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Integrated multilevel circulation in dense urban areas: the effect of multiple interacting constraints on the use of complex urban areas

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Abstract. In this paper we present research into patterns of space use and pedestrian movement in two multilevel urban complexes. Data on movement behaviour were gathered by direct observation within the Barbican and South Bank complexes in London. Conventional space-syntax analysis of spatial configuration has shown that the ability to predict patterns of pedestrian movement in urban areas decreases as those areas become less 'intelligible', where intelligibility is defined as the correlation between local and global configurational measures within a space-syntax analysis. Both the Barbican and the South Bank areas are relatively unintelligible in comparison with their urban context. Poor predictions of pedestrian flows were found in both cases by using a conventional space-syntax analysis. A method was then developed for including additional variables into an 'integrated multilevel circulation model' (IMCM) which describes factors such as grade separation, attractors and generators of movement, the depth properties of primary routes, and local factors such as the visibility of transition spaces, in addition to conventional space-syntax properties. This model was found to be able to predict observed patterns of pedestrian movement with much greater accuracy in the two case-study areas, and before and after changes to the configuration of routes in the South Bank area. By excluding one variable at a time from the model, the order of significance of the different additional factors was investigated. The main finding was that horizontal change of direction was a more significant factor than vertical grade separation in determining observed movement flows.

Introduction

Space-syntax analysis of urban pedestrian movement has shown that, in general, observed pedestrian flow rates are best 'post-dicted' by a restricted radius measure of spatial integration (Hillier, 1996; Hillier et al, 1993). Hillier, in empirical studies of Barnsbury in North London, found a good correlation ($r^2 = 0.734$) between the logarithm of pedestrian flows and radius 3 integration (Hillier, 1996, page 164). This means that, statistically speaking, about three quarters of the variation in pedestrian flows from space to space can be predicted directly by variations in integration. Two further cases at King's Cross and in the City of London 'within the wall' (Hillier et al, 1993, pages 45 and 55) also show remarkable correlations between global integration and the logarithm of pedestrian flows. In spite of the presence of attractors and generators of movement, correlations between the two variables show great strength and reliability, with $r^2 = 0.547$ in both cases. Hillier hypothesises, however, that this result appears to rely on the degree of 'intelligibility' of the system, defined as the correlation between local and global measures of configuration (Hillier et al, 1993, page 61). In systems where local and global measures are poorly correlated, movement flows are less well predicted by measures of spatial configuration; in systems where the local and global integration variables are well correlated, predictions of pedestrian movement from spatial configuration are more powerful. In this paper we tackle the issue of the degree to which it is possible to make predictions of patterns of pedestrian movement in large and relatively unintelligible multilevel urban complexes.

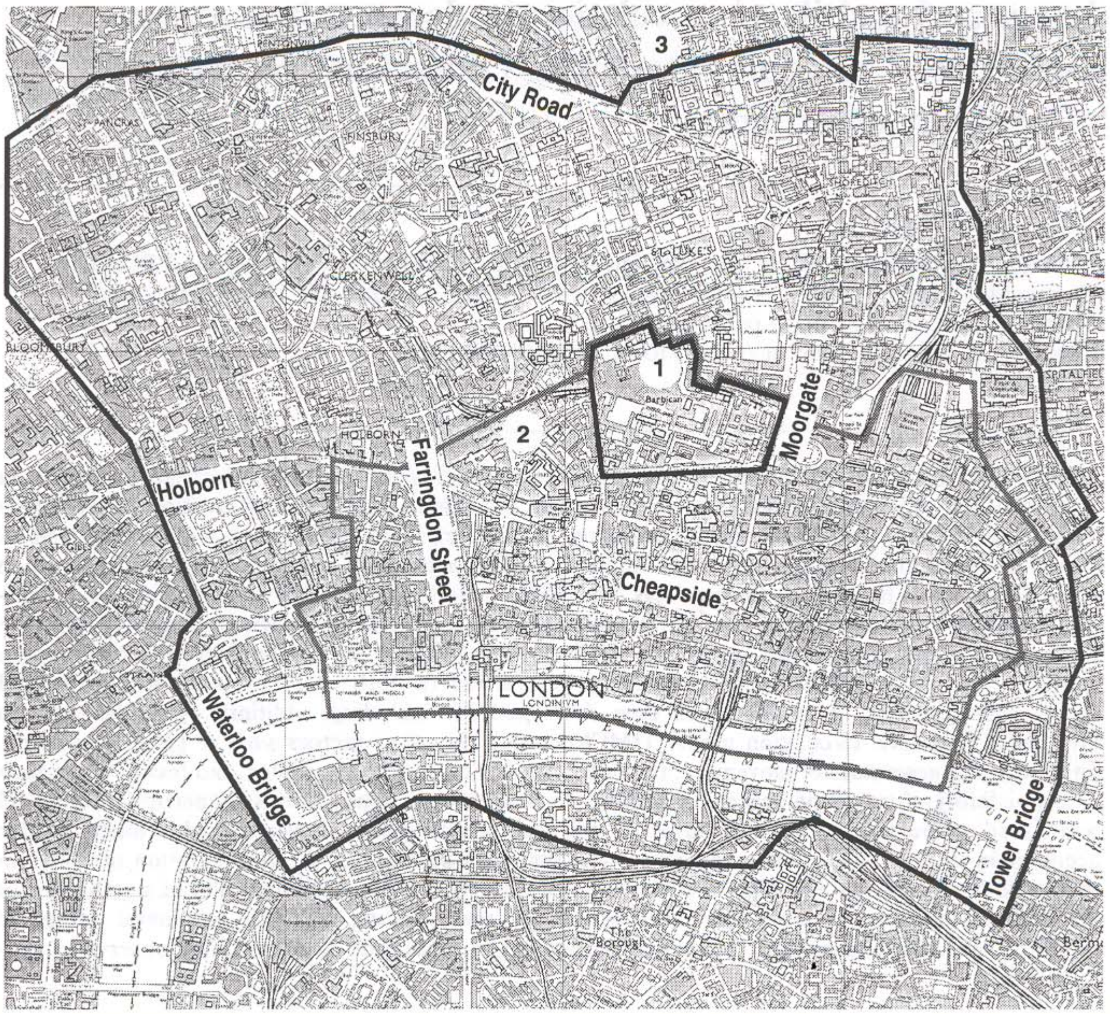


Figure 1. Ordnance Survey map showing the Barbican (1) and its surroundings (2).

Large multilevel complexes of the kind considered in this paper generally house mixed uses, including major generators and attractors for pedestrian movement. They often have large and relatively unintelligible circulation systems, including multilevel decks and complex transitions between levels. All of these factors make it difficult not only for users to read the spatial structure, but also for designers and planners to predict likely movement patterns and to locate facilities optimally with regard to accessibility. Both of the case studies presented in this paper are of this type. The Barbican development to the north of the City of London comprises a mix of housing, offices, schools, a large conference centre, and an arts complex (figure 1). The development arose out of discussions of multiuse urban development during the late 1950s (Chamberlin et al, 1959, pages 1 – 2). The South Bank Centre on the south side of the Thames near Waterloo Station houses a large multifunctional arts and cultural complex (figure 2). Its early design following the Festival of Britain made use of concepts of the 'multilevel city' (*Architect's Journal*, 1961). Both areas have been criticised for creating poor connections to the surrounding urban fabric and for the pathological use of certain of their spaces (Academy Editions, 1994, page 8; Pushkarev and Zupan, 1975, page 173).

The multilevel circulation systems in both complexes were originally designed to separate vehicles from pedestrians and this has led to pedestrianised decks and walkways in both cases, with service roads and areas of parking at lower levels

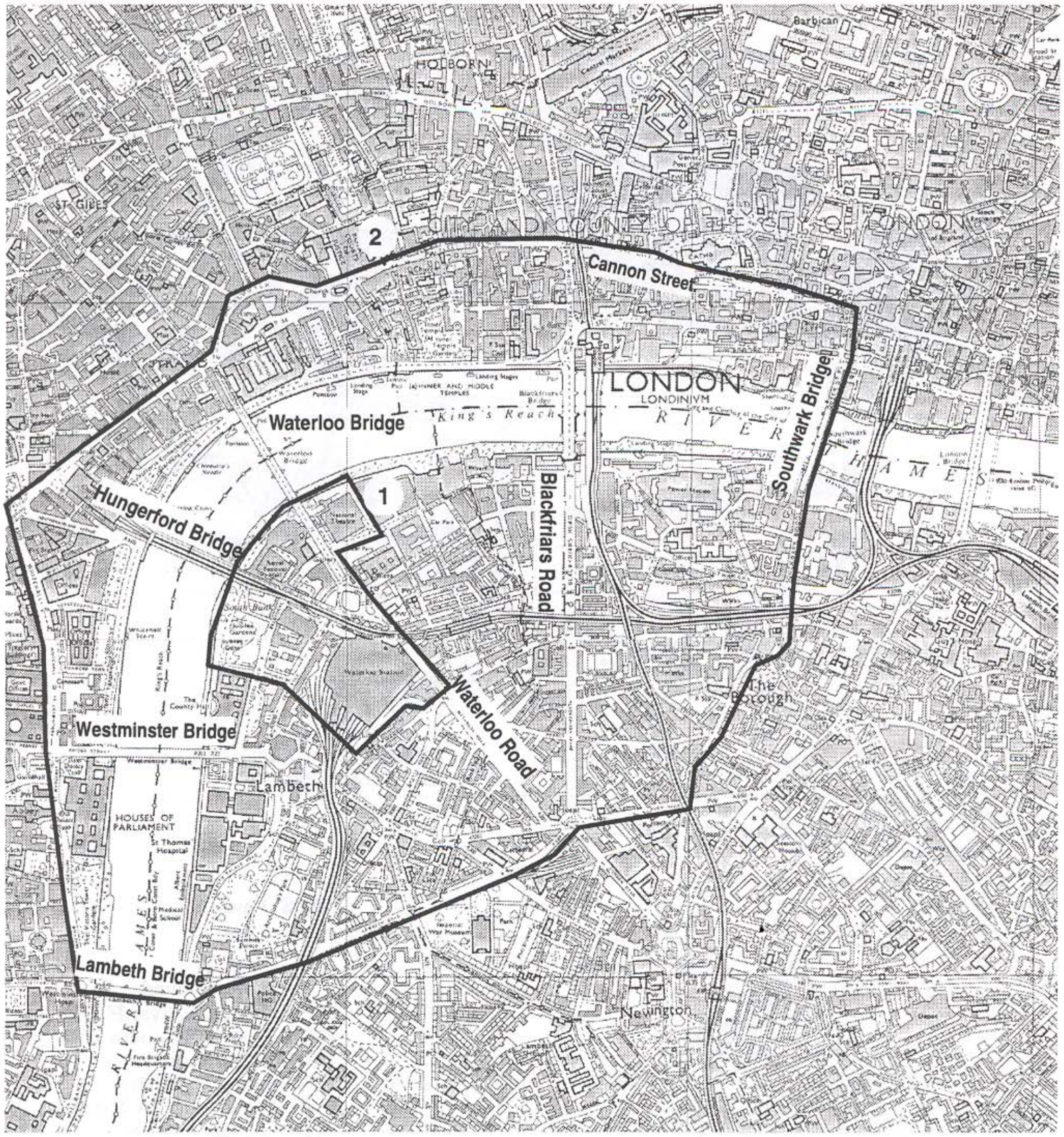


Figure 2. Ordnance Survey map showing the South Bank (1) and its surroundings (2).

(figures 3 and 4). This type of pedestrian deck has been successful in resolving conflicts between pedestrians and vehicles; however, this has often led to a concentration of pedestrian movement onto a relatively restricted series of spaces within the complex. In many cases this means that there are significant differences in the pedestrian occupancy of different spaces, ranging from overcrowding in one location to virtually no movement in a nearby space, with radical differences in space utilisation on different levels. Of particular concern is the creation of underused spaces which have been found to be prone to vandalism, occupation, and unsanctioned use. The Barbican study area is bounded by Aldersgate Street, London Wall, Moorgate, and Ropemaker Street to the north of the financial and business district of the City of London (see area marked in figure 1 and more detailed map in figure 3). The South Bank study area is defined by the triangle between Westminster and Waterloo Bridges, Waterloo Station, and the Thames (see figures 2 and 4).

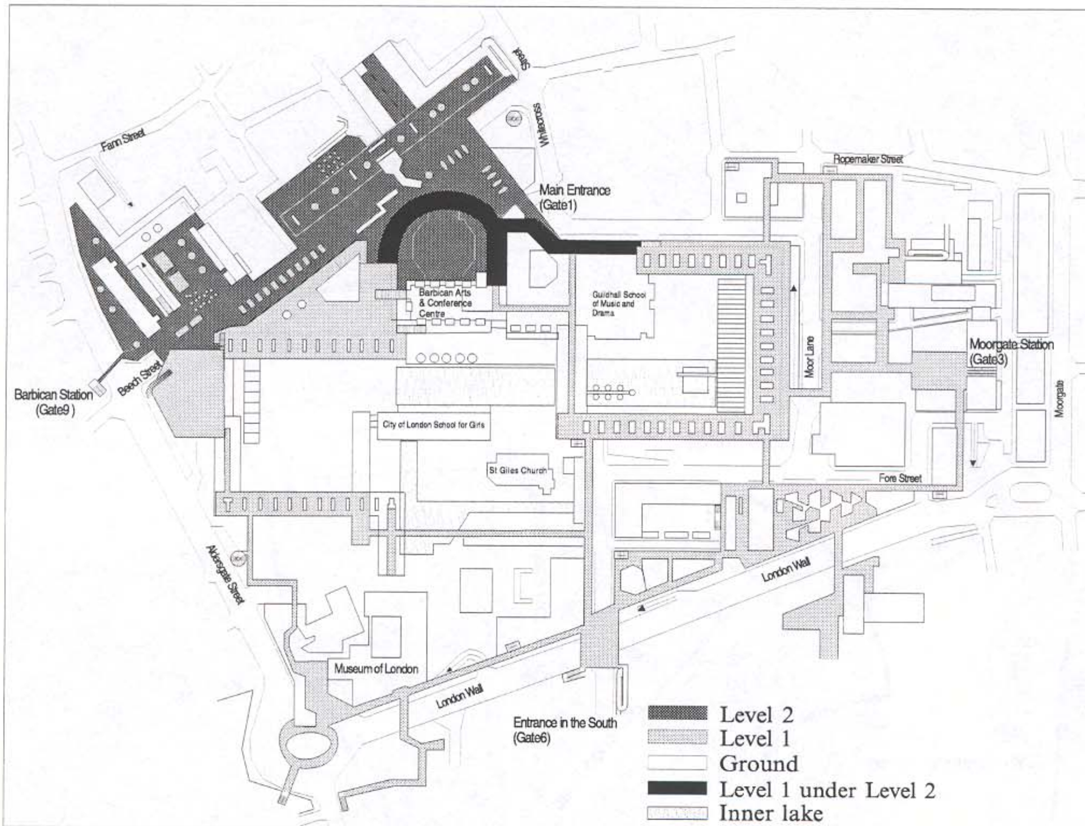
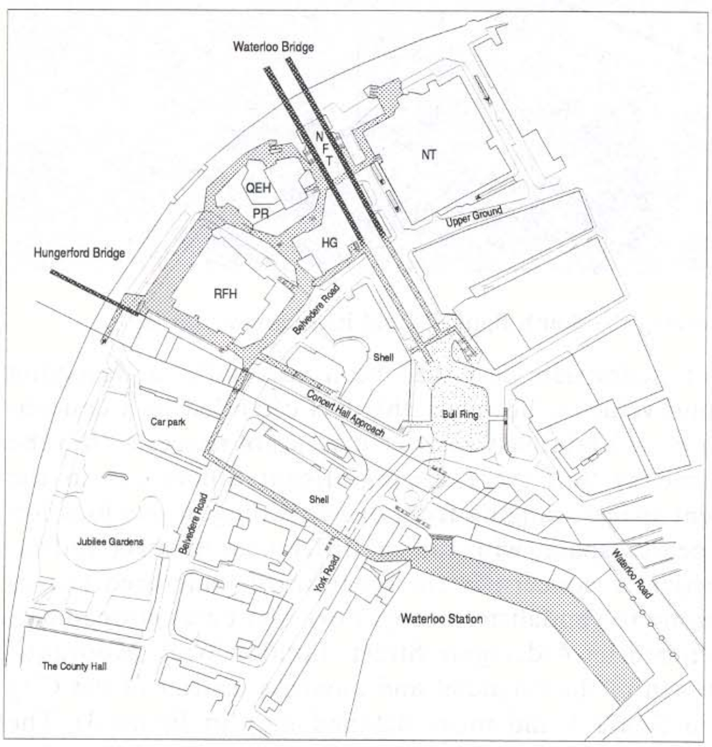


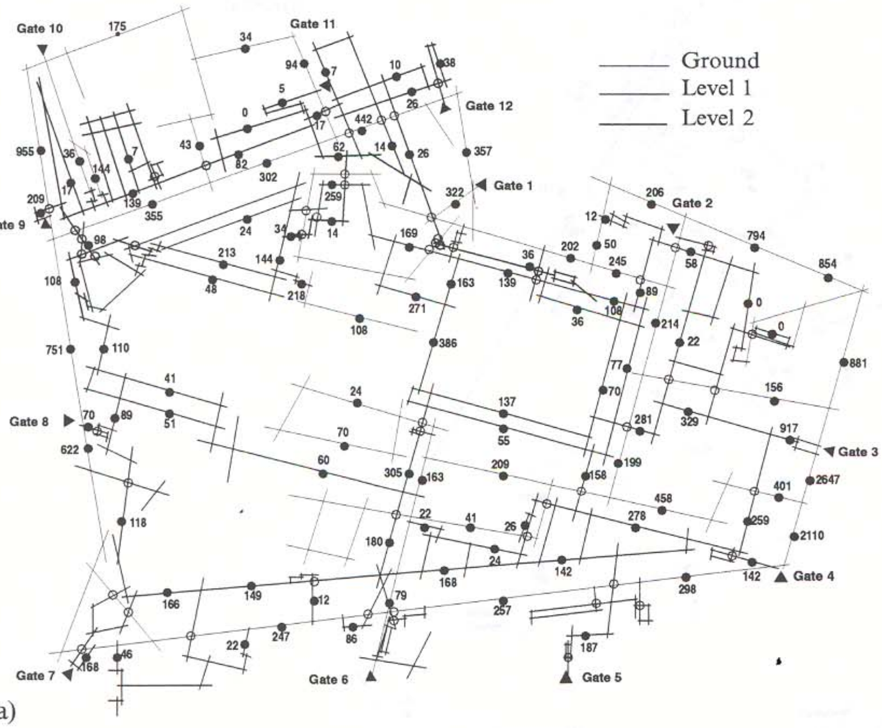
Figure 3. Multilevel system of the Barbican.



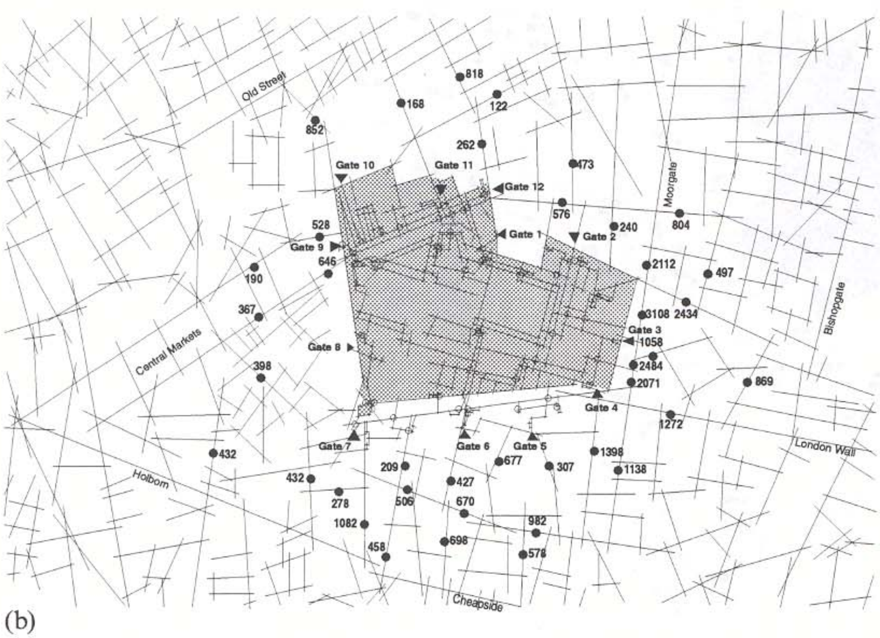
Level 2
Level 1
Ground
Underground
RFH, Royal Festival Hall
QEH, Queen Elizabeth Hall
PR, Purcell Room
HG, Hayward Gallery
NFT, National Film Theatre
NT, National Theatre

Figure 4. Multilevel system of the South Bank.

Following a description of the observations of pedestrian movement, and the space-syntax analysis of the two areas, we present the development of an 'integrated multilevel circulation model' (IMCM). We then proceed to discuss the role played by various additional factors in the IMCM, including depth in the axial map and in the node map, the embedding in the surrounding urban context, grade separation, the effects of the primary pedestrian routes through each complex, and the effects of detailed design of the vertical transition spaces linking levels. Finally, conclusions are drawn on the relative significance of each of these factors in predicting pedestrian flows.



(a)

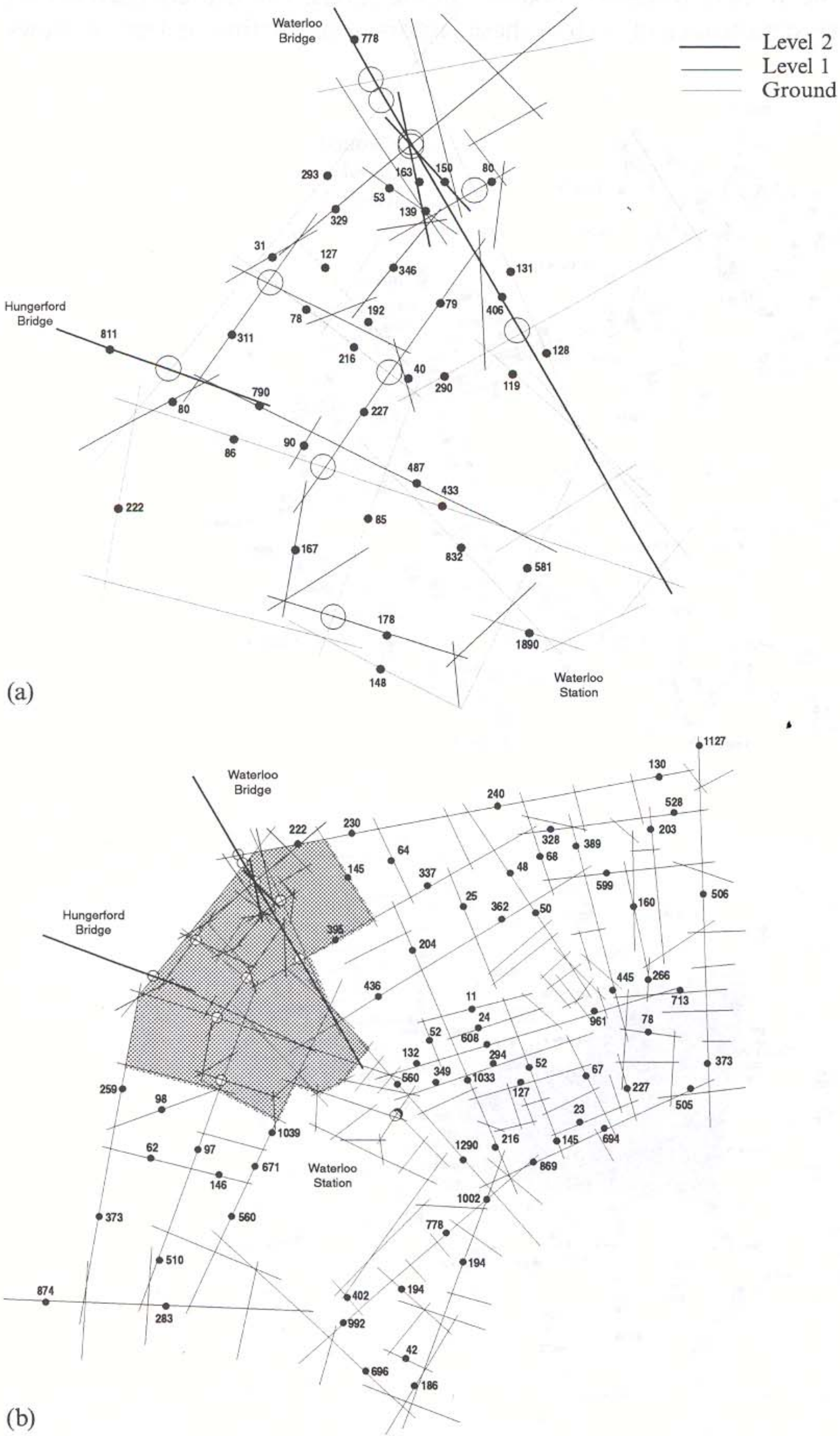


(b)

Figure 5. Mean all-day movement rates per hour for adult pedestrians in the Barbican precinct (a) and the surroundings (b).

Spatial configuration and movement patterns in the two case-study areas

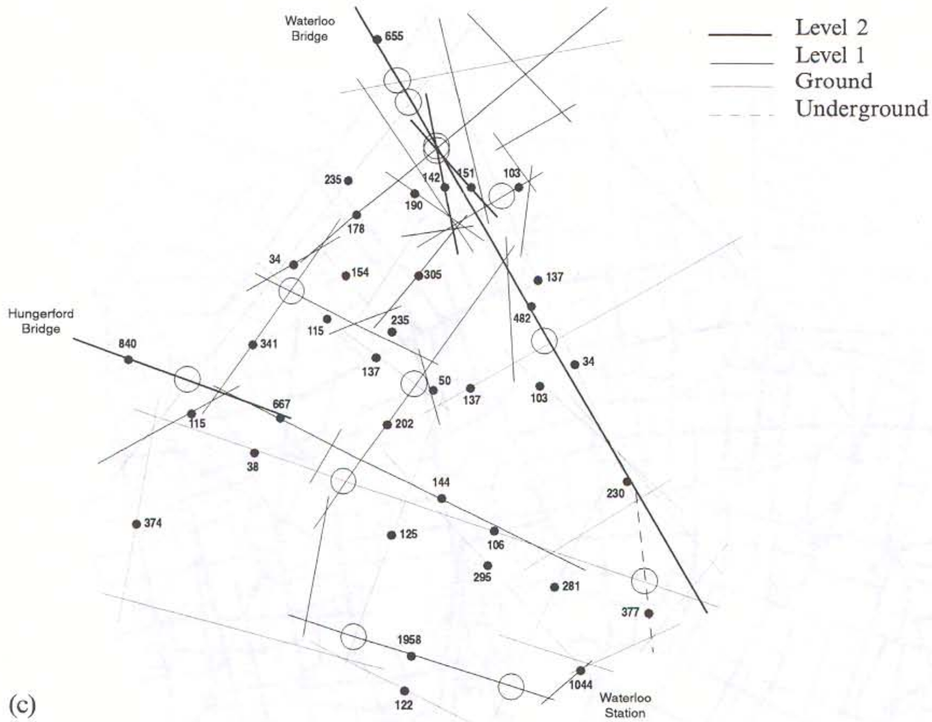
There were two forms of primary data input: the numbers of pedestrians passing a particular point over a period of time, and measures of the configuration of the space networks. The movement data were obtained by using the 'gate' method of observation, in which a stationary observer counts all people crossing a notional gate across the survey segment. These data were gathered at different times of day with each set of



(a)

(b)

Figure 6. Daily mean movement rates per hour for adult pedestrians in the South Bank: the precinct (a), and its surroundings before (b) and after (c) spatial alterations.



(c)

Figure 6 (continued).

observations lasting five minutes. The time periods were 8 – 10 AM, 10 – 12 noon, 12 noon – 2 PM, 2 – 4 PM, 4 – 6 PM, giving a total sampling period of 25 minutes for each gate location. Figures 5 and 6 show the all-day average flow rates for adult pedestrians (expressed in people per hour) for all observed street segments in the Barbican and the South Bank, respectively. For the Barbican, 9920 people were counted on 113 street segments within the precinct, and 13 176 people on 36 segments in the immediate surrounding area. For the South Bank, two sets of observations were made before and after the completion of the Waterloo International Terminal, which have resulted in changes to the spatial structure around the station. A new underground street crossing was created in front of the station's main entrance and a new direct link was made at concourse level to the raised pedestrian bridge across the York Road connecting to the walkway system through the Shell building. For the South Bank 4735 people were observed before and 4575 people after the spatial alterations on 35 route segments. Average flows for individual gates in both study areas are between five and six people per minute. These two sets of data are therefore detailed, robust, and comparable in terms of their spatial coverage and their coverage of times of day.

Figure 1 is an Ordinance Survey map showing the areas modelled by using space-syntax techniques. The area marked 1 is the observation area of the Barbican precinct and the area marked 3 is the largest area of analysis making up an 'axial map', in which the fewest and longest lines of sight and access are passed through all the open space available for through movement in the area under consideration. The Barbican is surrounded mainly by highly dense office areas, with the core of the CBD to the south, although to the immediate north there are further housing areas. Figure 7 shows a black and white screen output from 'Axman', the space-syntax modelling software developed by the Unit for Architectural Studies, Bartlett Graduate School of Architecture and Planning, University College London, in which the axial map of the area is shaded according to integration values. The shading shows from black, for the most integrated

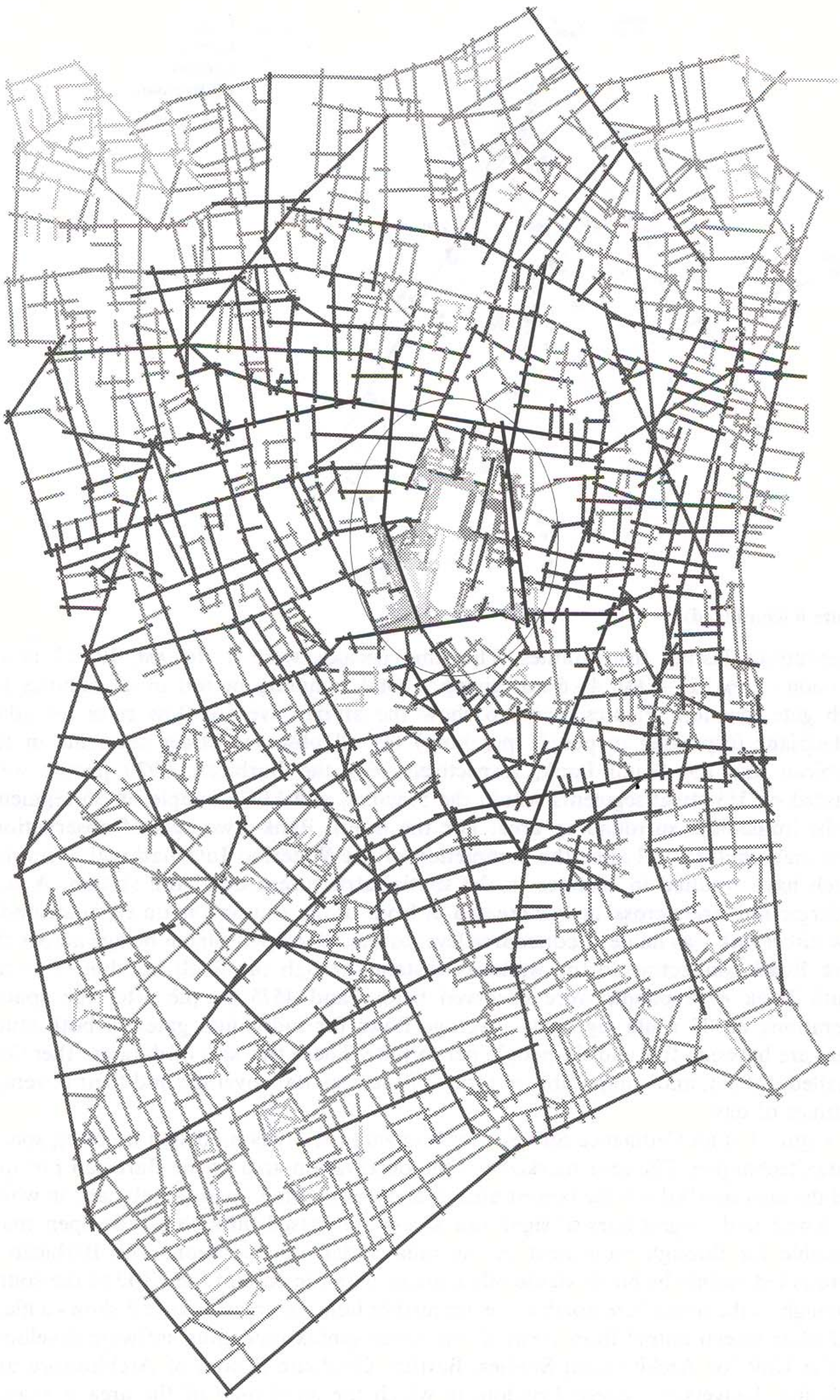


Figure 7. Global integration of the Barbican: the area encircled is the Barbican precinct.

(and shallowest from all other lines on average), through to light grey, for the least integrated (deepest on average). This integration map clearly shows the main structure of the integrated lines, in which Aldersgate Street, Moorgate, Holborn Viaduct, and Cheapside are picked up as the main focus of integration in the area. It is clear that the Barbican is segregated structurally from its surrounding context even though it has direct connections to the highly integrated axial lines at the edge of the precinct, such as Aldersgate Street, London Wall, and Moorgate. The degree of this structural segregation can be inferred from the degree of accessibility measured in axial depth from the major surrounding routes shown in figure 8. The highly integrated surrounding streets at about 10 m and 500 m from the edge of the Barbican precinct are the starting points of the two depth measurements. All of the spaces in the system therefore have their own depth values calculated from the selected axial lines. The selected depth points at 10 m and 500 m consist of a series of highly integrated streets surrounding the precincts within a catchment area: Aldersgate Street, London Wall, Moorfields, and Ropemaker Street at 10 m; and Holborn Viaduct, Cheapside, Moorgate, City Road, and Old Street at 500 m.

Scattergrams in figures 8(a) and 8(b) plot integration against axial depth in which the lines within the Barbican are shown as large grey points and those in the surrounding context as small black points. The Barbican points are amongst the deepest in the area (to the far right of the scatter) but are also located in the lower part of the scatters, indicating that at a given depth they are the more segregated spaces. Most of the spaces in the Barbican arts and conference centre occupy the deepest points in the system, between depths 8 to 15 and 11 to 16 at 10 m and 500 m, respectively. If we compare the scatters in figure 8 to those in figure 9 which plot similar points for the Cheapside – Bank of England area, we can see that it is possible to reach any point within 4 or 5 steps in depth from its surrounding major streets within the City of London.

It is likely that the structural segregation of the Barbican precinct from its surrounding context has a direct effect on both intelligibility (defined as the correlation between connectivity and global integration; see Hillier, 1996, page 129) and the local area effect (defined as the correlation between local integration (radius 3) and global integration; see Hillier, 1996, page 171) shown in figures 8(c) and 8(d), respectively, with the dark points representing all the spaces in the precincts and the grey points representing those in the surrounding context. The structure of the scatters of dark points are messy when compared with those of the scatters in dark points shown in figures 9(c) and 9(d) representing the heart of the City of London. The regression line of the dark points in figure 9(d) crosses that of the whole system at a steep angle. It is thought that linearity of the scatter plotting local integration against global integration suggests a strong relation of local parts and global structure in an urban area, with a powerful effect on the definition of a local area. The scatters of the Barbican show that there is virtually no relationship between local and global integration, and they are if anything less well related than the whole of the remaining contextual area, in spite of the relatively small number of spaces and their geographic proximity. Hillier has suggested that a poor relationship between the two radii of integration implies a broken relationship of interfaces in functional terms with consequences for the 'movement economy'. This may eventually lead the movement system of an area to a pure origin – destination movement pattern (Hillier, 1996, page 178).

Figure 5 shows the area surrounding Moorgate Station (named as Gate 3) to be the most heavily used space in the Barbican. However, the movement rate drops significantly even at just one step of depth from the station. For example, whereas Fore Street Avenue in the eastern part of the precinct which leads to Fore Street and Moor Lane from

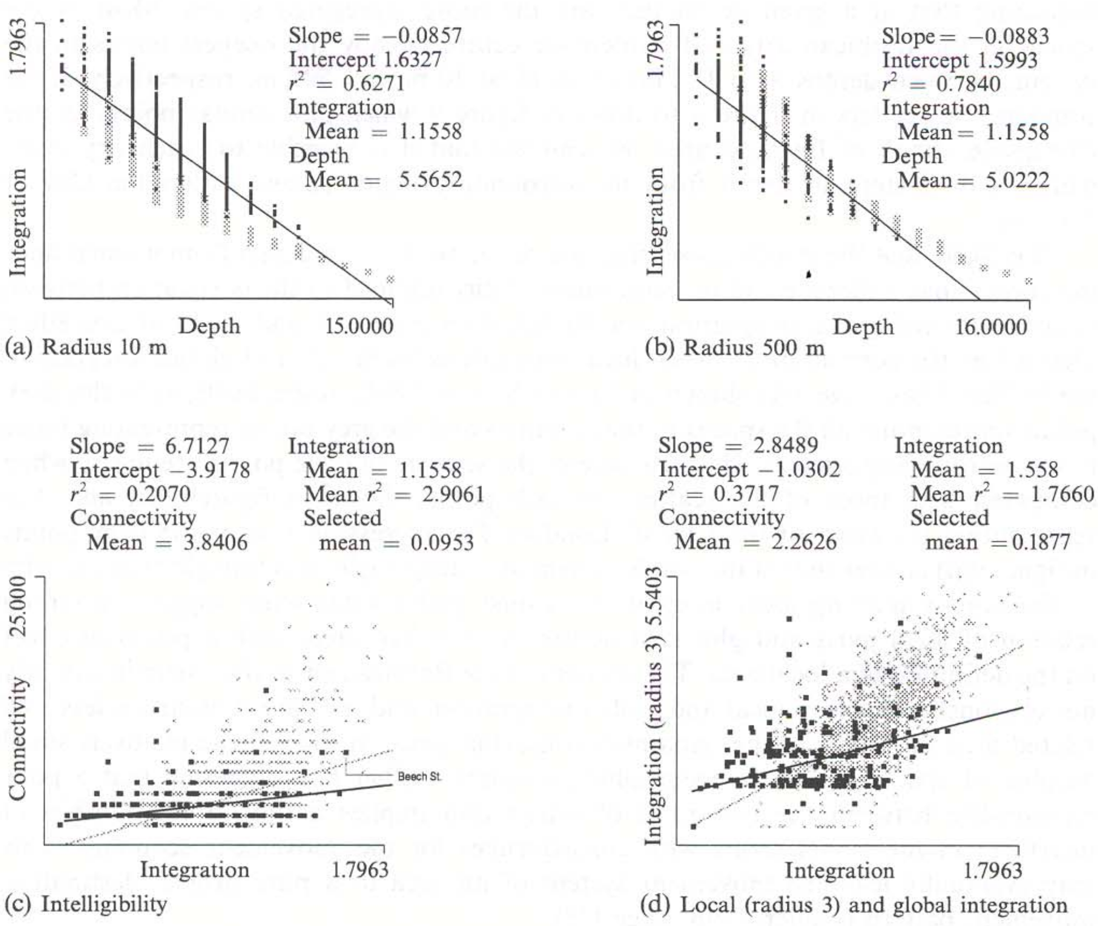


Figure 8. Two accessibilities [radius 10 m (a) and 500 m (b); all spaces in the Barbican in large grey points], intelligibility, and local area effect [(c) and (d) respectively; all spaces in the Barbican in large dark points].

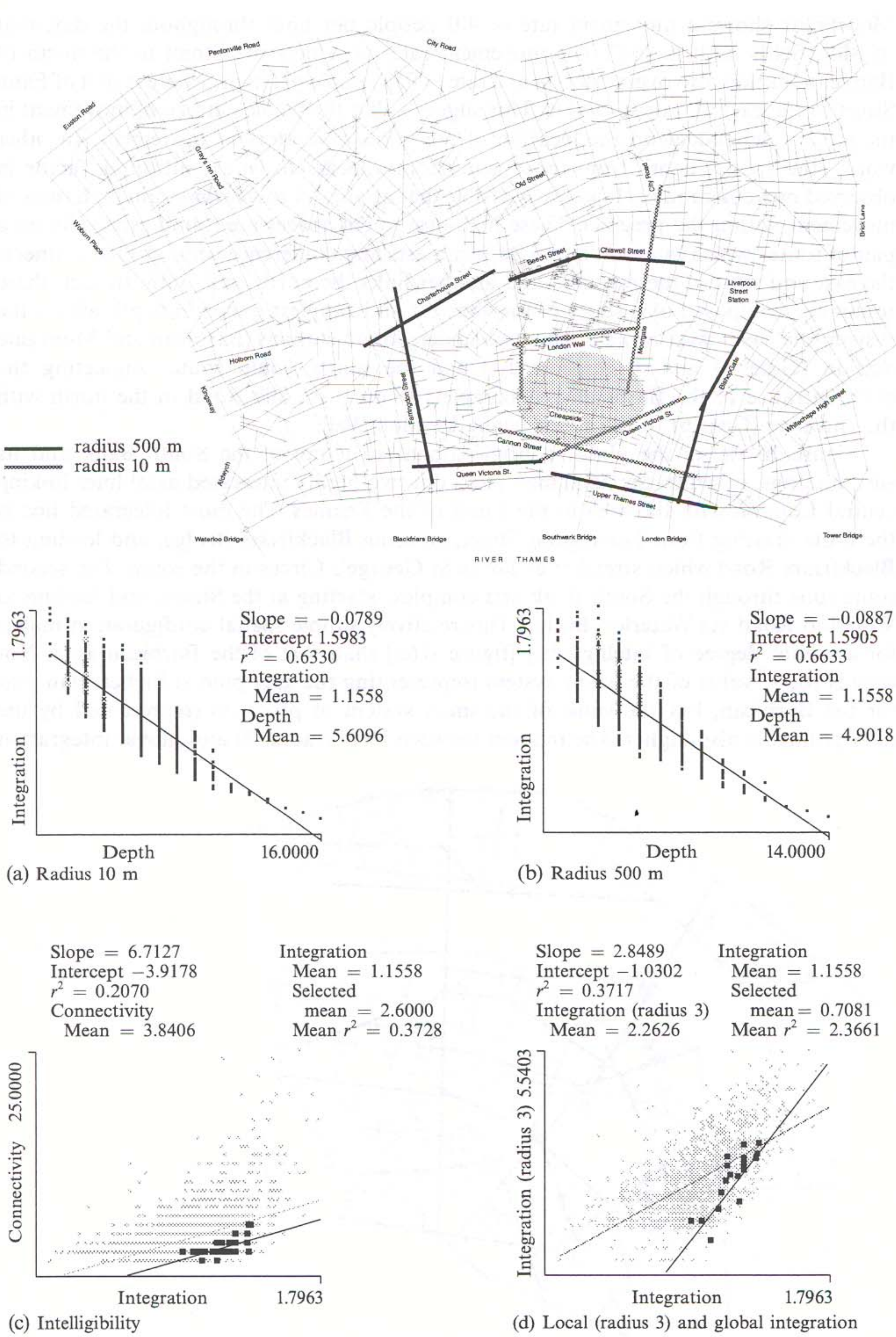


Figure 9. Two accessibilities [radius 10 m (a) and 500 m (b); all spaces in the Cheapside area (encircled in grey) in large grey points], intelligibility, and local area effect [(c) and (d) respectively; all spaces in the Cheapside area in large dark points].

Moorfields shows a movement rate of 401 people per hour throughout the day, that of Moorfields itself is 2647. The movement rate on Aldersgate Street to the north of Barbican Station also overperforms at a rate of 955 people per hour, whereas that of Fann Street to the east of it drops to 176. This suggests that the whole pattern of movement in the area is dependent on the location of the main generators of movement. In other words, the spatial depth from those generators appears to be a controlling factor in observed movement rates. It is clearly visible that a series of routes maintain high rates of movement within the precinct. These high-movement spaces are found especially on a pair of routes which intersect at the Barbican arts and conference centres. One connects the east and west of the precinct, and another links the north and south. In fact, these routes are composed of a series of the shortest and simplest routes in depth within the system: the east – west route linking two underground stations [Barbican and Moorgate Station (Gates 9 and 3, respectively)] and the north – south route connecting the main entrance of the Barbican arts complex (Gate 1) on Silk Road in the north with the entrance (Gate 6) to the south facing London Wall.

Figure 10 shows the global configurational structure of the South Bank and its surroundings, in which the axial map picks out two highly integrated axial lines linking central London with the area to the south of the Thames. The most integrated line is the route starting from Farringdon Street, crossing Blackfriars Bridge, and leading to Blackfriars Road which stretches as far as St George's Circus in the south. The second route runs through the South Bank arts complex, starting at the Strand and leading to Waterloo Road via Waterloo Bridge. This relatively simple spatial configuration makes for a higher degree of intelligibility [figure 11(c)] than that of the Barbican area. Not only is the r^2 value of the whole system (representing the grey points) higher than that for the Barbican, but the value of the small system of precincts (represented by the dark points) is also higher. The relation between local (radius 3) and global integration

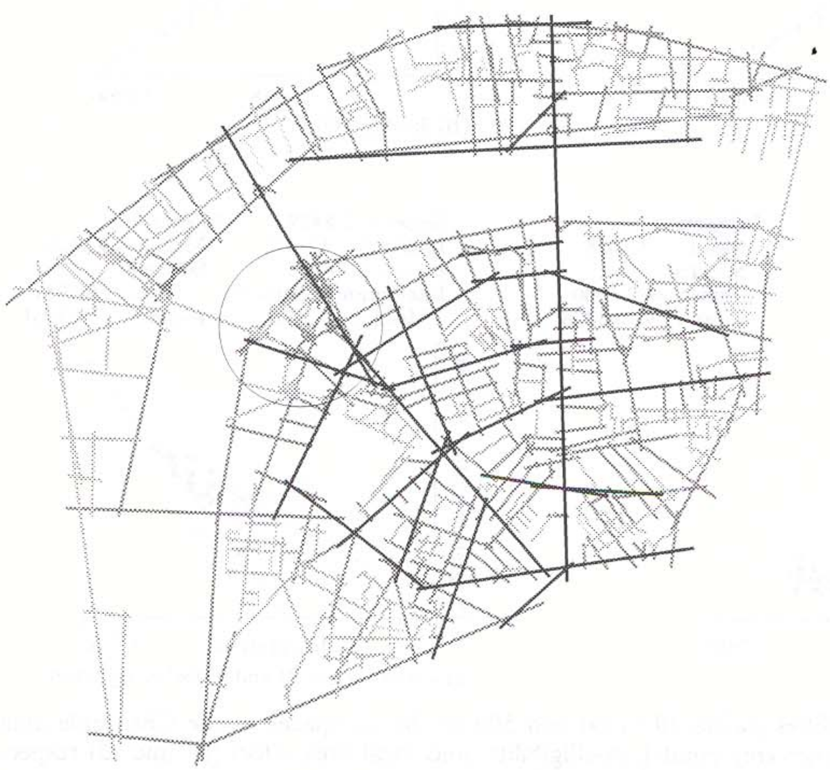


Figure 10. Global integration of the South Bank (the area encircled is the South Bank precinct), with the most integrated lines in heavy black through to the most segregated in light grey.

Figure 11. Two accessibilities [radius 10 m (a) and 500 m (b); all spaces in the South Bank in large grey points], intelligibility, and local area effect in the South Bank [(c) and (d) respectively; all spaces in the South Bank in large dark points].

[figure 11(d)] also shows more linearity which means a higher 'integration interface' in syntactic terms (Hillier 1996, page 174). Two scattergrams [figures 11(a) and 11(b)] show that the South Bank is relatively more accessible than the Barbican, in which the deepest spaces are within 4 or 5 steps from the designated axial lines in radii 10 m and 500 m, respectively. The opening of the new Waterloo International Terminal afforded an opportunity to examine the effect of changes in the spatial structure on movement patterns. Therefore we have carried out the gate observations on the same street segments after the spatial alterations to the surroundings of the station in 1994.

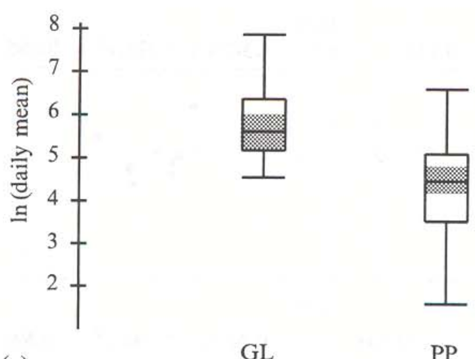
Before the changes in spatial structure, there were two major routes connecting the station with the two bridges to the north. These routes showed higher movement rates than others in the area [figure 6(a)]. The highest movement rates were observed on a series of spaces starting from Waterloo Station and leading into the footway of Hungerford Bridge through the elevated pedestrian deck of the South Bank complex and Concert Hall approach. The second series of high-movement rates were observed on a route connecting the station with Waterloo Bridge through the Bull Ring. However, this route showed an extreme contrast in movement rates between peak and off-peak periods. After the completion of the new terminal, alterations to the spatial structure around the station concourse area followed in which the most significant change was the reopening of a gate on the station's concourse level which leads to the footbridge across York Road and through the Shell building. Major movement flows around the station shifted from its main entrance through Victory Arch toward the route of the raised pedestrian deck [figure 6(c)]. New underground passages were created in front of the station's entrance to link the station with the Bull Ring which eventually leads to Waterloo Bridge. It is notable that there was no significant decrease in the movement rates on this route even though the changes introduced more grade separation and changes of axial depth.

We can see immediately from the observations shown in figure 6 that movement rates on the routes which interconnect the two bridges and the station with the most direct and simplest lines in axial depth are much higher than the others. In 1991 Daswatte also found higher performance on a series of prioritised spaces (Daswatte, 1991). He observed that movement patterns in this area were affected significantly by physical settings, such as generators and attractors of movement and land uses, and concluded that the prioritisation of a series of spaces by these design factors had resulted in the broken-down urban characteristics of this area. Overperformance of the prioritised routes may lead to underperformance of spaces in other areas or even in immediately adjacent spaces. In fact, before the reopening of the footbridge under the Shell building, its mean movement rate was 178 adults per hour which was nearly the same as the rate on the ground under the bridge (148 people per hour) [figure 6(a)]. However, the movement rate on the footbridge increased dramatically after the reopening of the gate on the station's concourse level. The mean movement rate on the bridge rose to 1958 adults per hour whereas that on the street under the bridge decreased only slightly to 122 people per hour [figure 6(c)].

Multiple levels of spatial configuration and syntactic analysis

It has been shown that movement patterns in highly unintelligible spaces, such as the multilevel spaces in these case studies, were strongly biased by local design factors and their interactions, such as the presence of generators and attractors of movement, grade-separated multiple levels, and the design of vertical transitional spaces, such as stairs, ramps, escalators, and lifts. Prioritisation of particular routes for movement seems to be a direct result of these factors. In other words, a significantly different pattern of space use is evident between the overperforming and underperforming routes. Boxplots in figure 12 show how significantly the most direct and simplest routes in depth between each of the generators [the global (GL) routes] were prioritised by pedestrians. It is easy to see the difference in the logged mean daily movement rates between the prioritised spaces and the remainder. Figure 13 (over) shows scattergrams plotting logged movement rates against integration values read from the global integration maps. The overall strength of correlations shown in the scatters are weak in all three cases [figures 13(a1), 13(b1), and 13(c1)]. Even when the areas are subdivided and different grade levels considered separately, there is no significant improvement except in two cases [figures 13(b5) and 13(c4)]. These two scattergrams, however, are unreliable, not only owing to the small number of observed segments in each, but also because the other scattergrams do not show a reliable correlation. These scattergrams make it clear that space-syntax modelling techniques are not immediately applicable to predict pedestrian movement patterns in unintelligible multilevel spaces.

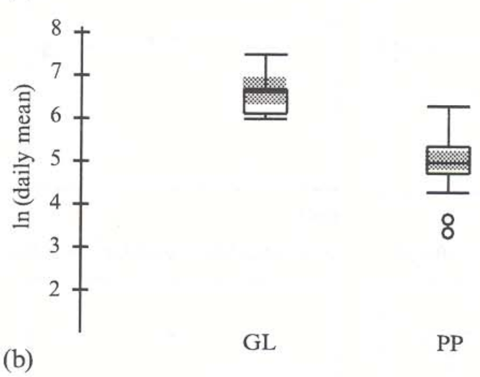
These findings show that it is hard to predict movement patterns by using only integration values in the two case-study areas. The poor relationship between movement



Group	Count	Mean	Median	Variance	Range
GL	25	5.84545	5.63840	0.721967	3.29620
PP	68	4.38897	4.51595	1.25171	5.06770

F ratio: 34.871, $p \leqslant 0.0001$

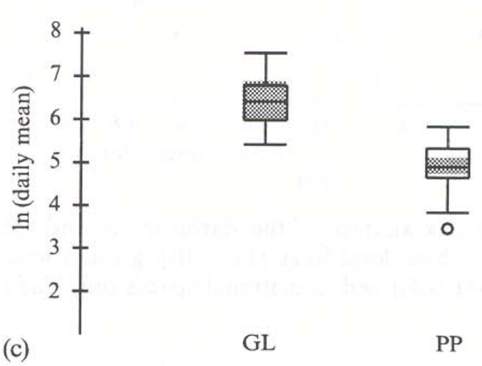
(a)



Group	Count	Mean	Median	Variance	Range
GL	8	6.57000	6.66450	0.245681	1.53800
PP	26	5.03577	5.05250	0.440704	2.93100

F ratio: 36.177, $p \leqslant 0.0001$

(b)



Group	Count	Mean	Median	Variance	Range
GL	8	6.47530	6.49400	0.424199	2.14010
PP	27	4.97014	4.95300	0.373470	2.41080

F ratio: 36.388, $p \leqslant 0.0001$

(c)

Figure 12. Daily mean movement rates on the most direct and simplest routes (GL) and the peripheral routes (PP) in axial depth in the Barbican (a) and the South Bank before (b) and after (c) spatial alterations.

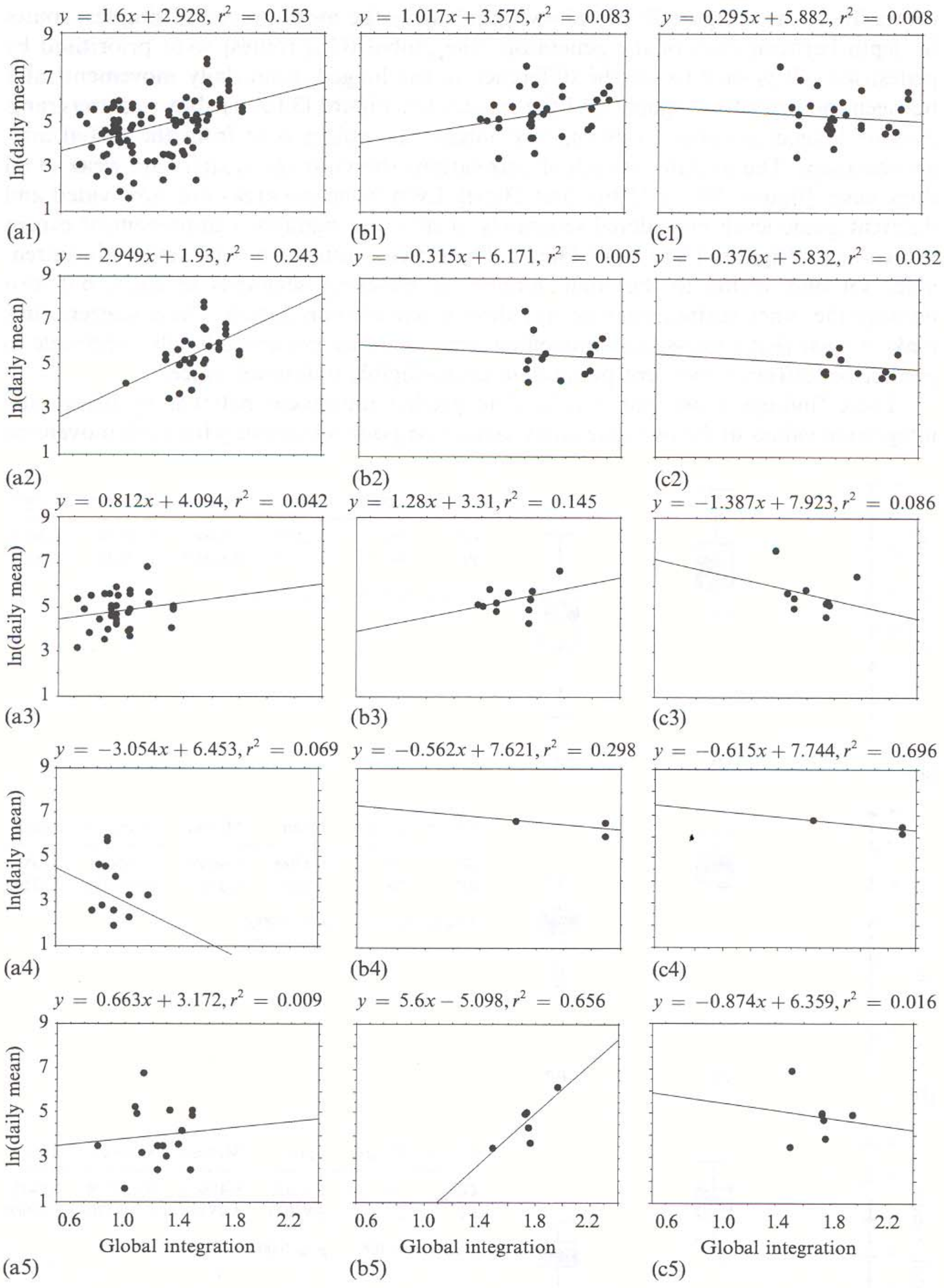


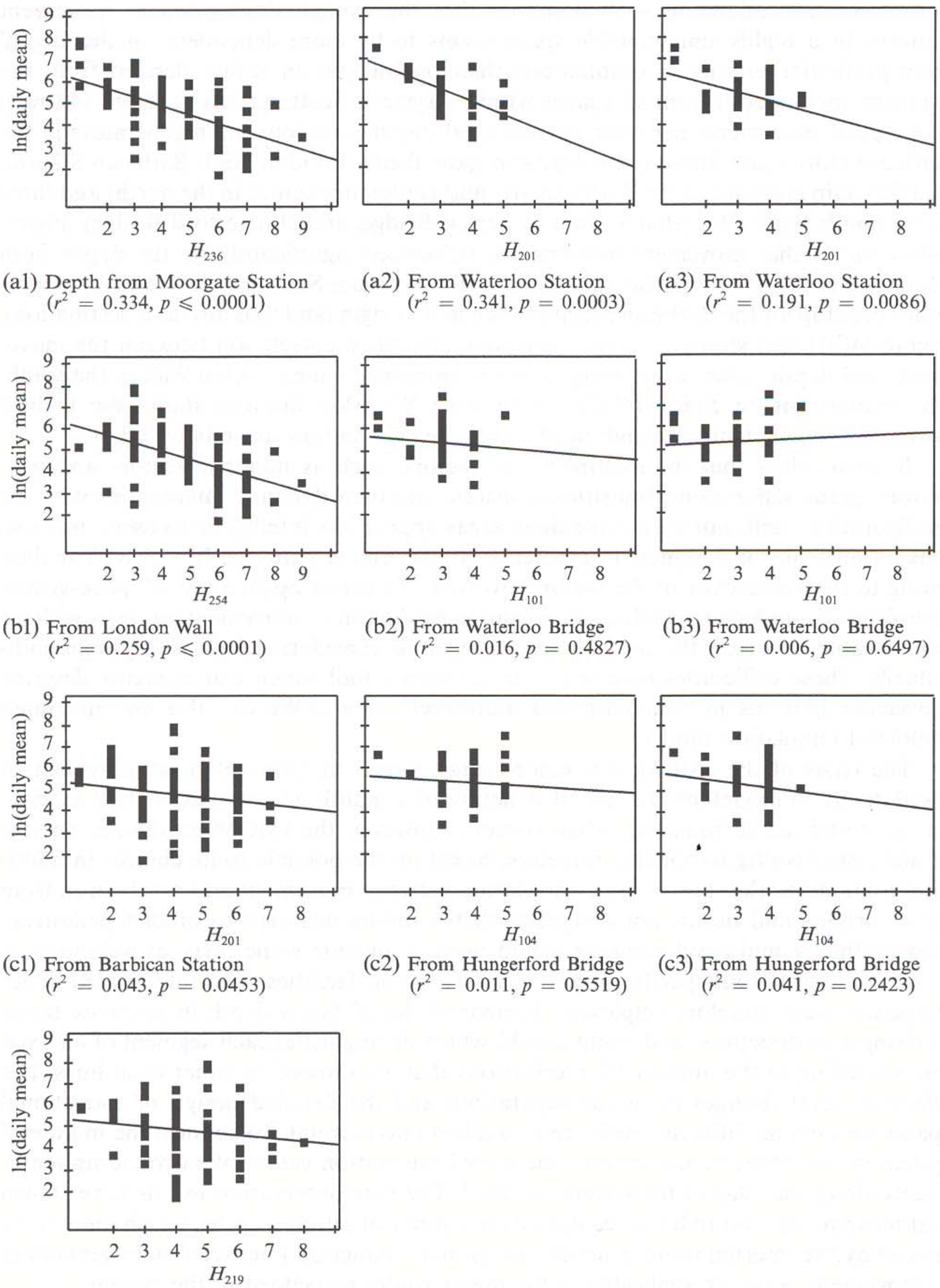
Figure 13. Scattergrams showing the results of space-syntax analysis of the Barbican (a), and the South Bank before (b) and after (c) spatial alteration; whole level [(a1), (b1), (c1)], ground level [(a2), (b2), (c2)], level 1 [(a3), (b3), (c3)], level 2 [(a4), (b4), (c4)] and transitional spaces only [(a5), (b5), (c5)].

and integration allows us to hypothesise that the explicit description of movement patterns in a highly unintelligible space seems to be more dependent on the 'depth' from particular origins or destinations than on integration values derived from the syntactic mean depth from all spaces within a system. Scattergrams in figure 14 (over) plot logged movements per hour against axial depth from four main generators in the Barbican (Moorgate Station, the southern 'gate' facing London Wall, Barbican Station, and the main entrance of the Barbican arts and conference centre in the north) and three in the South Bank (Waterloo Station, Waterloo Bridge, and Hungerford Bridge). Figure 14(a1) shows that movement patterns are influenced significantly by the depth from Moorgate Station. This seems to suggest that Moorgate Station is favoured by pedestrians heading for the Barbican precincts as a main origin (and thus also as a destination). Figure 14(b1) also shows a positive tendency towards a correlation between the movements and depth values originating from the entrance facing London Wall in the south. The scattergram in figure 14(a2) (depth from Waterloo Station) shows the highest correlation coefficient, although in all cases the correlations are relatively low.

It seems clear that the multiplicity of factors, such as major attractors and generators, grade separations, transitional spaces, and their dynamic interactions with the configuration itself, not only make these areas appear less intelligible to users, but also make it difficult for designers to predict likely movement patterns. It is also clear that, owing to the complexity of the factors involved, the direct application of space-syntax techniques is unlikely to produce an adequate prediction of movement patterns without considerable effort on the part of the modeller in considering local subsystems individually. These difficulties have led us to develop a tool which can explicitly describe movement patterns in mixed-use and multilevel systems. We call this an 'integrated multilevel circulation model'.

The basis of the IMCM is a space-syntax model in terms of its employment of 'axial depth' in modelling the spatial structure of a multilevel complex, as well as in its use to model the surrounding urban context. However, the IMCM introduces a range of additional configurational parameters, based on the possible route choices in multilevel route networks. The positive correlation between movement and axial depth from major origins and destinations suggests that a model intended to predict pedestrian flows within a multilevel complex would need to include some form of weighting in terms of depths from specific origin and destination facilities. Two interrelated depth properties were therefore employed: 'horizontal depth' (axial depth in syntactic terms of changes in direction), and 'point depth', which distinguishes each segment of an axial line according to the number of intersections that are crossed by other axial lines. The effects of level changes (or grade separation) and the detailed design of transitional spaces connecting different levels are also taken into account. To connect the multilevel system to the larger urban context, the global integration values of surrounding major streets along the edge of the system are used. The gate observation results have shown that movements tend to be concentrated on a series of selected routes which seem to be shaped by the internal route structure (or 'global interaction') between main generators of movement, a factor applicable to the major routes embedded in the system.

All of these parameters are based on principles that we can infer from observed pedestrian movement behaviour, but which can also be objectively quantified and attributed to each axial segment in a multilevel complex on the basis of its morphology and knowledge of the major attractor and generator facilities alone. The way that IMCM brings all the factors together is essentially by weighting the factors outlined in the previous paragraph according to equation (2) below. This formula is the result of empirical investigation of the observed pedestrian flows in the two case-study areas in



(a1) Depth from Moorgate Station ($r^2 = 0.334$, $p \leqslant 0.0001$)

(a2) From Waterloo Station ($r^2 = 0.341$, $p = 0.0003$)

(a3) From Waterloo Station ($r^2 = 0.191$, $p = 0.0086$)

(b1) From London Wall ($r^2 = 0.259$, $p \leqslant 0.0001$)

(b2) From Waterloo Bridge ($r^2 = 0.016$, $p = 0.4827$)

(b3) From Waterloo Bridge ($r^2 = 0.006$, $p = 0.6497$)

(c1) From Barbican Station ($r^2 = 0.043$, $p = 0.0453$)

(c2) From Hungerford Bridge ($r^2 = 0.011$, $p = 0.5519$)

(c3) From Hungerford Bridge ($r^2 = 0.041$, $p = 0.2423$)

(d1) From the main entrance of the Barbican ($r^2 = 0.024$, $p = 0.1377$)

Figure 14. Scattergrams plotting logged movements per hour against depth from main generators in the Barbican [(a1) – (d1)] and the South Bank before [(a2) – (c2)] and after [(a3) – (c3)] spatial alterations.

which each factor has been weighted according to its apparent effects on pedestrian route choice. These factors will now be described in more detail.

Configurational properties: two interrelated depth properties

Figure 15 shows how to construct a basic node map with the two depth properties of horizontal depth (H) and point depth (P) in a complex which has two entrances generating the same amount of movement on a single level. Both depth values are calculated cumulatively from each of the two entrances (table 1, see over). Each depth property is based on the set of the most direct and simplest lines of movement that could be chosen by pedestrians. It is based on the assumption that people tend to choose the most direct route (consisting of the fewest changes of direction) to move from one space to the next (Hillier et al, 1993; Marchand, 1974). Its mapping is similar to axial mapping that is made up of a set of the fewest and longest lines of sight but, to eliminate the effect of a uniform value for all segments along the same axial line, IMCM has incorporated point depth which differentiates each segment of an axial line according to the number of intersections that must be passed on a route. Point depth from the major generator of movement breaks the line into segments which are the spaces between street intersections. These are the points at which pedestrians must consider which is the most direct and simplest route when confronted with choices of direction. Existing research (Hillier et al, 1993) has shown that horizontal depth (axial depth) is the primary component of movement in most urban areas. In the IMCM formula therefore we have given a greater weight to horizontal depth by taking the logarithm of point depth. This is not just arbitrary. Other variations were tried and the logarithm performed best in the present study.

The node map in figure 15 consists of 12 street segments and 6 intersections in which the final result (S^{HP}), the sum of the horizontal depth value and the logarithm of point depth [$H+\ln(P)$], is shown in table 1. Because there are two possible origins in this example, the value attributed to a particular segment in the map is the smaller of the two S^{HP} values on each segment calculated from each entrance (nodes a and k), in which the shallowest segments are line 1 and line 12 just in front of the entrances, and the deepest segment is line 8. The result shows that the shallowest lines of movement will be: starting from entrance 1, line 1, and line 3, and a straight line connecting lines 12, 10, and 6 from entrance 2. In this way the final depth selection for a specific street segment is the smallest of the depth values derived from each entrance or main generator of movement in the system. This process of depth selection is one of the factors which differentiates IMCM mapping from axial mapping.

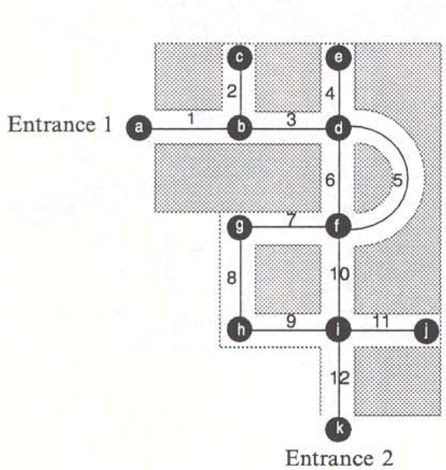


Figure 15. Node mapping of the hypothetical model.

Table 1. Calculation of the sums of the two depth properties (S^{HP}) in the hypothetical model: horizontal depth (H) and point depth (P).

Line	H_1	H_2	P_1	P_2	$\ln(P_1)$	$\ln(P_2)$	$H_1+\ln(P_1)$	$H_2+\ln(P_2)$	$S^{\mathrm{HP}}=\text{minimum}[H+\ln(P)]$
1	1	2	1	5	0.0000	1.6090	1.0000	3.6090	1.0000
2	2	3	2	5	0.6931	1.6090	2.6930	4.6090	2.6930
3	1	2	2	4	0.6931	1.3860	1.6930	3.3860	1.6930
4	2	1	3	4	1.0990	1.3860	3.0990	2.3860	2.3860
5	2	2	3	3	1.0990	1.0990	3.0990	3.0990	3.0990
6	2	1	3	3	1.0990	1.0990	3.0990	2.0990	2.0990
7	3	2	4	3	1.3860	1.0990	4.3860	3.0990	3.0990
8	4	3	5	3	1.6090	1.0990	5.6090	4.0990	4.0990
9	3	2	5	2	1.6090	0.6931	4.6090	2.6930	2.6930
10	2	1	4	2	1.3860	0.6931	3.3860	1.6930	1.6930
11	3	2	5	2	1.6090	0.6931	4.6090	2.6930	2.6930
12	2	1	5	1	1.6090	0.0000	3.6090	1.0000	1.0000

Figure 16 shows the multilayered node map of the Barbican in which four major generators of movement are set up from each direction: these are Moorgate Station in the west, Barbican Station in the east, an entrance facing London Wall in the south, and the main entrance of the Barbican arts complex in the north. There are two different maps in the South Bank because of the spatial alterations, before and after the completion of Waterloo International Terminal (figure 17). Three major generators were selected in accordance with the triangular shape of the configuration of the area: Waterloo Station in the south, Waterloo Bridge in the north, and Hungerford Bridge in the north-west. It is notable that the correlations between S^{HP} and observed movement in figures 18(a), 18(b), and 18(c) far exceed those of r^2 in figures 13(a1), 13(b1), and 13(c1).

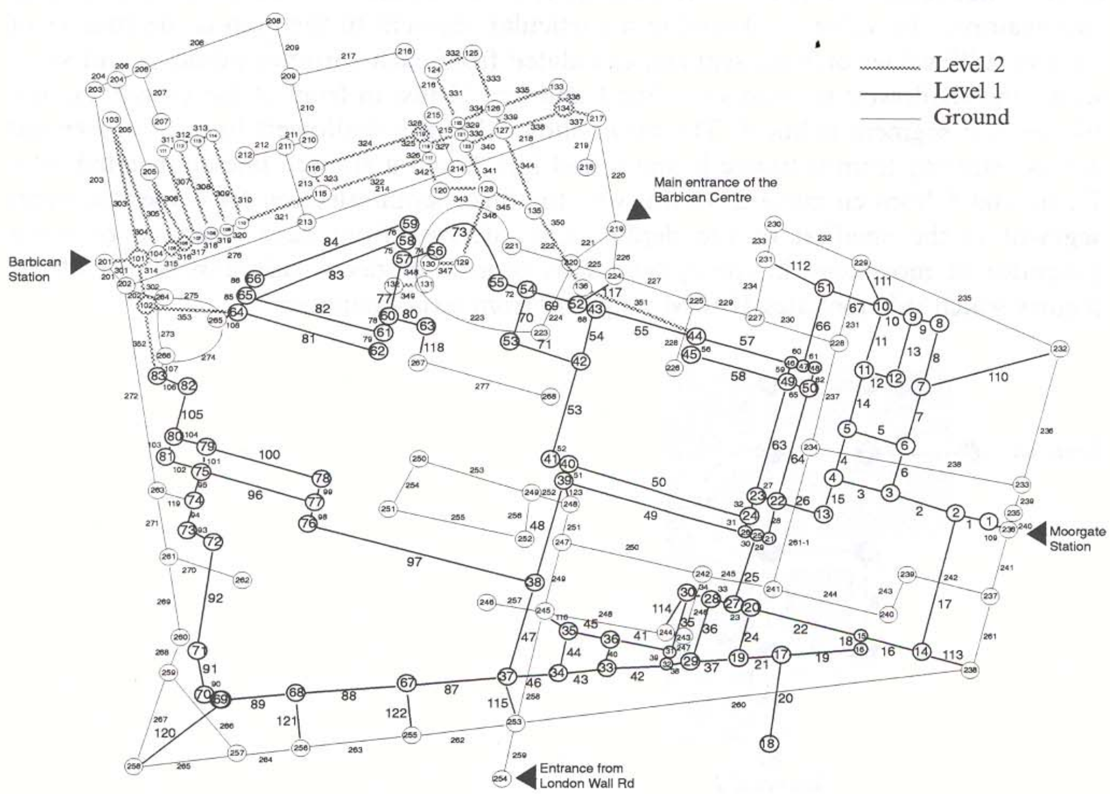


Figure 16. Multilayered node map of the Barbican.

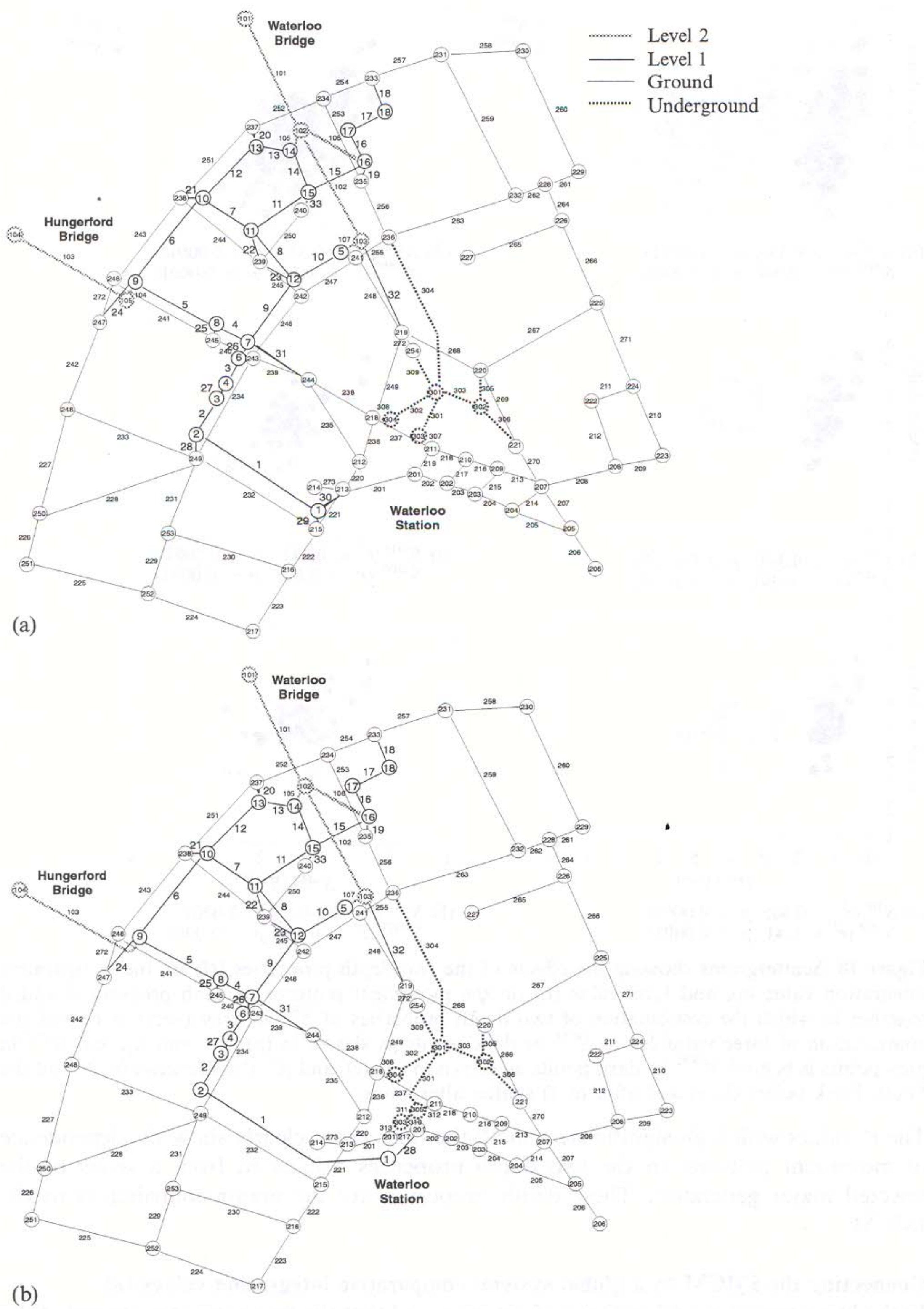
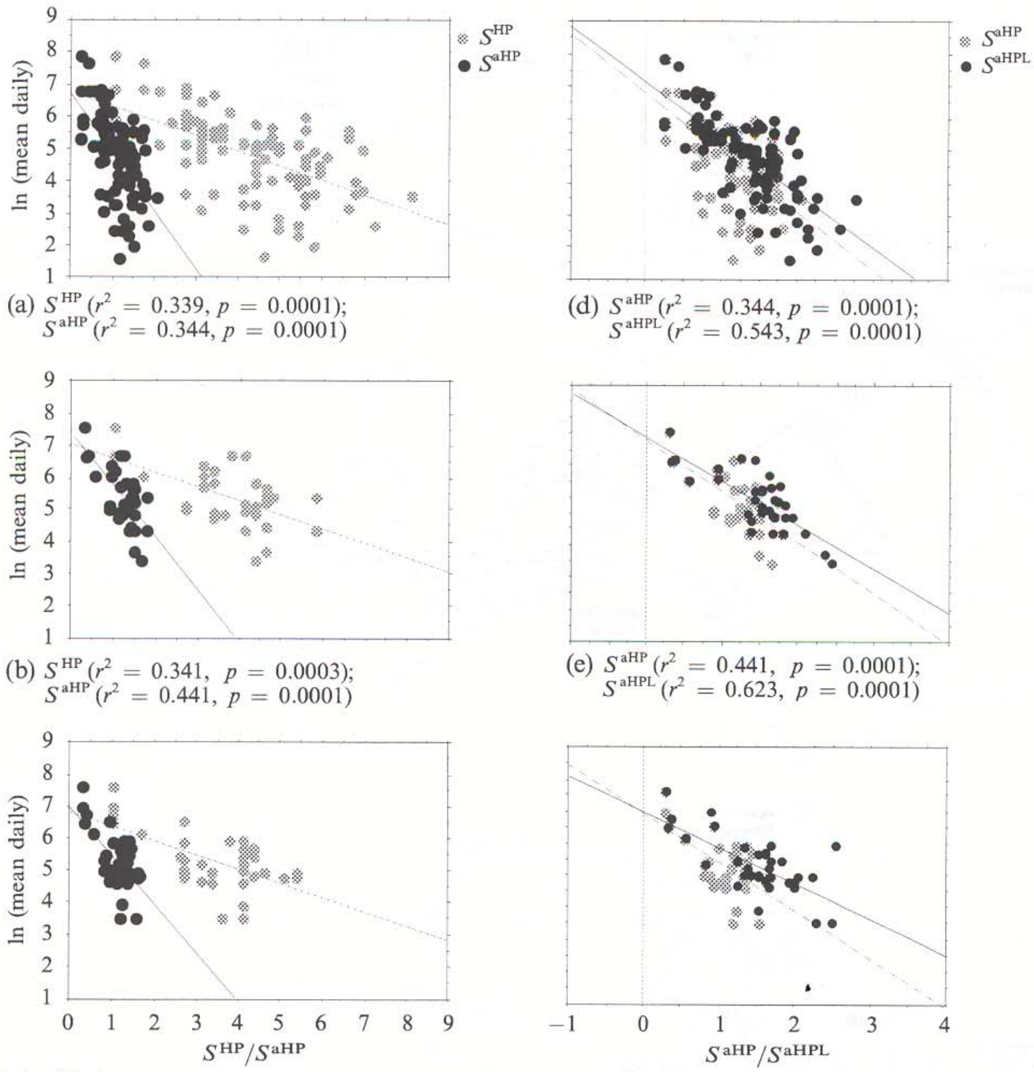


Figure 17. Multilayered node map of the South Bank before (a) and after (b) spatial alterations.



(a) S^{HP} ($r^2 = 0.339$, $p = 0.0001$); S^{aHP} ($r^2 = 0.344$, $p = 0.0001$)

(d) S^{aHP} ($r^2 = 0.344$, $p = 0.0001$); S^{aHPL} ($r^2 = 0.543$, $p = 0.0001$)

(b) S^{HP} ($r^2 = 0.341$, $p = 0.0003$); S^{aHP} ($r^2 = 0.441$, $p = 0.0001$)

(e) S^{aHP} ($r^2 = 0.441$, $p = 0.0001$); S^{aHPL} ($r^2 = 0.623$, $p = 0.0001$)

(c) S^{HP} ($r^2 = 0.365$, $p = 0.0001$); S^{aHP} ($r^2 = 0.41$, $p = 0.0001$)

(f) S^{aHP} ($r^2 = 0.41$, $p = 0.0001$); S^{aHPL} ($r^2 = 0.507$, $p = 0.0001$)

Figure 18. Scattergrams showing the effects of the two depth properties (H, P), the comparative integration value (a), and level value (L) on the movement patterns as each property is added together in which the combination of two depth properties of S^{HP} in grey points is behind the combination of three variables of S^{aHP} in dark points as shown in (a), (b), and (c), and S^{aHP} in grey points is behind S^{aHPL} in dark points as shown in (d), (e), and (f): the Barbican (a, d) and the South Bank before (b, e) and after (c, f) spatial alterations.

The r^2 values with high significances in all the three cases clearly show the dependence of movement patterns on the two depth properties calculated from a series of the selected major generators. These depth properties are the major contributors to the IMCM.

Connecting the IMCM to a global system: comparative integration values (*a*)

In the hypothetical model in figure 15 we proposed that the two entrances generated the same amount of movement. However, in a real urban context the different edges of a multilevel complex are likely to differ in terms of the movement rates that they generate. It is clear that the rate of movement of each entrance is closely associated with the spatial structure of its immediate surroundings. The node map, however, does not take into account the effect of the spatial structure of the surroundings on the system. To take account of the effect of the global urban system, a configurational parameter from the syntactic analysis is introduced: this is a set of comparatively calculated integration values of the surrounding major streets along the edge of a multilevel urban complex, denoted as 'a'. This process therefore gives the adjacent streets a different weight of connections with the surrounding urban fabric according to their global integration values, in which the sum of all the comparative integration values is always 1. This parameter allows the IMCM to deal with any likely changes in the global urban structure with the employment of a set of a values. Though the number of a values depends on the configuration of the area, empirical experiments to date suggest that one from each direction is adequate. Four a values in the Barbican were taken from four directions: Aldersgate Street in the west, Moorgate in the east, Whitecross Street in the north, and London Wall in the south. All of these spaces are treated as ground-level spaces. The South Bank has three a values: one from Waterloo Road on the street level, and the others from Hungerford Bridge and Waterloo Bridge at level 2 (two above ground level).

The a value can be expressed as follows:

$$a_i = \left[\sum_{i=1}^{n}(x - x_i)\right] \bigg/ \left[(n-1)\sum_{i=1}^{n} x_i\right], \qquad i = 1, 2, \ldots, n, \quad n \geqslant 2, \tag{1}$$

where a is the comparative integration value of a selected major street, x is the global integration value from the axial mapping, i is a selected major street, and n is the total number of major streets under consideration as generators on the boundary of the system. This formula expresses the global integration value of each major street as a proportion of the integration values of all the major streets under consideration. It also reverses the order so that the more integrated streets have smaller values and the more segregated streets larger values. It is thereby in line with the two depth properties (H, P), in which higher values indicate greater depth and thus segregation. The following example shows how the four a values in the Barbican are calculated:

$$a_{254} = \frac{(1.7963 + 1.6948 + 1.7632 + 1.5748) - 1.7963}{(4-1)(1.7963 + 1.6948 + 1.7632 + 1.5748)} = 0.2457,$$

$$a_{201} = \frac{(1.7963 + 1.6948 + 1.7632 + 1.5748) - 1.6948}{(4-1)(1.7963 + 1.6948 + 1.7632 + 1.5748)} = 0.2506,$$

$$a_{236} = \frac{(1.7963 + 1.6948 + 1.7632 + 1.5748) - 1.7632}{(4-1)(1.7963 + 1.6948 + 1.7632 + 1.5748)} = 0.2473,$$

$$a_{219} = \frac{(1.7963 + 1.6948 + 1.7632 + 1.5748) - 1.5748}{(4-1)(1.7963 + 1.6948 + 1.7632 + 1.5748)} = 0.2565.$$

Table 2 (over) shows the global integration values and their a values. When the a value is added to the sum of the two depth properties (S^{aHP}), as shown in figures 18(a), 18(b), and 18(c) (in black points), not only does the correlation coefficient of S^{aHP} improve with movement but it also visibly tightens the scatters in all three cases.

The effect of grade separation on the pedestrian movement: level values (L)

It has been observed that multiple levels of circulation can make pedestrians more easily confused and disoriented. Passini (1992) reports that, if there are no visual connections between levels, pedestrians generally develop two different cognitive maps, one at ground level and one of the subsurface, and they have difficulty in bringing these together. Multilevel underground complexes are notorious for making people feel disoriented, and they consequently feel trapped. Montello and Pick (1993) have also proposed a possible link between wayfinding difficulties in complex multilevel spaces and the pedestrian's

Table 2. Transformation of the global integration values (A_n^{rr}) into the comparative integration values (a).

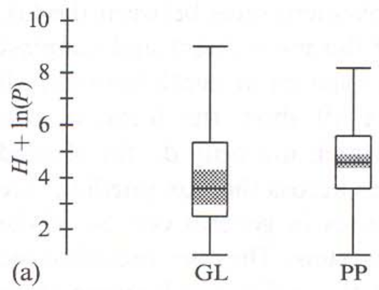
Major streets	Node	A_n^{rr}	a
The Barbican			
London Wall	254	1.7963	0.2457
Aldersgate Street	201	1.6948	0.2506
Moorgate	236	1.7632	0.2473
Whitecross Street	219	1.5748	0.2565
The South Bank			
Waterloo Road	201	2.6307	0.2998
Waterloo Bridge	101	2.2956	0.3253
Hungerford Bridge	104	1.6428	0.3750

ability to integrate separately learned cognitive maps of vertically aligned spaces into an interrelated single framework. These studies imply a close relationship between multiple levels of spatial configuration and the subject's cognition of those systems. We might suppose therefore that grade separation would have a detectable effect on patterns of movements. This is the main reason why the level value 'L' is employed in the IMCM. The three sets of movement observations have shown in general that movement rates decrease with levels of vertical separation from the surrounding streets and generators of movement.

Investigation of the movement data suggests that density of movement varies between levels in a relatively predictable way. This means that in general the changes of movement rate can be expressed numerically as follows: starting from ground level (L_0) as 0, first level (L_1) as 1, second level (L_2) as 3, and third level (L_3) as 4. The values of the level changes in the vertical transition spaces are slightly different but can be also expressed numerically as follows: the transitional spaces between the ground and the first level ($L_1 - T$) as 2, between the first and the second level ($L_2 - T$) as 3, and between the second and the third level ($L_3 - T$) as 4. As a space becomes increasingly separated by level changes from the surrounding context, the L value of that level increases and the movement rates decrease. These numerical values are the outcomes of empirical investigation on the multilevel urban complexes. Scattergrams 18(d), 18(e), and 18(f) demonstrate how significantly the inclusion of the L value affects the IMCM. When L is applied to a S^{aHP} (grey points) to give S^{aHPL} (dark points), the correlation coefficients increase dramatically in all three cases. This suggests that movement patterns in the multiple levels of spaces are affected significantly by the multiple levels themselves. The Barbican shows the most significant improvement in its r^2 value (0.543) but the highest one is 0.623 in the South Bank before the spatial alterations [figure 18(e)]. However, the effect of the grade separation on the movement pattern is apparently robust, even after the changes in spatial structure around Waterloo Station [figure 18(f)].

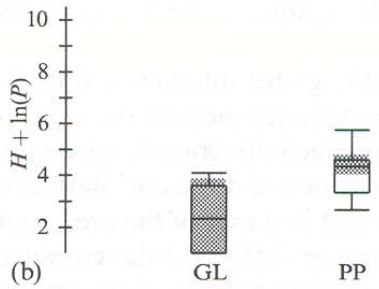
Global interactions between main generators (G): the major routes embedded in the system

The most significant factor showing consistency in the model is the measure of the configuration of the internal route structure with respect to its area context. The gate observations show two different groups of movement spaces: small numbers of high-movement rate spaces are concentrated in a series of prioritised spaces (mainly the routes consisting of the shallowest routes connecting the major generators in the system which we have designated as GL routes), and large numbers of low-movement rate spaces, mainly on the peripheral routes (designated PP, see figure 12). It is apparent



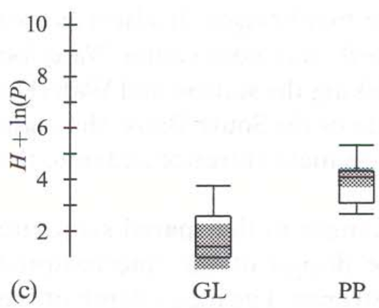
Group	Count	Mean	Median	Variance	Range
GL	48	3.82068	3.60940	3.91873	8.07940
PP	197	4.59207	4.60940	1.82014	7.19720

F ratio: 10.317, $p \leqslant 0.0015$



Group	Count	Mean	Median	Variance	Range
GL	8	2.38363	2.39600	1.80897	3.09900
PP	26	4.14258	4.38600	0.634188	3.09900

F ratio: 21.239, $p \leqslant 0.0001$



Group	Count	Mean	Median	Variance	Range
GL	8	1.84842	1.34655	1.13896	2.79180
PP	27	3.83456	4.09860	0.695947	2.69320

F ratio: 30.819, $p \leqslant 0.0001$

Figure 19. Boxplots showing the difference of the depth as a combination of two depth properties of $H + \ln(P)$ on the global interaction routes (GL) and the other routes (PP): the Barbican (a); the South Bank before (b) and after (c) spatial alterations.

Table 3. The global interaction routes (GL).

BB/SB	GL routes	Node numbers
BB	BS–MS	201–101–102–64–65–61–60–57–56–55–54–52–43–53 42–41–40–24–23–22–13–4–3–2–1–236
	SE–ME	254–253–37–38–39–40–41–42–43–52–224–219
SB before spatial alteration	WS–HB	201–213–212–244–7–8–9–105–104 211–218
	WS–WB	201–211–303–301–254–219–103–102–101
SB after spatial alteration	WS–HB	1–2–3–4–6–7–8–9–104
	WS–WB	1–201–303–305–301–254–219–103–102–101

Notes: BS, Barbican Station; MS, Moorgate Station; ME, main entrance of the Barbican arts and conference centre; SE, London Wall entrance; WS, Waterloo Station; HB, Hungerford Bridge; WB, Waterloo Bridge.

that there is a statistically significant difference in the movement rates between the GL and PP routes. These routes in fact consist of a series of the most direct and simplest routes in terms of mean depth, a series of the shallowest spaces in depth between all the major generators in the system. Boxplots in figure 19 show the mean depths $[H + \ln(P)]$ on the two different GL and PP routes, in which not only do the shaded areas in the boxes not overlap but also the horizontal lines across the box (median) are always lower on GL routes. This means that the GL routes in general consist of the shallowest spaces connecting the major generators in the system. They are therefore the most direct and simplest routes in terms of depth, and the difference between their mean depths and those of the PP routes is statistically significant in terms of its median and F ratio in all three cases.

Table 3 shows a series of node numbers constituting the global interaction lines in the two major routes. The number of generators in the system depends on the configuration of the area but it is likely that one generator from each direction is adequate. The four generators in the Barbican (BB) are each taken from one direction: Barbican Station (BS) and Moorgate Station (MS) connecting the west and east of the area, and the main entrance of the Barbican arts and conference centre (ME) and the entrance facing London Wall (SE) linking the north and south. In the South Bank, there are the three major generators, namely Waterloo Station and the two bridges. It also has two main shallowest routes in terms of depth (the GL routes): one connecting Waterloo Station and Hungerford Bridge (WS – HB), and another linking the station and Waterloo Bridge (WS – WB). After the changes to the spatial structure of the South Bank, the main movement flows from the station were diverted away from its main entrance and onto the footbridge across York Road through the Shell building.

It is apparent that these diversions are due to the changes in the spatial structure around the station's concourse area resulting from the design of the international station and changes to pedestrian road crossings at the entrance. The mean depth of the system after the spatial alterations, in general, became shallower than before the changes, as shown in the boxplots of figures 19(b) and 19(c). It is notable that the prioritisation of movement on the GL routes increased after the spatial alterations, as shown in the greater difference of the median and F ratio after the spatial changes. As this measure of the configuration of the route structure within the system significantly affects movement patterns, a negative weighting of $G = -0.7$ is applied to the GL routes in the IMCM in order to reflect their prioritisation for movement. Scattergrams in figure 20 confirm that there is a significant improvement in correlation for S^{aHPLG} (dark points) in all three cases, compared with S^{aHPL} (light grey points). This inclusion of the global interaction value (G) has resulted in the shift of most of the grey points in the upper left of the scattergrams further left, which consequently produces better correlations.

Transitional spaces connecting different levels (T)

Vertical transition spaces consisting of stairs, ramps, escalators, and lifts connect different levels in the complex and link the multilevel system with the surrounding urban fabric at the edge of the complex. They become an essential part of multilevel systems by controlling the accessibility of the system. It is likely that movement patterns are also affected by their configuration, which can be defined objectively by four elements: type of vista, degree of enclosure, transition type (for example, stair, ramp, etc), and the connection with main streets. Each element is scored and then they are added together to give a value of the transitional spaces (T) denoting the relative 'obviousness' and ease of use of these key transition links. After that, we take a logarithm of the sum of the four elements (T) in order to balance it with other

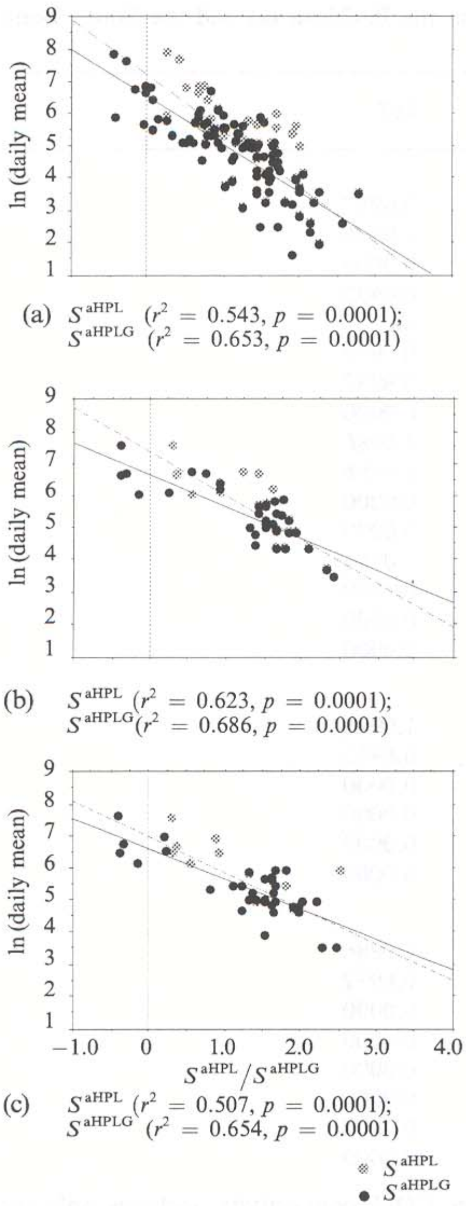


Figure 20. Scattergrams showing the effect of the global interactions (G) on the description of the movement patterns in which the combination of four variables of S^{aHPL} in grey points is behind S^{aHPLG} in dark points: the Barbican (a), and the South Bank before (b) and after (c) spatial alterations.

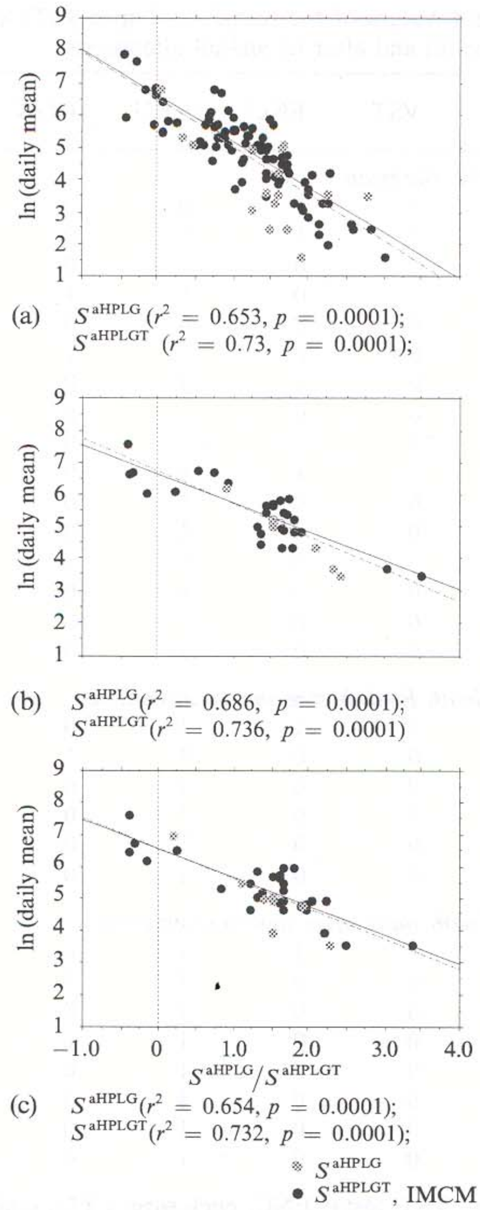


Figure 21. Scattergrams showing the effect of the transitional spaces (T) on the movement patterns in the Barbican (a), and the South Bank before (b) and after (c) spatial alterations, in which the grey points are the transitional spaces before the T value is applied.

variables. To simplify the model, the value of each element is designed only to have a value of 1 (negative effect) or 0 (positive effect) according to the degree of obviousness of each element. Isovists from the inside of the transitional spaces are defined as a set of all points visible from a given vantage point in a space. This determines how much visual contact can be made and it consequently contributes to the visibility of transitional spaces to pedestrians passing nearby. Transitional spaces which are not visible from the outside attract hardly any movement. However, when a transitional space is exposed to the outside, and therefore clearly visible, it has a higher potential for attracting movement. It is apparent that escalators and lifts are favoured over stairs and ramps.

Table 4. Values of the transitional spaces (T) and ln T in the Barbican (a) and the South Bank before (b) and after (c) spatial alterations.

Line	VST	ENC	CFG	CON	T	ln T
(a) *The Barbican*						
109	1	1	0	0	2	0.6932
112	1	1	1	0	3	1.0986
113	0	0	1	0	1	0.0000
114	0	0	1	1	2	0.6932
115	0	0	0	0	0	na
116	0	0	1	1	2	0.6932
119	0	1	1	0	2	0.6932
120	0	0	1	0	1	0.0000
122	1	1	1	0	3	1.0986
301	1	1	1	0	3	1.0986
305	0	0	1	0	1	0.0000
306	0	0	1	0	1	0.0000
328	1	0	1	1	3	1.0986
337	0	0	1	0	1	0.0000
349	0	0	1	0	1	0.0000
351	0	0	1	0	1	0.0000
(b) *South Bank before spatial alterations*						
21	1	1	1	0	3	1.0986
23	0	0	1	1	2	0.6932
24	0	0	1	0	1	0.0000
31	0	0	1	0	1	0.0000
105	0	0	1	0	1	0.0000
106	0	0	1	0	1	0.0000
(c) *South Bank after spatial alterations*						
21	1	1	1	0	3	1.0986
23	0	0	1	1	2	0.6932
24	0	0	1	0	1	0.0000
28	0	0	1	0	1	0.0000
31	0	0	1	0	1	0.0000
105	0	0	1	0	1	0.0000
106	0	0	1	0	1	0.0000
309	0	0	1	0	1	0.0000

Notes: VST, vista; ENC, enclosure; CFG, configuration; CON, connectivity; includes only the transitional spaces under consideration; na, not applicable.

This difference in the transition type is included by giving a value of 1 to stairs and ramps, and of 0 to escalators and lifts. It is also clear that transitional spaces which are connected with main streets have more potential for attracting movement than those which are not. A value of 0 (positive effect) is applied if they are connected directly to a main street, and a value of 1 (negative effect) is applied if they are not. When the T value is applied to the transitional spaces as shown in table 4, it tightens the scatters and therefore improves their correlations (figure 21). The dark points in the scatters result from the inclusion of all the factors in the IMCM, in which all three r^2 values exceed 0.7.

Conclusion: the integrated multilevel circulation model

The configurational properties of the model interact with each other so closely that it appears difficult to define the relationship between them. However, the IMCM results presented above have shown that the multiple parameters and their interactions can be isolated and examined parameter by parameter. The parameters included in the model depend on principles we can infer from patterns of observed pedestrian movement behaviour, but can be quantified and attributed to individual spaces in a multilevel complex. The final formula of the IMCM can be expressed as follows:

$$\boldsymbol{M}^{\mathrm{IMCM}} = \mathrm{minimum}\left[a_i\left(H_i + \ln(P_i) + L\right)\right] + G + \ln(T)\,, \tag{2}$$

and

$$a_i = \left[\sum_{i=1}^{n}(x_i - x_i)\right] \Big/ \left[(n-1)\sum_{i=1}^{n} x_i\right], \qquad i = 1 \sim n, \quad n \geqslant 2\,, \tag{3}$$

where

a is the comparative integration value;
H is the horizontal depth;
P is the point depth;
L is the level value.

For level values :

$L_0 = 0$
$L_1 = 1, \quad L_1 - T = 2,$
$L_2 = 3, \quad L_2 - T = 3,$
$L_3 = 4, \quad L_3 - T = 4,$

G ($= -0.7$) is the global interaction space between main generators,
T is the value of transitional space (sum of the scores).

For the values of transitional space:

type of vista (bad = 1, good = 0),
degree of enclosure (enclosed = 1, exposed = 0),
configuration (stairs and ramps = 1, or escalators and lifts = 0),
connection with the main streets (connected to back streets = 1, connected to main streets = 0),

x is the space-syntax global integration value,
i is the designated generator,
n is total number of main generators.

The IMCM method appears to be quite successful in predicting pedestrian movements in all three cases we have studied so far (figure 22). It is notable that this modelling method describes explicitly movement patterns on each grade level individually and for complexes as a whole. Each level has a good correlation on its own from ground level to level 2. Figure 22 shows that the Barbican is more stable in its quality and strength of the scatters than the two cases in the South Bank. It seems possible that this difference is due to the relatively small number of observation locations in the South Bank. Table 5 shows the process of inclusion of the different factors in the IMCM in which we already get a good correlation in all the three cases with only the combination of two depth properties, namely horizontal and segment depth (S^{HP}). The process is incremental (figure 23), allowing each of the various properties to be included or excluded from the model, and so the effect of each property can be quantified in terms of the difference it makes to the prediction of observed movement. This method gives an order of statistical ranking between the parameters in the model. Figure 24 shows a performance of the six variables in the three cases, in which the correlation coefficients in the vertical axis are calculated by excluding variables one at a time from the unified model. Although each of the three cases shows a slightly different order, we can read a general trend from the figure. It shows that H has the most effect as well as the highest variation among the three cases. The other variables G, L, T, and P change with less variation.

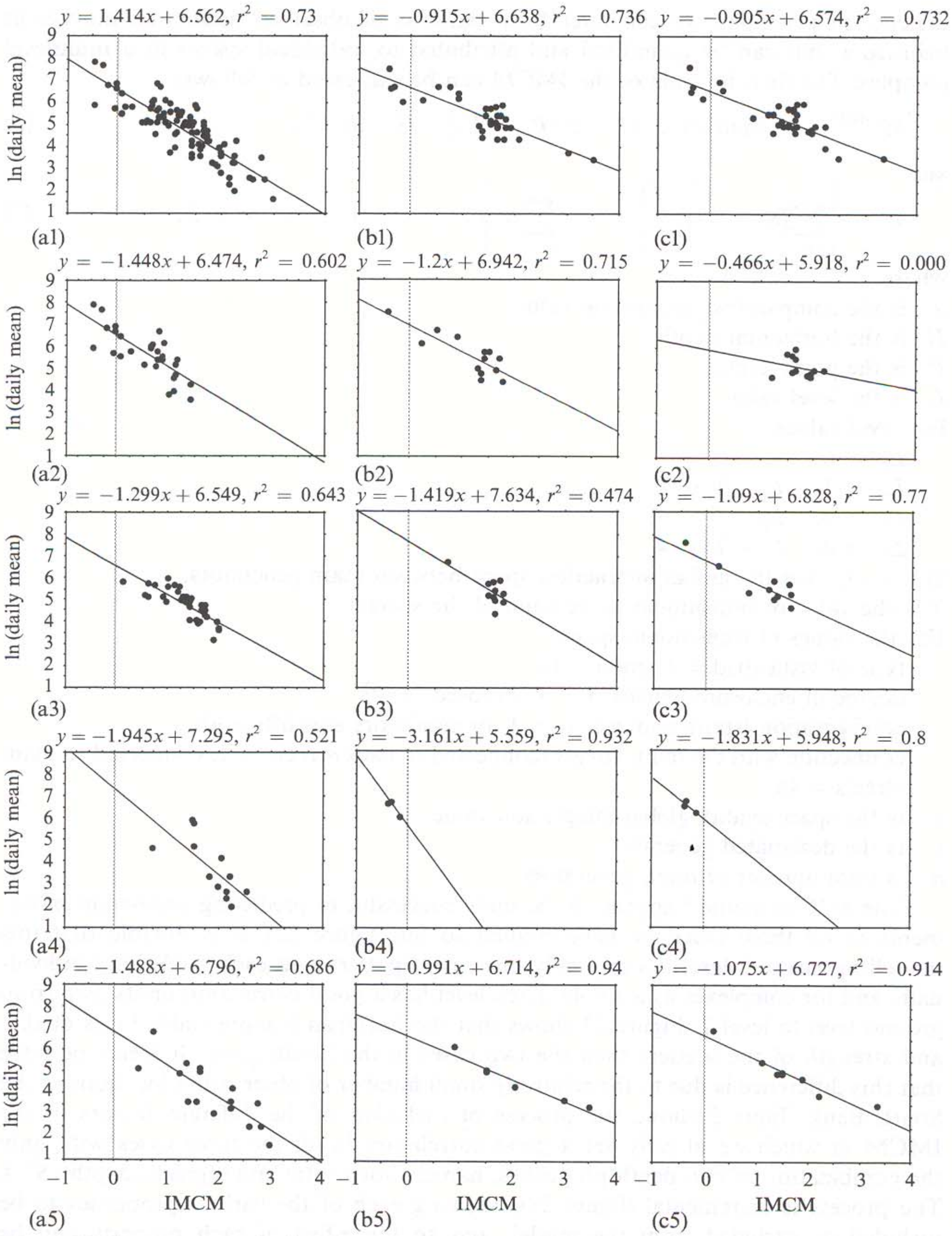


Figure 22. Scattergrams plotting logged movements against the IMCM in the Barbican (a), and the South Bank before (b) and after (c) the spatial alteration: whole level [(a1), (b1), (c1)], ground level only [(a2), (b2), (c2)], level 1 only [(a3), (b3), (c3)], level 2 only [(a4), (b4), (c4)], and transitional spaces only [(a5), (b5), (c5)].

It is particularly notable that there is a clear difference in the H value not only between the two case-study areas but also between the two cases in the South Bank. This difference implies that the South Bank is more grade separated than the Barbican and therefore that the horizontal depth has less effect on the former area than the latter. The increased correlation coefficient for H in the South Bank (after the spatial alterations) also represents changes in its spatial structure, in which its spatial depth,

Table 5. Development of the IMCM in the Barbican (a) and the South Bank before (b) and after (c) spatial alterations.

$-a$	r^2	r	$+a$	Formula	r^2	r
(a) *The Barbican*						
S^{HP}	0.339	0.582	S^{aHP}	minimum $[a(H + \ln P)]$	0.344	0.586
S^{HL}	0.554	0.745	S^{aHL}	minimum $[a(H + L)]$	0.525	0.724
S^{PL}	0.350	0.592	S^{aPL}	minimum $[a(\ln P + L)]$	0.358	0.599
S^{HPL}	0.541	0.736	S^{aHPL}	minimum $[a(H + \ln P + L)]$	0.543	0.737
S^{HPGT}	0.482	0.694	S^{aHPGT}	minimum $[a(H + \ln P)] + G + \ln T$	0.634	0.796
S^{HLGT}	0.670	0.819	S^{aHLGT}	minimum $[a(H + L)] + G + \ln T$	0.725	0.852
S^{PLGT}	0.430	0.655	S^{aPLGT}	minimum $[a(\ln P + L)] + G + \ln T$	0.548	0.740
S^{HPLGT}	0.639	0.799	S^{aHPLGT} (IMCM)	minimum $[a(H + \ln P + L)] + G + \ln T$	0.730	0.854
S^{HPLG}	0.598	0.773	S^{aHPLG}	minimum $[a(H + \ln P + L)] + G$	0.653	0.808
S^{HPLT}	0.582	0.763	S^{aHPLT}	minimum $[a(H + \ln P + L)] + \ln T$	0.616	0.785
(b) *South Bank before spatial alterations*						
S^{HP}	0.341	0.584	S^{aHP}	minimum $[a(H + \ln P)]$	0.441	0.664
S^{HL}	0.638	0.799	S^{aHL}	minimum $[a(H + L)]$	0.605	0.778
S^{PL}	0.438	0.661	S^{aPL}	minimum $[a(\ln P + L)]$	0.481	0.694
S^{HPL}	0.615	0.784	S^{aHPL}	minimum $[a(H + \ln P + L)]$	0.623	0.790
S^{HPGT}	0.499	0.706	S^{aHPGT}	minimum $[a(H + \ln P)] + G + \ln T$	0.637	0.798
S^{HLGT}	0.734	0.857	S^{aHLGT}	minimum $[a(H + L)] + G + \ln T$	0.766	0.875
S^{PLGT}	0.536	0.732	S^{aPLGT}	minimum $[a(\ln P + L)] + G + \ln T$	0.651	0.807
S^{HPLGT}	0.700	0.836	S^{aHPLGT} (IMCM)	minimum $[a(H + \ln P + L)] + G + \ln T$	0.736	0.858
S^{HPLG}	0.676	0.822	S^{aHPLG}	minimum $[a(H + \ln P + L)] + G$	0.686	0.828
S^{HPLT}	0.643	0.802	S^{aHPLT}	minimum $[a(H + \ln P + L)] + \ln T$	0.645	0.803
(c) *South Bank after spatial alterations*						
S^{HP}	0.365	0.604	S^{aHP}	minimum $[a(H + \ln P)]$	0.410	0.641
S^{HL}	0.491	0.700	S^{aHL}	minimum $[a(H + L)]$	0.481	0.694
S^{PL}	0.359	0.600	S^{aPL}	minimum $[a(\ln P + L)]$	0.384	0.620
S^{HPL}	0.499	0.706	S^{aHPL}	minimum $[a(H + \ln P + L)]$	0.507	0.712
S^{HPGT}	0.497	0.705	S^{aHPGT}	minimum $[a(H + \ln P)] + G + \ln T$	0.632	0.795
S^{HLGT}	0.616	0.785	S^{aHLGT}	minimum $[a(H + L)] + G + \ln T$	0.739	0.860
S^{PLGT}	0.501	0.708	S^{aPLGT}	minimum $[a(\ln P + L)] + G + \ln T$	0.699	0.836
S^{HPLGT}	0.607	0.779	S^{aHPLGT} (IMCM)	minimum $[a(H + \ln P + L)] + G + \ln T$	0.732	0.856
S^{HPLG}	0.565	0.751	S^{aHPLG}	minimum $[a(H + \ln P + L)] + G$	0.654	0.809
S^{HPLT}	0.544	0.737	S^{aHPLT}	minimum $[a(H + \ln P + L)] + \ln T$	0.599	0.774

Note: see text for an explanation of the variables.

in general, has become shallower after the spatial alterations. On the basis of this modelling technique, further research is necessary to understand more details of the hierarchical relationships between these configurational properties and their dynamic interactions. However, as the IMCM method has already demonstrated an ability to predict movements in the three cases which we have studied so far, this methodology may prove to be of wider application not only in the explicit description of movement patterns in highly complex and unintelligible environments, but also in the verification of the dynamic relationship between apparently heterogeneous variables within a configurational model.

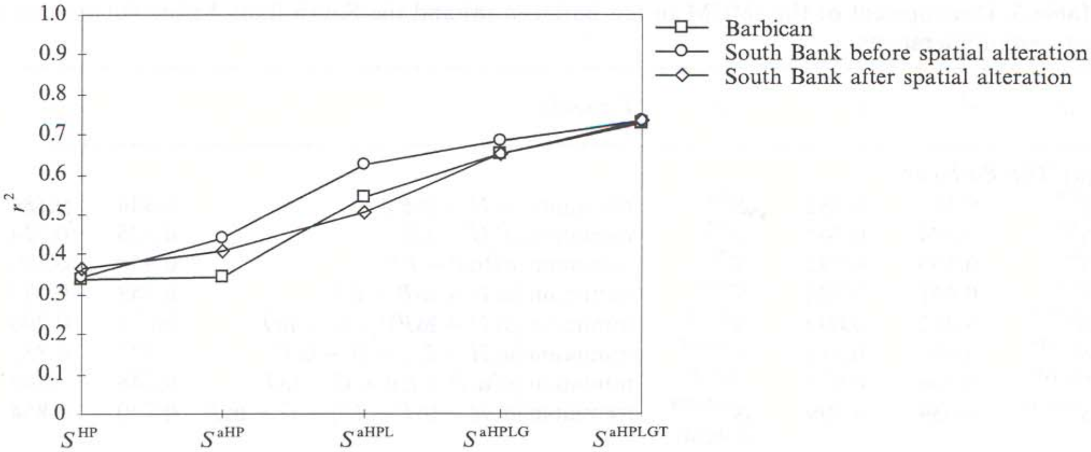


Figure 23. The process of IMCM development in three cases including the whole level: from the basic combination of two depth properties of S^{HP} to the final result of S^{HPLGT} (IMCM).

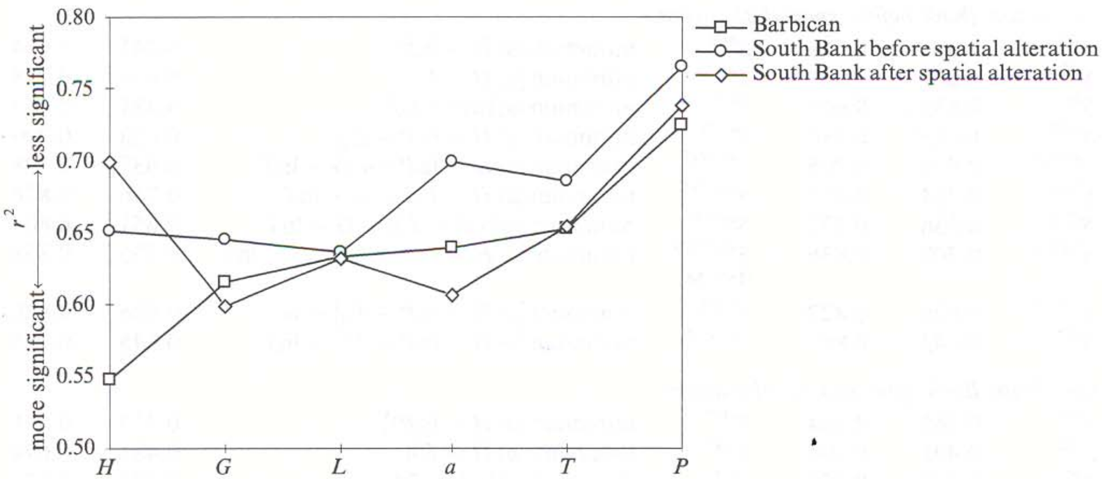


Figure 24. Order of statistical significance among six properties of the IMCM.

References

Academy Editions, 1994 *Designing the Future of the South Bank* (Academy Editions, London)

Architects' Journal, 1961, "South Bank development—the next stage", 30 March, pages 469 – 478

Chamberlin, Powell and Bon, 1959 *Report to the Court of Common Council of the Corporation of the City of London on Residential Development within the Barbican Area* (Corporation of London, London)

Daswatte C, 1991, "The South Bank: an urban pathology", MSc thesis, Unit for Architectural Studies, University College London, England

Hillier B, 1996 *Space is the Machine* (Cambridge University Press, Cambridge)

Hillier B, Penn A, Hanson J, Grajewski Z, Xu J, 1993, "Natural movement: or, configuration and attraction in urban pedestrian movement" *Environment and Planning B: Planning and Design* **20** 29 – 66

Marchand B, 1974, "Pedestrian traffic planning and the perception of the urban environment: a French example" *Environment and Planning A* **6** 491 – 507

Montello D R, Pick H L, 1993, "Integrating knowledge of vertically aligned large-scale spaces" *Environment and Behaviour* **25** (4) 457 – 484

Passini R, 1992 *Wayfinding in Architecture* (Van Nostand Reinhold, New York)

Pushkarev B, Zupan J M, 1975 *Urban Space for Pedestrians* (MIT Press, Cambridge, MA)