundred metres walked. This also approximates to the rate per minute of walking time. It is useful to set these figures against the urban norm for residential streets of about 2.7 persons per hundred metres per minute (phm/min).

Positive and negative attractors?

Mean movement rates for each area are tabulated in table 1, with and without main shopping streets. Even without shopping streets, there are very large differences in these rates in the different areas, and there seems to be a pattern to these differences. Of the seven urban areas which are not estates those to the east and north of the canal (areas 2–East, 3–Northeast, and 4–North) have an overall mean encounter rate of about 1.64 adults phm/min, whereas those to the west and south (areas 5–West, 6–Southwest, 7–South, and 1–Southeast) have a mean of 5.51 phm/min. These differences seem to correspond broadly to the difference between 'grid-integration' areas and 'line-integration' areas. They also correspond broadly to the pattern of attractors. The highest average rates are found in the South area, immediately below the entrances of King's Cross and St Pancras railway stations, and the second highest in the West area which includes the major shopping centre of Camden High Street.

If we look in more detail at the movement rates set out in figure 10, it certainly seems to be the influence of attractors on the pattern that is initially striking. Not only are the highest levels of movement in the immediate vicinity of station entrances and Camden High Street, but, more strikingly, movement levels appear to fall away in all directions as lines recede from these major attractors. For example, in all cases where two sections of the same street have been observed in the vicinity of King's Cross station entrance or Camden High Street, the segment more distant from the attractor has substantially lower movement rates than the closer one. This effect is so consistent that it is tempting to define strong attractors in terms of this falloff, as much as in terms of unusual concentrations of movement.

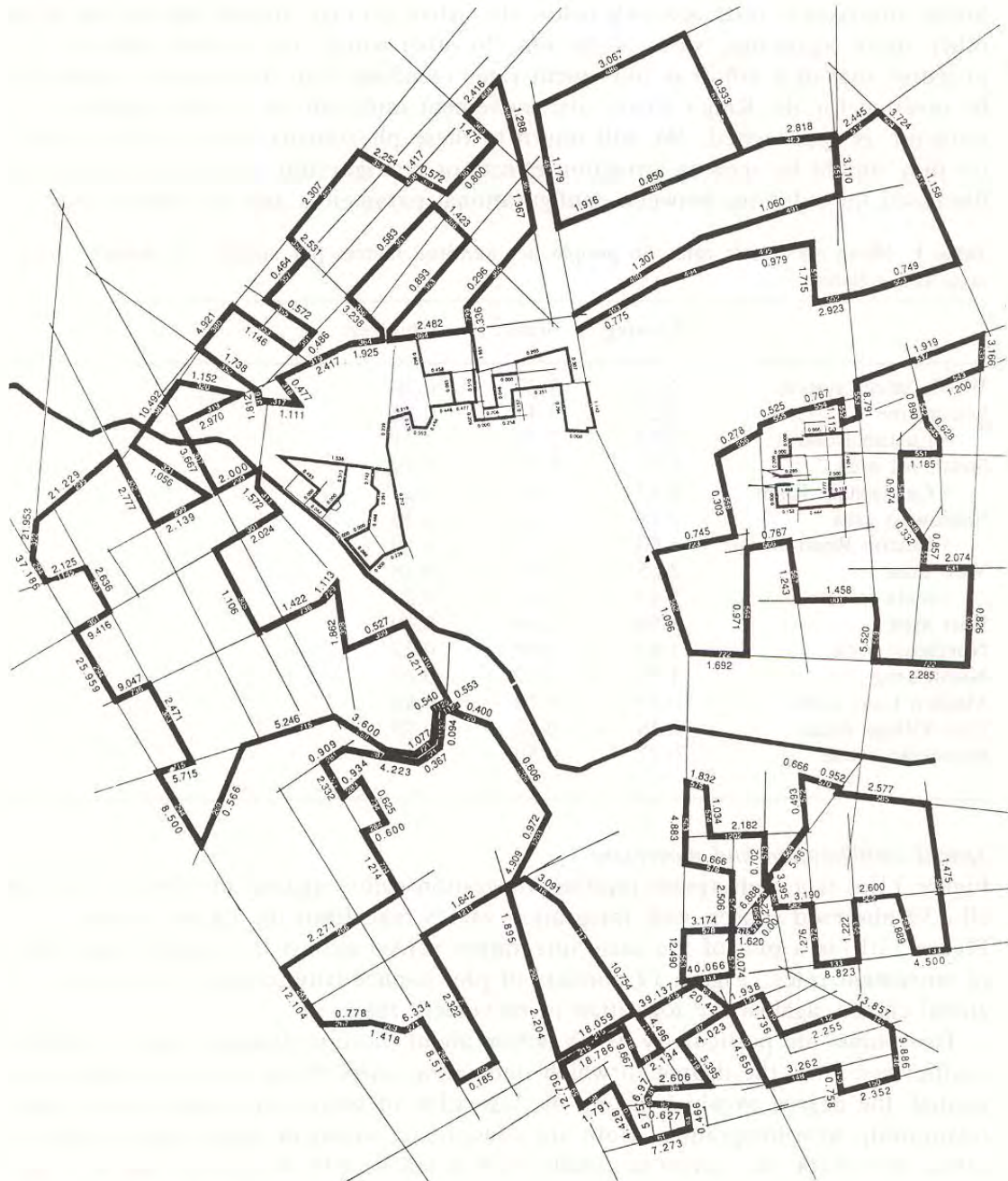


Figure 10. Observed spaces around the King's Cross area inscribed with the numbers of moving adults per 100 m.

If we do so, however, then it seems we must also acknowledge the existence of two kinds of *negative* attractors, corresponding to the two aspects of this definition. First, all three housing estates appear as negative attractors in that their average movement rates are, at 0.365 phm/min, about an order of magnitude lower than the general urban average for residential streets of 2.7 phm/min, or the King's Cross area overall average of 4.12 phm/min. The estates are as conspicuously empty of movement as attractor streets are full.

Second, the King's Cross site north of the stations at present constitutes a large hole in the urban fabric, and it is striking that movement rates all round the site north of the stations are very low, and seem to become lower as the periphery of the site is approached. Even in the highly integrating area of the York Way–Copenhagen Street intersection rates are well below the urban average, though not as low as the other, more segregated, sides of the site. In other words, the second attractor property, that of a falloff in movement rates receding from the attractor, seems to be inverted for the King's Cross site: movement rates fall off as the 'negative attractor' is approached. We will return to these phenomena later to discuss how far they should be seen as attraction effects or configuration effects, after we have discussed the relations between configurational parameters and movement rates.

Table 1. Mean encounter rates (in people per hundred metres per minute) for King's Cross area and subareas.

	Moving	Static	Children
Whole street system	4.12	1.27	0.20
South area	7.27	1.47	0.22
+Euston Road	9.02	2.16	0.21
Southeast area	2.71	0.86	0.19
+Caledonian Road	4.22	1.01	0.20
Southwest area	2.68	1.02	0.20
+Euston Road	4.80	1.73	0.19
West area	3.25	0.95	0.18
+main streets	5.47	1.87	0.28
East area	1.58	1.10	0.30
Northeast area	1.81	0.89	0.22
North area	1.58	0.27	0.23
Maiden Lane estate	0.27	0.10	0.88
Elm Village estate	0.28	0.22	0.73
Bemerton estate	0.57	0.50	0.44

Spatial configuration and movement

Figure 11(a) is a scattergram plotting integration values against movement rates for all 239 observed spaces, with integration values read from the largest system. Figure 11(b) is a plot of the same integration values against the natural logarithm of movement rates. Figure 12 consists of plot connectivity, control value, and global choice, against the logarithm of movement rates.

Two points are particularly worth noting about these scattergrams and correlation coefficients: first, the degree to which integration outperforms other variables; and, second, the degree to which taking the logarithm of movement rates linearises the relationship with integration. Both are consistently found in space-syntax studies of urban movement: movement is usually post-dicted best by integration against logged movement rates.

In view of the strength of attractor effects already noted, the strength and quality of the scatter seems to be a quite remarkable result, all the more so in

view of the fact that for most lines only one or two segments were observed, and observations were carried out at all times of day and through extremes of weather conditions. Multiple regression confirms the superiority of integration, and shows that adding the effects of other variables does little to improve the overall prediction. In spite of the presence of attractors, it seems, the relationship between the pattern of integration, derived from a purely configurational analysis of the grid, and the pattern of real movement is both strong and pervasive.

But why, we might ask, is the relation logarithmic? We can throw light on this and explore the data further by breaking the data down into its ten subareas. Table 2 tabulates key results from the area-by-area analysis, most notably the correlation between integration and the logarithm of movement rates for each area, the correlation between integration and unlogged movement rates, and the correlation between integration and unlogged movement for each of the areas excluding their shopping streets (that is, their main attractor spaces). Figure 13 shows scattergrams

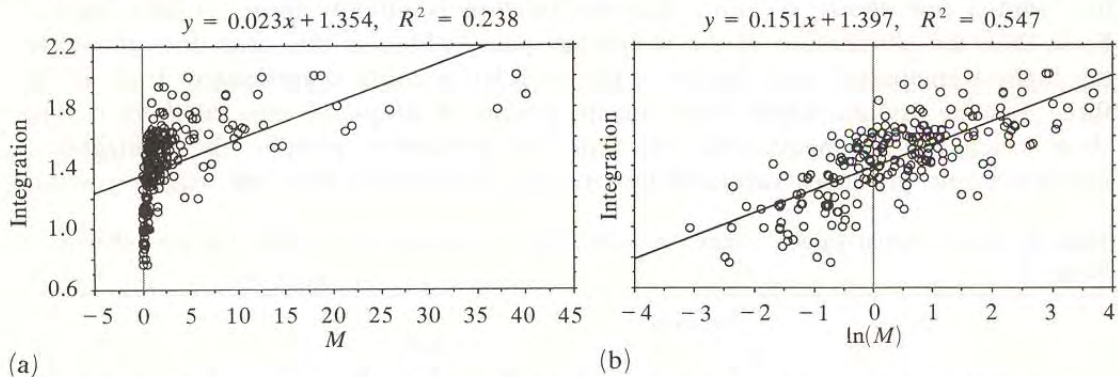


Figure 11. (a) A scattergram plotting integration values against movement rates (M) for all 239 observed spaces, with integration values read from the largest system, (b) the same integration values plotted against the natural logarithm of movement rates.

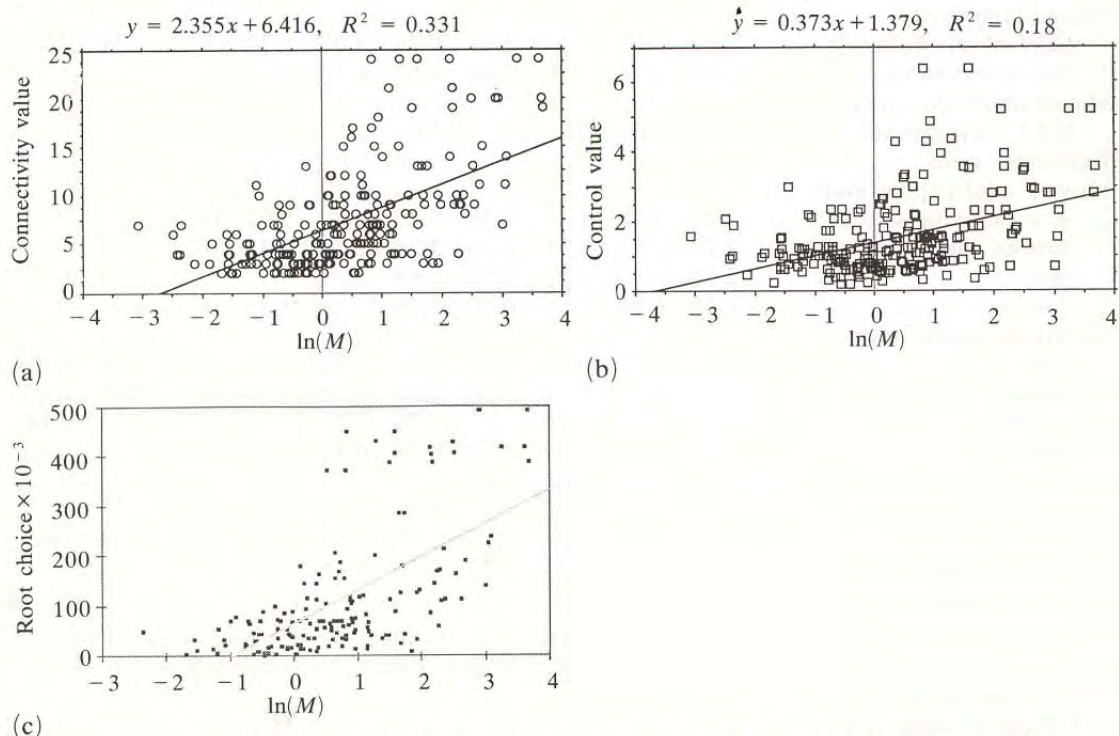


Figure 12. Plots of (a) connectivity values, (b) control values, and (c) global choice values against the natural logarithm of movement rates (M).

for each of these three relations for all areas. In all cases, integration values are still read from the largest system.

These data show certain remarkable consistencies. The first column shows that in all cases except the Northeast area (3), correlations between integration and logged movement rates are strong and highly significant, in spite of the fact that integration is still being read from the largest area. In the case of the Northeast area, it is clear that the area does not operate as a single area, but as two subareas, one residential, the other light industrial, linked and separated by a major road. The scattergram reflects this split.

The second column shows that when movement rates are unlogged, a number of spaces appear well above the regression line. These spaces, it turns out, are in all cases the spaces with groups of shops. The third column shows that, when plotted without these spaces, the relation between integration and movement becomes directly linear. In the case of the North area (4), in which the route observed has only one line with a few shops, we find that the relation is already more or less linear. Even then the elimination of the shopping space (which in this case does not have the highest encounter rate) improves the correlation quite significantly. Last, in all three housing estates, where there are no groups of shops (in area 10 there is one shop which has no measurable effect on the movement pattern) the unlogged encounter rate produces substantially stronger correlations than the logged version.

Table 2. Mean spatial values, encounter rates, and correlation coefficients for ten subareas of King's Cross.

	Subarea ^a									
	1	2	3	4	5	6	7	8	9	10
Integration of system										
1211 observations ^b	0.63	0.66	0.65	0.69	0.67	0.65	0.67	0.92	1.14	0.88
796 observations ^c	0.65	0.72		0.71	0.62	0.66	0.69			
Mean connectivity										
1211 observations ^b	7.63	8.07	5.59	8.31	9.14	8.06	8.74	5.22	4.86	3.75
796 observations ^c	6.86	5.46		7.68	9.57	6.12	7.63			
Maximum connectivity										
1211 observations ^b	19	21	21	24	24	20	20	10	7	6
Encounter rates										
Moving adults (phm/min)										
with shopping streets	4.22	1.58	1.81	1.58	5.47	4.80	9.02	0.27	0.31	0.57
without shopping streets	2.71	1.58	1.81	1.58	3.25	2.68	3.39	0.27	0.31	0.57
men	2.76	0.93	1.02	0.78	2.88	2.97	5.77	0.13	0.14	0.27
women	1.46	0.65	0.78	0.80	2.58	1.83	3.25	0.14	0.17	0.30
Stationary adults (phm)										
men	0.71	0.78	0.64	0.17	0.92	1.10	1.35	0.06	0.12	0.43
women	0.30	0.33	0.25	0.10	0.95	0.63	0.81	0.04	0.08	0.07
all adults	5.23	2.69	2.70	1.85	7.34	6.53	11.18	0.37	0.51	1.06
children	0.20	0.30	0.22	0.23	0.28	0.19	0.21	0.88	0.73	0.44
Pearson's <i>r</i> correlation coefficient between integration and										
log of moving adults	0.71	0.70	0.25	0.67	0.78	0.64	0.80	0.68	0.70	0.62
moving adults ^d	0.54	0.56	0.25	0.70	0.55	0.51	0.79	0.74	0.74	0.67
moving adults, without shopping streets ^d	0.73	0.72	0.41	0.72	0.70	0.66	0.82			

^a 1 southeast area, 2 east area, 3 northeast area, 4 north area, 5 west area, 6 southwest area, 7 south area, 8 Maiden Lane estate, 9 Elm Village estate, 10 Bemerton estate.

^b With housing estates.

^c Without housing estates.

^d Not log transformed.

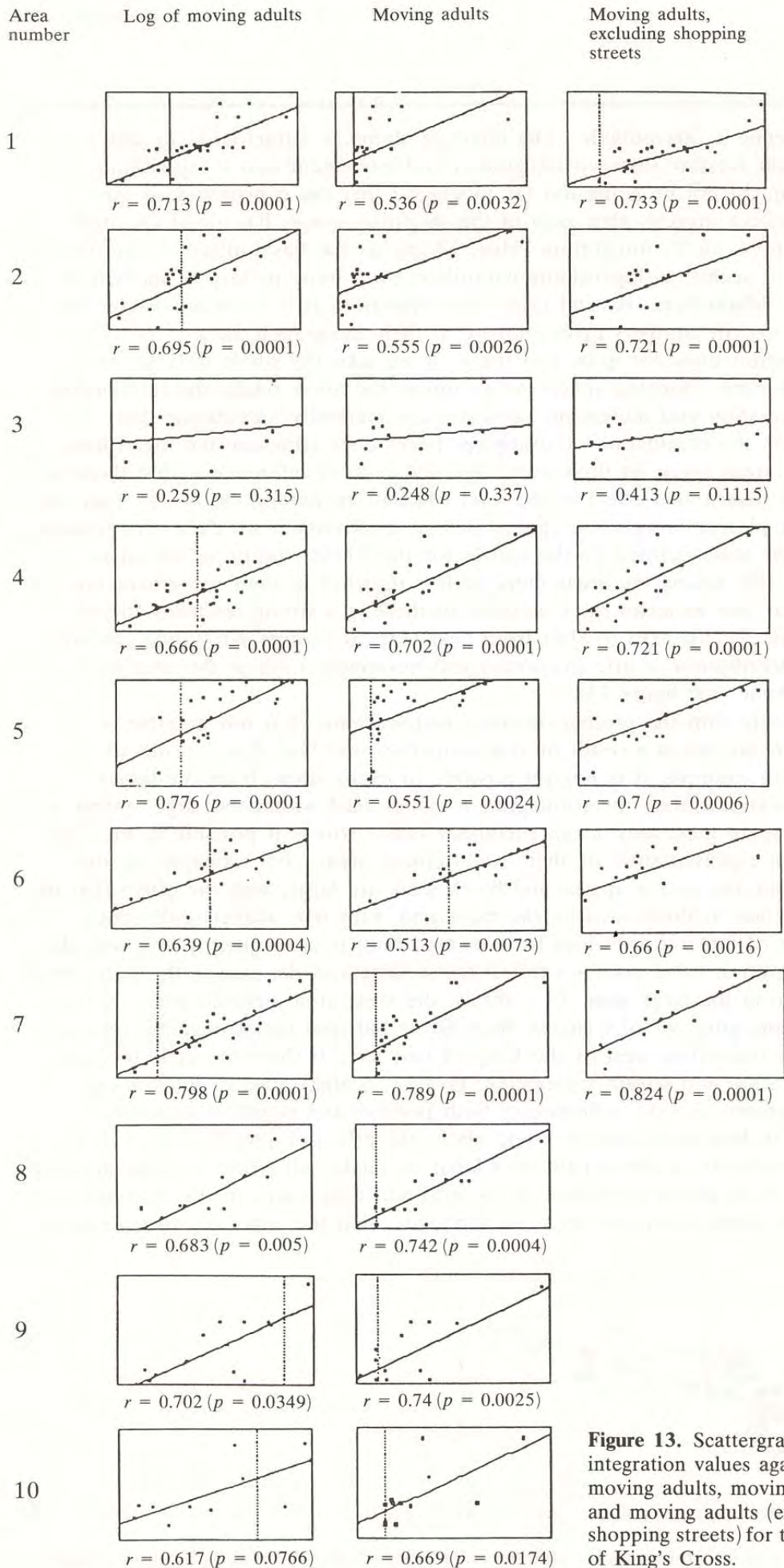


Figure 13. Scattergrams plotting integration values against logged moving adults, moving adults, and moving adults (excluding shopping streets) for ten subareas of King's Cross.

The inference is unavoidable. The effect of shops as attractors is to shift a basically linear relation between integration and movement into a logarithmic relation. It might not be going too far to suggest that the consistency of the logarithmic effect suggests that each of the shopping spaces has about the right number of shops for its integration value. Shops, as the basic attractors in urban areas, work, it seems, as logarithmic multipliers on a basic pattern of movement defined by configuration. By and large, they appear to have been located in the right spaces and in numbers proportionate to their integration value.

But the matter does not quite end there. If we take the whole data set and eliminate the same shopping spaces as we did in the areas singly, the relationship between integration and movement rates remains markedly logarithmic (see figure 14). As the elimination of shopping spaces does eliminate the logarithmic effect in the areas taken on their own, the only possible inference is that there is also a global logarithmic effect at the level of relations among the areas. This can be shown by plotting integration against unlogged movement for each area (except area 3) on the scale defined by the scatter for the whole system [as shown in figure 11(a)]. By setting the areas more or less in order of their movement rates, it becomes clear that as mean rates increase so there is a strong tendency for the regression line for the area to shift from near vertical to near horizontal. In other words, the distribution of grid properties and movement rates at the area level is itself logarithmic (see figure 15).

Unfortunately with the present database and software, it is not possible to ascertain how far this is a result of grid properties and how it is a result of attractors. For example, it is not yet possible to excise areas from the larger system and compute their mean integration values read within the large system in order to compare them with mean encounter rates. Nor is it possible to take the ten routes as representative of their well-defined areas. For example, in the Northeast area, the grid is sparse and block sizes are large, with the effect that the observation route is dominated by the main grid, with few smaller scale spaces.

The range of integration values for observed lines is consequently less, and the average integration value does not reflect the weakness of the area in the distribution of integration in the large area. In contrast, the West area includes not only the major shopping attractor of Camden High Street but also the strongly segregated region to the immediate west of the King's Cross site. It therefore includes both strong integration and strong segregation, giving it a high range of integration values, and shows also the influence of both positive and negative attractors.

However, it does seem that over and above the effect of specific attractors in the area, there is also a global pattern of what we might call attractor areas, and that these reflect both global properties of the grid and differences in the distribution of attractors. It seems likely, but we cannot be sure, that the latter is consequent on

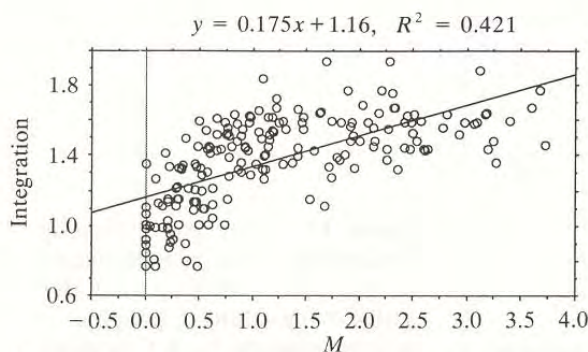


Figure 14. Plot of integration against numbers of moving adults (M) in all nonshopping streets.

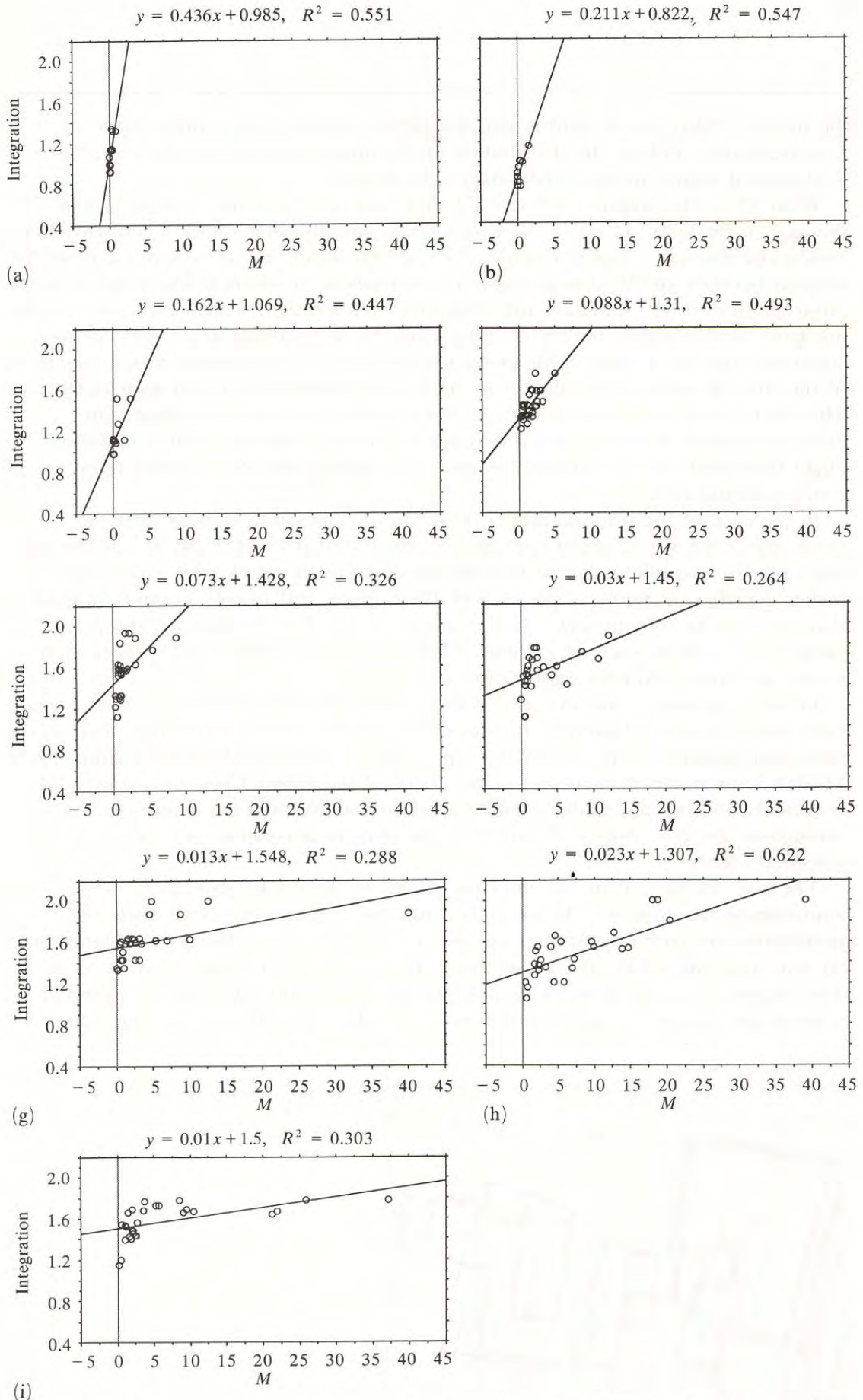


Figure 15. Plots of integration against numbers of moving adults (M) in (a) Maiden Lane estate, (b) Elm Village estate, (c) Bemerton estate, (d) North area, (e) East area, (f) Southwest area, (g) Southeast area, (h) South area, (i) West area.

the former. What can be said is that the global pattern of area differences in movement rates follows the distribution of the integration core of the whole area, as discussed earlier in this paper, singularly closely.

What about the 'negative attractors'? Are they also basically configurational? In the case of the falloff effect of the King's Cross site, the site is both a configurational lacuna and also has a radical absence of attractors. Intuitively, in view of the powerful relation between spatial configuration and movement, it seems unlikely that a major interruption of route continuity and destination availability in a substantial area would not have local 'negative multiplier' effects on the surrounding area. This, in turn could be expected to have a knock-on negative effect on attractors in the vicinity of the site. However, it is difficult to show this unambiguously and numerically. This would seem to be an area where much further research is needed. On present evidence, it seems only a reasonable inference that the almost uniform blight that seems to characterise the area surrounding the site is a long-term configurational effect.

In the case of the housing estates, however, it is possible to show that the extraordinarily low movement rates are a configurational effect. First, we can eliminate one obvious possibility: that of housing density. On the whole, the estates have higher densities, in terms of population, floor space, and usually ground coverage, than their urban surroundings. Nor is it easy to see how the lack of groups of shops could lead to such an extreme diminution of movement rates. There is, it seems, no simple attractor explanation.

In fact it is easy to use the axial map to show that the reduction of movement rates results from configuration not attraction. Figure 16 is a 'ten-minute map' of the movement pattern on the observed route in one of the three housing estates, the Maiden Lane estate immediately to the north of the King's Cross site. Each dot represents one moving adult encountered during an average ten-minute period throughout the day (that is, it multiplies the phm/m movement rate by ten to give graphical clarity).

The map shows that on the lines peripheral to the estate, movement rates approximate the norm for the area. On the lines entering the estate from the periphery—one axial step deep—rates are considerably lower, though still significant. At two axial steps into the estate rates drop again, then again at three steps. This negative relation between axial depth and movement rates can be shown as a scattergram (figure 17) and indexed by a correlation coefficient (in this case

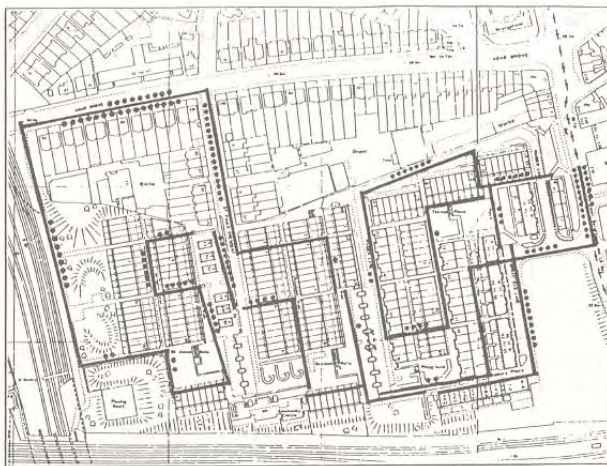


Figure 16. 'Ten minute map' of the movement pattern by adults on the observed route in the Maiden Lane estate.

$r = 0.793$, probability $p < 0.0001$). This rapid falloff in movement with depth is a very common property for housing estates, and shows graphically how spatial configuration freezes out all natural movement from the estate.

The configurational influence of spatial segregation on movement within the estates can be confirmed by looking at average integration values and movement rates for the estates and contrasting them to the street areas. We find that the mean integration value of observed lines in the urban areas is 1.508, very close to the average for London streets as a whole, with a minimum of 1.045 and a maximum of 2.004. The mean movement rate is 3.943 phm/min, or 2.982 phm/min without main shopping streets. In the estates, the mean integration is 1.020, that is well below the *minimum* for the street areas, and the maximum is 1.522, or about the mean for street areas. The mean movement rate is 0.365 phm/min.

It is not possible to tabulate mean integration against average movement rates for all of the areas, because current technology does not permit the excision of a group of connected spaces while still reading their integration values from the larger system. To use only the observed spaces in each area would entail the risk that the sample of spaces does not truly represent the area. We can, however, divide the whole data set into a number of integration bands with equal numbers of spaces and check the average integration of these against mean movement rates. Figure 18 shows this for six integration bands, yielding a correlation of $r = 0.99$.

The effect of low movement rates on awareness of others can be further clarified by setting rates against the mean length of axial lines in areas to derive a figure for how much time a pedestrian spends in and out of visual contact with other people. For urban residential streets, a mean natural movement rate of 2.7 phm/min, coupled to a mean length of axial line of about 300 m, ensures that a pedestrian is in virtually constant visual contact with others, and usually with several. A mean rate

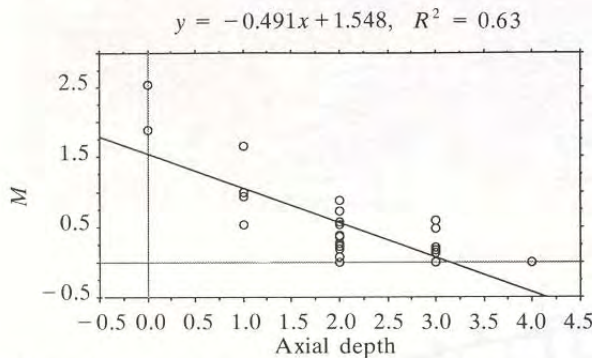


Figure 17. The negative relation between axial depth from the exterior and movement rates (M) ($r = 0.793$, $p < 0.000$).

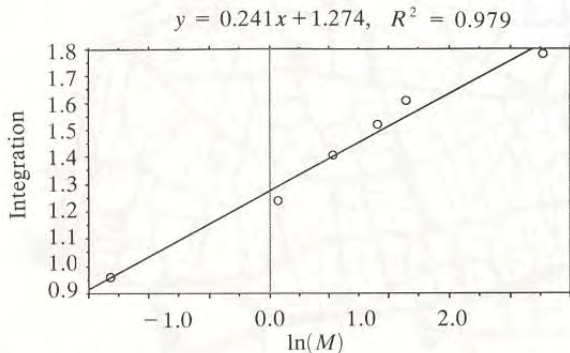


Figure 18. The average integration of six equal-sized groups of spaces against mean movement rates (M) for the whole dataset ($r = 0.99$, $p < 0.0001$).

of 0.27 phm/min, and a mean axial length of 50 m (as found on this estate) would mean that a pedestrian would be *out* of visual contact for about 88% of the time, a remarkable reversal of urban norms. As we have observed elsewhere, many housing estates have lower degrees of awareness of others through movement in the middle of the day than even quiet residential areas have at midnight. Coupled to the scaling down of space which is an almost invariable property of such estates, one begins to arrive at a numerical picture of the extreme sense of isolation which people often report in modern housing estates.

Case study 2: the City of London

These inferences may be explored further by looking at a study of the City of London carried out for the Mansion House Square public inquiry in 1984 to try to establish whether or not the proposed square would work—and leading, incidentally, to the prediction that it would work very well. Again this review deals only with the analytic aspects of the study relevant to natural movement.

Figure 19 is a plan of the City of London 'within the walls', figure 20 is a black-on-white space map, and figure 21 is its axial map. Figure 22 shows the three routes observed during the study, and table 3 is a tabulation of the movement rates for each



Figure 19. Plan of the City of London 'within the walls'.



Figure 20. Black-on-white space map of the City of London.

of the five time periods for the two central routes with averages for all time periods taken together, for the morning and afternoon taken together, and for the two rush-hour periods taken together. The third route is omitted both because it was primarily concerned with the modern development around St Pauls rather than with the urban fabric of the city, and because it is too close to the western periphery to the City to be comparable with the other two routes. Because it was shown that the distribution of rates was very similar for the morning, afternoon, and midday periods (though the last had of course much higher rates), and contrasted to the rush-hour periods when the distribution was different in quite marked ways, the figures used below will be the average for the three middle periods of the day.

Figure 23(a) is the scattergram for integration values plotted against movement rates in the two routes.

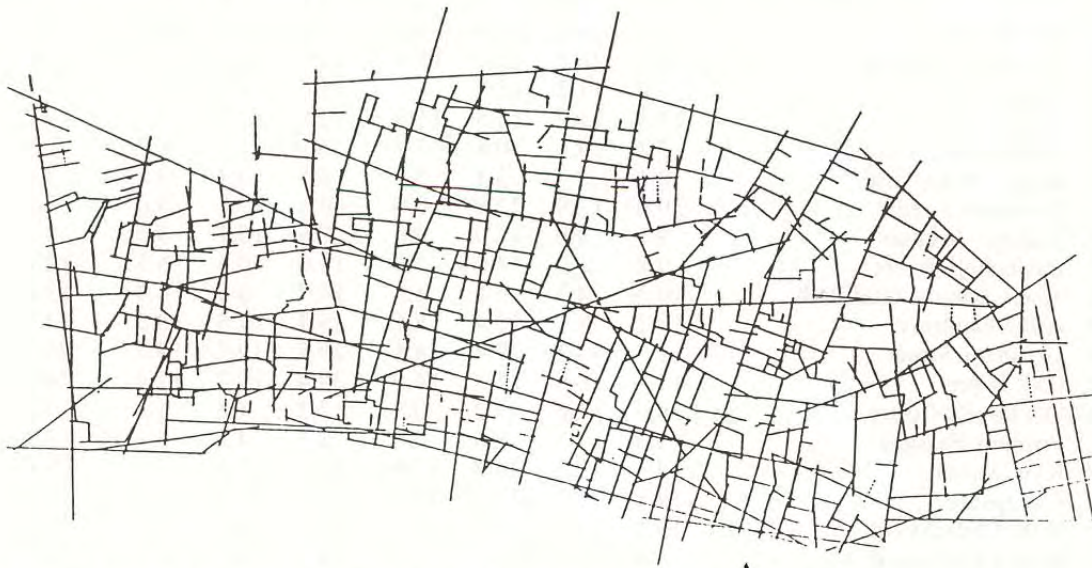
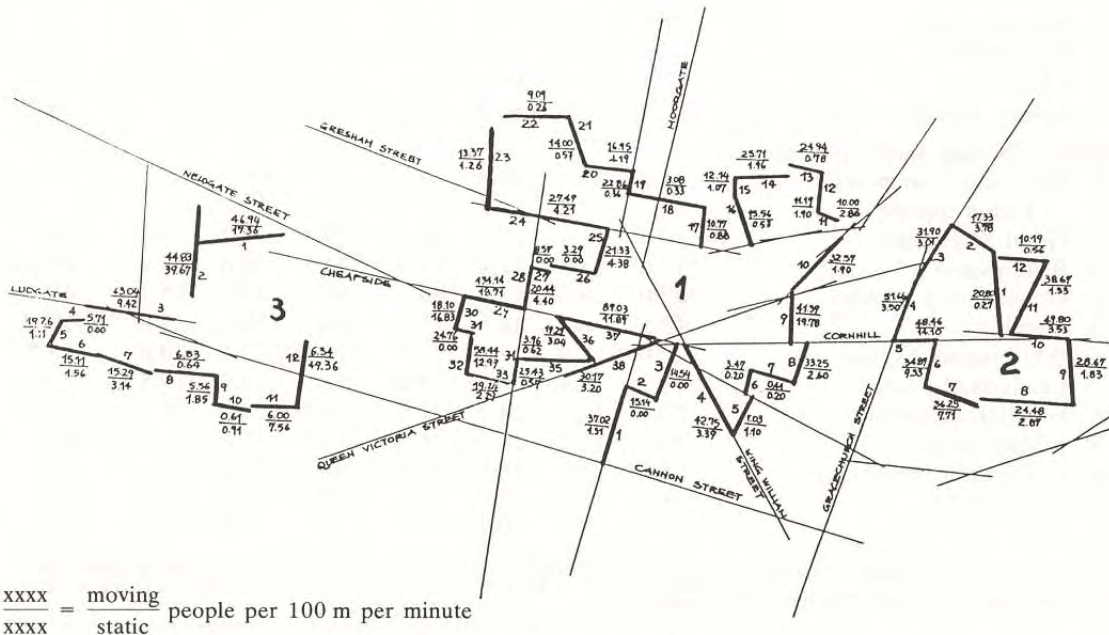


Figure 21. Axial map of the City of London 'within the walls'.



$$\frac{\text{xxxx}}{\text{xxxx}} = \frac{\text{moving}}{\text{static}} \text{ people per 100 m per minute}$$

Figure 22. Three observed routes annotated through the City of London, with density of moving and static people during the midday period (12-2 PM).

Table 3. City of London—movement rates for each of the 5 time periods for the two central routes (route 1 and route 2).

	Time period					Average ^a		
	1	2	3	4	5	all	AM/PM	rush-hour
<i>Route 1 (moving people per 100 m)</i>								
1. Walbrook	86.1	17.8	37.0	18.3	110.3	53.9	18.1	98.2
2. St Stefan's Row	9.3	4.3	15.1	5.4	10.0	8.8	4.9	9.7
3. Mansion House Place	15.8	4.5	14.5	6.8	17.3	11.8	5.6	16.5
4. King William Street	32.6	24.4	42.8	23.0	33.8	31.3	23.7	33.2
5. Abchurch Lane	9.0	4.1	7.0	5.5	8.5	6.8	4.8	8.7
6. Cornhill, Lombard Street Alley	2.1	1.2	3.5	2.4	5.5	2.9	1.8	3.8
7. Change Alley	1.0	1.4	0.4	0.6	1.2	0.9	1.0	1.1
8. Birch Lane	18.8	14.5	33.2	14.3	14.2	19.0	14.4	16.5
9. Royal Exchange Building	40.3	20.0	41.3	23.3	41.0	33.2	21.6	40.6
10. Old Broad Street	38.1	18.3	32.6	14.6	37.8	28.3	16.5	37.9
11. Austin Friars	9.4	5.6	10.0	8.1	8.3	8.3	6.8	8.9
12. Austin Friars	6.7	6.7	11.2	6.7	5.8	7.4	6.7	6.2
13. Austin Friars	12.4	20.6	24.9	9.6	7.0	14.9	15.1	9.7
14. Copthall Building	12.1	20.2	25.7	14.8	11.9	16.9	17.5	12.0
15. Angel Court	7.9	11.2	12.1	6.1	5.0	8.5	8.7	6.5
16. Angel Court	13.5	11.2	15.5	11.8	13.8	13.2	11.5	13.0
17. Tokenhouse yard	7.2	4.6	10.8	7.7	8.7	7.8	6.2	7.9
18. King's Arms yard	3.1	3.1	3.1	3.3	4.5	3.4	3.2	3.8
19. Coleman Street	30.0	12.9	22.9	5.0	40.4	22.2	9.0	35.2
20. Masons Avenue	9.1	8.0	17.0	9.0	7.6	10.1	8.5	8.3
21. Basinghall Street	9.8	5.2	14.0	7.9	15.0	10.4	6.5	12.4
22. Space behind Guildhall	10.5	4.5	9.1	4.3	14.7	8.6	4.4	12.6
23. Aldenmanbury	10.1	8.1	13.4	8.5	19.3	11.9	8.3	14.7
24. Gresham Street	12.7	14.1	27.4	14.4	29.8	19.7	14.3	21.2
25. Old Jewry	17.8	10.0	21.3	14.9	34.4	19.7	12.4	26.1
26. St Olave's Court	0.4	1.6	3.2	0.8	2.2	1.6	1.2	1.3
27. Prudent Passage	3.3	7.8	8.6	0.0	1.1	4.2	3.9	2.2
28. King Street	14.4	11.5	20.4	12.5	26.9	17.2	12.0	20.6
29. Cheapside	54.8	45.0	134.1	38.9	65.3	67.6	41.9	60.1
30. Bow Churchyard	14.1	8.1	18.1	10.2	24.1	14.9	9.2	19.1
31. Bow Churchyard Alley	15.6	11.1	24.8	7.6	24.4	16.7	9.4	20.0
32. Bow Lane	24.2	17.9	58.4	22.1	42.7	33.1	20.0	33.5
33. Watling Street	11.8	12.4	19.2	11.0	29.1	16.7	11.7	20.4
34. Queen Street	14.0	14.7	25.4	9.4	12.3	15.2	12.0	13.2
35. Pancras Lane	1.6	2.5	4.0	2.9	4.2	3.0	2.7	2.9
36. Bucklersbury	45.6	7.7	19.3	16.1	65.6	30.9	11.9	55.6
37. Cheapside	43.1	36.1	89.0	45.6	71.9	57.1	40.9	57.5
38. Queen Victoria Street	27.9	19.3	30.2	20.7	30.8	25.8	20.0	29.3
<i>Route 2 (moving people per 100 m)</i>								
1. P&O and Commercial Union Square	31.2	7.9	20.8	8.5	32.5	20.2	8.2	31.9
2. Great St Helen's	30.3	11.1	17.3	10.2	27.1	19.2	10.7	28.7
3. Bishopsgate	57.6	15.6	31.9	14.3	73.5	38.6	14.9	65.6
4. Gracechurch Street	67.0	26.2	51.7	24.3	68.3	47.5	25.2	67.7
5. Cornhill	43.5	36.4	48.5	19.2	44.1	38.3	27.8	43.8
6. Whittington Avenue	22.0	18.9	34.9	22.7	16.9	23.1	20.8	19.4
7. Leadenhall Place	21.2	19.4	36.2	19.6	22.9	23.9	19.5	22.1
8. Fenchurch Avenue	28.1	19.1	24.5	21.0	19.5	22.4	20.1	23.8
9. Billiter Street	34.0	17.2	28.7	16.7	58.5	31.0	16.9	46.2
10. Leadenhall Street	68.2	24.5	49.8	19.2	66.3	45.6	21.9	67.3
11. St Mary Axe	38.0	18.4	38.7	13.2	33.7	28.4	15.8	35.9
12. Undershaft	6.1	4.3	10.2	4.4	4.6	5.9	4.4	5.4

^a Average over all time periods, average over morning period 2 and afternoon period 4 (AM/PM), and average over two rush-hour periods.

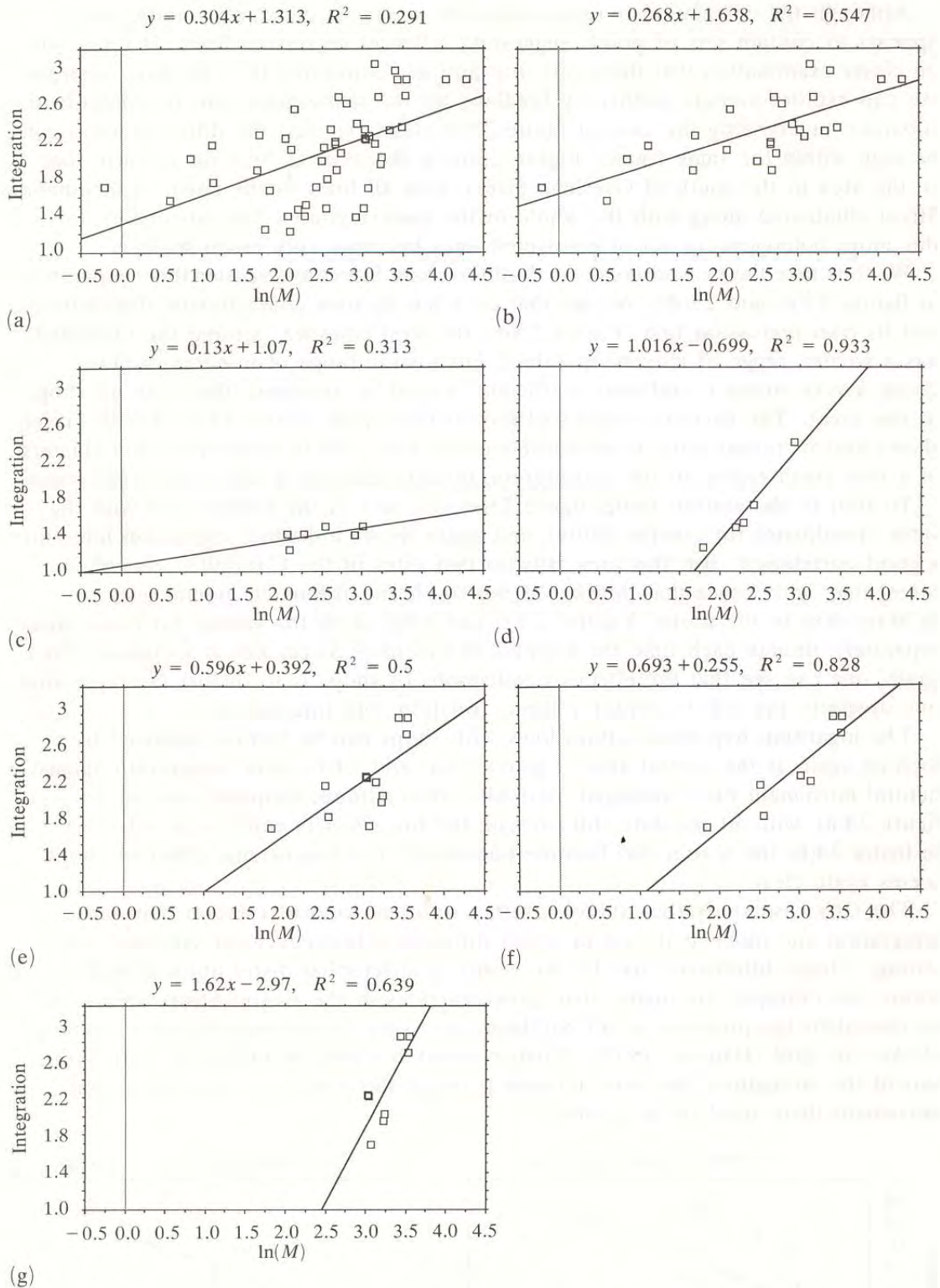


Figure 23. Scattergrams plotting integration values against logged movement rates (M) for (a) all lines in the two routes, (b) the 'central' area on its own, that is the area to the south of Gresham Street, (c) the eastern subarea to the north of Gresham Street around Austin Friars, (d) the western subarea to the north of Gresham Street and around the Guildhall, (e) the eastern route, (f) the eastern route subarea with the much quieter area of St Mary Axe to the north, (g) the eastern route subarea with Leadenhall Market to the south.

Although the correlation is respectable, the scatter is decidedly untidy, and appears to contain sets of points suggesting different regression lines. It turns out on closer examination that these sets of points are connected lines forming subareas. We can explore matters further by breaking up the scattergram into its component subareas, but holding the axes of figure 23(a) steady so that the different areas can be seen within the same frame. Figure 23(b) is the 'central' area on its own, that is, the area to the south of Gresham Street, with all lines to the north of Gresham Street eliminated along with the whole of the eastern route. The correlation for this more homogeneous set of connected lines becomes very much stronger.

We then take the two subareas north of Gresham Street and scatter them separately in figures 23(c) and 23(d). We see that each has its own characteristic distribution and its own regression line. Figure 23(d), the west complex (around the Guildhall) has a narrow range of movement values, but a wide range of integration values, giving a very strong correlation coefficient, logged or unlogged (there are no shops in this area). The eastern complex of the northern area [figure 23(c), Austin Friars] shows narrow ranges both in natural movement rates and in integration, and clusters in a very small region of the scattergram, though retaining a reasonable correlation.

To turn to the eastern route, figure 23(e) is a plot of the scatter (still with the same coordinates for comparability), and again shows a distinct regression line and a good correlation. But this area falls on two sides of the Cornhill-Leadenhall Street line, with Leadenhall Market to the south and the much quieter area of St Mary Axe to the north. Figures 23(f) and 23(g) show the scatter for these areas separately, though each time the Cornhill-Leadenhall Street line is included. Once again, one can see that the effect of collections of shops is to distort the regression line upwards, but still to conserve the correlation with integration.

The logarithm hypothesis about lines with shops can be further explored by looking again at the central area. Figures 24(a) and 24(b) show integration against natural movement rates unlogged, first with, then without shopping streets. In figure 24(a), with all the data still present, the log effect is easily seen, whereas in figure 24(b) the scatter has become linearised. The logarithmic effect of shops seems again clear.

The City case study thus shows a rather different kind of relation between integration and movement, one in which differences between local subareas seem strong. These differences may be the result of differential distribution of built forms (for example, the higher than expected rates in the Austin Friars area could be caused by the presence of tall buildings), or to the distinctively regional character of the City grid (Hanson, 1989). Further research would be needed to clarify this. But of the strength of the basic relation between the pattern of integration and movement there need be no doubt.

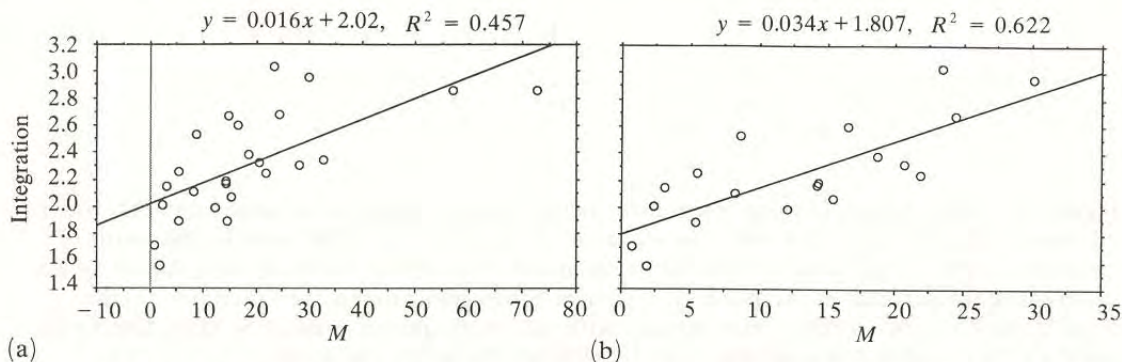


Figure 24. Plot of integration against natural movement rates (M) unlogged (a) with and (b) without shopping streets.

Case study 3: a South London housing estate

Further aspects of the relation between integration and natural movement may be explored by looking at the relevant parts of a study of the relations between spatial patterns and crime, recently carried out in collaboration with the Crime Prevention Unit of the Home Office. The study of natural movement in and around the estate was part of the study because it seemed possible that it might be an intervening variable between space and the vulnerability of locations to different kinds of crime.

Figure 25 is the map of the estate, figure 26 its black-on-white map in its surrounding urban area, and figure 27 its axial map. Four different levels of representation were used for calculating spatial values: the estate only without its surrounding streets (measures suffixed 1); the estate with its surrounding streets (suffixed 2); the estate plus the street system in the surrounding urban area as shown in figure 26, but without housing estates (suffixed 3); and the last plus other housing estates in the area (suffixed 4).

Of particular interest here is the effect of reading integration values from the four different systems in post-dicting the pattern of movement. Figures 28(a)-(d) show scattergrams for movement rates using the four systems. The best representation is the third, the estate plus its urban surroundings, which gives a correlation coefficient of $r = 0.752$.

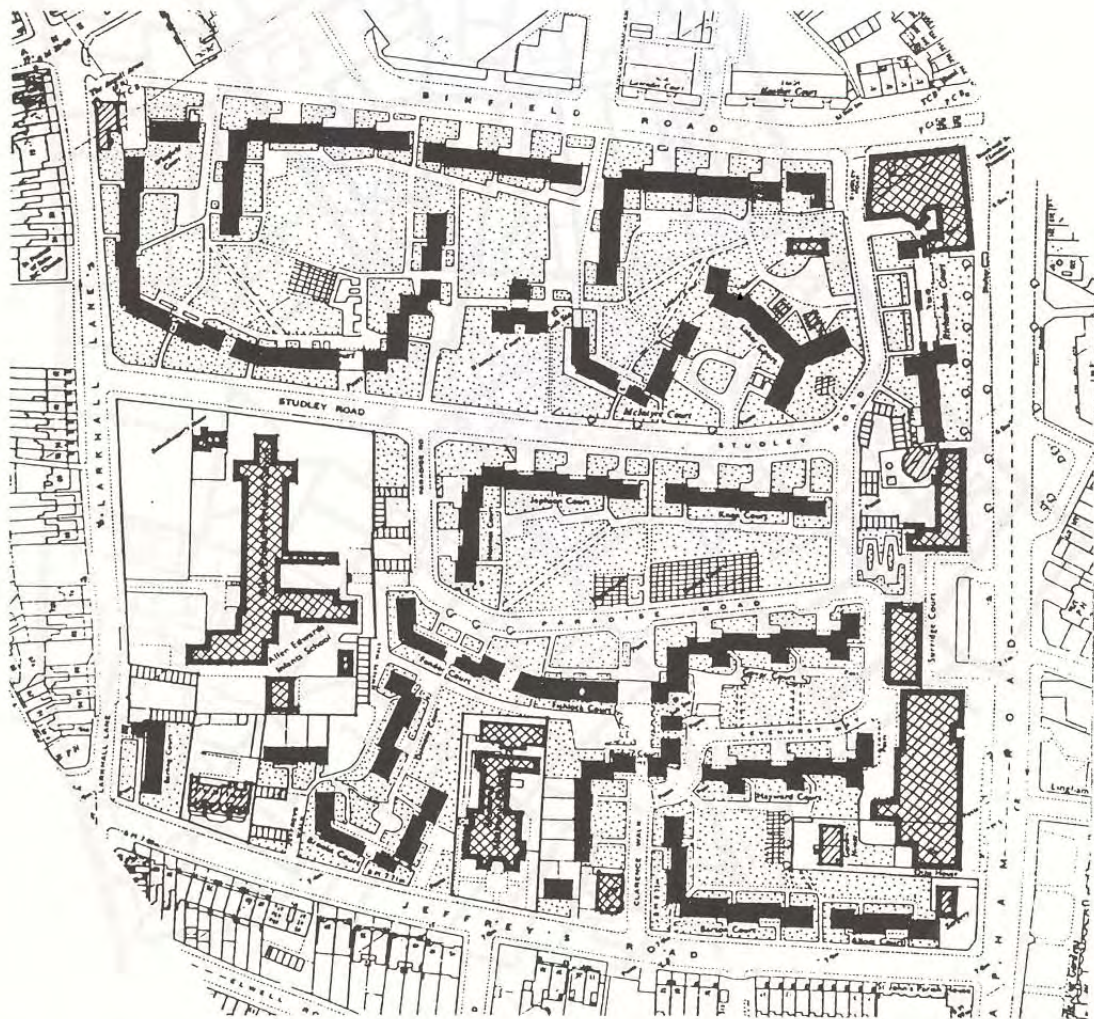


Figure 25. Plan of a South London housing estate.

Dividing the data into the surrounding area, figures 29(a) and 29(b), and the estate, figure 29(c) (using this reference system) and using the untransformed movement rates, we find that the surrounding area is strongly logarithmic, but the estate itself is not. The correlation coefficient for the surrounding area is also a good deal better than for the estate interior, even though this estate is relatively open and permeable to its surroundings. Once again, we find that movement rates fall rapidly with depth from the outside and indeed we again find depth from the outside strongly negatively correlated with integration.

The relation of these patterns to the spatial distribution of crime on the estate has been explored in the remainder of this study. A series of strong—though occasionally complex—relationships have been found between spatial patterns and crime.



Figure 26. 'Black-on-white' map of the estate in its urban context (including other housing estates).

But these are not our theme here. The results are now being written up separately, and are currently available as a working paper.

Other studies

A considerable body of other studies now exists, some published, others as aspects of applied research or PhD theses. A number are worth referring to here. First, a study of Highgate and its contextual area was carried out for the Islington Health Authority as part of a development initiative for a major site in the area. The study was of particular interest because Highgate is essentially a single main street on an important through route, but surrounded by an area with a rather suburban character in that the islands are very large, and the buildings are relatively low density.



Figure 27. Axial map of the estate and its urban context (including all other housing estates).

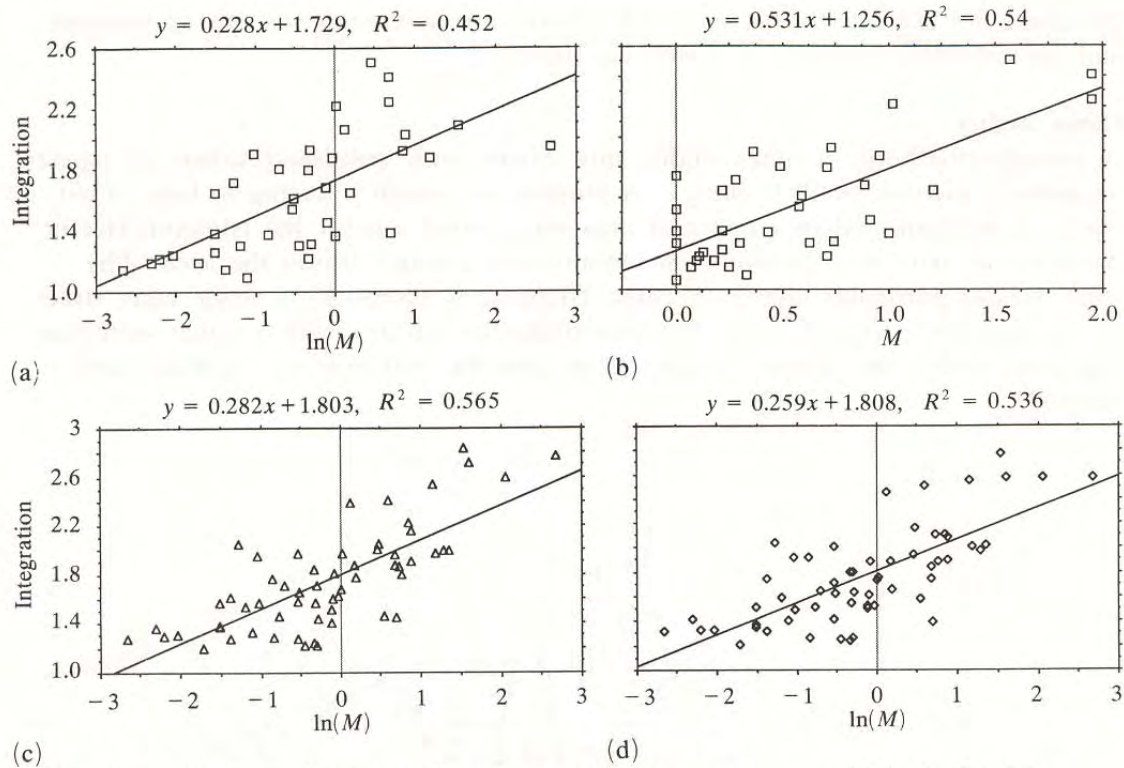


Figure 28. Scattergrams for integration values against movement rates (M) calculated in (a) system 1, (b) system 2, (c) system 3, (d) system 4.

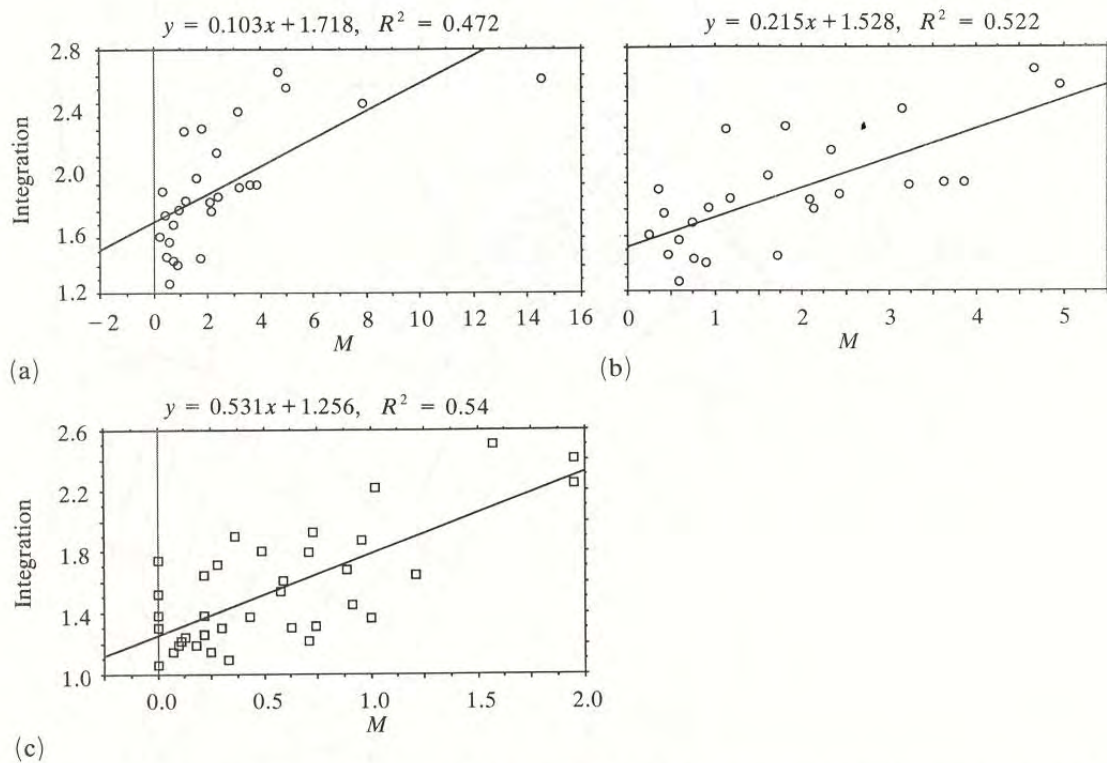


Figure 29. (a) Scattergram of integration in system 3 against untransformed movement rates (M) of the surrounding area, (b) with the two attractor spaces excluded, and (c) for the estate itself.

Two scattergrams are sufficient for our purposes here. Figure 30(a) shows the relation between integration and unlogged movement rates, and figure 30(b) the same relation taking the logarithm of movement ($r = 0.818$, $p = 0.000$). The highest movement spaces are the three observed sections of the High Street. The logarithmic effects of the attractors here closely follow those of the previous cases, and without them the relation is linearised.

Previously published cases include Hillier et al (1987), in which a series of studies of urban areas, suburban areas, and housing estates are reported, in all cases with strong and significant relations between integration and movement. In this paper a number of cases are reported where integration works less directly or less well in post-dicting movement, though still in all cases reaching high levels of statistical significance. It is hypothesised that this lower performance is caused by the absence of a 'second-order' configurational property called 'intelligibility', defined as the degree of correlation between the connectivity of lines and their integration value. That is, between what can be seen of the line visually and locally, and how this relates to the importance of the line in the system as a whole. This hypothesis is currently being explored in theoretical studies being carried out in the Unit for Architectural Studies.

Also recently published is a set of studies of six Greek towns by Peponis et al in an issue of *Ekistics* devoted to space-syntax research (Peponis et al, 1989). All show strong correlations between spatial parameters and observed movement, with integration again the strongest performer. This study is unusual in the degree to which the detailed morphology of the towns is considered and the effects of, for example, the opening and closing of shops. Xu Jianming in a doctoral study has found strong correlations in all nine housing estates studied, though again with variations which, he hypothesises, could be the result of the degree to which 'intelligibility' as defined above is present in the system. Krüger reports (personal communication) good correlations in all but one of a set of studies of urban areas in Brazilian towns. In the nonconforming case, the study was based on a single round of observations (the norm is 20–30) by undergraduate students. Inspection of maps suggests, however, that the contextual area for the study was insufficient to give an adequate syntactic picture of the study area.

Apart from Krüger's anomaly, no cases are known where sufficient analysis and observation has not led to a significant relation of some kind between integration and movement. The proposition that the results of such studies as these permits us to offer a theory of *natural movement*—that is, movement which is, *ceteris paribus*, determined by the configuration of the grid—is thus supported by a range of studies sufficient to suggest that configuration ought to be given at least equal weight as attraction in the design of urban areas. Cases are not standard, however, and much remains to be understood about the *ceteris paribus* clause.

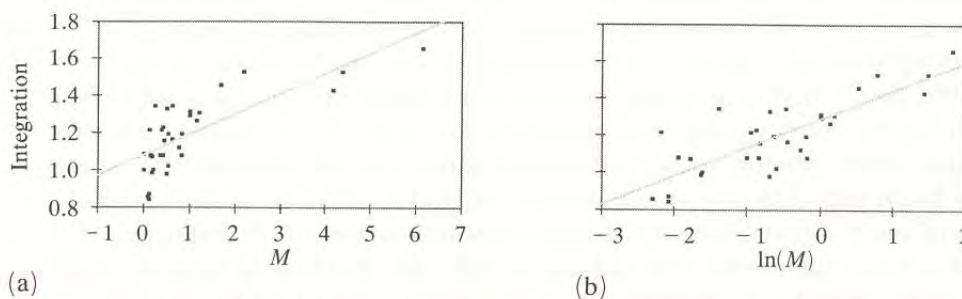


Figure 30. The relation between integration and (a) unlogged and (b) logarithm of movement rates in the Highgate study area.

Implication for theory: why axiality? why linearity?

If such structures as integrating cores are as fundamental to urban form as the results of natural movement studies suggest, then there are implications for theory which go beyond the analytic theories we need in research, and into the normative theories we use in design. Recent debates about urban space have been much preoccupied with two theoretical questions: which urban *scale* is the 'human scale' and how do urban forms become *intelligible*? Most commonly, answers are sought in some interpretation of historical precedent. The scale question leads to a proposal to reproduce the allegedly smaller scale environments of the past, and the intelligibility question to a proposal to introduce historically meaningful monuments and landmarks to act as orientational devices in the urban landscape.

The implication of natural movement studies would seem to be that both scale and intelligibility are in the first instance questions of the morphology of space and cannot be separated from the spatial configuration of the grid itself. There is also a clear implication that there has been a substantial misreading of urban morphological history. Human scale in urban space seems to be more about ensuring that scale is sufficiently large rather than small, and intelligibility seems to arise in the first instance as a product of the same upwards scale effects, rather than from physical cues and symbols—though these undoubtedly also play some role.

These issues can, we believe, be clarified by posing two questions implied by our results: first, why axiality? That is, why should the axial organisation of space be so fundamental? And, second, why linearity? That is, why should the relation between spatial and functional patterns be a simple linear one? To answer these questions we must depart for a moment from the formal and statistical analysis of spatial and functional patterns and consider urban space and form from the point of view of the individual subject who experiences it and uses it. If axiality and linearity are key morphological properties of urban space and function, then there must be some sense in which both 'get into the head' of individuals and come out as behaviour.

On the first question, why axiality? two kinds of data converge: first, the effects of descaling modern space, especially residential space, which we looked at in the King's Cross study, and, second, data on syntactic aspects of simulated urban form generation. On the first, we may turn back to figure 7 and remind ourselves that a prime spatial attribute of modern housing estates is the *reduction* of spatial scale and the increase in spatial complexity. This is as true of the medium-rise estates to the west of the Caledonian Road as it is of low-rise estates to the north and west of the King's Cross site. It is also as true of geometrically ordered designs as of more organic-seeming layouts. Much analytic experience has convinced us that both of these are generic properties of modern layouts.

As shown in Hillier et al (1987), and since confirmed by further studies, the functional effects of this down-scaling of space are usually that the integration core is peripheralised, so that the estate interior lacks structure; that, consequently, movement is peripheralised, and people simply move out of the estate by the shortest possible route; that a dramatic falloff in movement rates occurs with depth, so much so that it becomes normal for people to find themselves on their own for most of the time when moving about within an estate; and that probabilistic social interfaces are disrupted. The net result is that distinctive sense of isolation amidst high densities of people that characterises so many housing estates. Extensive studies of such environments have persuaded us that the problem of spatial scale in modern design is not the overscaling of space, but its radical underscaling.

We may come at this issue from another angle by looking at scale in urban form generally. It has been noted in previous texts commenting on attempts to simulate

urban spatial properties through partially randomised cell-aggregation processes that local rules for growth that work for small aggregations do not work for larger aggregations because too labyrinthine a complexity is created (Hillier and Hanson, 1984). We find that in real urban aggregates axial and convex scales tend to be increased in line with the scale of the growing object. For example, aggregates at the scale of a hamlet may be maximally two or three axial steps deep from their periphery. However, aggregates at the scale of towns are often also maximally two or three steps deep. The rules that govern growth change, it seems, with scale, in the manner of an allotropic process, and they do so in order to maintain certain parameters—for example that of depth—if not at a constant level, then at least at a level considerably less than would occur if the rule of growth did not change.

We call such rules 'globalising rules': they have the effect of maintaining the coherence of the growing global object from the point of view of what we might call the 'peripatetic subject'—a hypothetical individual moving around the system at ground level. Sometimes these globalising rules take quite precise forms. In the premodern City of London, for example, whichever City gate was entered the 'centre' (that is, where Cheapside and the western radial routes meet) could be reached in three axial steps, provided only that at every point of choice the longest available line of sight was followed. One could teach an automaton to find the way to the City centre—perhaps because for all intents and purposes a stranger entering a town for the first time is a kind of spatial automaton.

More generally, we note in the City of London a tendency which we might call the 'conservation of shallowness'. Again and again one finds that, say, a back alley route that in plan might appear tortuous, on the ground is not tortuous at all, because the axial organisation of space is far less complex than the convex organisation. Often there is a point where a line of sight goes back to the last major spatial event—say a major line, or a larger convex element—and another leads on to the next. Scaling axial lines upwards to pass through series of convex spaces seems to be the prime means by which this 'on the ground' intelligibility is created.

We also often find in urban systems a rather more complex principle which we might call the conservation of axial integration: the grid maintains the same degree of mean syntactic integration as a whole as for its parts (see Krüger, 1989). This 'conservation of integration' is found in cities with a high degree of integration, such as the City of London (Hanson, 1989) and also in cities with very much lower degrees of integration, for example some of the cities of the Sahara and North Africa (Loumi, 1988). Arab towns are much less integrated than the City of London; but like London the mean integration of their parts, analysed independently, closely approximates the mean integration of the whole.

In many urban cultures, it seems, integration is a morphological constant, independent of the size of the system. The means by which this is achieved seems to be, once again, the globalising rules whereby axial and convex scale is increased in proportion to the scale of the system. The laws of urban growth that govern the constancy of integration within a culture appear to be more general than any tendency to specific degrees of integration. This suggests that the 'human scale' in space is not a metric absolute, but is relative both to culture and to the size of the urban system, and is an important means of maintaining intelligibility and functionality in urban space.

If urban space does tend to conserve certain cultural constants by the adjustment of scale, then may this also explain why we find linear, and transformable linear, relationships between axial integration and movement? The possibility is the more intriguing given the current preoccupation with nonlinear models: one feels one

must justify even looking for linear relationships in the apparent chaos of human *peripateia*.

Be that as it may, linearity from space pattern to functional outcome is, we suggest, not just a phenomenon which we discover as observers and investigators, but one which is built into the urban grid itself as an objective property. Urban grids, we suggest, evolve and grow in such a way as to ensure that natural movement is linearly predictable from spatial pattern, because the structuring—and therefore the predictability—of movement is the fundamental purpose of the grid; and the control of axial scale is the fundamental means by which the growing urban grid, within the laws of a particular culture, calibrates itself so as to generate and maintain a differentiated probabilistic encounter field with the interface properties specified by that culture.

We may develop this argument by looking more closely at fractal theory, and especially at its central concept of self-similarity: that is the propensity for systems to repeat, or nearly repeat, their forms at different hierarchical levels. To anyone familiar with the recent debate about architectural and urban space the property of self-similarity will be familiar. The idea of a hierarchical nesting of similar or identical levels of spatial organisation, reflecting different levels of social organisation—individuals, families, groups of neighbours, neighbourhoods, and so on—has been fundamental to how designers and theorists have sought to conceptualise the ‘urban part’ and how they may be combined so as to form an urban whole. The theory that at all spatial levels humans formed groups which require a hierarchically separated environment (those based on ‘human territoriality’ were merely the most scientifically pretentious of such theories) has become the normative paradigm that has underpinned much 20th-century design.

Natural movement studies, and syntactic studies of urban historical morphology, show how erroneous and how pernicious the assumption of hierarchical self-similarity has been in architecture and urban design. It has provided the theoretical support, now unstated, now explicit, for the creation of an historically unprecedented urban grid, one preoccupied at each level with local separation and identity at the expense of global interrelationships, and as a result creating the fragmentary, overlocalised, and overhierarchised enclaves that are the final urban product of the mid-20th century design schools. In schools of architecture, indeed, the otiose notion of ‘spatial hierarchy’ has often been taken to be coterminous with order and structure in space.

But, however otiose, the notion of hierarchy is an attempt to describe a fundamental phenomenon of urbanism: that of the manifest existence of different scales of spatial organisation. How may this be understood without the simplifications of ‘hierarchy’? Let us proceed empirically and consider the map of the City of London from the point of view of a ‘peripatetic subject’—that is a hypothetical individual moving about the grid.

Imagine an individual walking eastwards up Cornhill from its western end. As the observer moves, he or she becomes aware of two levels of spatial organisation: one which relates him or her to the global scale of the grid and one which relates him or her to the much smaller scale system of ‘alleys and courts’ of the block interiors. The peripatetic observer is given as many glimpses of the one as of the other. Although one scale is large and the other small, at both scales the observer sees a constant pattern in which axuality overcomes the tendency for space to become convexly localised.

As a result, both the intelligibility of the large scale, above the observer’s level of immediate awareness, and the intelligibility of the smaller scale, potentially below the observer’s level of awareness, are maintained by what appears to be a

principle of sufficient axiality. Provided only that the observer continues to move, he or she will continue to experience movement as an interface between urban scales.

This two-way (from the moving subject) principle of sufficient axiality is not a metric invariant but a syntactic organising principle. Its effect is to maintain a kind of constancy between levels of space organisation that conserves intelligibility at the scale of the peripatetic subject. If space became too complex above or below the level of the peripatetic subject, then intelligibility would be lost, and the most obvious route to this loss would be the loss of axiality.

As it seems logically necessary that the relation between spatial configuration and its functioning—that is, its predictability—must pass through the intelligibility of the configuration to the subject, then it also seems likely that the principle of sufficient axiality which conserves intelligibility is the means by which functional predictability is conserved as an objective property of the system. In other words, it is the axial organisation of urban space that ensures that people both understand it, and can intuitively predict its functional consequences.

Linearity, it might be speculated, arises from this, that is from the regular construction of the system of space in such a way as to conserve the relation of the peripatetic subject both to the small and to the large scales of space, and to keep both scales within his or her compass of understanding. The association between space configuration and natural movement thus becomes the prime determinant of urban spatial form, and the linearity of the relation between the two becomes an objective property of the urban system rather than simply a latter-day discovery by outside observers.

The ubiquity of the 'principle of sufficient axiality' requires us, I believe, to propose a redefinition of the human scale in a generally upwards direction. The 'human scale' means scaling spatial elements upwards to preserve the intelligibility and functionality of the system in accordance with the size of the system, and to keep both within the compass of the peripatetic observer. In this view, the human scale is about preserving the intelligibility of the inevitably large-scale systems within which we live, in spite of its complexity at the small scale and sheer metric size at the large. It is also a means of conserving the predictability of human movement from the grid which is the essential purpose of the grid. By means of a constant principle—though within the confines of a given culture—axiality becomes the means by which linearity is itself rendered a constant. In other words, the issue of structure in space appears to be intimately bound up with that of scale, and vice versa.

One further speculation may be permissible. If attractors are found to have a logarithmic effect on movement, and if this may be taken to imply that the degree to which attractors appear on lines with a given degree of integration is also logarithmic, then it would surely follow that this would have implications for the scale of buildings, more specifically for their height. If the centre of a growing urban system maintains itself as the integration core of the system, then we should expect the height of its buildings to increase logarithmically in order to provide the attractor floor-space permitted by its degree of integration. If, on the other hand, the 'historic core' of the town is not maintained as the core of integration, then the increase in height would be much less. Both types of case would appear to exist.

The implications of natural movement for urban design are straightforward. If we wish to design for well-used urban space, then we must design with the knowledge that integration is a global variable, and movement in particular spaces is not determined in the main by the local properties of that space, but by its configurational relation to the larger urban system.

Methodological aids to achieve this in design are also straightforward, and are set out elsewhere (Hillier, 1988). To make sure that a new urban development works in terms of natural movement, one must first analyse the spatial and functional logic of the surrounding area by carrying out a computer analysis and observational study. Then, on the basis of the pattern revealed, candidate design proposals may be inserted into the computer model to analyse how they will create a pattern of integration within the development site, and how this will relate to that of the existing area. On this basis, reasonable predictions may be made of how the design will affect natural movement within and around the site.

In a sense, one might say that by emphasising natural movement, space syntax offers a normative idea of what constitutes good design and a successful outcome. However, experience suggests that there are many different ways to design a ghetto, but very few ways of designing an integrated system. Space syntax need only be invoked for the more difficult task. In this, however, it often offers no more than a powerful aid to the designer's intuition and intentions. It does not tell designers what to do. It helps them to understand what they are doing.

References

- Hanson J, 1989 *Order and Structure in Urban Space: A Morphological History of the City of London* PhD thesis, Bartlett School of Architecture and Planning, University College London, London
- Hillier B, 1988, "Against enclosure", in *Rehumanising Housing* Eds N Teymur, T Markus, T Wooley (Butterworth, Sevenoaks, Kent) pp 63-85
- Hillier B, Hanson J, 1984 *The Social Logic of Space* (Cambridge University Press, Cambridge)
- Hillier B, Burdett R, Peponis J, Penn A, 1987, "Creating life; or, does architecture determine anything?" *Architecture and Behaviour* special issue on the work of the Unit for Architectural Studies, Bartlett School of Architecture and Planning, University College London, London 3(3) 233-250
- Krüger M, 1989, "On node and axial grid maps: distance measures and related topics", paper given at the European Conference on the Representation and Management of Urban Change, University Centre, University of Cambridge, 28-29 September; working paper, Bartlett School of Architecture and Planning, University College London, London
- Krüger M, Turkeinicz B, 1988, "Synchrony in urban form", paper presented at the Third Seminar on Urban Design in Brazil, University of Brasilia, October; copy available from Department of Architecture, University of Brasilia
- Loumi A, 1988 *Spatial Configuration in Towns in North Africa* PhD thesis, Bartlett School of Architecture and Planning, University College London, London
- Peponis J, Hadjinikolaou E, Livieratos C, Fatouros D A, 1989, "The spatial core of urban culture" *Ekistics* 334-335 43-55
- Pushkarev B, Zupan J, 1975 *Urban Space for Pedestrians* (MIT Press, Cambridge, MA)