The distribution of use of public space in urban areas

THE DISTRIBUTION OF USE OF PUBLIC SPACE IN URBAN AREAS

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ABSTRACT

Space Syntax is a technique (originally developed at the Bartlett School of Architecture, London) for morphological analysis of urban areas and urban plans. It relates morphological features to the distribution of use of public space. It claims to predict movement patterns in urban areas.
In this paper we report on results of an analysis of three neighbourhoods in the City of Eindhoven, The Netherlands. A study was conducted as a pilot for the analysis of 24 neighbourhoods throughout The Netherlands.
The results show that Space Syntax does to some extent predict movement patterns. However, the predictions for car traffic are far better than those for pedestrian movement. In the discussion section we describe a possibility to improve the prediction of pedestrian movement patterns by using the data set of the larger survey.

1 INTRODUCTION

The importance of Space Syntax lies in relating morphology and human behaviour. Under this general heading a wide range of topics has been researched. For example: the function of the morphological structure of buildings in way-finding processes (Peponis et al., 1990), spatial patterns of crime in urban areas (Hillier et al., 1989a), social implications of different ways of structuring city form in the third world (De Holanda, 1989), and the relation of the spatial structure of townships in South-Africa with the mechanisms of control in the apartheid ideology (Mills, 1989).
Perhaps the most important and most heavily researched topic is the relationship of the morphological structure of urban areas and (mostly pedestrian) movement patterns (Hillier et al., 1983; Hillier and Hanson, 1984; Hillier et al., 1987; Hillier, 1988; Hillier et al., 1989b; Hillier et al., 1990; Peponis et al., 1989). It has been argued that Space Syntax can predict the distribution of use of public space, but only few studies are concerned with systematically testing this hypotheses.
In this paper we present a way to test this aspect of Space Syntax systematically. We report on the results of a survey conducted in three neighbourhoods in the City of Eindhoven, The Netherlands, as a pilot for a wider survey concerning 24 urban neighbourhoods.

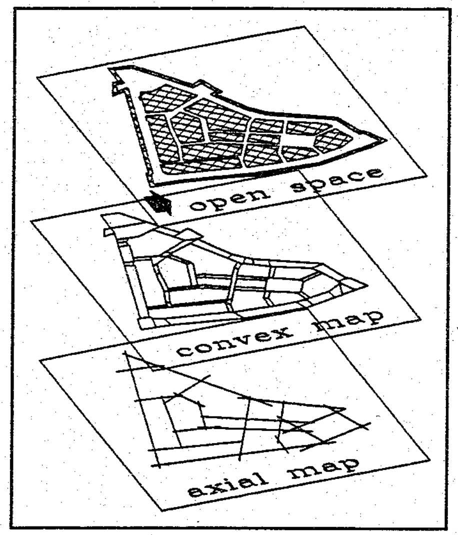


Figure 1

2 SPACE SYNTAX

The model of Space Syntax used in this study differs from the original one developed at the Bartlett School of Architecture, London. The main difference concerns an extended concept of integration as expressed in the mathematical level of integration.

2.1 Representation of Urban Areas
To apply Space Syntax it is necessary to

construct a graphical representation of an urban area. This is typically done by dividing the total space of the area into public and non-public space. Public space can only be continuous and is called the Open Space of the area. This Open Space is divided into the least set of fattest Convex Spaces. By definition no tangent can be drawn on the perimeter of a Convex Space that passes through that space at any point.
On basis of both the Open Space and the configuration of the Convex Spaces the Axial Map of an area can be drawn. The Axial Map contains the least set of the longest straight lines that can be drawn in the Open Space so that every Convex Space is crossed by at least one such line. The number of lines is called L[1]. Figure 1 shows the Open Space, the Convex Map and the Axial Map of a small neighbourhood in the City of Eindhoven, the Netherlands. In Space Syntax mainly the Axial Map is being used as the representation of the morphological structure of an urban neighbourhood.
Not all public space is accessible to car traffic. Therefore the Open Space of a neighbourhood differs for pedestrians and motorists. It is advisable to make two different analyses of every neighbourhood: one based on the Open Space for pedestrians and one based on the Open Space for motorists. In the Dutch situation the Open Space for pedestrians coincides with the Open Space for cyclists.

2.2 Integration

In Space Syntax distance always means topological distance and we will refer to it as Depth or D. Depth is measured in steps. The depth between two lines of an axial line that intersect is 1. In every other case it is the minimal number of lines that must be crossed in order to get from one line to the other, plus 1. The sum of the depths of a line to all the other lines of the Axial Map is called the total depth or $_TD$ of that line.
When a line of an Axial Map has a low $_TD$ value the Axial Map will look shallow from this point of view: all the other lines are very near. The Axial Map will look much deeper from lines with higher $_TD$ values. Maps with a low mean $_TD$ value will, from most lines, look more shallow than maps with a high mean $_TD$ value.
The distinction between deep and shallow is central to Space Syntax. Urban areas are described and compared in terms of the depth and shallowness of their Axial Maps. It is supposed that the distribution of $_TD$ values across the lines of the Axial Map corresponds to the distribution of use of public space (Hillier et al., 1983; Hillier and Hanson, 1984; Hillier et al., 1987; Hillier, 1988; Hillier et al., 1989b; Hillier et al., 1990; Peponis et al., 1989).
Lines or Axial Maps that are shallow are called integrated. This form of integration is called *global* integration because it takes into account all the lines of the Axial Map.
$_TD$ values can be standardised in a measure that is independent of the number of lines. Simulation studies have shown the Integration Score (I) to be a reliable measure (Teklenburg et al., 1991). High I values indicate integration, low values segregation. In equation:

$$I = \frac{\ln(\frac{L-2}{2})}{\ln({}_TD-L+1)} \qquad (1)$$

The public space outside the area that is being analyzed is called the Carrier Space and is referred to as Y. Y is considered to be a single entity. Every line of an Axial Map has a Depth from Y. Depth from Y is referred to as $_YD$. A line is supposed to intersect with Y only in the case that it would intersect with at least three lines that could be drawn in Y if an Axial Map of that area had been made, and none of these three lines is a line or an extension of a line of the Axial Map that is being analyzed.
For lines that intersect with Y, $_YD$ equals 1. In every other case $_YD$ equals 2 plus the minimal number of lines that must be crossed in order to get to a line with $_YD = 1$.
The mean Depth from Y for an Axial Map can be calculated by taking the mean of the individual $_YD$ values of the lines of the map. This mean depth is referred to as $_Y\overline{D}$.
This measure is even *more global* than the integration expressed in the Integration Score, as it not only takes into account a number of lines of an Axial Map but also the Carrier Space.
Axial Maps with low $_Y\overline{D}$ values and lines with low $_YD$ values are called integrated towards Y. It is inconvenient that, contrary to I values, *low* $_YD$ values indicate *integration* and high values indicate segregation. The solution to this problem lies in the construction of a measure called the Relative Depth from Y. For any line of an Axial Map this measure is defined as the mean Depth from Y of that Axial Map minus the Depth from Y of that line. In equation:

$$^r_YD = {}_Y\overline{D} - {}_YD \qquad (2)$$

2.3 Mathematical Level of Integration

Space Syntax seems to have some trouble predicting the distribution of use of public space using only I values because of a bias for the edges of urban areas (Hillier, 1988; Hillier et al., 1989a; Hillier et al., 1989b; Hillier et al., 1990). It seems reasonable to assume that this has something to do with what is happening outside

the area, therefore with Y.
It is possible to construct a third level of integration in between global integration and Depth from Y. Global integration means integrated towards all the lines of an Axial Map. Depth from Y means integrated towards Y. Y and 'all the lines of an Axial Map' are entities that can be pointed to on map. As the third level of integration has no such entity, we call it a mathematical level of integration.
The mathematical level of integration corrects I values for the Depth from Y. This means for example that lines with high I values but low ${}^{r}_{Y}D$ values are considered to be less integrated than lines with the same I values and high ${}^{r}_{Y}D$ values. On the mathematical level of integration for every line of an Axial Map a ranking value or R is being calculated. The ranking value of a line is defined as the sum of the Relative Depth from Y of that line and the integration score of that line multiplied with a correctional number. This correctional number should express that the mathematical level of integration will be closer to Depth from Y in case of small Axial Maps and/or maps that are shallow towards Y. Large maps and/or maps that are deep towards Y should be closer to global integration. This will be the case if we use the following equation:

$$R = \left(\alpha L - \frac{\beta}{{}_{Y}\overline{D}}\right) I + {}^{r}_{Y}D \qquad (3)$$

We suppose that, instead of I values, the distribution of R values across an Axial Map corresponds to the distribution of use.
In equation (3) the value of parameters α and ß determine how near the mathematical level of integration is to Depth from Y, e.g. how big the influence of Y is on the distribution of integration. The parameters will have to be calibrated, using actual data of the distribution of use of public space. As these are not yet available, we decided (for the purpose of the pilot study) to make some assumptions about how big an influence could be considered reasonable for different types of Axial Maps. This leads to:

$${}_{Y}\overline{D} \leq 1.5:$$
$$R = I + {}^{r}_{Y}D$$

$${}_{Y}\overline{D} > 1.5:$$
$$R = \left(\frac{14L({}_{Y}\overline{D} - 1.5) + 27}{18\,{}_{Y}\overline{D}}\right) I + {}^{r}_{Y}D \qquad (4)$$

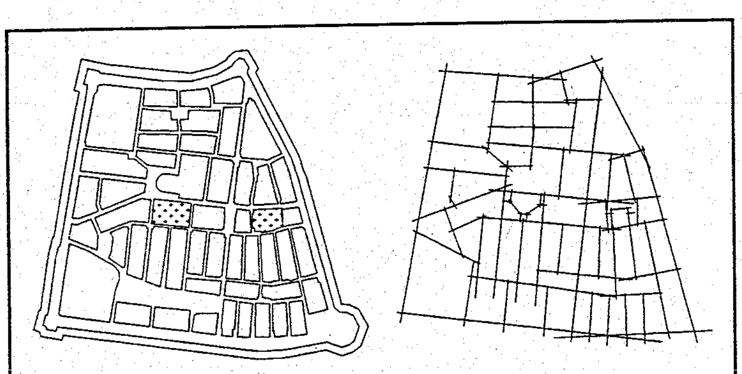


Figure 2:
De Roosten, 1920-1940

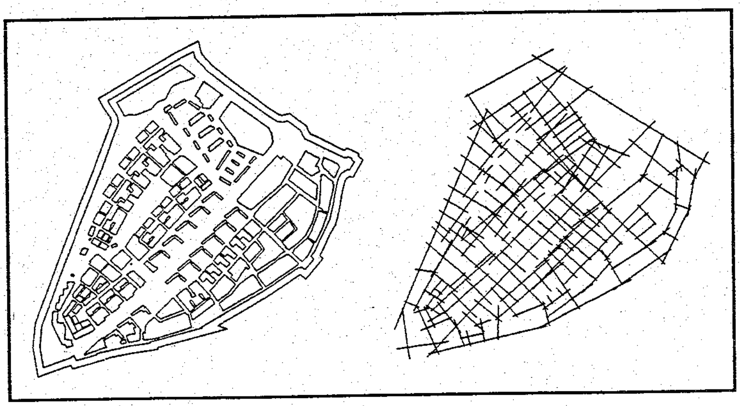


Figure 3:
Blaarthem, 1940-1960

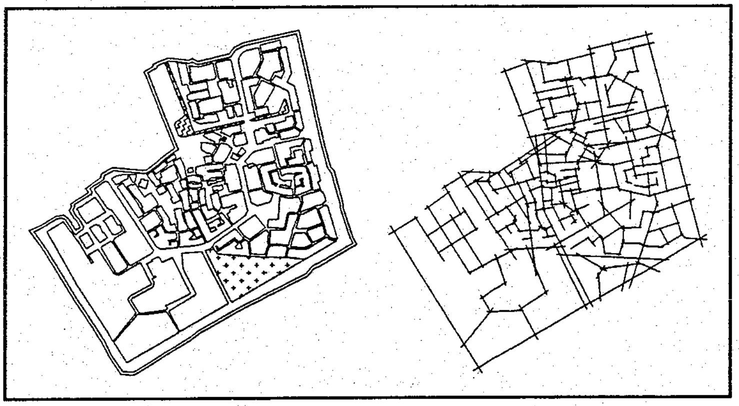


Figure 4:
Achtse Barrier, after 1980

3 THE NEIGHBOURHOODS

The three urban neighbourhoods we choose for the pilot are part of the sample of 24 neighbourhoods for the larger survey. The 24 neighbourhoods represent a wide range of morphology types that can be found throughout The Netherlands. The three neighbourhoods chosen are all part of the same town (Eindhoven), but differ in age.

3.1 Characteristics

Figures 2-4 show the three neighbourhoods, their Open Space (for pedestrians) and the corresponding Axial Maps. In the Open Space Maps some areas are hatched with little crosses. These areas represent Accessible Landscaped Areas. They are considered to be Open Space, but the lines drawn in them follow the pathways in the areas and are only extended as far as the first Convex Space outside the Landscaped Area.

Table 1: morphological characteristics

	De Roosten		Blaarthem		Achtse Barrier	
	ped.*	mot.**	ped.*	mot.**	ped.*	mot.**
age	1920-1940		1940-1960		after 1980	
area	69.1 ha		98.6 ha		115.9 ha	
number of lines	70	67	158	168	214	184
mean length of lines	233.0	261.1	201.0	135.2	141.4	115.1
number of lines in sample	30	30	40	42	54	46
percentage	42.9	44.8	25.3	25	25.2	25
mean length of sample-lines	240.6	274.9	213.2	130.1	147.6	122.2
number of lines / area	1.01	0.97	1.60	1.70	1.85	1.59
mean $_{Y}D$	2.4	2.21	3	3.86	3.40	6.42
number of lines with $_{Y}D=1$	10	12	6	7	6	3
lines $_{Y}D=1$ / number of lines	0.14	0.18	0.04	0.04	0.03	0.02
I						
mean	0.707	0.702	0.729	0.671	0.686	0.631
minimum	0.633	0.656	0.658	0.625	0.654	0.593
maximum	0.764	0.788	0.822	0.738	0.734	0.669
range	0.101	0.132	0.164	0.113	0.080	0.076
R						
minimum	12.035	10.153	36.712	44.549	59.076	59.255
maximum	16.403	15.508	51.629	60.375	70.464	77.528

*neighbourhood analysed for pedestrians and cyclists
**neighbourhood analysed for motorcars

The boundaries of the neighbourhoods coincide with the boundaries used to describe neighbourhoods for statistical purposes as used by local authorities. Most of the boundaries are natural: main roads, canals and streams. Only the northern boundary of Achtse Barrier is somewhat artificial. This means that De Roosten and Blaarthem are likely to be real entities. Achtse Barrier is such to a much lesser extent.
Table 1 shows some morphological characteristics of the three neighbourhoods. It is clear that the number of lines of the axial map increases as the neighbourhood is younger. The mean length of the lines decreases. As the neighbourhoods differ in area, the ratio of the number of lines and area expresses how much a neighbourhood is broken up by the lines. This ratio increases as the neighbourhood is younger. It is remarkable that the difference between the axial maps for pedestrians and for motorists gets bigger as the neighbourhood is younger.
The number of lines with ${}_{Y}D$ = 1 decreases as the neighbourhood is younger, and so does the ratio of that number of lines and the number of lines of the axial map. ${}_{Y}\overline{D}$ values increase as the neighbourhood is younger. This shows that older neighbourhoods are much more accessible from what is happening outside them than the younger ones.
For each Axial Map I and R values were computed. Table 1 shows the aggregated results. As R is an ordinal value no mean was computed. It is clear that the three neighbourhoods differ morphologically: in mean I value, in the range of R values and in difference between analysis for pedestrians and motorists.

3.2 The Sample of Lines

In order to analyze the correlations between the distribution of R values and the distribution of use of public space, for each Axial Map a sample was taken out of the lines of the map. The samples were stratified. The population of lines was divided into four sets according to their ranking in R value (using equation 4). Each set randomly produced 25% of the sample lines. The geographical distribution of the sample lines across the Axial Map was checked and considered to be satisfying.
The samples contain 25% of the lines of the Axial Map, with a minimum of 30 lines.
Table 1 shows that the mean length of the sample lines differs very little from the population mean. This, together with the stratification and the satisfying geographical distribution across the Axial Map, indicates that the samples give a good impression of the Axial Maps as a whole.

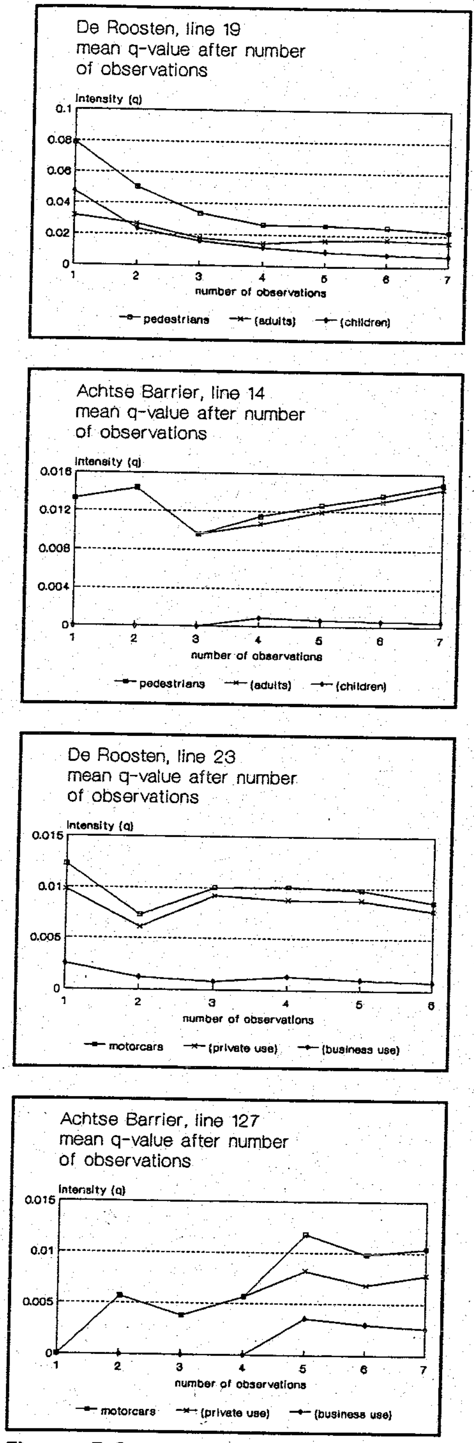
4 MOVING OBSERVER METHOD

The intensity of use of a line of an Axial Map can be described as the sum of the intensities of use of the Convex Spaces that are crossed by that line. So the number of people (or motorcars) present in those Convex Spaces should be counted.

A moving observer technique was used to count the number of people (or motorcars) present in the Convex Spaces that are crossed by the sample lines. The observations were made while walking along a sample line.
As there is some evidence for difference in adult and child use of public space, pedestrians and cyclists were observed in two categories: adults (≥ 16 years of age) and children (< 16 years of age, not accompanied by adults). Motorcars were observed in two categories as well: private and business use. The category business use contains heavy traffic and light traffic that can easily be recognised as business use (like a company van).
The measure of intensity of presence of people (or motorcars) along a line is derived from the moving observer method designed by the Transport and Road Research Laboratory, England (Heere en Akkerman, 1973).
Let t_a be the time an observer needs to walk along a line in the one direction and t_b the time he needs in the other direction. Direction a and b cover one observation. The observer counts the number of people moving in the opposite direction, plus the number of static people he encounters. Let these numbers be x_a for direction a and x_b for direction b. At the same time the observer counts the number of people moving in the same direction that are passing him, minus the number of people moving in the same direction that are passed by him. Let these numbers be y_a for the one direction and y_b for the opposite direction. Now the intensity (q) can be expressed in:

$$q = \frac{x_a + x_b + y_a + y_b}{t_a + t_b} \qquad (5)$$

Intensity can be seen as the mean number of people (or motorcars) present in any cross section over a line. The moving observer method designed by the Transport and Road Research Laboratory assumes a continuous traffic flow. As this is obviously not the case along most of the sample lines, the computed q-values can only be ordinal values.
After ten observations (per line) new observations do not substantially contribute to the mean q-value over the observations (Heere en



Figures 5-8

Akkermans, 1973). So every sample line was observed ten times. Due to practical problems during the observations a number of lines was observed a smaller number of times.
The observations were made on monday afternoons, tuesdays, wednesday mornings and thursdays during two weeks in the month of june.

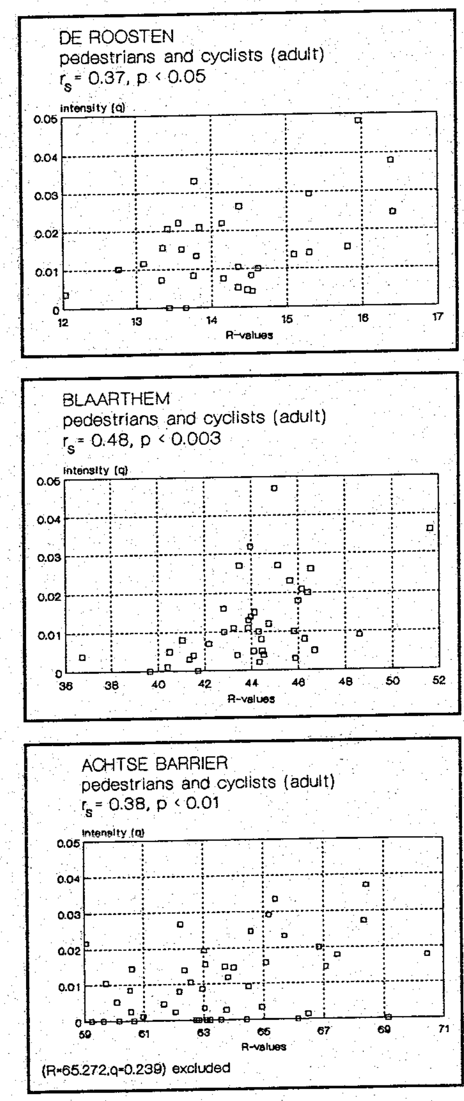
5 RESULTS

Table 2 shows the mean q-values for the three neighbourhoods. In all cases intensities for children are much lower than for adults. In Blaarthem they are extremely low. Intensities for business used motorcars are lower than for private use. Extreme low intensities were found in Achtse Barrier.
Figures 5-8 show examples of the contribution of individual observations to the mean q-value of a line. It seems that most of the time mean q-values stabilise after six or seven observations.
Table 3 shows the results of correlation analyses between R or I values, and the observed q-values. As q-values (as well as R values) are ordinal, Spearmans Ranking Correlationcoefficient (r_s) was used. In two neighbourhoods correlations for car traffic are much higher than for pedestrians. In the case of Blaarthem the opposite is the case. This may be caused by the low intensities for pedestrians.
Correlations for adult pedestrians are much higher and much more significant than for children. The significance problem may be caused by the observed low intensities. The difference between correlations for private used motorcars and business use is not very large. Correlations are always higher for private used motorcars though.
In most cases correlations for R values are higher than for I values. For pedestrians and cyclists the differences are small, they are much larger for car traffic.
As intensities for children and business used cars are low, we concentrated on adults and private used motorcars. Now in nearly all cases correlations for R values are higher than for I values, private used motorcars in Blaarthem being the only exception. The correlation for private used motorcars in that neighbourhood is much lower than in the other neighbourhoods.
Figures 9-11 show scattergrams of R values against q-values for adult pedestrians and cyclists in the three neighbourhoods. Correlations are not very high, but significant and the relations seem linear.
Figures 12-14 show scattergrams of R values against q-values for private used motorcars. Correlations are much higher (with the exception of Blaarthem). The relations do not seem to be as linear as for pedestrians.
Some observations are excluded from the scattergrams, due to high q-values. These high values coincide with lines representing (parts of) main roads of the City of Eindhoven, a line re-

Table 2: mean intensities (q)

	De Roosten		Blaarthem		Achtse Barrier	
	ped.*	mot.**	ped.*	mot.**	ped.*	mot.**
total	0.019		0.013		0.022	
adults	0.015		0.012		0.015	
children	0.004		0.001		0.007	
total		0.057		0.014		0.015
private use		0.047		0.012		0.014
business use		0.009		0.002		0.001

*pedestrians and cyclists
**motorcars



Figures 9-11

presenting a road giving access to an industrial area and a line representing a road in a shopping mall opposite to a large supermarket.

6 DISCUSSION

Is Space Syntax capable of predicting movement patterns? One must be careful to answer this question based on the results of this project. The number of neighbourhoods analyzed was restricted. R values are ordinal, and so are the observed q-values. For some forms of behaviour (especially child movement patterns) correlations are low and not very significant. Keeping this in mind, we can only reach a tentative conclusion. The results of the analyses seem to suggest that there exists an ordinal relationship between the morphology of urban areas and intensity of some types of movement.

An important conclusion of this project must be that the mathematical level of integration as expressed in R values gives a better overall performance than global integration as expressed in I values. Correcting the Integration Score for $_{Y}D$ values may very well solve the problem of bias occurring at the edges of analyzed areas.

In this pilot study we did not calibrate the parameters of equation (3): three neighbourhoods is not a data set large enough to rely on. Instead we used fixed parameters, based on some assumptions of how large an influence of $_{Y}D$ values on the Integration Score would be reasonable. It appears that these fixed parameters are reasonably suitable to predict the distribution of use of public space by private used motorcars. To a minor degree they can be used to predict the distribution of use of public space for business used motorcars. The correlation between integration measures and pedestrian movement is however substantially lower. For children their seems to be no relation at all between intensity and R values using the fixed parameters.

Table 3: correlations

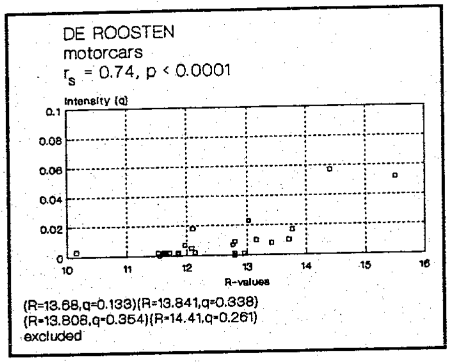
			ped.: total	ped.: adults	ped.: children	mot.: total	mot.: private	mot.: business
De Roosten	ped.*	R	0.239 p<0.20	0.370 p<0.05	0.157 p<0.40			
		I	0.319 p<0.09	0.328 p<0.08	0.185 p<0.32			
	mot.**	R				0.733 p<0.00	0.740 p<0.00	0.575 p<0.00
		I				0.512 p<0.01	0.520 p<0.01	0.270 p<0.16
Blaarthem	ped.*	R	0.463 p<0.00	0.477 p<0.00	0.018 p<0.91			
		I	0.417 p<0.01	0.442 p<0.01	0.092 p<0.5			
	mot.**	R				0.322 p<0.04	0.391 p<0.01	0.342 p<0.284
		I				0.356 p<0.02	0.394 p<0.01	0.362 p<0.02
Achtse Barrier	ped.*	R	0.283 p<0.05	0.380 p<0.01	0.146 p<0.32			
		I	0.252 p<0.08	0.349 p<0.02	0.089 p<0.54			
	mot.**	R				0.665 p<0.00	0.668 p<0.00	0.529 p<0.00
		I				0.642 p<0.00	0.653 p<0.00	0.445 p<0.00

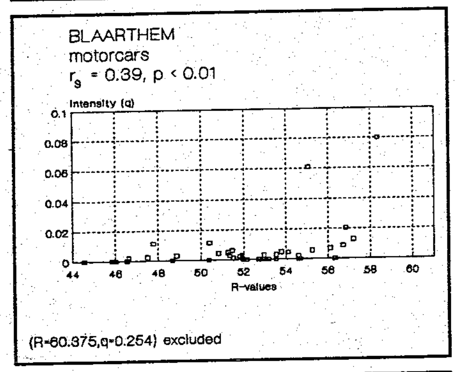
*pedestrians and cyclists
**motorcars

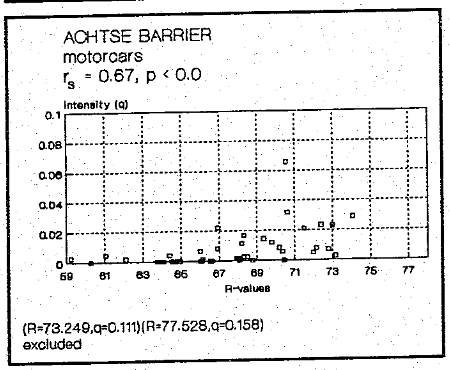
Global integration and Depth from Y are physical integration levels. They are also discreet levels of integration. One can imagine a continuum of integration between them:

Depth from Y
|
R values
|
Global Integration

The parameters in equation (3) determine the level of integration between Depth from Y and global integration. They determine how near the distribution of R values across an Axial Map is to the distribution of global integration.
Thinking this way the level of integration as expressed by the fixed parameters suites the relationship between the morphological structure of an urban neighbourhood and the distribution of public space by private used motorcars. In the cases of business used motorcars and adult pedestrians and cyclists other parameters will have to be used: these relationships may very well exist on another level of integration. One can imagine the relationship for business used motorcars on a level closer to Depth from Y, for adult pedestrians on a level closer to global integration. The parameters can be calibrated based on a data set existing of a large number of neighbourhoods, representing a wide range of morphology types.
The case of child pedestrians may be different from the other ones. One can imagine the radius of action of children to be very small. Therefore it might be possible that the range of integration levels between Depth from Y and global integration does not cover child use of public space.







Figures 12-14

If this is the case, a more local measure of integration will have to be constructed to describe the relation of morphology and distribution of use of public space. Based on the results of this pilot study it is very difficult to tell whether this will be a good direction of research: the observed intensities for children are too low to give reliable results.
To some extent Space Syntax seems able to predict movement patterns. In doing so the predictions for car traffic are better than those for pedestrians. It might very well be that, in spite of calibrating the model based on a large set of neighbourhoods, the performance of Space Syntax will always be better for car traffic than for pedestrians. In Space Syntax the representation of the morphological structure is topological. One can imagine motorists to minimise distances by minimising turns, which would suite a topological model. For pedestrians the real distance might be more important in minimising distances.

NOTES

1. This notation differs from the notation used at the Bartlett School of Architecture (they use k) and so will most of the notation we use.

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