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MODELING STREET CONNECTIVITY AND PEDESTRIAN MOVEMENT ACCORDING TO STANDARD GIS STREET NETWORK REPRESENTATIONS

018

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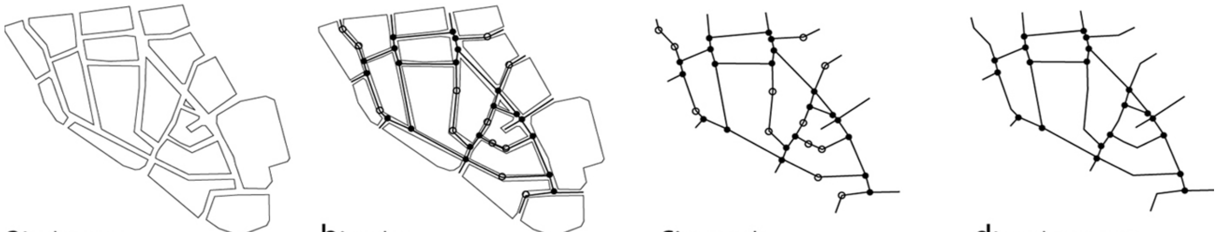
Abstract

We study three 1 mile x 1 mile areas in Atlanta to establish correlations between street configuration and densities of pedestrian movement. Two kinds of analysis are used: first, standard syntactic analysis applied to axial maps drawn to cover surrounding areas large enough so that Radius 3 Integration values assigned to observation spaces suffer no edge effects; second, new techniques of analysis that can be applied to standard GIS representations of street center-lines. It is shown that the new measures post-dict movement densities as well as the standard syntactic measures.

Can Alternative Measures of Street Connectivity be Used to Express Hypotheses on the Theory of Natural Movement?

The relationship between the distribution of pedestrian movement and the spatial structure of street layouts is well established (Hillier et al 1987; Peponis et al 1989; Hillier et al 1993; Penn et al 1998; Hillier and Iida 2005). The most cited pioneering studies have relied on "axial maps" of street networks drawn by the researchers. Here we discuss how far the correlation can also be replicated based on new measures of street connectivity (Peponis et al 2006). The new measures have been developed to allow the analysis of standard GIS-based representations of street networks according to street center-lines.

The unit of analysis is the road segment rather than the axial line. Road segments extend between choice nodes, or street intersections at which movement can proceed in two or more alternative directions. No equivalent of the axial line is constructed. Figure 1 illustrates the new unit of analysis by clarifying the difference between road segments and street segments.



a: urban area b: nodes c: network d: road segments

○line node
●road node

Figure 1:

Definition of road segments

Analysis is based on finding the subset of street center-lines and parts of lines that can be reached subject to some limitation. When the limitation is metric distance, the total length of street reached is called Metric Reach, R_v, and the set of street segments S_v. When the limitation is a number of permissible direction changes, the total length of streets reached is called Directional Reach, R_u, and the set of street segments S_u. When combined metric and direction-change thresholds are applied, the total length of street reached is called Metric-Directional Reach, R_w, and the set of street segments S_w. Given some measure of reach, analysis proceeds by computing the average number of direction changes needed to get to the average portion of street length in the corresponding subset of street center-lines and parts of center-lines. Direction changes are simply added up, same as with the calculation of depth according to axial maps. However, a direction change is defined as a rotation of the center-line of movement by more than a specified angle. Thus, unlike traditional axial map analysis, we are dealing with a parametric definition of what counts as a direction change. A second parametric variable, “the very small street segment threshold”, specifies the very small street segments as a proportion of the average road segment. When the computation reaches any sequence of very small segments, the associated angles of direction changes are added instead of being considered one at a time. A direction change is identified when the sum of consecutive angles crosses the set threshold. Depending on whether the number of direction changes for the average accessible unit of street length is based on R_v, R_u or R_w, we symbolize the mean directional distance associated with a road segment by D_v, D_u or D_w.

At this stage we report results based on the following measures: first, R_v for 1 mile, D_v for 1mile, 10^o angle threshold and 0.10 very small segment threshold; second, R_u for 0 direction changes, 10^o angle threshold and 0.20 very small segment threshold. This is equivalent to measuring the length of the axial line that covers the center of a road segment, except that our computation of what we call “directional elements” allows that a directional element bifurcates at very small angles and thus includes street lengths branching at very small angles from a common point of origin; third, R_u for 2 direction changes, 10^o angle threshold and 0.20 very small segment threshold, as well as D_u for the same parameters.

Various quantitative measures have been introduced in the literature to evaluate pedestrian accessibility and measure street connectivity. The distance between origins and destinations for walking and the total length of streets covering an area have been suggested by some authors (Aultman-Hall et al 1997) to describe how the character of streets differs at neighborhood and regional levels. Pedestrian Route Directness, which measures the ratio between a chosen pedestrian route distance and the ‘crow-fly’ distance to a particular destination, has been studied (Hess 1997; Randall and Baetz 2001) as an indicator of how accessible a neighborhood is to the pedestrians. Some researchers have chosen to calculate the density and pattern of intersections, average block areas and block face lengths per unit area to capture the degree of network connectivity (Southworth and Owens 1993; Krizek 2003; Cervero and Kockelman 1997; Siksna 1997). Each of these measures is aimed to explain a (slightly or considerably) different aspect of connectivity pertinent to pedestrian accessibility. However, most of the analyses mentioned here do not involve extensive data collection on actual densities of pedestrian movement. Thus, space syntax still represents a rare attempt to develop an empirically tested model of the distribution of pedestrian movement according to the configuration of streets.

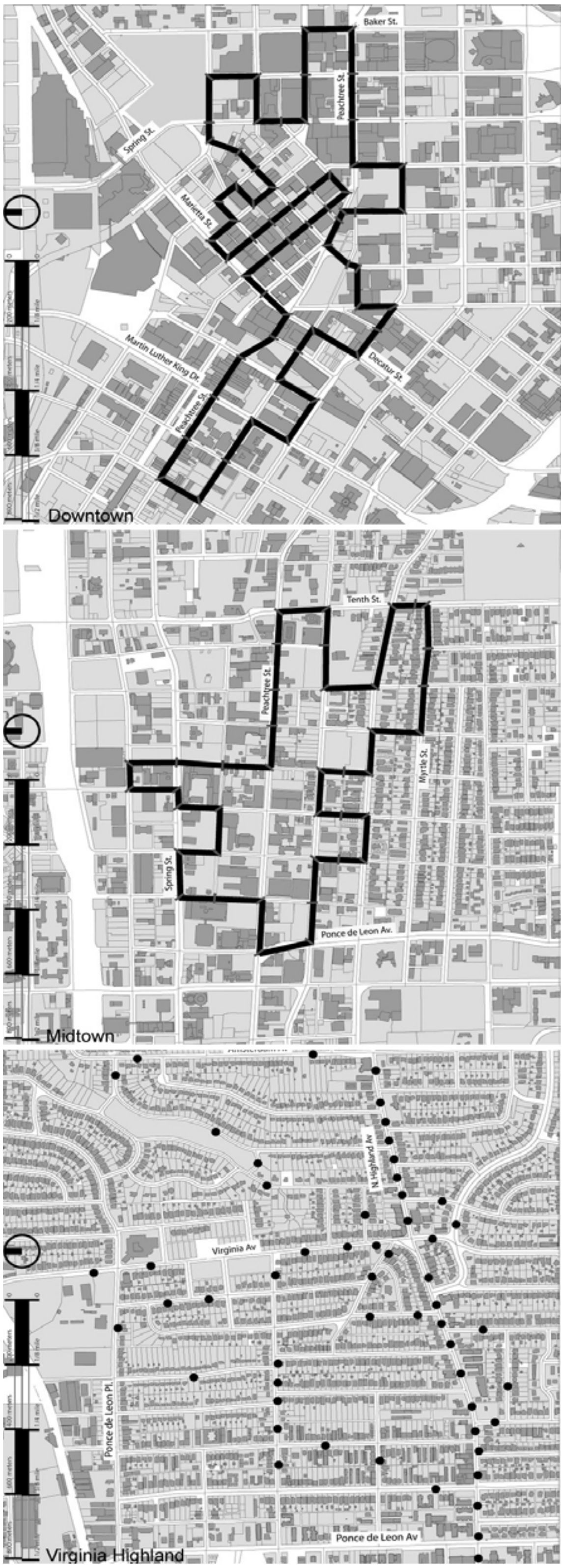
Three Areas in Atlanta

Atlanta is not a pedestrian friendly city. With half the population of Washington D.C. and San Francisco, Metropolitan Atlanta is extended over 50 percent more urbanized land (approximately about 1200 square miles), and per capita driving on average is 35 miles daily, which is two and one-half times more than that of the New York region (Dunphy and Fisher 1996). Bearing these extremities in mind, we have chosen to study three areas in particular. The first area, which had been previously studied in the 1990s (Peponis et al 1997), is Downtown Atlanta (average block area 1.7 hectares), that includes some of the most densely populated road segments within the city. The second area is Midtown (average block area 3.04 hectares), which has recently experienced very rapid mixed-use growth with explicit attempts by the city of Atlanta and Midtown Coalition to encourage walking through the provision of remodeled sidewalks. The third study area is the Virginia Highland neighborhood (average block area 7.5 hectares), developed in the early 1900s, which remains a pedestrian oriented environment attracting visitors to its shops, restaurants and bars. Our expectation, based on our everyday experience of the neighborhood, was that pedestrian movement, while of low intensity, would be better distributed than in other areas. We have not, at this point, completed our study of Buckhead, a post 1960s “edge city” which was previously studied in the 1990s. Population densities calculated according to the 2000 US census for the three areas investigated here are 2603, 2726 and 1608 per square kilometer respectively. These figures do not include estimates of the people who work in each area and commute in daily.

Figure 2 shows the 3 areas and marks the observation sets for each area. In the cases of Downtown and Midtown, we followed the method of the moving observer; while in the case of Virginia Highland, we followed the method of gate counts. We completed 20 rounds of observation during working hours in Downtown and Midtown, and 20 minutes of observation for each gate in Virginia Highland, distributed over 10 different periods including evening hours when the area attracts more visitors. Figure 3 shows graphically the distribution of movement densities using different line thicknesses for Downtown and Midtown, and circles of different diameters for Virginia Highland. Figure 4 provides statistical information on pedestrian densities.

We observed 62 road segments in Downtown and 42 in Midtown. When observations are aggregated and averaged by axial line, our observations cover 33 axial lines in Downtown and 18 in Midtown. In Virginia Highland we observed 55 gates. When gates on the same axial line are added and averaged, our observations cover 25 axial lines. Thus we have observed a total of 159 road segments and can characterize movement for 76 axial lines.

Figure 4 shows how strongly the three areas differ. The median density of moving pedestrians per 100 meters or per minute is 68.7, 18.9 and 0.9 for Downtown, Midtown and Virginia Highland respectively, while the corresponding means are 122.9, 31.8 and 1.3.



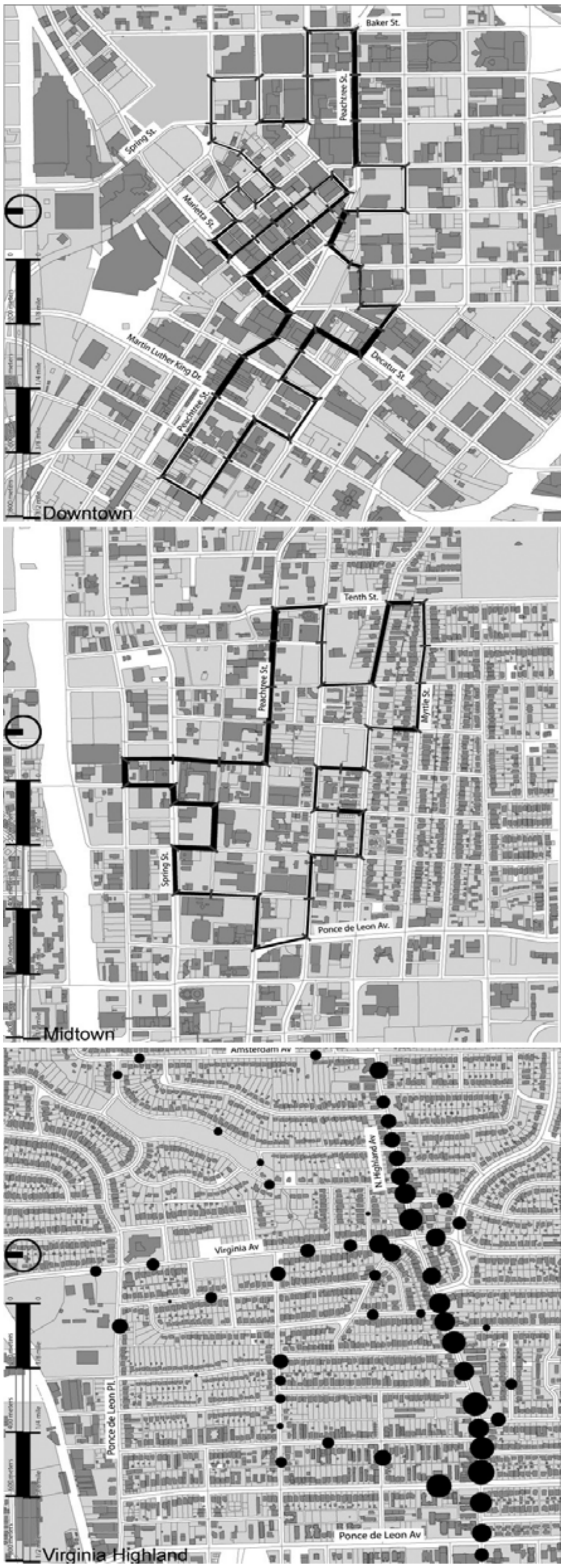


Figure 2:

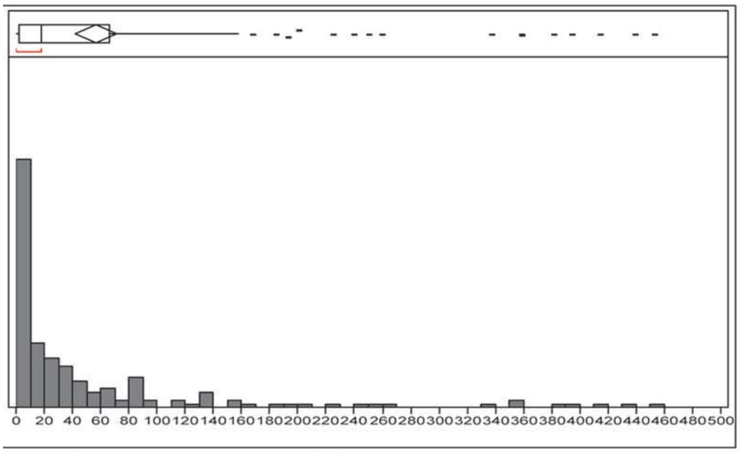
Location of observations (left)

Figure 3:

Graphic representation of observed pedestrian densities (right)

Figure 4:

Statistical profile of observed pedestrian densities (next page)



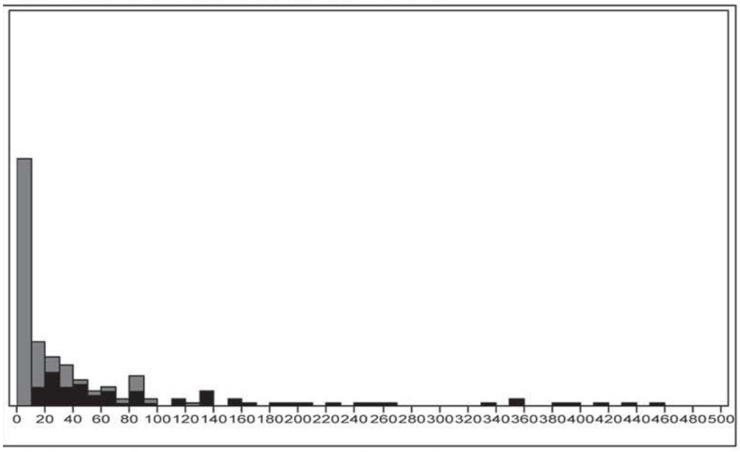
moving/100m or moving/minute, all observations

Quantiles

100.0%	maximum	453.48
99.5%		453.48
97.5%		394.87
90.0%		168.33
75.0%	quartile	66.67
50.0%	median	17.91
25.0%	quartile	1.80
10.0%		0.35
2.5%		0.10
0.5%		0.00
0.0%	minimum	0.00

Moments

Mean	56.767302
Std Dev	95.243727
Std Err Mean	7.5533189
upper 95% Mean	71.685802
lower 95% Mean	41.848801
N	159
Sum Wgt	159
Sum	9026.0009
Variance	9071.3676
Skewness	2.5455764
Kurtosis	6.3119343
CV	167.77921
N Missing	0



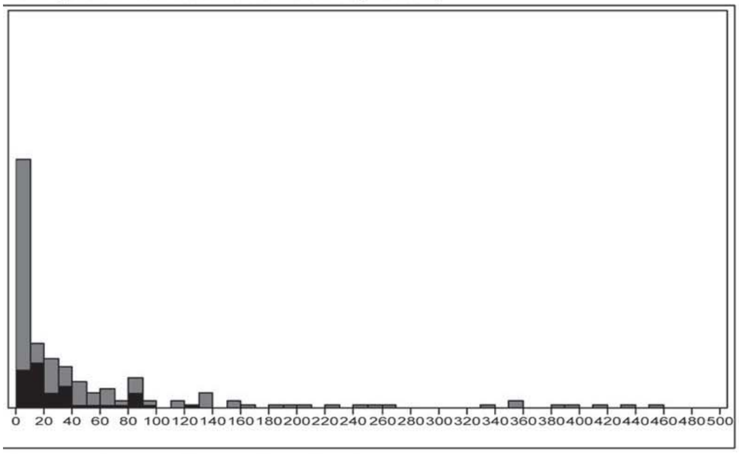
moving/100m Downtown observations (in black)

Quantiles

100.0%	maximum	453.48
99.5%		453.48
97.5%		445.55
90.0%		359.33
75.0%	quartile	172.47
50.0%	median	68.65
25.0%	quartile	31.11
10.0%		20.79
2.5%		14.07
0.5%		11.48
0.0%	minimum	11.48

Moments

Mean	122.89509
Std Dev	123.41183
Std Err Mean	15.673318
upper 95% Mean	154.23582
lower 95% Mean	91.554353
N	62
Sum Wgt	62
Sum	7619.4955
Variance	15230.479
Skewness	1.3719168
Kurtosis	0.807935
CV	100.42047
N Missing	0



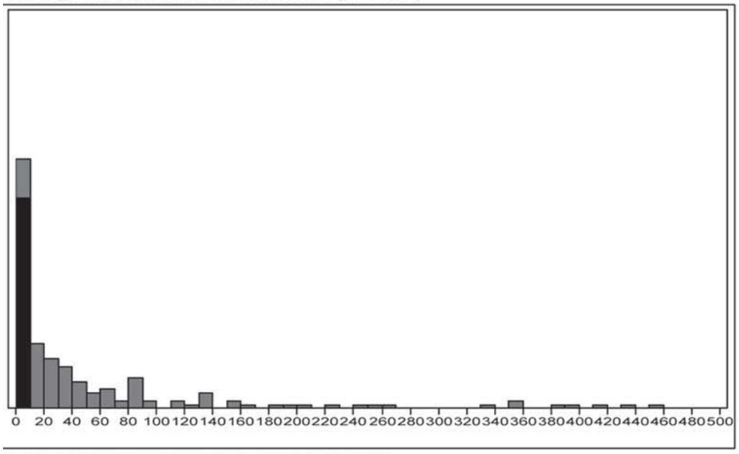
moving/100m Midtown observations (in black)

Quantiles

100.0%	maximum	125.00
99.5%		125.00
97.5%		122.48
90.0%		84.28
75.0%	quartile	39.20
50.0%	median	18.92
25.0%	quartile	10.49
10.0%		6.45
2.5%		4.93
0.5%		4.93
0.0%	minimum	4.93

Moments

Mean	31.762034
Std Dev	30.301974
Std Err Mean	4.6756962
upper 95% Mean	41.204794
lower 95% Mean	22.319274
N	42
Sum Wgt	42
Sum	1334.0054
Variance	918.20966
Skewness	1.4126729
Kurtosis	1.1407022
CV	95.403129
N Missing	0



moving/minute Virginia Highland (in black)

Quantiles

100.0%	maximum	5.9000
99.5%		5.9000
97.5%		5.5200
90.0%		2.9300
75.0%	quartile	1.9500
50.0%	median	0.9000
25.0%	quartile	0.3000
10.0%		0.1500
2.5%		0.0200
0.5%		0.0000
0.0%	minimum	0.0000

Moments

Mean	1.3181818
Std Dev	1.2698922
Std Err Mean	0.1712322
upper 95% Mean	1.6614818
lower 95% Mean	0.9748819
N	55
Sum Wgt	55
Sum	72.5
Variance	1.6126263
Skewness	1.5179058
Kurtosis	2.6519158
CV	96.336652
N Missing	0

The Distribution of Pedestrian Movement Densities as a Function of Axial Integration

Each observation area was analyzed based on a standard axial map drawn to cover the surroundings in such a way that computations of Integration Radius 3 for observed lines would not suffer any edge effects. In all cases, axial maps cover areas at least as large as 3 miles x 3 miles. In order to replicate methodologies used in the past, when several observation segments or gates were found on the same axial line, values were averaged as appropriate so that each line was associated with one estimate of pedestrian density only. The results of the correlation analysis (Linear Pearson correlations) are shown in Table 1.

Table 1:

Correlations between axial integration and pedestrian movement densities

	Correlation (r) between LogMov/100meters or LogMov/min and axial Integration	Correlation (r) between LogMov/100meters or LogMov/min and axial Integration radius 3
Downtown Atlanta	0.57 (0.0005)	0.28 (0.1126)
Midtown Atlanta	0.05 (0.8538)	0.01 (0.9766)
Virginia-Highland	0.57 (0.0030)	0.73 (0.0001)
All observations	0.92 (0.0001)	0.53 (0.0001)

The correlations for all observed lines are not to be discussed much, because they correspond to a very polarized scatter-plot due to the fact that Virginia Highland has much lower pedestrian densities and much lower Integration values as compared to the other two areas. We note that the correlation between pedestrian movement and Integration for Downtown is almost identical to the one reported in the earlier study, r value of 0.55, (Peponis et al 1997) even though the observation spaces are not identical. However, the earlier study showed a higher correlation for Integration Radius 3, namely 0.39, as compared to the new value of 0.28. To interpret this difference we notice that our new study encompasses a greater number of sub-areas that appear distinct from a land use point of view (intensive high rise developments, the old low rise Poplar district, and sparsely developed blocks south of the Peachtree-Marietta intersection). The inclusion of sub-areas, which may be characterized by a different orientation of pedestrian movement with respect to the local street system, can account for the lower correlation to Integration Radius 3 that we obtained. However, in both studies, Integration proves to offer stronger post-diction of pedestrian movement than Integration Radius 3.

Midtown strikingly fails to show any correlation between syntactic structure and pedestrian movement. Our findings suggest that the pedestrians observed in the area do not orient their movement according to the syntactic structure of the surrounding street fabric. This is surprising given the deliberate policies to create a pedestrian friendly mixed-use environment. We interpret the result to imply that pedestrian movement is oriented to local attractors, whether high rise residential buildings or the various restaurants and bars (all mostly along Peachtree Street with only occasional emphasis on West Peachtree, Spring Street or the transverse streets) and has not yet become tuned to the larger surrounding fabric.

The correlations for Virginia Highland are high, as would be expected, with a particularly strong correlation of movement densities to Integration Radius 3. Thus, while movement in Downtown appears to be distributed according to a global rather than a local scale or syntactic integration, movement in Virginia Highland is even more strongly distributed according to a local scale.

When Midtown is excluded from the data set, our results indicate that syntactic variables account for 30 to 50 percent of the variation of pedestrian movement densities. While this is a high proportion, our results also point to the possible effect of other factors. We speculate that these factors include not only the variation of land development by parcel, but also the location of parking facilities. Much movement occurs between a parking facility and a particular destination. This contributes to the fragmentary overall nature of movement. With the exception of some areas in Downtown, there appears to be little casual, exploratory, distributed movement around the three areas.

The Distribution of Pedestrian Movement Densities as a Function of the New Measures of Street Connectivity

We now turn to the analysis of the same observations according to the existing GIS representations of street-center lines and the new variables introduced earlier. For the purposes of this particular analysis we have excluded freeways (Interstates) since they do not factor in pedestrian movement. The results (linear Pearson correlations) are presented in Table 2.

Table 2:

Correlations between measures of street connectivity and pedestrian movement densities

	Correlation (r) between LogMov/100m or LogMov/min and R_v(1mile)	Correlation (r) between LogMov/100m or LogMov/min and $D_v(1mile,10^o,0.10)$	Correlation (r) between LogMov/100m or LogMov/min and $R_v(1mile)/ D_v(1mile,10^o,0.10)$	Correlation (r) between LogMov/100m or LogMov/min and $R_u(0d, 10^o,0.20)$	Correlation (r) between LogMov/100m or LogMov/min and $R_u(2d, 10^o,0.20)$	Correlation (r) between LogMov/100m or LogMov/min and $D_u(2d,10^o,0.20)$	Correlation (r) between LogMov/100m or LogMov/min and $R_u(2d, 10^o,0.20)/ D_u(2d,10^o,0.20)$
Downtown Atlanta	0.27 (0.0327)	-0.43 (0.0004)	0.51 (0.0001)	0.14 (0.2728)	0.08 (0.5590)	0.21 (0.1006)	0.07 (0.5786)
Midtown Atlanta	0.17 (0.2934)	0.30 (0.0548)	-0.19 (0.2360)	0.07 (0.6349)	0.08 (0.6171)	0.38 (0.0110)	0.12 (0.4569)
Virginia-Highland	0.63 (0.0001)	-0.53 (0.0001)	0.73 (0.0001)	0.45 (0.0007)	0.54 (0.0001)	0.19 (0.1587)	0.53 (0.0001)
All observations	0.90 (0.0001)	-0.37 (0.0001)	0.76 (0.0001)	0.04 (0.5895)	0.22 (0.0044)	0.45 (0.0001)	0.20 (0.0101)

Results obtained for all observations considered as a single set are based on a polarized scatter-plot and consequently will not be discussed as indicative of a trend. This is consistent with the standard syntactic analysis reported earlier. Equally consistent with the previous results is the rather poor ability of the new measures to post-dict movement densities in Midtown. The only significant correlation is between movement density and Directional Reach computed for two direction changes subject to a 10^o threshold angle and a 0.20 very small segment threshold (7th column). Even this correlation, however, is based on a scatter-plot which is dominated by outliers. When we consider Midtown and Downtown, the best correlations are obtained when we divide Metric Reach for 1 mile radius by Directional Distance based on metric reach, subject to a 10^o threshold angle and a 0.20 very small segment threshold. This composite variable takes on higher values as the metric reach of a space increases and its directional depth decreases. In simple English, this is equivalent to saying that road segments from which more street length is accessible within 1 mile walking radius, taking fewer turns to get everywhere, draw greater volumes of pedestrians.

The correlation for Downtown (0.51) is very close to the best correlation previously obtained with syntactic Integration (0.57). In the case of Virginia Highland, the correlation (0.73) is exactly as strong as the one obtained with syntactic Integration radius 3.

Discussion

Our work is still in progress and conclusions are, at this stage, tentative. First, our observation data in Atlanta yields less strong correlations than those previously obtained by similar studies in London (Hillier et al 1993) or in some Greek cities (Peponis et al 1989). In Atlanta, pedestrian movement is less tuned to the spatial structure of streets and may be affected more strongly by other factors, including the juxtaposition of drastically different development densities and the distribution of parking. Second, the new measures seem to work as well as the standard syntactic measures in modeling the manner in which the street network affects pedestrian flows. This merits further discussion.

Both standard syntactic measures and the new measures are sensitive to direction changes, in other words to the underlying topology of streets. In standard syntactic analysis direction changes are not defined parametrically. This, of course, has changed when angular analysis and fractional analysis have been introduced (Dalton 2001). The new measures used in this paper are inherently parametric, in that one can vary what counts as a direction change. At the same time our measures are not sensitive to the magnitude of a direction change as is angular analysis. There is, however, general agreement in principle that direction changes are important in determining how likely it is that a given space will attract greater flows of movement as compared to its surroundings. This is true whether we give a non parametric (standard syntax) or a parametric (new measures) definition of what counts as a direction change, or whether we decide to measure the magnitude of all direction changes and define angular distances (angular analysis). The common underlying hypothesis is that direction changes do matter, because they impose a cognitive load on navigation and the processes of cognitive mapping that are associated with navigation.

Standard space syntax, however, does less to express street connectivity in terms of density. Here we use the term density to refer to the amount of street which is available within a given metric range. The syntactic measure of connectivity (the number of street intersections per line) could be construed as a measure of density had it been explicitly relativized by line length. In standard syntax, however, metric properties are not emphasized as much as topological ones. In making these comments we do not underestimate the continuous preoccupation with metric properties in the work of Hillier since 1999. On the contrary, we converge with a main thrust of this work, namely that metric properties have to be introduced at the foundations of the theory of syntax. Consistent with this our new measures express the density of street connectivity directly. Our results indicate that a measure of density (Metric Reach) plays as important a role in the distribution of movement as a measure of direction changes (Directional Distance).

Finally, we note that the new measure that was aimed at emulating Integration Radius 3, in other words the average directional distance to all spaces that can be reached within up to two direction changes, did not contribute much to our modeling of pedestrian movement. The same negative finding seems to apply to our measures of directional reach, whether at zero direction changes (conceptually equivalent to measuring the length of axial lines, but with parametric twists), or at 2 direction changes. We think that too strong an interpretation of these results is premature. At this stage, it is important to acknowledge that our new measures allow us to draw a distinction between street connectivity as measured subject to metric thresholds and street connectivity as measured subject to directional thresholds. As our data base and our analyses expand, we might be able to throw more light on the interplay between measures of direction change and measures of the density of connections as determinants of pedestrian flows. For now, we hypothesize that we are dealing with the interplay between potentiality (density) and structure (directional bias based on configuration).

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