intelligent space

Planning For Movement

Measuring and Modelling Pedestrian Flows in Cities

Dr. Jake Desyllas and Elspeth Duxbury

www.intelligentspace.com

About this article

This paper was presented at the Royal Institute of Chartered Surveyors conference in 2000.

Further information

More publications about ISP's work on modelling pedestrian movement in cities are available for download from www.intelligentspace.com.

intelligent space

Intelligent Space Partnership
81 Rivington Street, London EC2A 3AY
phone +44 (0) 20 7739 9729 fax +44 (0) 20 7739 9547 www.intelligentspace.com
Partners: Dr. Jake Desyllas B.A. M.Sc. Ph.D., Elspeth Duxbury B.Sc. M.S.c.

PLANNING FOR MOVEMENT:
Measuring and Modelling Pedestrian Flows in Cities

Dr. Jake Desyllas (jdesyllas@intelligentspace.com)
Elspeth Duxbury (eduxbury@intelligentspace.com)

Intelligent Space
68 Great Eastern Street
London EC2A 3JT
Tel: +44 20 7739 9729
Fax: +44 20 7739 9547

RICS Conference London 2000

PLANNING FOR MOVEMENT:
Measuring and Modelling Pedestrian Flows in Cities

1 ABSTRACT

Visibility Graph Analysis (VGA) is a technique for the representation and analysis of urban spatial structure. This paper evaluates the use of this technique as a tool to model pedestrian movement by quantifying the influence of urban morphology. A sample of pedestrian movement counts on individual pavements in a study area of Central London is used to test the correlation of measures from the VGA with observed flows. The results show a significantly higher correlation between visibility measures and pedestrian movement than obtained with simple pavement width or capacity measures. The potential for this technique's application in the evaluation of new planning is discussed.

2 INTRODUCTION

This article applies the technique of Visibility Graph Analysis (VGA) to represent and analyse urban spatial structure. Firstly, the background to this technique will be introduced in this section. A case study of empirical data on pedestrian movement flows will then be presented in section 3. The relationship between VGA measures of urban morphology with the observed pedestrian movement data is tested through regression models in section 4 and conclusions will be made in section 5.

2.1 Does urban spatial structure influence pedestrian movement?

The research question explored in this paper is whether the morphology of the built environment itself influences pedestrian movement. This research question belongs to the area of social science investigating the often-unintended social consequences that spatial structures have back onto society (Hillier 1985). Once a spatial structure such as an urban area has been created, it seems to offer unexpected social potentials and problems. The way that people use an area depends not on what planners or architects might have expected but on these potentials offered by the spatial structure itself. What are the laws that govern the use of spatial structure that we find, however it was created and for whatever original purpose? These questions are the starting point for a research programme attempting to isolate the independent role of spatial structure on the functioning of society. One important way in which the environment might be shown to influence social activities is in the determination of pedestrian movement.

2.2 Background to Visibility Graphs

Visibility graph Analysis is an innovative method of quantifying the spatial structure of a building or an urban street network. Visibility Graphs analyse the extent to which any point in a spatial network is visible from any other. Where points are not directly visible, graph measures of the matrix of all points can be calculated to test how many intervening points are needed for one point to 'see' all others. Other graph relationships can be calculated, such as the 'clustering co-efficient', which tests the inter-visibility of a point's neighbours and the 'mean depth', which provides accessibility measures of each point relative to the whole graph.

Visibility Graphs were first used by Braaxma in a study of airports to identify the visual and spatial relationship between various facilities that a passenger must find (Braaksma and Cook 1980). They have recently been the subject of interest in geocomputation (deBerg, van Krefeld et al. 1997) and in architectural analysis (Turner, Doxa et al. 1999; Turner and Penn 1999). Published research testing the relationship of VGA to pedestrian movement has been exclusively on studies within buildings, such as the Tate Gallery (Batty, Conroy et al. 1998; Turner and Penn 1999). Turner and Penn published findings on the extent to which the occupancy of gallery rooms by visitors could be explained by a combination of their area and mean depth within the visibility graph, finding that these two factors predicted to r squared=.634.

The only published comparative test of Visibility Graph Analysis with previous techniques for measuring urban morphology is from a study of a department store (Turner and Penn 1999). The results showed a higher correlation between graph measures of mean depth and pedestrian movement when calculated with a VGA representation than with the older technique of manually drawn 'axial lines' (a set of sight lines considered as a graph).

Previous techniques for graph representation of urban areas (such as the 'axial map') have often been used to calculate 'mean depth' measures of the graph of intervisible points, whereby the average shortest path between each node and all others is calculated using the fewest necessary intervening visible nodes. However, the very low mean depths of visibility graphs make any depth analysis subject to what is termed 'edge effect'. Depth measures are only really useable in spatial analysis when some criteria for defining a bounded system can be made[1] (the edge of the system). In buildings, this is often possible because buildings are quite literally bounded spatial systems, often with an unambiguous edge.

However, in cities it is hard to define the 'edge' of a neighbourhood's street system. The entire city can be analysed, but this requires a vast amount of data and even then, some objective definition of the 'edge' must be defined. The other way to overcome the limits of edge effect is to use local measures that are not dependent on any relations to the entire graph, such as the visual connectivity of a point (which is essentially its visibility) or the clustering co-efficient (Turner, Doxa et al. 1999). This is the technique used in this study.

---

[1] Depth calculations within a limited number of steps in a graph analysis can be accurately calculated if a much larger system is processed than the real study area. However, the depth of all points from the edge must be systematically calculated and those areas that fall within a set number of steps from the edge must be removed from study as their values will be incorrect.

3 CASE STUDY OF PEDESTRIAN MOVEMENT

Before testing the efficacy of measures of urban spatial structure in a model of movement determination, we first present the evidence of pedestrian movement that the model will seek to explain. Observations are used from a study of the area around St Giles Circus in Central London, shown in Figure 1. This data is from an analysis of movement flows and safety in the area carried out by Intelligent Space on behalf of Camden Council.

St Giles' Circus is a strategically important junction that joins areas of Bloomsbury, Fitzrovia, Soho and Covent Garden. The junction is crucial to the flow of traffic and pedestrians between these areas of London and is also an important public transport interchange facility with 15 bus routes and Tottenham Court Road Underground Station (which handles more than 100,000 people per day). Oxford Street, which enters the Circus from the West, is one of the most important retail streets in the world and has higher average pedestrian flow counts than any other street in the UK.

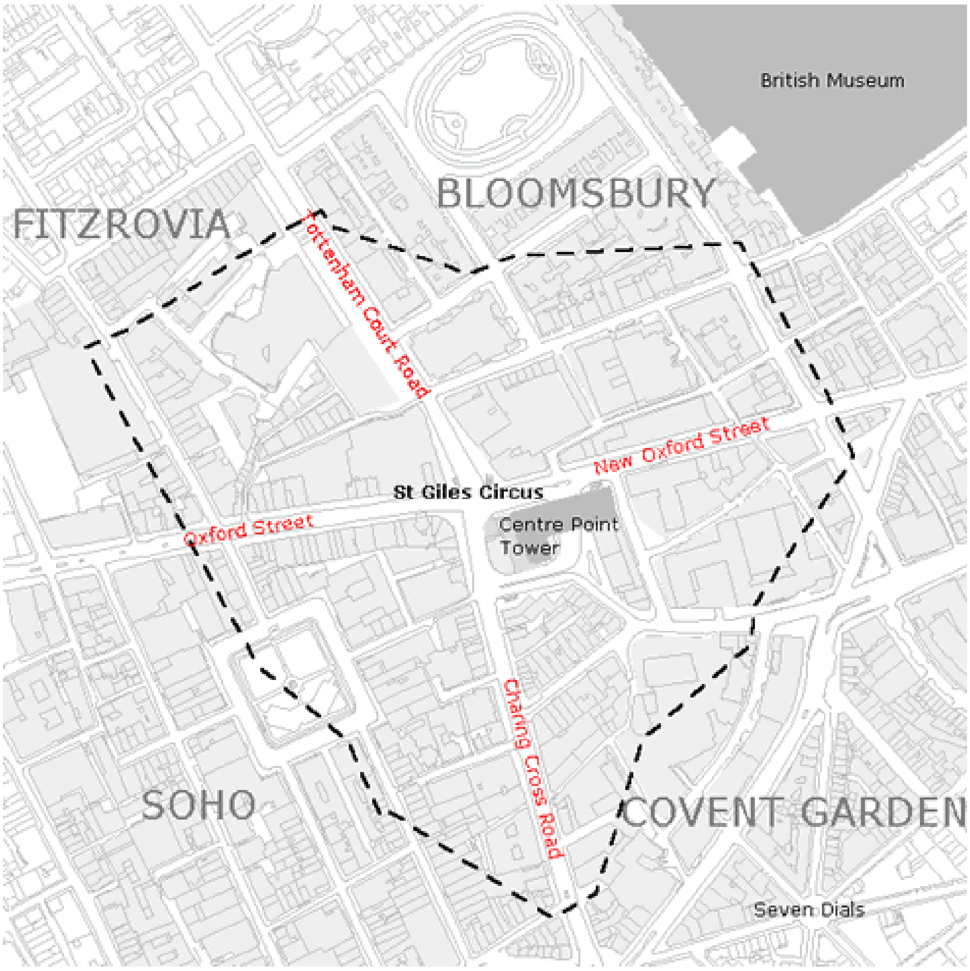


Figure 1: Study area

3.1 Methodology for measuring Pedestrian Flow

In order to measure the differences in pedestrian flows on pavements in the area, observation counts were undertaken at 84 locations, shown in Figure 2. The number of passing pedestrians was sampled for 5 minute periods within every hour from 08:00 to 20:00 on Saturday 18/03/00 and Tuesday 21/03/00. Table 1 below shows the differences in all day average pedestrian flows per hour between the observed pavements. Within this relatively small study area, there is a large variation in the number of pedestrians using each pavement. Movement on weekdays ranges from an average of 0 people per hour on some pavements to 1766 people per hour on others and at the weekends from 0 to 2183 per hour.

	Mean	Median	Std. Dev.	Std. Error	Min	Max
Mean Weekday flow per hour	321	162	427	46.538	0	1766
Mean Saturday flow per hour	342	137	503	54.910	0	2183

Table 1: Average Pedestrian flows in the study area

3.2 Spatial Differences in Pedestrian Flows

The pedestrian movement observations have been linked to pavement polygons that represent the pavement area on which each count was taken. These are held within a spatial database using a Geographic Information System (GIS). The pavement areas are shown in grey on Figure 2. This linking of data within a spatial database allows us to represent the results of the survey in maps to see the spatial pattern of movement. The pattern of average pedestrian movement can be seen in Figure 3 . The colour scale used is a spectral range where red denotes the highest movement down to blue for the lowest.

Figure 2: Observation gates for pedestrian movement counts

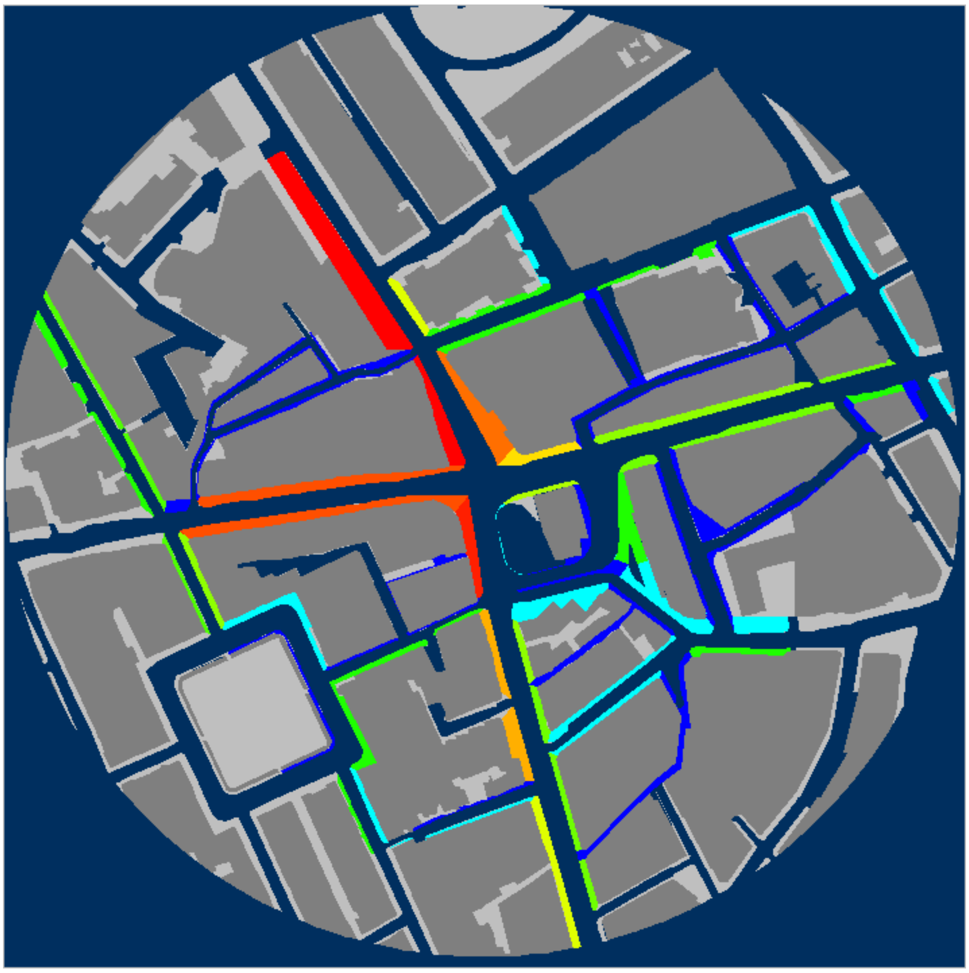


Figure 3: Average Movement on each Pavement

The first striking characteristic of the pattern of movement is the dominance of the main streets of Oxford Street and Tottenham Court Road, especially at the blocks nearest St. Giles' Circus. Looking at the street as a whole by summing the movement on both sides of the street, on a Saturday there are about 3,625 people per hour walking down Oxford Street, which implies a total of approximately 43,500 moving people during the daylight hours observed (8am to 8pm). Tottenham Court Road has a total of 36,850 people passing in daylight hours at the block nearest St Giles' Circus on a Saturday.

There is a notable difference in flow between the East and West sides of the Tottenham Court Road-Charing Cross Road route. On average, the movement on the Western side is double that on the Eastern side of this route. One important consideration in the difference in pedestrian movement is the lack of a pavement on the eastern side of Charing Cross Road adjacent to centre point tower. There is no formal footpath, but there is a narrow kerb (of approximately 40cm in width) located next to the 'Swimming Pool', as can be seen in Figure 4 below.

Figure 4: The narrow kerb next to the 'Swimming Pool' under Centre Point

This break in the space available to pedestrians walking on the North South route through the area leads to a strong imbalance in the number of pedestrians on each side of the road. The number of pedestrians is higher on the Western side for all the street blocks in the observation area (more than double), but unsurprisingly the block adjacent to Centre Point shows a much stronger imbalance, with movement almost 8 times higher on weekdays and 12 times higher on Saturday.

3.3 Temporal differences in pedestrian flow

The spatial differences in movement are relatively stable over time. This is evidenced in the similarity between the pattern of movement on a Saturday and that during the week. Figure 5 below shows the strong statistical correlation between movement on weekdays and Saturdays, with each point representing one of the pavements that was observed.

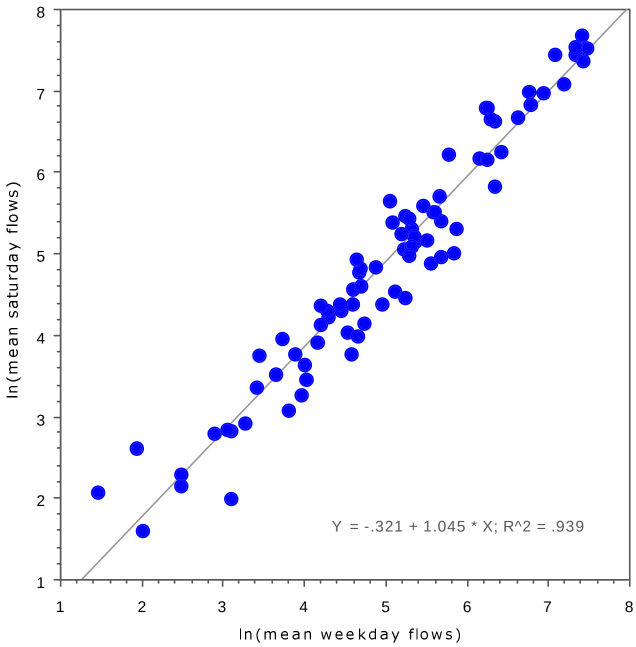


Figure 5: Correlation between movement on each pavement on a weekday and a Saturday

Overall, the mean level of movement on a Saturday is a little greater than that on the weekday (342 : 320 people per hour). Movement is higher on Oxford Street and Charing Cross Road (the two main routes used by shoppers and tourists within the area).

The most pronounced difference between weekdays and Saturdays is the time of day at which the pedestrian flows peak. Figure 6 below shows the percentage difference from the mean movement in each hour of the day to show the difference in peak flow[2]. The weekday flows peak at 8-9am, 1-2pm and 5-6pm. These are the times generally associated with office workers' movement (arriving at work, lunchtime and going home). On the Saturday, the pattern of movement is quite different: there is a gentle build up in pedestrian movement from 8 in the morning to a single peak between 3-4 in the afternoon. This is more reflective of the shopper and visitor pattern of use, with people travelling into town later in the morning, and moving around a lot during their visit rather than staying in a building.

[2] The error bars show 1 standard error.

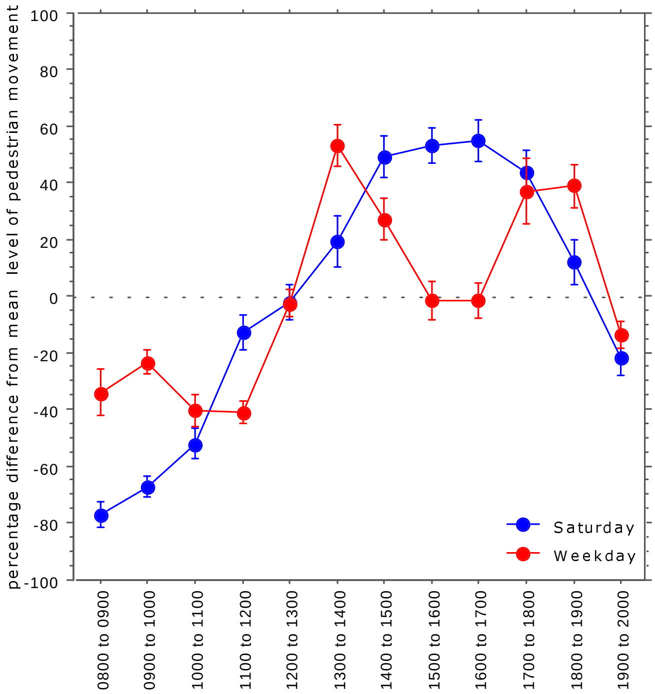


Figure 6: Pedestrian movement peaks on Saturdays and Weekdays

3.4 The Influence of pavement width on pedestrian flow

Strong differences in the absolute flow of pedestrians moving along each pavement in the area have been observed. However, pavements are not uniform in size and there are differences in the amount of available pavement width for pedestrians to use. Crowding on pavements can lead to pedestrian movement congestion, which it seems reasonable to assume would reduce observed pedestrian flows much like a traffic jam reduces the flow of cars.

There is a positive relationship between the number of moving pedestrians and the width of the pavements to accommodate them within the area[3], as can be seen in Figure 7 below (each dot in the scatter is a pavement). However there are some significant outliers. Some streets have wider pavements than would be expected for the level of movement on them. St Giles' High Street is an interesting example of this. The narrow kerb next to the 'Swimming Pool' under Centre Point tower is the one point (the most upper-left point in the scatter) that has significantly less pavement than would be expected for the level of movement.

[3] The more crowded pavements are *below* the regression line in Figure 7, whilst the less crowded are above the regression line.

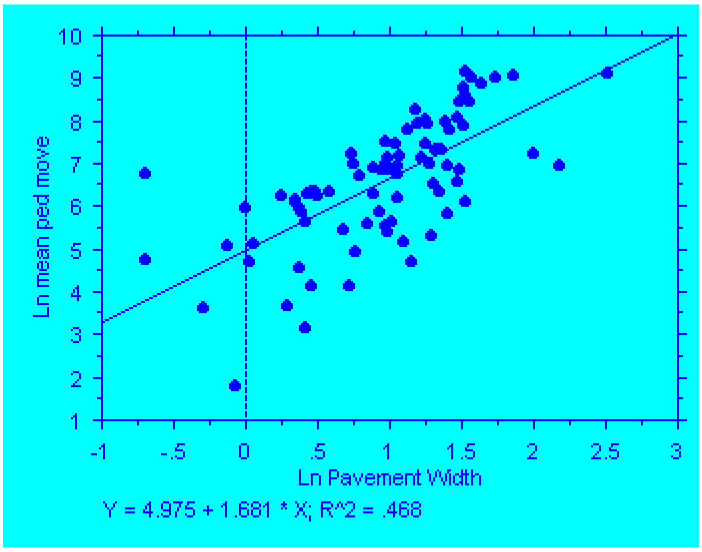


Figure 7: Relationship between pavement width and average number of passing pedestrians

These differences in the relationship between width and flow can be seen as a measure of the crowding of the pavement. Their spatial pattern is shown in Figure 8. As might be expected, the most heavily used pavements on Oxford Street and on the Western side of Tottenham Court Road and Charing Cross Road show much higher levels of crowding than the back streets. However, the highest level of movement per available width is shown on the tiny pavement that borders the 'Swimming Pool' on the Eastern side of Charing Cross road underneath Centre Point (pictured in Figure 4 on page 8). This has significantly higher levels of crowding than any other route.

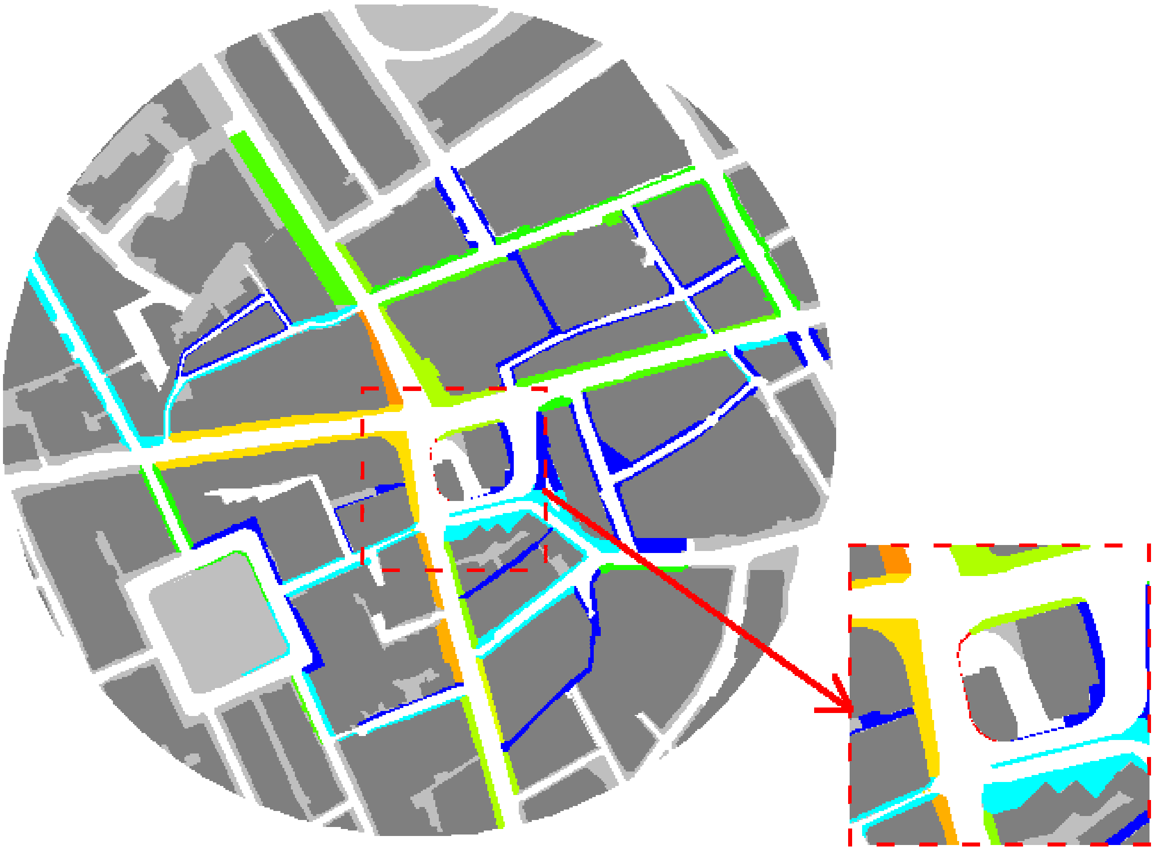


Figure 8: Pedestrian flow per m of available pavement width

The findings of the pedestrian movement study showed that there is a general relationship between pedestrian flow and pavement width in the area, as was seen in Figure 7. It may be that this is the result of long-term planning adaptations to demand, whereby streets with more movement have had their pavement width increased. However, this begs the question as to what determines demand for pavement space being higher on some streets than others? Is there a role for the spatial structure of the city in influencing movement routes? This is the subject of the next section.

4 MEASURING URBAN SPATIAL STRUCTURE

Having outlined the evidence of a case study on pedestrian flows, we now can investigate whether there is a relationship between urban spatial structure and these use patterns. To do this we need a measure of urban spatial structure and a theoretical model of the relationship to movement that can be tested with observed data. Model definition is a matter of trial and error learning, as Krugman suggested;

> "you make a set of clearly untrue simplifications to get the system down to something you can handle; those simplifications are dictated partly by guesses about what is important, partly by the modelling techniques available. And the end result, if the model is a good one, is an improved insight into why the vastly more complex real system behaves the way it does."
>
> (Krugman 1995) p71

The modelling approach adopted in this article is a regression model using some independent measure of spatial structure to correlate against the dependent variable of observed pedestrian movement flows. If there is a significant statistical relationship between the independent spatial variable and the dependent variable of pedestrian movement, then we have a model of a process that requires some theoretical explanation.

What is the best independent representation and measure of spatial structure? Although any measure of the environment is a simplification, that simplification must describe the environment in some way that is susceptible to analysis. This makes it possible to use some measure of spatial characteristics that can be tested against pedestrian movement. The measure can be judged on how objective, reproducible and universally applicable it is and how well it predicts pedestrian movement. The method used here is Visibility Graph Analysis and its strengths and limits will now be evaluated.

4.1 Visibility Graph Analysis

4.1.1 Methodology

Visibility Graphs were calculated using the ‘Fathom’ Visibility Graph Analysis software created by Intelligent Space of London, UK. This software calculates the visibility matrix on a regular grid of points within the area[4]. This process can be applied to any urban area or building to create comparable measures of the intervisibility of public spaces in different environments. By using the same parameter of grid resolution and the same sampling techniques for movement observation, the relationship between spatial measures calculated in the Visibility Graph and pedestrian movement in different cities and cultures can be investigated. Figure 9 below shows a graphic representation of the visibility of all pedestrian spaces in the St Giles Circus study area calculated with Visibility Graph Analysis. The colour scale used is a spectral range with red denoting the highest visibility through to deep blue denoting the most secluded areas.

[4] As has been noted, the very low mean depths of visibility graphs make measures of integration unusable without analysing the entire city. Therefore only the local measure of point connectivity (or visibility) was tested. Even the so-called ‘local’ measure of visibility required a much larger area of the city to be processed, extending far beyond the study area on long streets such as Oxford Street as far as would be visible from any point in the study area. This was in order to ensure that values for visibility within the study area were correct.

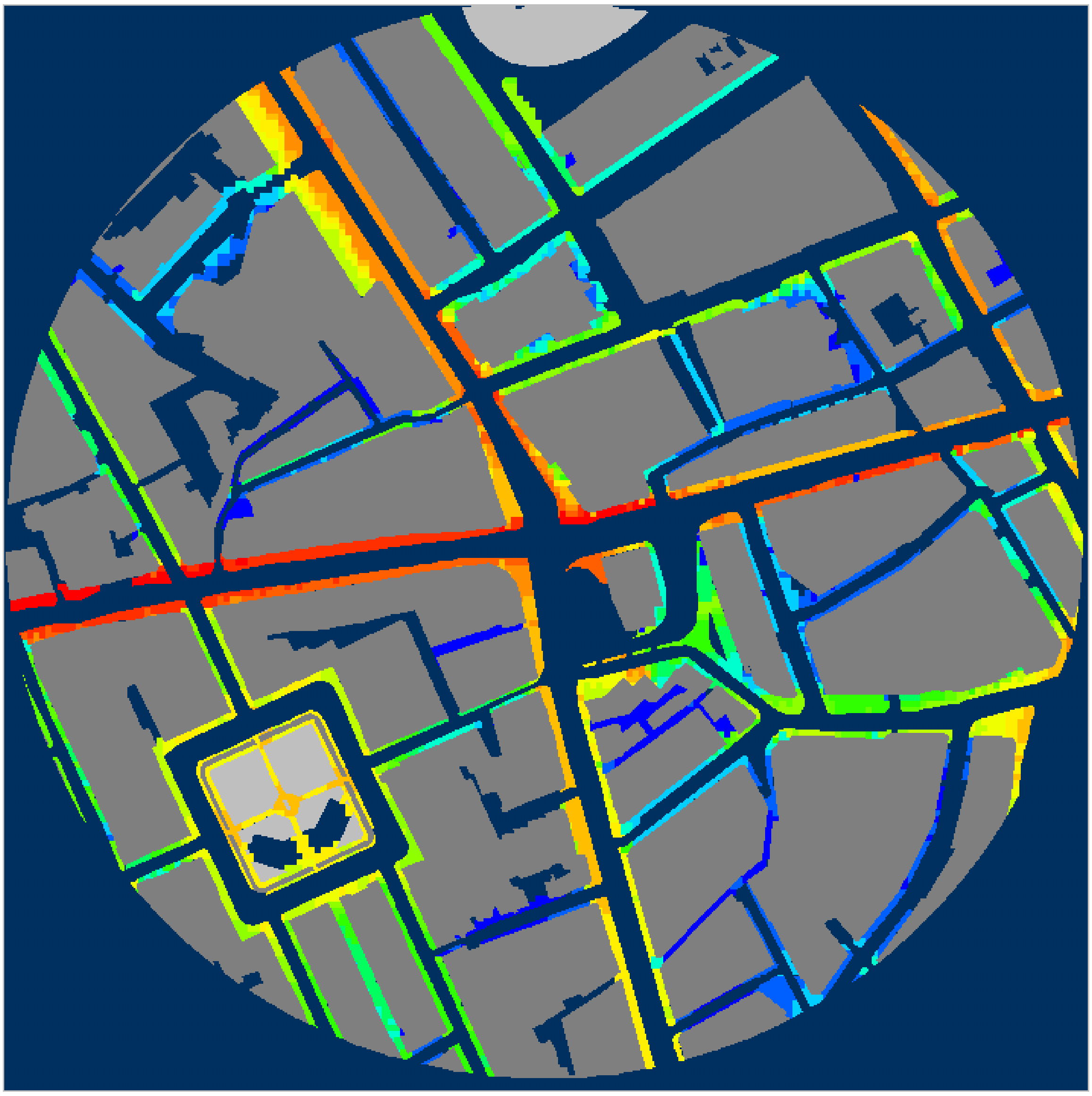
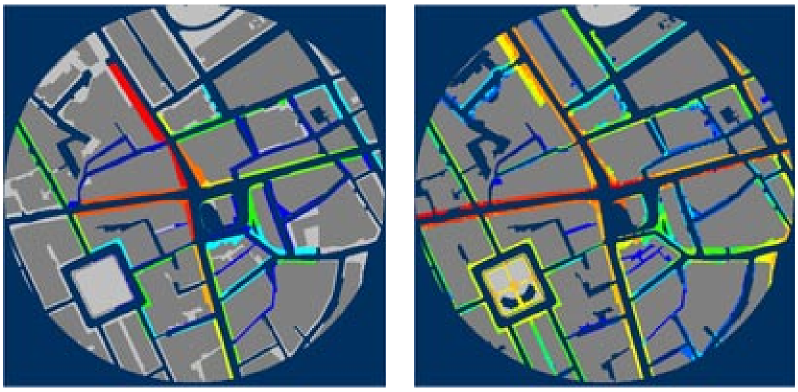


Figure 9: Visibility of pedestrian space in the study area calculated with VGA (colour scale)

4.1.2 results

The visibility Graph Analysis of the study area shows some striking characteristics of the urban morphology underlying the pattern of movement. The most visible routes through the area (Oxford Street and Tottenham Court Road) are also those with the highest visibility for pedestrians. The effect of Centre Point Tower on cutting off the visibility of St Giles High Street can also be seen in the analysis, which shows a strong distinction between the Circus and the area behind the tower. The pattern of visibility underlies the distribution of movement in the area, which in turn supports the distribution of commercial land uses so that all three resemble each other: Oxford street is the most visible route as well as having the most pedestrian movement and the highest concentration of retail uses.

The visual similarity between this spatial analysis and the observed pedestrian flow data can be seen in Figure 10 below.



(a) Pedestrian movement flows (c) VGA visibility

Figure 10: Comparison of pedestrian movement and Visibility Graph Analysis in the study area

This visual similarity can also be explored statistically by linking the VGA measures on each of the pavement spaces to the observed pedestrian flows. This is undertaken in a Geographic Information System and exported to a statistical package to facilitate regression modelling.

The relationship between visibility and movement is better with a higher grid resolution of 3m than 5m. The higher grid resolution creates a more accurate representation of the streetscape, showing fine scale differences in what pedestrians can see. For ln average movement, the mean visibility of points on a pavement predicts to r^{2}=.456 when a grid of 5 metres is used. When the grid resolution is increased to 3m the correlation rises to r^{2}=.625. For both cases p=<.0001.

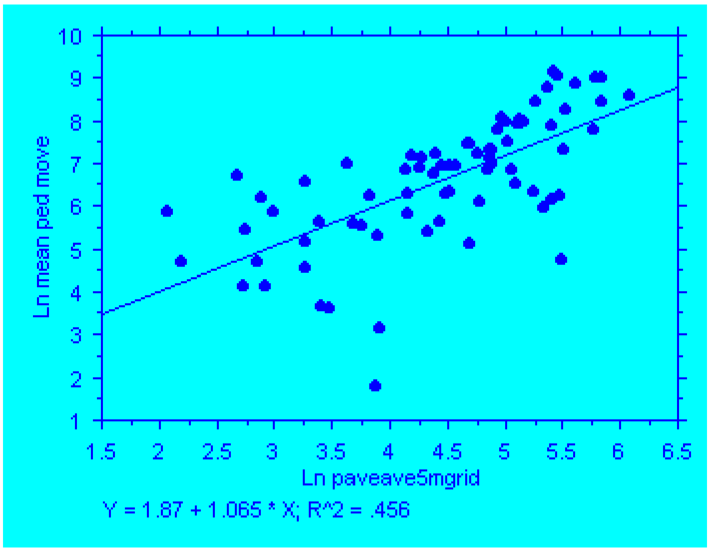


Figure 11: Correlation between Ln mean Visibility (5m grid) per pavement and Ln mean pedestrian movement

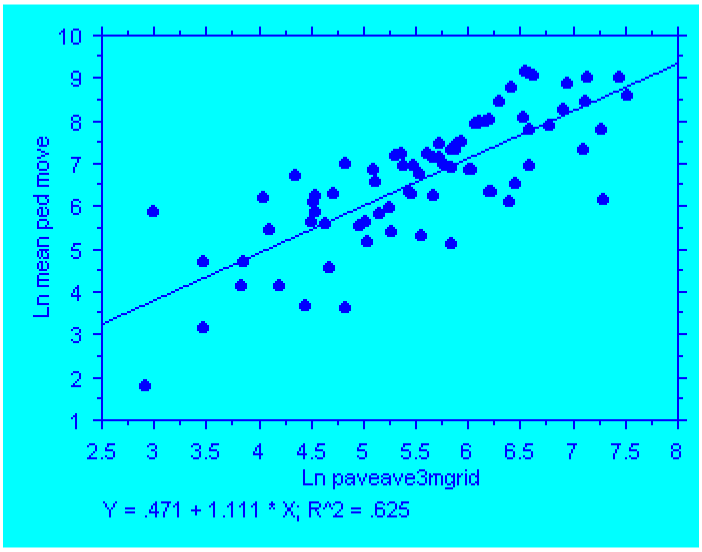


Figure 12: Correlation between Ln mean Visibility (3m grid) per pavement and Ln mean pedestrian movement

4.1.2.1 'Gate' Visibility and Movement

Although increases to the resolution of the grid increased the performance of visibility as a predictor of movement, the correlation was not improved by taking visibility only in a restricted area around the gate where movement was counted. For average visibility within a buffer of 5m radius around the gate, the correlation with a grid of 5m was only r^2=.19 and when the higher resolution grid of 3m was used it rose only to r^2=.425, as can be seen in Figure 13 below.

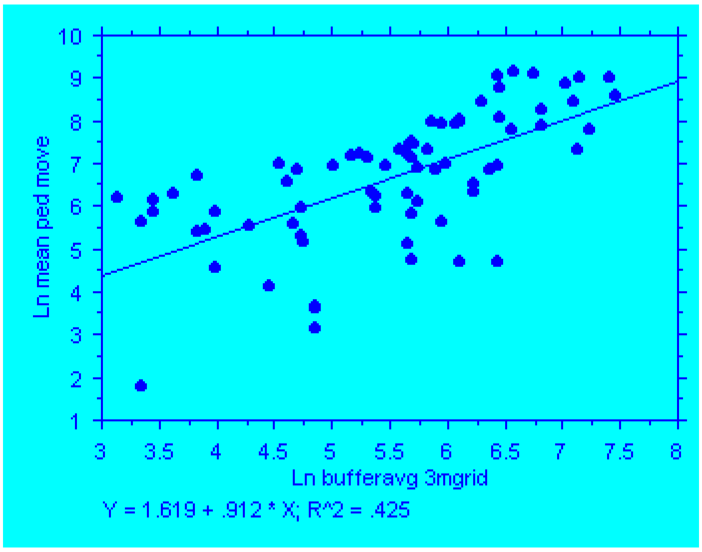


Figure 13: Correlation between Ln mean Visibility (3m grid) per gate buffer and Ln mean pedestrian movement

4.1.2.2 movement per m of available pavement width

Pavement width also has a positive influence on visibility, as can be seen by the .34 correlation of the two in Figure 14 below. In this sense the measure of visibility captures the differences from pavement widths and the correlation between visibility and movement is therefore reduced when movement is controlled for pavement width. Nonetheless it is still significant at r^2=.556.

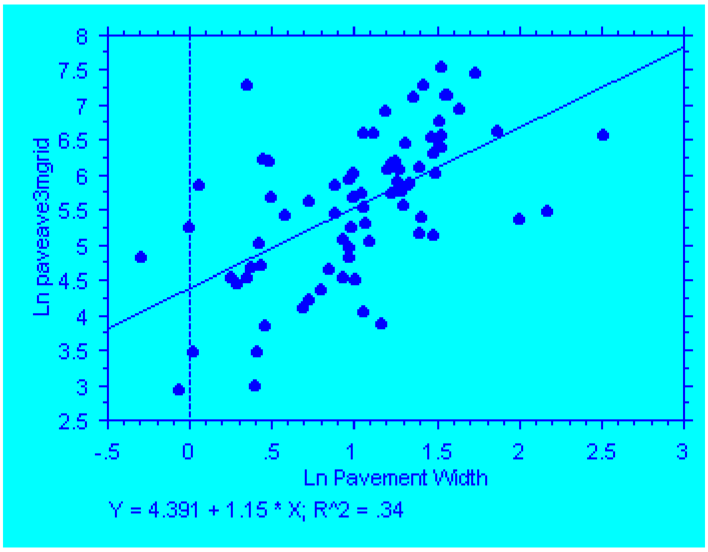


Figure 14: Correlation between Pavement Width and Visibility

5 CONCLUSIONS

This paper has explored the potential of measures of visibility to model the influence of urban layout on pedestrian movement. We have presented a study of observed pedestrian movement in which flows vary significantly from street block to street block and on different sides of the street. The capacity of pavements (pavement width) can be used to explain some of this variance, but measures of pedestrian visibility within the urban layout have been found to correlate much more powerfully. The strongest correlate of movement was visibility of pedestrian space (measured as the mean connectivity of VGA seed points spaced on pavements with a 3m grid). It seems that the relatively unplanned layout of the street system itself has come to influence pedestrian movement dispersal within it over time. This may also have influenced the pattern of commercial land uses as they have evolved in the area, since the most visible routes of Oxford Street and Tottenham Court Road are also those with the highest concentration of pedestrian oriented land uses.

This relationship between the visibility of spaces within the street grid and the distribution of pedestrian flows can be used to model the potential impact of new planning schemes. At least as far as the influence of layout is concerned, models using Visibility Graph Analysis can be constructed for urban design plans to simulate the potential pedestrian flows under alternative schemes. This can help avoid the 'dead spaces' and dangerous pedestrian vehicle conflicts that undermine the vitality of some spaces, such as those around St Giles Circus.

The results of this paper raise interesting questions for further research. Why does the local measure of visibility correlate so well with movement? This finding is especially interesting as it has been suggested by the theory of 'natural movement' that location within a wider framework of the surrounding city should be more important in determining movement (Hillier 1996) rather than the local properties of a space, such as its visibility. Perhaps because greater visual reach into surrounding streets is used as a heuristic by pedestrians seeking to travel on more direct routes. Or perhaps we will find that when large enough Visibility Graphs can be constructed to calculate more global graph measures that these do indeed predict better than visibility alone. These findings can be tested by independent researchers on different cases because we now have a technique to measure urban morphology that is objective and universally applicable. The more powerful correlations shown in this paper suggest that the testing will bring very interesting results.

6 ACKNOWLEDGEMENTS

Many thanks to Camden Council for their co-operation, especially Andy Kemp.

7 BIBLIOGRAPHY

Batty, M., R. Conroy, et al. (1998). The Virtual Tate. London, CASA.
Braaksma, J. P. and W. J. Cook (1980). “Human orientation in transportation terminals.” Transportation Engineering Journal **TE2 106**(March): 189-203.
deBerg, M., M. van Krefeld, et al. (1997). Computational Geometry. Berlin, Springer Verlag.
Desyllas, J. and E. Duxbury (2000). Axial Maps And Visibility Graph Analysis: A Comparison Of Their Methodology And Use In Models Of Urban Pedestrian Movement. Space Syntax Third International Symposium, Atlanta, Georgia Tech.
Giddens, A. (1995). The Time-Space Constituent of Social Systems. A Contemprary Critique of Historical Materialism, Macmillan.
Hillier, B. (1985). “The Nature of the Artificial.” Geoforum **16**(2): 163-178.
Hillier, B. (1996). Space is the Machine. Cambridge, Cambridge University Press.
Krugman, P. (1995). Development, Geography and Economic Theory. London, MIT Press.
Ponsard, C. (1983). History of Spatial Economic Theory. Berlin.
Schelling, T. (1978). Micromotives and Macrobehaviour. New York, W.W. Norton.
Turner, A., M. Doxa, et al. (1999). “From Isovists to Visibility Graphs.” UCL website and forthcoming in Environment and Planning B.
Turner, A. and A. Penn (1999). Making Isovists Syntactic: Isovist Integration Analysis. Space Syntax Symposium, Brasilia, Brasil.