STREET CONNECTIVITY AND URBAN DENSITY:
spatial measures and their correlation

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Abstract

Measures of street configuration are correlated to measures of population, development and parcel densities for a sample of 25 urban areas in the Atlanta metropolis. This constitutes a contribution to modeling the co-variation of different aspects of the spatial structure of cities. The results also provide a foundation for discussing the appropriate ways for defining urban density from the point of view of designing cities.

What is Density?

Density is a rich but unresolved concept in urban theory. It is commonly measured according to population per unit area of urban land, or according to areas of buildings of different categories per unit area, or perhaps according to the volume of employment that is associated with particular categories of buildings. It is also used to refer to urban culture, specifically to the idea that cities are concentrations of different kinds of social practices, behaviors or relationships engendering different patterns of social, economic and cultural meaning, all of which interact based on spatial co-location, proximity or overlap. Thus, Sassen (2006, 38), for example, measures the density of the networks of market, trade and exchange as they become concentrated in the major metropolises and suggests that "the density of central places provides the social connectivity that allows a firm or market to maximize the benefits of its technological connectivity".

Between the characterizations of the human occupation of land and the characterizations of human culture, there lies a third kind of density, the density of the physical fabric of streets and the density of the subdivision of land. Street networks enable cities to function and provide the framework for shared life. What is more, as street networks remain relatively stable over long periods of time, they also act as the public constitutional framework that governs the redeployment of populations and land uses on private properties. Land subdivision also works as a slowly changing framework for the redeployment of land uses and populations. So, from the point of view of the evolution and design of cities the fundamental question is: how does the density of streets and land subdivision support the other kinds of density that are characteristic of urbanism?

With its emphasis on topological properties, space syntax has not traditionally (Hillier and Hanson 1984; Hillier 1996) addressed questions of density in a quantitative way. This is true despite the fact that the underlying question of how spatial density supports cultural, social and economic wealth is certainly at the very foundations of the theory of the social logic of space. Since 1999 Hillier (1999a; 1999b) has increasingly brought metric properties into the mainstream of syntactic research. Our discussion in this paper can be seen as a late contribution to this broadening of the scope of syntactic measures. However, our work is primarily aimed at taking some first steps towards addressing the larger question raised earlier.

We bring together on a GIS platform four kinds of measures of density applied to the sample of 25 areas in Atlanta: First, the density of streets, street intersections and urban blocks per unit area of urban land. Second, the density of connectivity measured according to the properties of Reach and Directional Distance per road segment, as recently defined by Peponis, Bafna and Zhang (2006). Third, the density of population per unit area, derived from census information about individual urban blocks. Fourth, the density of different categories of buildings derived from a parcel level data-base developed at Georgia Tech for the SMARTRAQ program (Strategies for Metro Atlanta's Regional Transportation and Air Quality) under the leadership of Steve French. The areas under study are widely distributed over the area of the Atlanta Regional Commission and cover a total of more than 500 Square Kilometers.

The Sample of Areas

Our sample of 25 areas was selected to include sections of the 19th century core of the city of Atlanta; areas developed in the 1900s such as Virginia Highland; suburbs of the 1930s near the city center such as Ansley Park; “edge cities” such as Dunwoody or Buckhead that have grown as post-1960s urban hubs in and around peripheral Interstate 285, historic cities that have been absorbed into the metropolitan fabric, such as Marietta and Decatur, and areas which are at the fringes of current development such as Crabapple. Thus, our sample represents a cross section of urban conditions in the Atlanta metropolitan area. Each area is initially defined by placing a 3.2x3.2 kilometer square (2 miles x 2 miles) over the street network, usually centered at what was held to be the center of an area of interest. At this stage, each urban area consists of 10.35 square kilometers, but the 3.2x3.2 kilometer square cuts through the urban blocks at the periphery of the area of interest. In order to include in the analysis only complete urban blocks, and the road segments surrounding them, we extend the areas to take into account not only blocks fully contained by the original 3.2x3.2 kilometer square, but also blocks intersected by it and blocks that might be contained within the blocks intersected. In this case, a block is defined as a polygon of urban land fully surrounded but not traversed by road segments. A block can be contained inside another block if a street extends inwards and then creates a loop and backs upon itself, and the space inside the loop is “an urban block” contained within a larger urban block. As a result of our strategy, some extended areas covered considerably more than the original 10.35 square kilometers. Some of the areas are shown in Figure 1of another paper in this volume (Peponis, Allen, Haynie, Scoppa, Zhang, 2007).

Reach and Directional Distance Briefly Defined

Metric Reach, R_v, is defined as the aggregate street length that is accessible from the mid-point of each road segment within a metric radius of actual movement. Road segments are the lengths of street that extend between two choice nodes or intersections. Here we use a radius of 1.6 kilometers. Distances are measured along street center lines, so we are not referring to street segments within a circle of 1.6 kilometers radius but to street segments that can actually be reached within 1.6 kilometer walk. Reach, therefore, is a measure of street density. Implicitly, it is a measure of urban potential: the greater the average R_v of an area the greater the interface between public streets and private properties, the greater the likely number of properties that are within range, the greater the likely number of potential destinations or land uses. The set of street segments and parts of street segments that are accessible within a radius of movement will be referred to as S_v. 004-03

Directional distance, D_v, subject to R_v, is a measure of the average number of direction changes that need to be taken to reach the average unit of street length in S_v. Like R_v, D_v is a parametric variable. It is defined not only subject to the metric radius used to define R_v but also subject to an angle threshold that allows us to define what we mean by “a direction change”. Here we speak of direction changes if the change of direction at the intersection of two street segments (the line segments that make up road segments) is greater than 10^o; also, we take into account another parameter. “The very small line segment threshold” is expressed as a proportion of the average road segment length in the system. When the calculation meets a sequence of line segments, each smaller than the “very small segment threshold,” it does not ask: what is the angle between two consecutive segments? Instead, it keeps adding angles to identify a direction change to the point when the cumulative angle exceeds the specified “threshold angle.” Here we report directional distances computed based on a 0.10 very small segment threshold.

A full discussion of how R_v and D_v co-vary with standard measures of urban morphology such as block size, street length per square kilometer, number of intersections per square kilometer or average distance between intersections (which is equivalent to average road segment length) is provided in another paper in this volume by Peponis, Allen, Haynie, Scoppa and Zhang, which reports an analysis of 118 urban areas from the 12 most populated urban metropolises in the US. The larger sample discussed in that paper includes the 25 areas that are further analyzed here.

In the next three section we discuss how Rv, Dv and standard morphological measures of urban form are related to: first, the subdivision of land; second the density of population residing within the areas; third, the density of buildings in the areas. Quantitative information about the areas is provided in Tables 1 and 2.

Our analysis suffers no edge effects because all areas were analyzed as part of the whole metropolitan fabric; even road segments at the edge of each area were analyzed as part of surroundings extending over many miles (See Peponis, Allen, Haynie, Scoppa, Zhang, 2007 in this volume).

Atlanta	# Blocks	Area (square kilometers)	Total Street Length (kilometers)	Street Length/sq.kilometer	Mean length of Road Segment (meters)	Block Area (hectares)	# Blocks/sq. kilometer	Number of choice intersections	Number of Intersections (choice) / sq kilometer	Rv(1.6 km)	Dv (1km, 10o, 0.10)
Alpharetta	154	20.89	149.25	7.14	164	13.58	7.37	526	25.18	11.33	7.88
Ansley Park	261	16.85	161.85	9.61	171	6.46	15.49	611	36.26	26.91	4.28
Avondale	167	14.29	135.04	9.45	197	8.57	11.69	444	31.07	20.07	6.29
Brookhaven	167	18.25	145.69	7.98	188	10.93	9.15	492	26.96	17.68	6.37
Buckhead	161	15.79	136.80	8.66	205	9.81	10.20	422	26.73	19.99	5.21
Candler Park	272	12.97	147.79	11.39	157	4.77	20.97	592	45.64	29.87	3.76
College Park	380	14.47	163.14	11.27	147	3.81	26.26	679	46.92	31.95	3.24
Crabapple	63	27.21	139.24	5.12	192	43.21	2.32	423	15.55	8.99	8.62
Decatur	217	14.29	140.90	9.86	161	6.59	15.19	535	37.44	25.70	5.49
Downtown	692	11.83	196.14	16.58	107	1.71	58.50	1069	90.36	52.48	3.21
Dunwoody	113	14.16	123.35	8.71	203	12.53	7.98	367	25.92	13.95	8.46
Fairburn	113	27.28	135.49	4.97	252	24.16	4.14	325	11.91	14.45	4.73
Fayetteville	136	37.48	198.57	5.30	214	27.58	3.63	542	14.46	12.00	6.94
Forest Park	216	17.42	163.10	9.36	181	8.07	12.40	581	33.35	22.74	4.93
Lawrenceville	168	26.97	180.11	6.68	190	16.22	6.23	562	20.84	14.86	5.77
Marietta	324	15.63	164.52	10.53	148	4.83	20.73	694	44.40	30.44	4.83
Norcross	117	21.51	148.04	6.88	207	18.39	5.44	422	19.62	13.21	6.7
Oakgrove	121	17.68	156.25	8.84	197	14.63	6.84	492	27.83	16.00	7.09
Peachtree City	142	25.42	166.21	6.54	188	17.92	5.59	508	19.98	12.44	7.43
Rosswell	146	22.23	161.04	7.24	178	15.25	6.57	532	23.93	14.45	6.35
Smyrna	221	14.86	156.09	10.50	154	6.73	14.87	624	41.99	21.72	5.79
Stone Mountain	141	20.55	142.14	6.92	190	14.59	6.86	442	21.51	16.62	6.79
Union City	107	24.33	119.95	4.93	212	22.76	4.40	339	13.93	14.07	6.43
Virginia Highland	227	17.00	151.87	8.93	179	7.50	13.35	541	31.82	25.08	5.12
West End	320	13.38	164.50	12.29	161	4.18	23.92	661	49.40	30.58	3.71

Table 1:

Morphological measures for 25 areas in Atlanta 2

Street Morphology and Parcel Density: A Fundamental Theorem

Table 3 shows the squares of linear Pearson correlation coefficients between morphological variables and parcel density. The correlations are computed twice, first taking all areas into account and second excluding Downtown. Downtown is an outlier regarding the number of blocks, the number of intersections, and street length per square kilometer, as well as regarding Rv. This is due to the effects of freeways, a great number of exit ramps and a major spaghetti intersection.

As street length and the number of choice intersections per square kilometer increase so does the density of parcels. As we discuss in the other paper in this volume (Peponis, Allen, Haynie, Scoppa, Zhang, 2007), there is a lot of co-variation between the morphological variables under consideration, and, at this stage, pending the creation of a larger sample, we are not investigating partial correlation coefficients.

Our results point to a fundamental conclusion. The density of streets increases in proportion to the density of properties, which is to the degree of land subdivision. This conclusion is intuitively expected but not less important for that matter. The density of the public network of streets increases to service a larger number of properties, which is a potentially larger number of property owners. By implication, the density of streets increases as the intensity of the public/private interface of an urban system increases. While this theorem has obvious implications for the social logic of city form, it probably arises from the interplay of social principles and the fundamental geometrical constrains that drive land subdivision. If properties are to be independently accessible from the public system, then it is to be expected that greater subdivision requires more street length because there is a limit to the practically useful depth/frontage ratio of the average property.

Table 2:
Parcel, population and development measures for 25 areas in Atlanta (top)

Table 3:
Correlations between measures of street morphology and parcel density (bottom)

Atlanta	Total # parcels	#Parcels/Sq. kilometer	Sq Meter Residential/Sq Kilometer	Sq Meter Non Residential /Sq. Kilometer	Population	Population/hectare
Alpharetta	4660	223.07	23584.55	9093.71	14893	7.13
Ansley Park	6055	359.35	68512.11	59327.69	25924	15.39
Avondale	7828	547.80	70058.78	12591.79	23392	16.37
Brookhaven	7281	398.96	58305.55	15049.03	30100	16.49
Buckhead	4737	300.00	57057.81	84152.76	22836	14.46
Candler Park	8658	667.54	79521.66	14708.03	21767	16.78
College Park	6491	448.58	46567.65	15139.69	18445	12.75
Crabapple	5186	190.59	29002.01	581.53	12929	4.75
Decatur	9887	691.88	92540.75	21145.28	20233	14.16
Downtown	4502	380.56	26169.06	147487.83	30795	26.03
Dunwoody	4010	283.19	63277.56	116846.13	13175	9.30
Fairburn	3301	121.00	10790.08	1517.04	7715	2.83
Fayetteville	5170	137.94	17524.71	4185.09	13301	3.55
Forest Park	5439	312.23	25709.32	7230.29	19276	11.07
Lawrenceville	6055	224.51	27318.96	14167.59	16562	6.14
Marietta	5338	341.52	44337.37	27148.97	17089	10.93
Norcross	5440	252.91	28290.23	49726.75	18944	8.81
Oakgrove	8638	488.57	103196.51	1456.20	18504	10.47
Peachtree City	4699	184.85	30719.91	8992.97	14402	5.67
Rosswell	5773	259.69	36517.71	13602.11	17307	7.79
Smyrna	6088	409.69	80346.97	11013.61	26089	17.56
Stone Mountain	5017	244.14	33236.97	5010.87	21233	10.33
Union City	3205	131.73	10266.95	4409.74	9746	4.01
Virginia Highland	8856	520.94	100415.12	9095.02	27367	16.10
West End	8528	637.37	71516.80	11717.06	23725	17.73

	Blocks/Sq kilometer	Choice Intersections/sq kilometer	Street Length/Sq kilometer	Distance Between Intersections (meters)	R_v	D_v
Parcels/Sq kilometer All areas	r^2=0.20 (0.0247)	r^2= 0.31 (0.0038)	r^2=0.46 (0.0002)	r^2=0.26 (negative) (0.0084)	r^2=0.31 (0.0036)	r^2=0.23 (negative) (0.0138)
Parcels/Sq kilometer Excluding Downtown	r^2=0.54 (0.0001)	r^2=0.64 (0.0001)	r^2=0.70 (0.0001)	r^2= 0.35 (negative) (0.0025)	r^2=0.55 (0.0001)	r^2=0.25 (negative) (0.0117)

Street Morphology and Population Density

Population densities in Atlanta are quite low. In most of our areas they are, for example, less than 10% of the population densities for the center of Athens, estimated by Doxiadis (1968, 118) as an average over the city's history (170 people per hectare). Table 4 shows the squares of linear Pearson correlation coefficients between morphological variables and parcel density. Population density also increases with all measures of street density. Higher population densities are particularly associated with more street length and more choice intersections per square kilometer as well as with higher R_v values. The result is intuitively expected given the previous result about the number of parcels. When we check for correlations between the average population per parcel and the measures of street morphology there are none. On the other hand the r^2 between population density and parcel density is 0.53 (0.0001).

Table 4:

Correlations between measures of street morphology and population density

	Blocks/Sq kilometer	Choice Intersections/sq kilometer	Street Length/Sq kilometer	Distance Between Intersections (meters)	R_v	D_v
People/Sq kilometer All areas	r^2=0.62 (0.0001)	r^2=0.72 (0.0001)	r^2=0.81 (0.0001)	r^2=0.50 (negative) (0.0001)	r^2=0.68 (0.0001)	r^2=0.36 (negative) (0.0014)

Street Morphology and Building Density

We have data on the total square meters of buildings, residential and non-residential, for each of the areas under study, based on which we can compute the density of buildings per square kilometer. As shown in Table 5, second and third row, there is a strong relation between the density of streets (street length per square kilometer) and the density of residential buildings per square kilometer, especially if Downtown is excluded from analysis. No similar tendency is evident for non-residential uses. The spurious correlations produced when Downtown is included collapse when Downtown is excluded from the data. Regarding non-residential uses, Downtown is an outlier not only with respect to morphological measures, but also with respect to the area of buildings.

Our results indicate that the density of non-residential land uses, as measured by the area of buildings, is not distributed according to the morphology of streets, at least not when we compare areas as wholes. The finding is not surprising. In Atlanta, as in many other cities, non-residential uses are of two kinds, those that gravitate towards relatively small parcels and blocks in dense areas, and those that are drawn to very large properties and urban blocks in areas where the street network is much less dense. On aggregate, therefore, there is no clear association between the density of streets and the total square meters of non-residential buildings.

Getting Inside Areas: The Spatial Distribution of Commercial and Recreational Land Uses

Most standard morphological measures of street configuration are good at quantifying the difference between areas but not able to quantify the differences between streets in the same area. This applies, for example, to the number of blocks and intersections, or to the length of street per square kilometer. On the other hand, syntactic measures, such as Metric Reach, not only capture differences between areas but also differences between one road segment and another within the same area. So, in this section, we are asking whether the variation of R_v 1.6 kilometer is associated with variations in the distribution of particular land uses.

Table 5:

Correlations between measures of street morphology and building areas per square km

	Blocks/Sq kilometer	Choice Intersections/sq kilometer	Street Length/Sq kilometer	Distance Between Intersections (meters)	R_v	D_v
Residential Sq meters of building/sq kilometer	r^2=0.02 (0.5177)	r^2=0.08 (0.1777)	r^2=0.19 (0.0294	r^2=0.07 (negative) (0.1941)	r^2=0.07 (0.2067)	r^2=0.03 (negative) (0.4058)
Residential Sq meters of building/sq kilometer Excluding Downtown	r^2=0.25 (0.0129)	r^2=0.39 (0.0011)	r^2=0.49 (0.0001)	r^2=0.19 (negative) (0.0327)	r^2=0.29 (0.0066)	r^2=0.07 (negative) (0.2261)
Non-residential Sq meters of building/sq kilometer	r^2=0.33 (0.0026)	r^2=0.29 (0.0054)	r^2=0.27 (0.0070)	r^2=0.09 (negative) (0.1303)	r^2=0.24 (0.0130)	r^2=0.03 (0.3916)
Non-residential Sq meters of building/sq kilometer Excluding Downtown	r^2=0.00 (0.7932)	r^2=0.00 (0.7319)	r^2=0.04 (0.3806)	r^2=0.01 (0.6974)	r^2=0.00 (0.8398)	r^2=0.01 (0.6902)

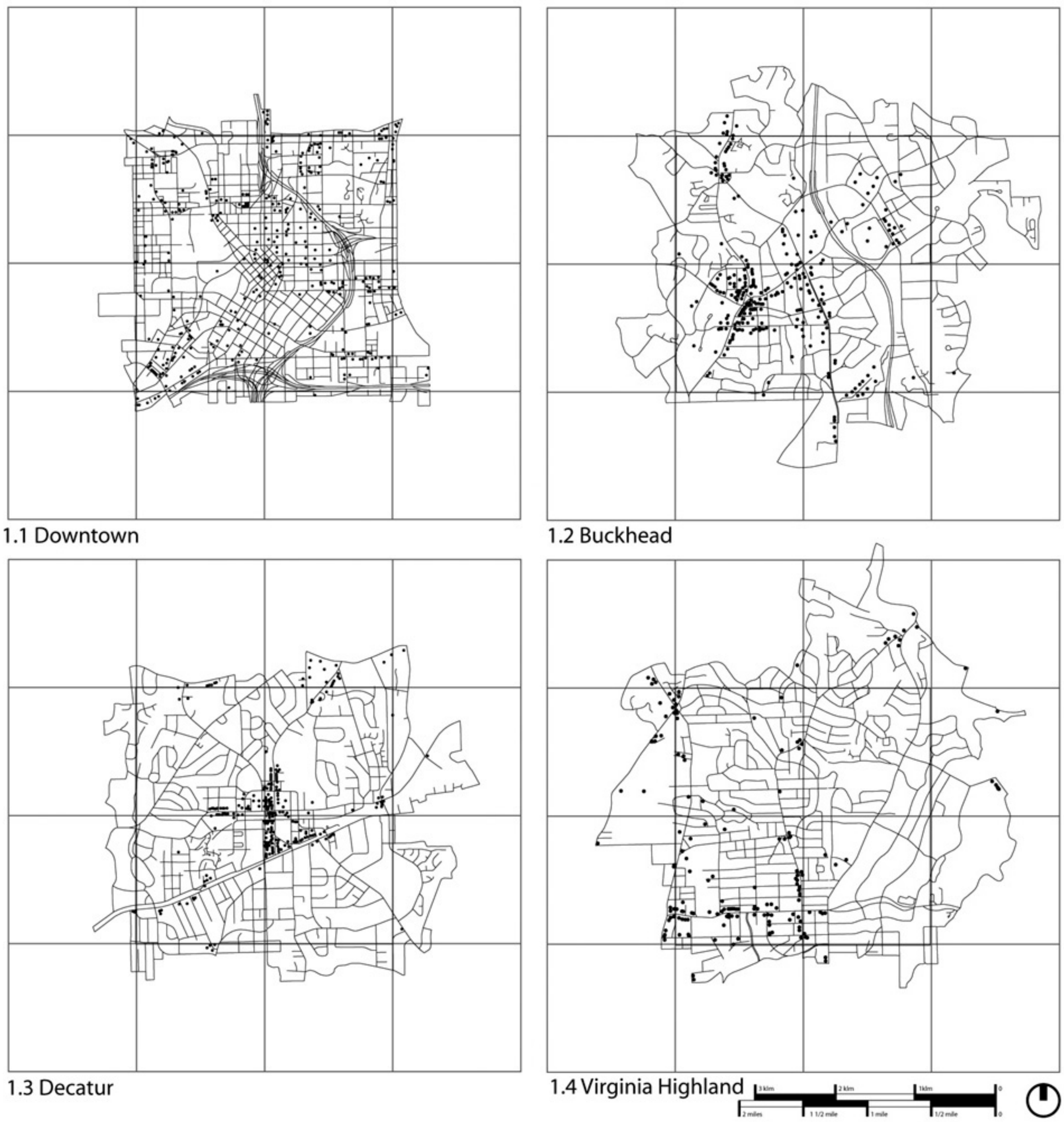
Our inquiry is limited by several factors. Our data-base has land uses already classified according to the categories used for tax assessment. We have no ability to refine classificatory criteria. We have chosen to look at commercial and recreational land uses. These include all kinds of shops (for example, neighborhood shopping centers, strip malls, department stores, street retail) as well as all kinds of places for social gathering (for example, restaurants, fast food shops, bars, coffee shops). On the other hand, gas stations and golf courses are also included in the respective categories. Still, based on intuition, commercial and recreational land uses might have a tendency to locate themselves so that they are more easily accessible from their surroundings and are a good starting point for our inquiry.

There are also technical limitations. The data is organized by parcel and we need to assign parcels to road segments. We used geo-coding in order to match the postal street addresses of parcels to the corresponding road segments. This process allowed us to match about 70% of the parcels in most cases, but with exceptions, such as Downtown, where we could match only 50% of the parcels due to a greater number of gaps in the information available about the addresses associated with road segments or the addresses associated with parcels.

Here, we will report some preliminary findings based on four areas: First, Virginia Highland, with a reputation as one of the most pedestrian-friendly neighborhoods in Atlanta and with many small retail shops, restaurants and bars; second, Decatur, an older city now absorbed in the metropolitan fabric that has invested in the creation of side walks and pedestrian streets to encourage pedestrian movement around its old urban core; third, Buckhead, which has attracted very high volumes of investment, including two of the largest shopping malls in the region as well as many high rise office and residential developments, and has grown into an urban center at the edge of the city of the 1960s; and fourth, Downtown Atlanta. Figure 1 shows the four areas, with the parcels that have commercial and recreational uses marked by circles. Figure 2 shows the same areas, with commercial and recreational land uses attached to road segments.

Figure 1:

Parcels with commercial and recreational land uses



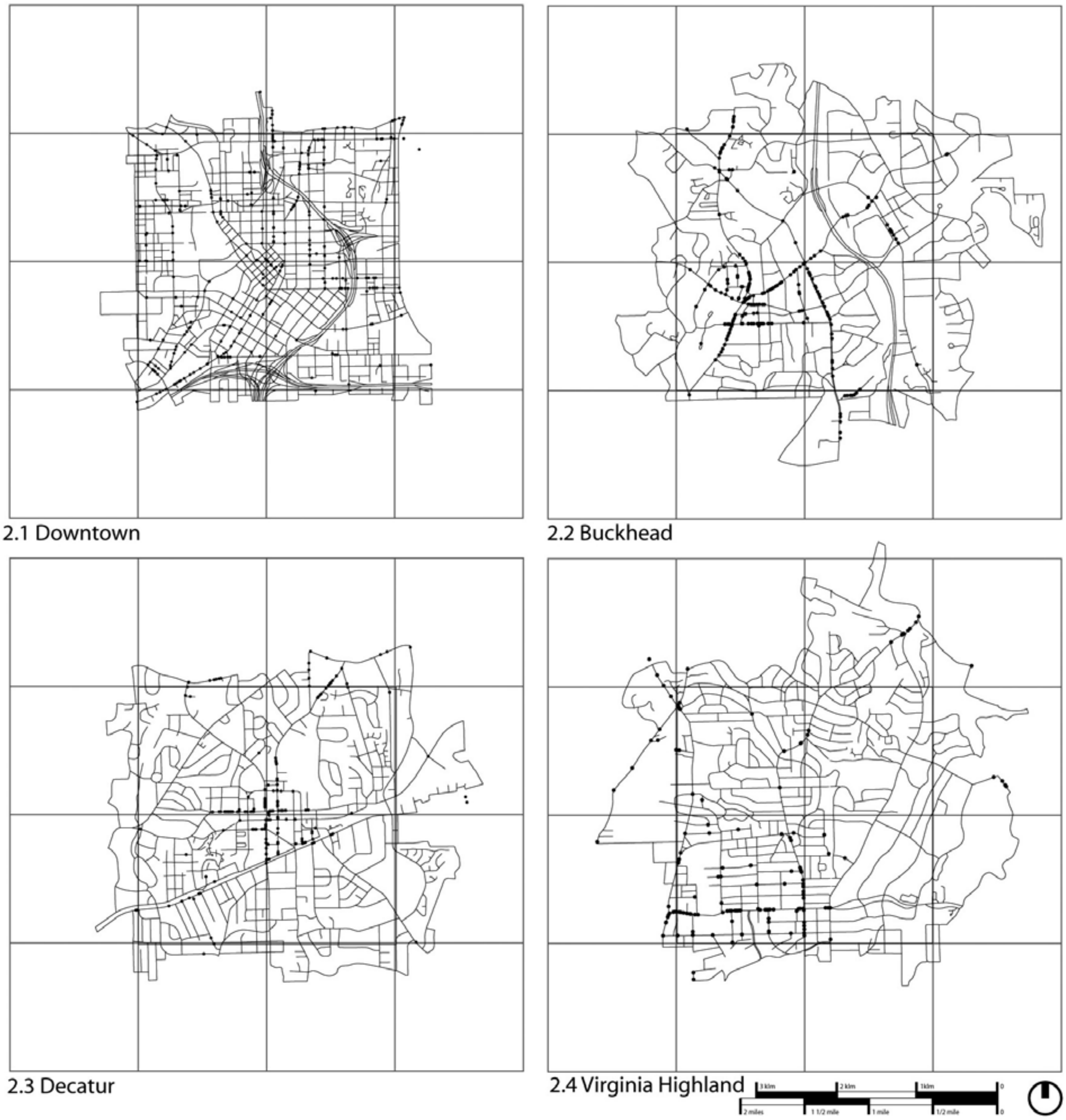
We have studied the co-variation of R_v(1.6 kilometer) and the number of parcels associated with commercial and recreational activities per street length – so as to normalize for differences in the lengths of the various road segments that are attached to at least one such parcel. The results of the analysis are shown in Figure 3. We propose that figure 3 should be looked at in two ways. First, as a simple plot of co-variation. Then, in relation to the correlation coefficient that can be computed based on the plot.

Taking the simple plot into account, we see that in the cases of Virginia Highland and Decatur, a clear triangle emerges on the plot: Segments with higher R_v values have a whole range of different densities of parcels with commercial and recreational uses; segments with lower R_v values have smaller ranges of such densities and the ranges become increasingly limited to low density values as the R_v

values get lower. Put more simply, in Virginia Highland and in Decatur, greater R_v values are associated with greater probabilities of high densities of commercial and recreational parcels. This tendency is only weakly evident in Buckhead and it is absent from Downtown. When we actually compute linear Pearson correlations based on the plots, we get significant correlations for Virginia Highland and Decatur but no significant correlations for Buckhead and Downtown. In the first two neighborhoods, variations in Rv account for about 10% of the variation in the density of plots associated with commercial and recreational land uses per length of road segment.

Figure 2:

Commercial and recreational uses by road segments



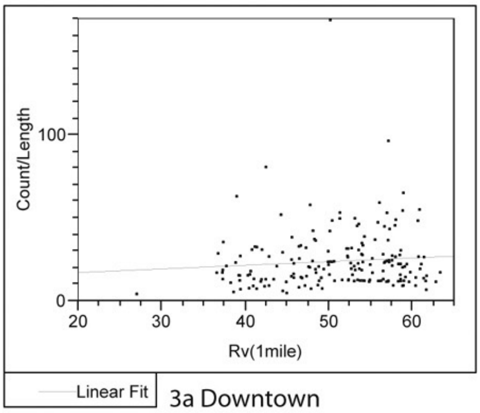
These are only preliminary results. They point in two directions. First, road-segment based measures of density, such as R_v, can be used to probe questions regarding the density of particular land uses within an area, based on the logic of street connectivity and configuration. Second, there may be different principles operating in different areas. Further work needs to explore whether areas such as Buckhead and Downtown can be better understood by varying some of the parameters of the analysis (for example the radius for the calculation

Figure 3

Plots of commercial and recreational parcels\road segment length against R_v

of R_v), whether entirely different configurational variables are also at play, or whether the distribution of the land uses under consideration simply does not follow a configurational logic at the scale of analysis of the individual road segment.

Bivariate Fit of Count/Length By Rv(1mile)



3a Downtown

Linear Fit

Count/Length = 12.394809 + 0.2202527 Rv(1mile)

Summary of Fit

RSquare	0.0077
RSquare Adj	0.002336
Root Mean Square Error	18.08054
Mean of Response	23.64497
Observations (or Sum Wgts)	187

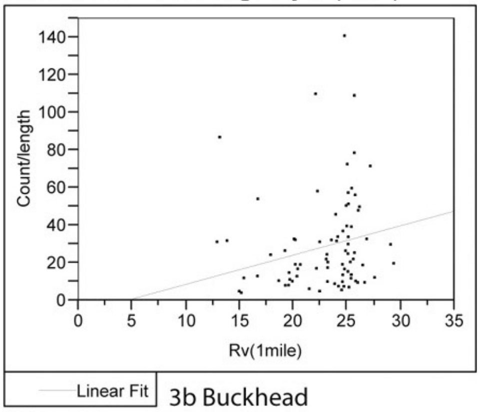
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	469.283	469.283	1.4355
Error	185	60477.591	326.906	Prob > F
C. Total	186	60946.873		0.2324

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	12.394809	9.482361	1.31	0.1928
Rv(1mile)	0.2202527	0.18383	1.20	0.2324

Bivariate Fit of Count/length By Rv(1mile)



3b Buckhead

Linear Fit

Count/length = -7.432689 + 1.5602475 Rv(1mile)

Summary of Fit

RSquare	0.045935
RSquare Adj	0.033381
Root Mean Square Error	25.07512
Mean of Response	28.61566
Observations (or Sum Wgts)	78

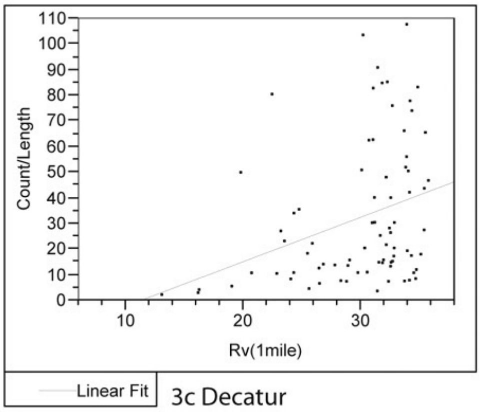
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2300.725	2300.73	3.6591
Error	76	47785.900	628.76	Prob > F
C. Total	77	50086.625		0.0595

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-7.432689	19.05768	-0.39	0.6976
Rv(1mile)	1.5602475	0.815651	1.91	0.0595

Bivariate Fit of Count/Length By Rv(1mile)



3c Decatur

Linear Fit

Count/Length = -19.93953 + 1.7353072 Rv(1mile)

Summary of Fit

RSquare	0.101375
RSquare Adj	0.089551
Root Mean Square Error	26.18913
Mean of Response	32.03922
Observations (or Sum Wgts)	78

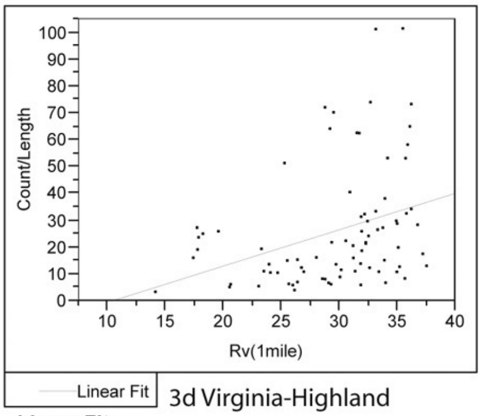
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5880.408	5880.41	8.5736
Error	76	52126.156	685.87	Prob > F
C. Total	77	58006.563		0.0045

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-19.93953	17.9978	-1.11	0.2714
Rv(1mile)	1.7353072	0.592644	2.93	0.0045

Bivariate Fit of Count/Length By Rv(1mile)



3d Virginia-Highland

Linear Fit

Count/Length = -14.32062 + 1.3520167 Rv(1mile)

Summary of Fit

RSquare	0.111395
RSquare Adj	0.100003
Root Mean Square Error	21.24069
Mean of Response	25.83161
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4411.520	4411.52	9.7780
Error	78	35191.017	451.17	Prob > F
C. Total	79	39602.537		0.0025

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-14.32062	13.05832	-1.10	0.2762
Rv(1mile)	1.3520167	0.432371	3.13	0.0025

Discussion

The results reported in this paper suggest that some of the conventional measures of urban density co-vary with the density of streets (parcel and population but also, to a lesser extent the square meters of residential buildings) and some not (square meters of non residential land uses). These results, however, constitute only a background for our pursuing a number of further questions; in its present form, our paper reports work in progress. We are seeking to expand the sample of areas, bringing in areas from other cities. The aim is not merely to put the findings reported here to further test, but also to check whether different cities have different profiles regarding the interaction between the density of the street network and other measures of density. This is the first question we are pursuing further.

The next question bears on city design. We noted that the street system is stable over relatively long periods of time and acts as a framework for changes in land use and population density; the question arises as to whether certain densities of streets (as measured by block sizes, distances between intersections, street length/sq. kilometer, R_v) can more flexibly accommodate a variety of land uses. To test this we need to sort our data not by area, but rather by ranges of block size and to study what statistical distributions of our other measures of density are associated with different block sizes.

The third question bears on the idea of the city as an interface of scales and arises with particular clarity in Atlanta. One of the qualities of Atlanta is the sharp change in development density over a very small distance, often within the same block. This, of course, can only occur if the block is sufficiently large to absorb such change. In some cases the sharp drop of development density allows an intense juxtaposition of high rise developments and small town houses, even single family houses. It also accentuates a familiar syntactic phenomenon, the organization of urban land by street face rather than by block. Thus, Atlanta allows us to study the occurrence of a distinctive kind of interface, one which accentuates the experience of the city as an organization of differences. In this context, the particular question we want to pursue is syntactic. What is the position of the blocks that absorb the sharpest density gradient drop relative to the surrounding network?

Finally, we need to extend our models of how particular land uses are distributed over a single area on the basis of the configurational situation of individual road segments or individual streets in their surroundings. This remains an important task in the refinement of theories that relate urban form to the patterns of urban function that are supported at a given point in time.

We end with a comment that brings us back to our opening statements. Measures of street configuration and density describe properties of the city as a physical artifact, but also properties of the street network as a framework within which other kinds of density vary over time. Traditionally, the design of the network of streets, whether determined according to an overall plan, or emergent according to an incremental process, has been the foundation for the creation of the city. More recently, planning has been more concerned with the spatial distribution of other kinds of density, including populations, land-uses, investments and resources of different kinds. We have started by referring to a quote that highlights how the tendency for these other kinds of density to become intensified over the geographical areas we call cities is still a fundamental and driving force for our society, economy and culture. So the question that continues to be interesting is how the more abstract kinds of density are founded on the specifically configured density of street networks and public/private interfaces on the ground. This question is fundamental to understanding how and why cities function, but it is also fundamental to the practices associated with making cities. Cities are not only certain kinds of density per square mile. They are also certain patterns of configuring density per parcel, block, street and, more importantly, per configurational principle applied to the design of street networks.

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