INTEGRATED MULTI-LEVEL CIRCULATION SYSTEMS (IMCS) IN DENSE URBAN AREAS

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0 Abstract

As spatial configurations become less intelligible, the ability of space syntax methods to predict observed movement patterns has generally been found to diminish. This paper describes research that attempts to bring a systematic methodology to modelling complex multi-level systems. The development of this methodology is described through two case studies of relatively unintelligible multi-level developments, the Barbican and the South Bank complexes, both in central London. Factors other than spatial configuration are incorporated in the model, including local visual factors, major generators and attractors of movement, and effects of grade separation. The model is then used to quantify the relative significance of these different factors in constructing pedestrian movement patterns. The paper concludes that in unintelligible multi-level systems it is necessary to take a range of factors into consideration in order to model pedestrian movement behaviour. Specifically, the distribution of movement in multiple level systems follows certain principles constrained by design factors as well as spatial configuration and it is their dynamic interrelations which determine the performance of circulation systems. Firstly, it is a general trend for pedestrians to choose the shortest and axially simplest routes. Secondly, pedestrians have a direction in mind and set their directions as soon as possible when embarking on a route. Finally, pedestrian decision behaviour in route choice is affected by their familiarity with an area. Axial depth from routes between the major attractors and generators of movement in the area also appears to be implicated. Grade transitions appear to have relatively little effect. Based on these patterns of route choice and decision behaviour, it is suggested that movement patterns in highly unintelligible areas, such as that often found in multi-level space, may prove predictable, but it is likely that models will need to incorporate a number of local and 'programmatic' variables in addition to the configurational description of an area.

1 Movement in multiple levels of space and its modelling

As cities have expanded, and urban populations have grown, usable, central urban space has become increasingly short in supply. In response we have seen planners resort to multi-level solutions for city centre schemes. However, in spite of the density gains of grade-separated urban cores, their design seems not to guarantee a sufficient number of people 'on the street' to sustain healthy urban function everywhere in the city. The "sufficiently dense concentration of people" referred as a key factor for viable urban life by Jane Jacobs (1961 p.200) seems generally to be missing or underperforming in these developments. On the contrary, there are often significant differences in the number of people, ranging from overcrowding in one place to virtually no movement in a nearby space, or between the same geographical locations but at different levels. In spite of the number of developments that have been seen in recent years, there is still a lack of understanding of the mechanisms that link density of land use to presence of people on the street.

It seems likely that a well-organised pattern of circulation is one of the basic elements required to prevent segregation and isolation. Movement, and its dependence on the configuration of the spatial structure in urban areas has received a certain amount of attention in recent years (Hillier & Penn, 1992 p.60). Research has found that spatial configuration itself is a major factor determining the ways people move through urban space as well as being influential in wayfinding in complex architectural environments (Hillier & Penn 1993a; Peponis et al, 1990) . Fundamentally, the finding is that patterns of pedestrian movement are related to the mean topological depth of the entire system from the point of view of a particular place. The measure of depth, relativised to take account of how deep a space might possibly be in a system of that size, is called 'global integration'. A number of studies have confirmed that, in general, patterns of pedestrian movement are related to one of a number of possible measures of spatial integration (Hillier et al. 1987; 1993a; Peponis et al 1989). However, different situations require different model sizes, different radius measures of integration and possibly different linearisations of the movement data, and give different regression equations. At present little is understood about the nature of how these precise differences in models arise, and whether they are purely idiosyncratic or are in any sense generalisable.

There are, however, findings in recent studies that suggest that there may be aspects of these models that are generalisable. In particular it has been noted that the degree to which it is possible to predict movement rates on the basis of integration in a system, appears to depend on the degree of 'intelligibility' of the system, where intelligibility is measured as the correlation between local and global configurational measures: connectivity and global integration for example. The more intelligible a system the more predictable are patterns of movement from measures of spatial configuration (Hillier et al 1987). Findings of a similar order have been made relating the degree to which two categories of people - adults and children - are brought into contact to the mean degree of integration of an area (Hillier 1996). System level effects of this sort give a powerful indication that in certain respects we may be dealing with generalisable phenomena, however, there is still little known about the boundaries of the current models. In particular we know very little about the conditions under which predictions can be made in highly unintelligible areas.

Research dealing with different movement patterns in multi-level systems is limited and mainly focuses on wayfinding and orientation without consideration of spatial configuration and the various types of transitional spaces (such as stairs, ramps, lifts and escalators). The ways that vertical transitional spaces connecting levels are linked with the horizontal space however, appears to have a significant effect on decision behaviour in direction-finding in large scale multi-level systems (Best, 1970). Passini's experiments (1992) show that wayfinding in multi-level systems, e.g. multi-storey buildings and underground structures, becomes a difficult task for users. It is likely that these wayfinding problems and failure to establish orientation in multi-level space are closely linked to the knowledge of how localised factors, such as visual accessibility, are interrelated with the whole pattern of multi-level structures.

A limited number of research papers dealing with multi-level circulation networks in 'skyway' and 'concourse' systems criticise their failure in terms of social and spatial segregation from surrounding urban fabric as a lack of "organisation" (Maitland, 159), "tangled subterranean networks" (Bednar, 180), failure to act as "social condensers" (Caliandro, 1983), and the undesirable relation between levels (Whyte, 1988; Zeidler, 1983). However, these critics themselves fail to explain objectively the recent failures in multi-level circulation networks in descriptive and explicit ways. With regard the pedestrian's competence in spatial cognition in multiple levels of space, it seems that people's abilities to encode and represent three-dimensional space have not been evaluated in many environmental-cognitive studies, although the possibility of three-dimensional cognitive maps has been raised and tested in a series of experiments. An experiment by Montello and Pick (1993) investigated this possibility by integrating separately learned cognitive maps of vertically aligned spaces into an inter-related single frame. It was shown that this three-dimensional cognitive map has a detectable effect on decision behaviour in route choice. In a separate study Peponis has found that the global structure of spatial configuration is a primary factor in route choice and wayfinding behaviour (Peponis et al, 1990).

Hillier and his team's work has shown that, statistically speaking, pedestrian flow rates for whole populations are predictable from measures of spatial configuration under conditions of 'intelligibility' (Hillier et al, 1987), however little attention has been paid to date to mechanisms at the level of the individual that might give rise to these population level effects. Some light might be brought to bear on these mechanisms through the study of 'unintelligible' systems in which the first order predictions appear to break down. Our strategy in the present study therefore, was to investigate whether the more local design factors through which 'unintelligibility' is created in complex multi-level systems could be incorporated into a model. The aim was first, to investigate whether such a model could be used to predict observed pedestrian movement rates, and second, by examining the effects on the model's ability to predict of including and excluding the representation of different local factors, to investigate which of those factors played a significant role in determining people's route choices.

Two intentionally cut-off and grade-separated urban complexes, the Barbican and the South Bank in central London, were selected as case study areas since each provides quite different morphological and architectural conditions and contexts, but both are criticised for their lack of intelligibility and for a breakdown in 'urban' characteristics. The Barbican is a mixed use complex including both an arts centre, a school and housing, and the South Bank is a multi-level cultural complex facing the River Thames. In both cases their multi-level circulation systems were originally designed to separate vehicles from pedestrians through the use of raised level pedestrian decks. This type of pedestrian deck has been successful in separating vehicles and pedestrians, however, it has led to the segregation of pedestrians from the ground level which has left the ground level devoid of pedestrian movement in some areas of each development, and great variations in levels of space use throughout each complex.

2 Observation methods

The investigation centred on gathering detailed first hand data on patterns of pedestrian movement and route choice in the two study areas. The aim of movement observations was to characterise movement patterns. Two types of data gathering method were used in this investigation. Direct observations of individual route choices were made using a moving observer to 'stalk' pedestrians, and average pedestrian flows at specific locations were gathered using a static observer at sample 'gate' locations. Stalking observations were carried out mainly to find out what kinds of spatial configuration and local characteristics affect the route choice behaviour of people and therefore their movement patterns. The gate data on route segments within the network were acquired for different times of day, with each set of observations lasting five minutes for each time period. 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.

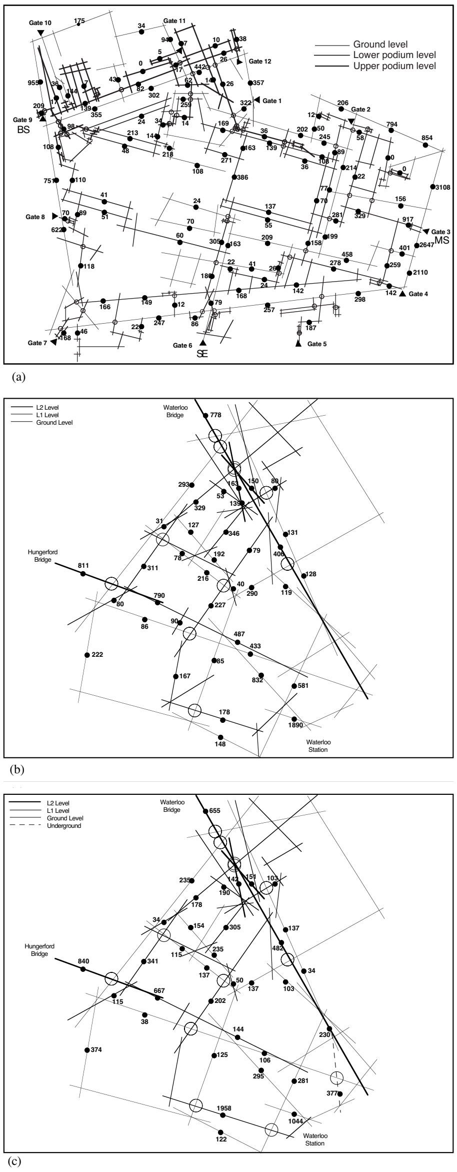

Figure 1. Daily mean flow rates per hour: the Barbican (a), the South Bank before (b) and after (c) the spatial alteration

Figure 2. Global integration of the Barbican (a) and the South Bank (b): note different scales

Within the two main study areas 184 route segments were observed, and counts were made in total of over 31,000 pedestrians by gate observation (figure 1). A total of six hundred people were randomly observed by stalking observations from three main generators on the South Bank (Waterloo Station, Waterloo Bridge and Hungerford Bridge) and three in the Barbican (Barbican Station, Moorgate Station and the southern 'gate'). It was noted that movement rates are affected by two types of route: whether pedestrians mainly kept to the shallowest routes in depth linking main generators in the area (GL), or the peripheral routes (PP) (figure 3). It was also possible in stalking observations to categorise individuals according to their familiarity with the area distinguishing qualitatively according to the speed and decisiveness individuals showed in making route choices. Those familiar with the area are noted as (F) and those who are not as (UF). We found that the number of people who are familiar with the areas is more than three times those who are not. Observed vertical level changes on routes (CV) and horizontal direction changes (CH) showed routes to be more vertically separated on the South Bank and a horizontally separated in the Barbican (figure 4). Mean observed vertical level changes in the South Bank were two steps greater than in the Barbican. Meanwhile, more frequent changes of horizontal direction occurred at the Barbican.

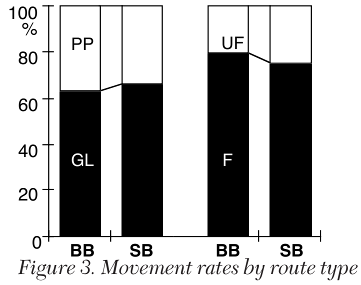

Figure 3. Movement rates by route type (GL,PP) and familiarity (F, UF)

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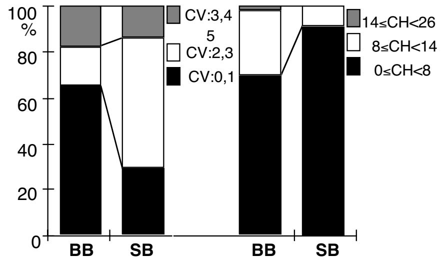
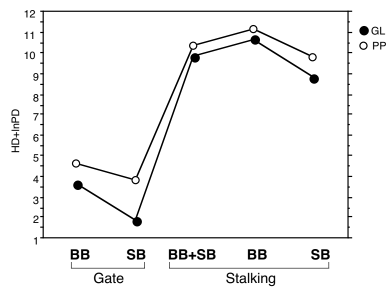


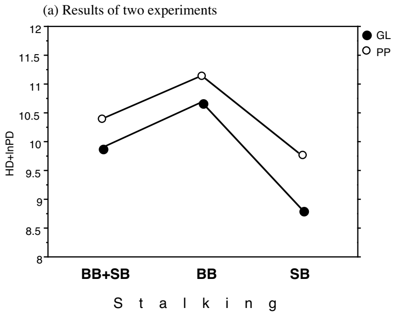
Figure 4. Movement rates by level (CV) and direction changes (CH)

3 Spatial depth and intersection (HD, PD): the shortest and simplest routes

Figure 5 shows that mean depth is statistically always shallower on the routes linking generators (GL) than on the peripheral (PP) routes in both study areas. This is inherent partly in the definition of the GL routes which consist of the shallowest routes connecting generators in the system in terms of two depth properties: the shortest and simplest route in axial terms (horizontal depth or HP) and the fewest segments traversed in a node map (point depth or PD). The median movement rate of people on GL routes at 82.5 is much higher than that of peripheral (PP) routes at 4.6 (figure 6). Figure 7 and 8, in which observations of stalking trails are categorised into several groups according to their origin and destination pairs, shows more detailed information about individual route choice decision behaviour. For example, all 27 people starting from Moorgate Station and heading for the Barbican art complex itself have chosen route (BBMS)A1 even though there are three different routes available and two of an equivalent metric distance. The favoured route (BBMS)A1 is the shallowest route in depth when we combine both axial discontinuity and segments traversed (HD+lnPD). We take the logarithm of PD in order to equalise the weight attributed to segments and axial discontinuities where the former always exceed the latter in number.



(a) Results of two experiments



(b) Stalking observation result only (OD pairs)

Figure 5. Scattegrams showing the depth on the shortest and simplest routes (GL) and the other routes (PP).

In the South Bank, these depth properties appear to have a similar effect on the pedestrians' route choice behaviour, as in the movement on the SBWS route originating from Waterloo Station and passing through Waterloo Bridge in figure 8. The comparison of the movement rate between route A1 (55%; 11 people out of 20) and B1 (25%; 5 out of 20) in SBWS highlights this pattern of pedestrians' route choice behaviour. Even though the A1 route is spatially more grade separated and environmentally more derelict than the B1 route, which is open to the air and keeping continuously on one level from the origin to the destination within the area, the movement rate on the A1 route is more than double. Based on the results of two empirical experiments (but mainly from the stalking observations), we suggest that two distinctive patterns of movement behaviour are interacting as follows. First, pedestrians' movement behaviour is to walk straight ahead wherever possible; second, the most direct route between major sources and sinks for movement is demonstrated through the primary GL route structure through an area.

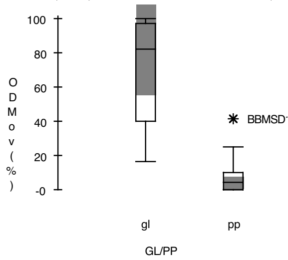


Figure 6. Boxplot showing movement rates of pedestrians who have followed GL and PP (stalking observation result only: OD pairs from figure 7 and 8)

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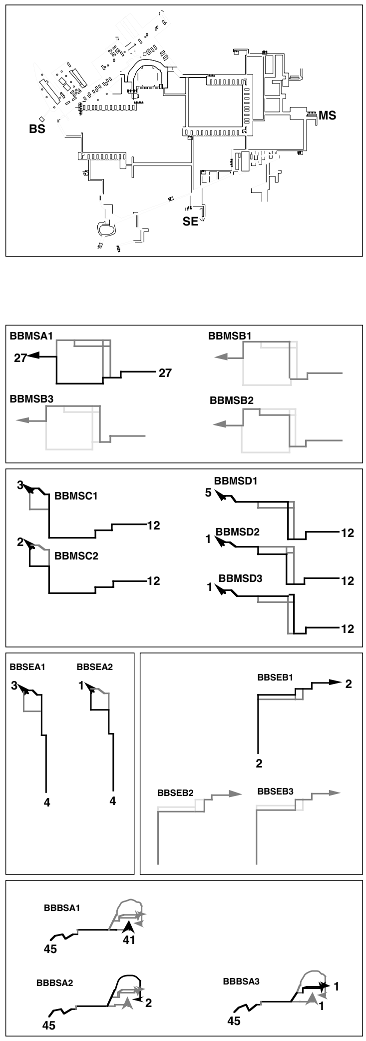


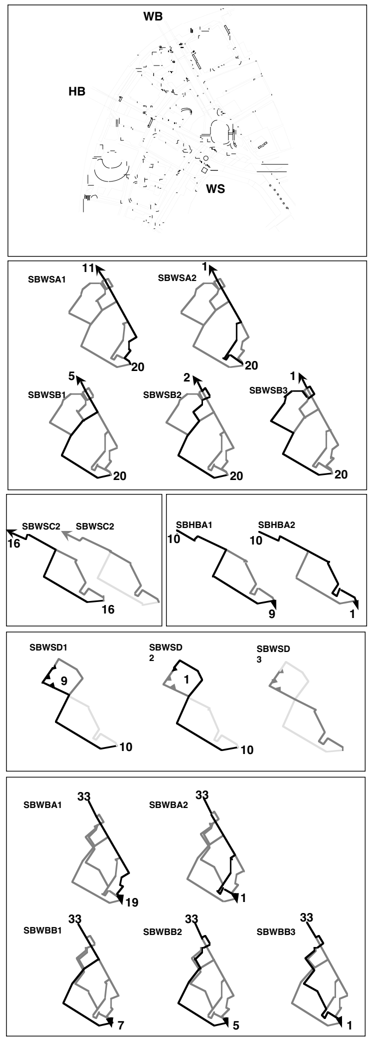
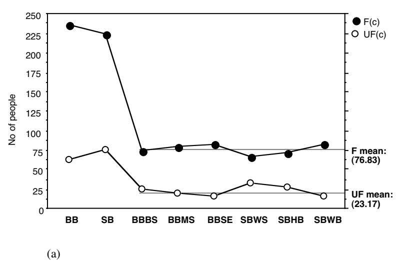


Figure 7. OD pairs grouped into several types of movement in the Barbican (selected routes in dark lines and alternatives in grey lines).

Figure 8. OD pairs grouped into several types of movement in the South Bank after the spatial alteration.

4 Man follows man: the effect of familiarity of a spatial structure on route choice decision behaviour

In both case study areas, pedestrians who are familiar with the area always appear to outnumber those who are not. In the Barbican, 237 people out of 300 (79%) were heading for the destinations with their own pre-defined knowledge and apparently without hesitation, but in contrast there were only 63 people (21%) who appeared to be entirely dependent on the limited information within their scope of visibility (figure 9). In case of the South Bank, slightly more people, 76 (25.33%) out of 300, appeared to rely on the local information while 224 (74.67%) appeared to be familiar with the area. The two sets of case study observations have shown that the actual number of pedestrians who are familiar with the areas (F) is higher than people who are not (UF), regardless of which type of route they selected (generator linking GL, or peripheral PP) (figure 10). It is likely that the main reason for the diverse route choice behaviour of those people who are familiar with the area is closely linked with their knowledge of pre-defined whole patterns of spatial structures. Under the circumstances of limited visibility and poorly posted signs around the areas, it seems possible that pedestrians who are unfamiliar with the areas tend to follow the flows of movement on the most direct and simplest routes, as well as being drawn by the presence of people itself. For this reason the number of people who are unfamiliar with the area is always higher on the GL routes than on the PP routes. This movement behaviour, which mainly affects the movement of people who are unfamiliar



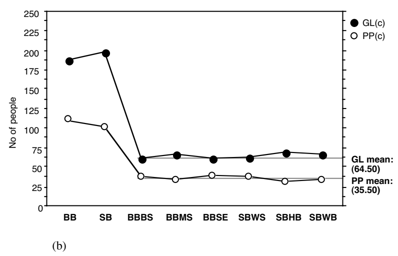
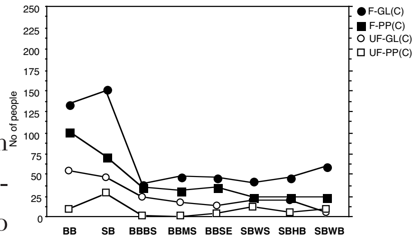


Figure 9. Movement rates by familiarity (a) and route type (b)

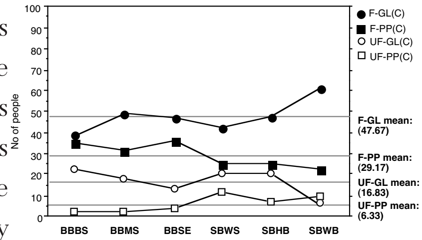
with the areas, has been continuously observed in both areas.

5 Global interaction routes as a main route and choice factor

Gate observation results show movement rates, segment by segment for the Barbican and two sets of movement rates for the South Bank, before and after spatial alterations affecting its links to Waterloo Station. In these three sets of observations, two different groups of movement spaces can be noted: There are small numbers of high movement rate spaces (mainly GL routes) and large numbers of low movement rate spaces mainly on peripheral routes (figure 11 (a), (b) and (c)). Stalking observation results show a higher contrast in movement rates on those two types of route than gate observation results; the median of the logged movement rate on the GL routes is 4.2 and that on the PP routes is just 1.6 in the Barbican (figure 11 (d)) and 4.5 for the former routes and 1.6 for the latter routes in the South Bank following the alterations (figure 11 (e)). Movement patterns categorised by their origin and destination pairs show significantly higher movement rates on the GL routes dominated by people who are familiar with the areas. Five origin and destination pairs in each case study area demonstrate that most pairs, except one in the Barbican, show higher movement rates on the GL routes than those on the PP routes and that eight pairs of movement patterns show higher proportions of pedestrians who are familiar with the areas than those who are not (figure 11 (d) and (e)). Significantly, visible contrasts in the movement rates between the GL and PP routes suggest that global interaction routes, the shallowest routes in depth among main generators, work as main routes connecting each generator.



(a)



(b)

Figure 10. Movement rates by familiarity on two types of route including the sums of each cases (a) and excluding them (b).

6 The effect of grade separation on the movement pattern

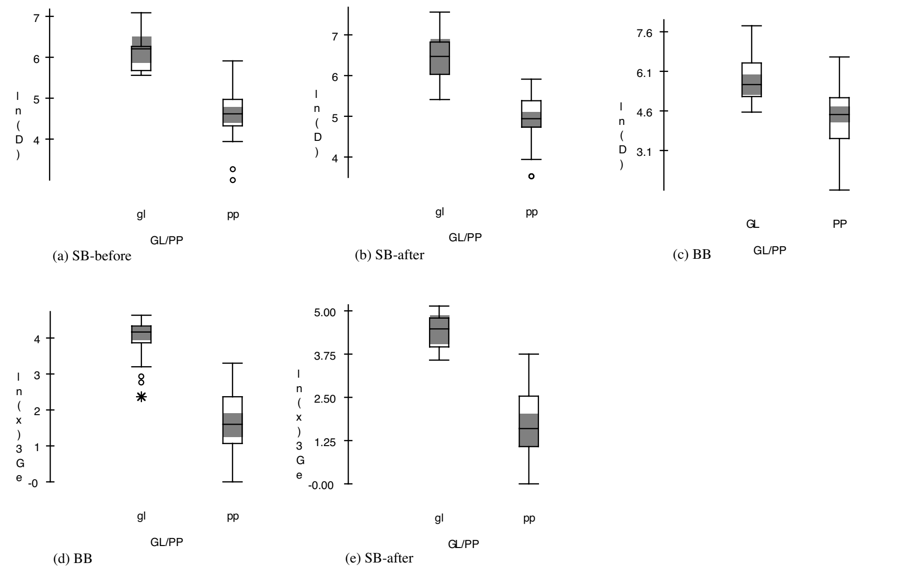


Figure 11. Movement rates on the GL and PP routes, observed by 'gate' (a ,b, c) and 'stalking (d,e) methods.

The results of the two different sets of stalking and gate observations, show higher movement rates on the GL routes than on the PP routes in both case study areas. Even though the movement rate is higher on GL routes than on PP routes in two case study areas, pedestrians on those routes experience more vertical level changes than on PP routes. GL routes are in general more grade-separated than PP routes and the grade-separation is higher in the South Bank (mean: 2.32 changes of vertical levels) than in the Barbican (mean: 1.55). Pedestrians on the GL routes in the South Bank undergo 2.62 vertical level changes from their origin while pedestrians on PP routes experience 1.75 level changes (figure 12 (a)). These comparatively frequent level changes on GL routes continue in all cases of movements starting from three generators, i.e. the movement from Waterloo Station (WS), from Hungerford Bridge (HB) and from Waterloo Bridge (WB). Figure 12 (a) shows that level changes are always higher on GL routes.

Level changes in the Barbican are fewer than at the South Bank. The Barbican's overall mean level change is 1.55, which is approximately half that at the South Bank (2.32). The movements of one hundred people starting from Barbican Station (BS) show the highest difference in the level changes between two types of routes. The rate of level change on the GL routes is 2.73 but on the PP routes is 1.53 (figure 12 (a)). Vertical level change on the GL routes (mean: 1.21 for MS and 1.05 for SE) is less frequent in both cases than on the peripheral routes (1.27 for MS and SE) in the Barbican. The relatively low change in vertical levels results from the fact that most of the Barbican complex is covered by a lower podium level (+1 level above ground level) except for a small part of the northern area that has two levels. It has been demonstrated that there are two characteristics in experiencing vertical level changes. Firstly there are more frequent level changes and higher movements on GL routes than on PP routes, and secondly familiarity with the area appears to have little bearing on the number of level changes on individual's routes. These notions suggest that pedestrians on the global interaction routes (GL) are relatively unconcerned with vertical level changes, regardless of their familiarity with the area. This relationship between the pattern of level changing and pedestrian movement rates implies that there is little effect of grade separation on pedestrian movement patterns as long as they are on the global interaction routes.

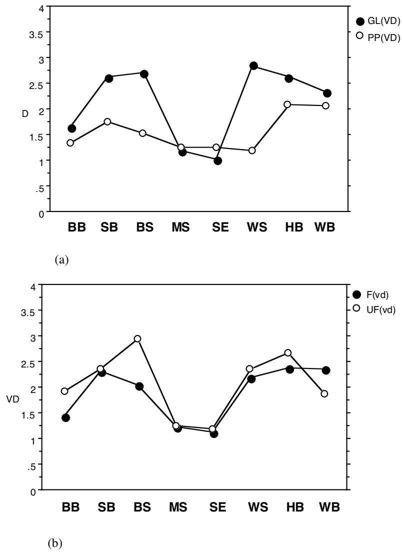


Figure 12. Vertical level changes on two types of route (GL, PP) (a) and by fmiliarity (F, UF) (b)

7 Multiple levels of spatial configuration and movement patterns

Figure 2 (a) and (b) are black & white screen outputs from 'Axman' showing the pattern of integration and segregation in the two areas. It is clear that in both cases the complex multi level areas of the two developments are structurally segregated from their surrounding context. However, the results of pedestrians' route choice and decision behaviour observations suggest that it would be unreasonable to expect 'natural movement' in these relatively unintelligible multi-level complexes. The movement patterns that have been observed in these areas are strongly biased by the embedding of origins and destinations within the spatial configuration and previous research has suggested that lack of intelligibility itself prejudices the ability of configurational models to predict movement patterns. Movement patterns in both areas fluctuate considerably according to time of day on particular routes and on particular levels, and this appears to be in accordance with the 'programmatic' nature of the attractors and generators of movement. The scattergrams in figure 13 (a) show the overall prediction of movement rates by radius n integration in the Barbican. It seems that the effect of highly unintelligible configurations on movement patterns is so significant that it has been difficult to describe an explicit movement pattern under these circumstances. Even when we subdivide the area and look at different levels separately improvements are only marginal, and do not allow us to develop an integrated model of the whole multi-level complex. It is apparent that not only does the presence of generators and attractors make the description of movement difficult, but also their dynamic interactions with the configuration itself appears to make the Barbican more unintelligible. Certainly, if the hypothesis that for those unfamiliar with an area the presence of people is itself an aid to intelligibility, then the programmatic nature and time fluctuations of the presence of people may itself add to the confusion experienced as a result of the unintelligible configuration.

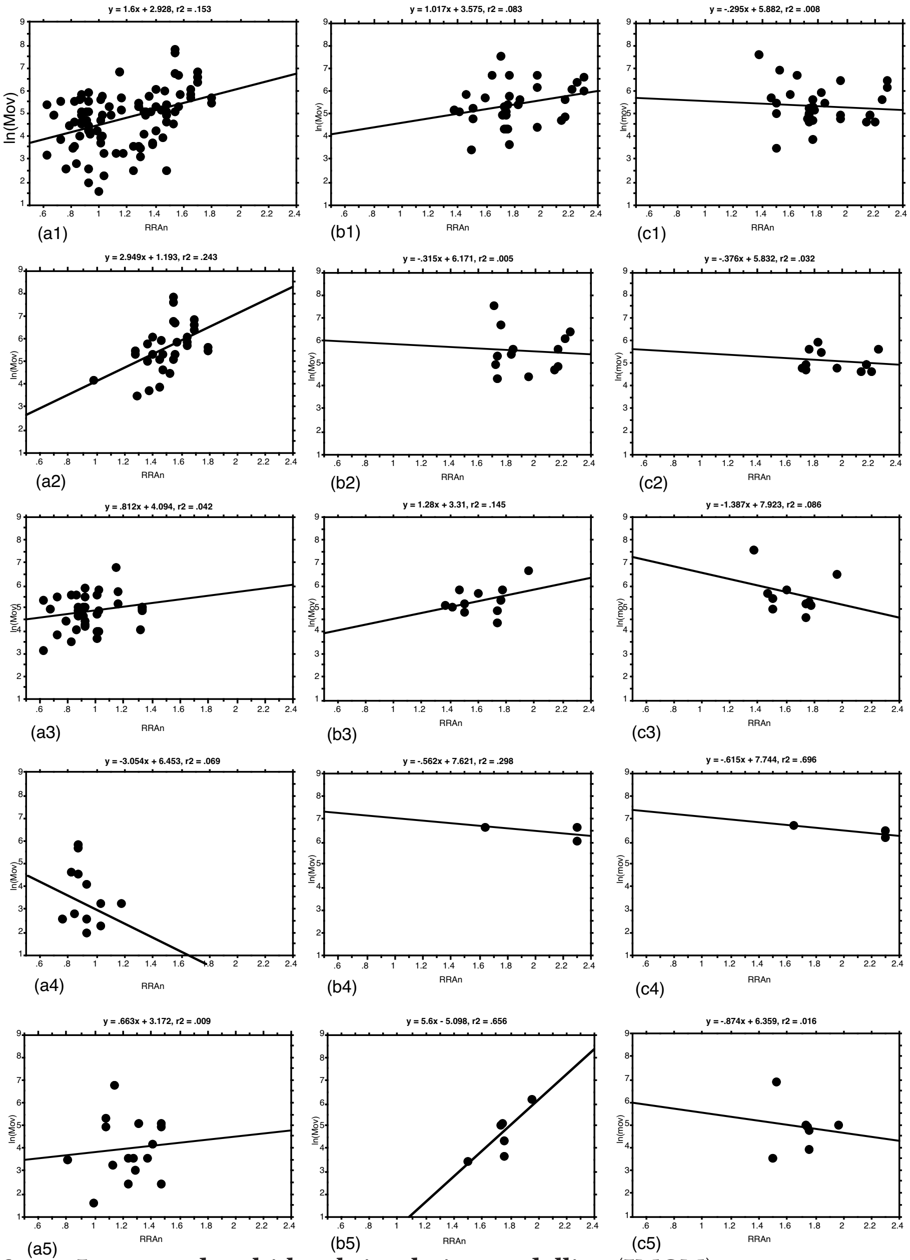


Figure 13. Scattergrams showing the results of Space Syntax analysis of the Barbican (a), and the South Bank before (b) and after (c) the spatial alteration; whole level (a1, b1, c1), ground level (a2, b2, c2), level 1 (a3, b3, c3), level 2 (a4, b4, c4) and gate only (a5, b5, c5).

8 Integrated multi-level circulation modelling (IMCM)

An integrated multi-level circulation system model (IMCS) was developed based upon the need to resolve two interrelated difficulties: first, it is difficult to predict movement patterns in multi-level space and second, therefore, it is hard to set up a way of appropriately co-ordinating three different layers of space - above ground, ground level and below ground - as well as the relationship to the surrounding urban fabric, during design. The basis of IMCM is a 'space syntax' model, in which the patterns of movement within urban areas are modelled by analysing the grid structure of the multi-level complex within a single Axman model. However, to measure the space structure of multi-level complexes, IMCM introduces a range of configurational parameters, based on the possible route choices in the multi-level route networks, in addition to conventional space syntax parameters.

These parameters can be categorised into a series of types as follows: two interrelated depth properties; horizontal depth (or changes of direction) (HD) and point depth (PD) which differentiates each segment of an axial line according to the number of intersections that must be passed on a route; and level value (Lv) for the level changes (or grade-separation); to connect the IMCM to the larger urban context, a set of integration values of surrounding major streets along the edge of the multi-level urban complex is calculated (a); global interactions between main generators (Gi), the major routes embedded in the system, a factor applicable to (GL routes); and gate values (Gt) of transitional spaces connecting different levels that are made up of four elements, type of vista, degree of enclosure, configuration and connection with the main streets, where each element is scored to give a total score denoting the relative 'obviousness' of these key transition links. The parameters in the model are based on principles we can infer from observed pedestrian movement behaviour, but which can be relatively objectively quantified and attributed to individual spaces in a multi-level complex.

The final formula of integrated multi-level circulation modelling (IMCM) can be expressed as follows:

$$MMV = Min\left[a_i\left(HD_i + \ln(PD_i) + Lv\right)\right] + Gi + \ln(Gt) \qquad [1]$$

$$a_i = \frac{\sum_{i=1}^{n} x_i - x_i}{(n-1)\sum_{i=1}^{n} x_i} \qquad \begin{pmatrix} i = 1 \sim n \\ n \geq 2 \end{pmatrix}, \qquad [2]$$

where *MMV* = multi-level movement value,
a = comparative integration value,
HD = horizontal depth,
PD = point depth,
Lv: = level value,
for level value: L0 (ground level) = 0,
L1(level-1) = 1 L1-Gt (gates to the level-1) = 2,
L2(level-2) = 3 L2-Gt (gates to the level-2) = 3,
L3(level-3) = 4 L3-Gt (gates to the level-3) = 4,
Gi = global interaction between generators,
for global interaction between generators (Gi) = -.7,
Gt = gate value,
for gate value which is made up of visibility (bad = 1 or good = 0),
enclosure (enclosed = 1 or exposed = 0),
type (stairs and ramps = 1 or escalators and lifts = 0),
connection (connected to back street = 1 or connected to main street = 0),
x = global integration value of the 'space syntax',
i = the number of main generators,
n = total number of main generators,

The configurational properties of the model at both global and local levels interact with each other so closely that it appears difficult to define the interconnected relationship between them. However, the IMCM modelling technique is quite successful in predicting pedestrian movements in the two multi-level complexes we have studied so far (figure 14). This modelling method also shows that it has an ability to predict the pedestrian movements on each grade level individually and as a whole. The process is incremental, allowing each of the various properties to be included or excluded from the model, an so the effect of each property quantified in terms of the difference it makes to the prediction of patterns of observed movement.

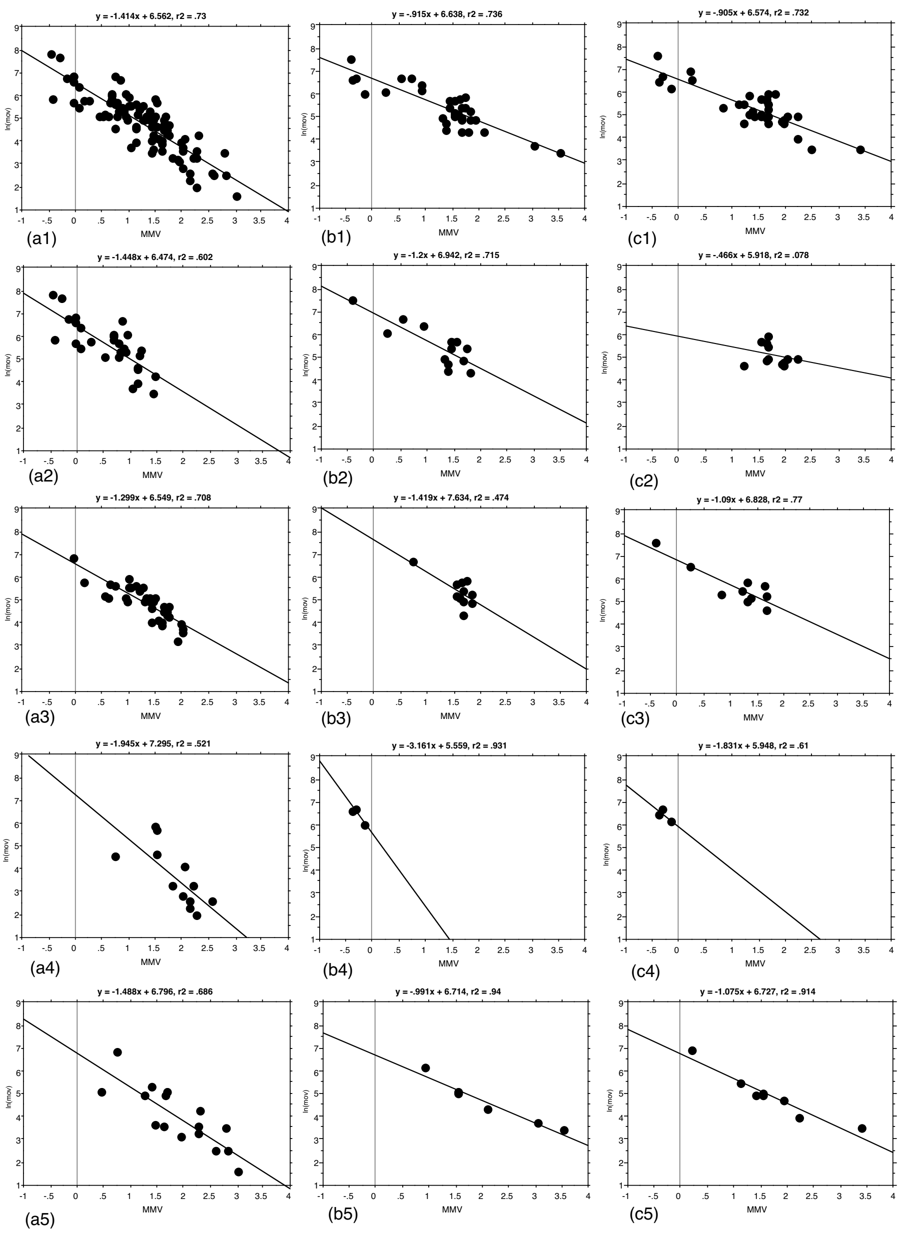


Figure 14. Scattergrams showing the results of IMCM of the Barbican (a), and the South Bank before (b) and after (c) the spatial alteration; whole level (a1, b1, c1), ground level (a2, b2, c2), level 1 (a3, b3, c3), level (a4, b4, c4) and gate only (a5, b5, c5).

The IMCM modelling process in the Barbican started from the combination of two depth properties horizontal and segment depth (HP), with a correlation coefficient of r=.582, and ends with a combination of global and local properties, with a strong correlation of r=.854. The relationship between variables in the South Bank shows strong correlation coefficients of MMV both before (r=. 858) and after (r=.856) the spatial alteration. The scattergrams showing each grade level individually, indicate that each level has a good correlation on its own, as well as from ground level to upper podium level, even though there are two scattergrams showing low correlations as follows: the lower podium level (b3) and the ground level (c2) in figure 14. Overall however, the inclusion of the series of additional variables in the model makes a powerful predictor of observed movement within a unified model of the whole multi-level complex.

What is particularly noteworthy is that by including variables one at a time we can derive an order of statistical significance between the different variables included in the model. Although each case study area has a different order, we can read a general trend as shown in figure 15. This shows that horizontal depth (HD) has the most effect, but PD, Lv, Gi and Gt change together with relatively little variation. This is an important finding, in that it gives first evidence that grade level changes appear to play only a relatively minor role in determining pedestrian movement behaviour in this type of urban complex. On the basis of this modelling technique, further research is necessary to understand the hierarchical relationship between variables and the pattern of pedestrian movement and route choice behaviour at a micro scale, however, we believe the methodology for unpacking the effects of a wide range of apparently heterogeneous variables may prove to be of wider application.

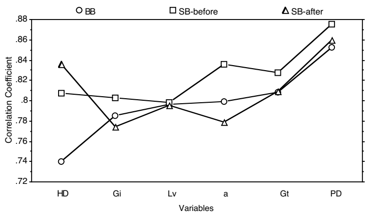


Figure 15. Order of significance among 6 variables.

9 Conclusion

With the growing concerns about the sustainability of urban environments in an urbanising world, demands for increased city centre densities have forced many cities to adopt integrated circulation systems. This has led to the three-dimensional disposition of urban landuses, and surface and subsurface space utilisation. Circulation systems, usually incorporated into multi-purpose and multi-functional complexes, have grown to become more complex and unintelligible in terms of spatial configuration and wayfinding performance with the increase of size and functional diversity. It has been argued that multiple design features, such as major attractors and generators drawing high-volumes of movement, grade-separation by multiple levels, and vigorous adaptation of transitional space connecting levels, have made it difficult for users to read the spatial structure as well as for designers and planners to predict likely movement patterns. This has created a need for methods which can explicitly describe multiple levels of spatial structure, as well as for in-depth studies of the interrelationship between the design variables and behaviour patterns in multiple levels of space.

On the basis of a global structure of spatial configuration and local properties of design elements, this study has presented evidence that it is possible to describe pedestrian movement patterns in multi-level of systems. This paper has shown that the pattern of space use in multiple level systems can be explicitly described by measuring multiple levels of spatial structure, which can be represented by the 'Integrated Multi-level Circulation Model' (IMCM). The development of this tool was described through two case studies of unintelligible multi-level complexes, the Barbican and the South Bank in central London. Factors other than spatial configuration were incorporated in the model, including local visual factors, major generators and attractors of movement, and effects of grade separation. The model was then used to quantify the effects of these different factors in constructing pedestrian movement patterns.

In unintelligible systems it turned out to be necessary to take a range of factors into consideration in order to model pedestrian movement behaviour. Specifically, the distribution of movement in multiple level systems follows certain principles constrained by design factors as well as spatial configuration and it is their dynamic interrelations that determine the performance of circulation systems. More precisely, in a less intelligible space, multiple levels of underground or above-ground networks for example, the predictability depends on three types of spatial properties: horizontal and vertical connectivity, global connections with the surrounding spatial structure through gates, and spatial interactions between the main programmatic generators in the system. In these two studies, the most significant factor showing consistency in the model was a measure of the configuration of the internal route structure with respect to the area context, and dependent on the changes in horizontal direction. Vertical level changes were found to be only of second order importance in the model.

References

Bednar M J 1989 *Interior pedestrian places*. (Whitney Library of Design, New York)

Best G 1970, "Direction-finding in large building", in *Architectural Psychology* Ed D Canter (RIBA, London) pp 72-76

Caliandro V 1978, "Street form and use: a survey of principal American street environments", in On *Streets*. Ed In S Anderson (MIT, Mass.) pp 151-186

Hillier B 1996 *Space is the machine*. (Cambridge University, Cambridge)

Hillier B & A Penn 1993a, "Virtuous circles, building science and the science of buildings: using computers to integrate product and process in the built environment "*The International Journal of Construction Information Technology*. **1**(4) 69-92

Hillier B et al 1993b, "Natural movement: or, configuration and attraction in urban pedestrian movement" *Environment and Planning B*. **20** 29-66

Hillier B & A Penn 1992, "Dense Civilisations: the Shape of Cities in the 21st Century" *Applied Energy* **43** 41-66.

Hillier B et al 1987 "Creating Life: or, does architecture determine anything?" in Architecture and Behaviour, vol. 3, no. 3, Editions de la Tour, 1987.

Jacobs J 1961 *The death and life of great American cities*. (Vintage Books, New York)

Maitland B 1990 *The new architecture of retail mall* (Architecture Design & Technology)

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

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

Peponis J et al Sep. 1990, "Finding the building in wayfinding" *Environment and Behaviour* **25** (5) 555-590

Whyte W H 1988 *City: rediscovering the centre* (Doubleday, New York)

Zeidler E H 1983 *Multi-use architecture in the urban context* (Karl Krämer Verlag, Stuttgart)