Using *LEED for Neighborhood Development* to compare Resource Efficiency in US Cities

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Abstract

This paper describes an approach for estimating the resource efficiency of a city, in terms of the location of residential areas and services, and the transportation energy associated with travel to and from these locations. By examining measures from the U.S. Green Building Council's *Leadership in Energy and Environmental Design for Neighborhood Development* (LEED-ND), and considering how these measures are related to transportation energy, a methodological approach is proposed and applied to 21 US cities. Resource efficiency is considered to be a measure of the functioning of the city, considered only from the point of view of residents.

1. Urban Patterns and Sustainability

This paper explores how some measures of LEED-ND can be a basis for providing a measure of resource efficiency in a city. This is done by comparing them to some emergent properties within a city, than can be described using a mathematical distribution. There is much literature available that discusses the impact of population density and transportation energy efficiency (Newman and Kenworthy, 1989), but the majority of studies that examine cities at the macro-level do not examine the patterns of behavior within the city. By exploring the population density, service densities and infrastructure as gradients from the city-center outwards, we can consider cities to be heterogeneous with parameters that describe this variation. These parameters can be visually and mathematically illustrated, leading to a greater understanding of how a city is functioning.

Urban economics has previously defined how and why cities form and identified many of these types of intra-city relationships (Fujita *et al.*, 1999) but this approach has not been linked with resource efficiency. This paper assumes that the driving forces of city formation and location choices are exogenous, but it explores how a static snapshot of the urban form can be used to estimate energy use. It presumes that exogenous location decisions can be influenced through policy or market incentives, which is one of the motivating factors for this study.

This granular analysis of urban performance takes into account the urban form within the city, and considers how an averaged measure of the form changes, from the city-center outwards. This approach would indicate what particular areas of the city can be improved, in terms of the LEED-ND criteria, and could provide a useful guide to urban planners. In addition, it attempts to identify what the limits of the city are. By identifying ranges of these parameters, we highlight what planners and policy-makers can realistically achieve to ensure that their city is as resource-efficient as possible.

Our approach assumes that cities are not disordered systems, but rather a form of urban complexity that has its basis in the regular ordering of size and shape across many spatial scales (Batty, 2005)[REF-check]. There is a growing body of work that is developing an integrated theory with regard to how cities evolve and develop (Batty, 2005; Bettencourt *et al.*, 2007), however this work explores the development of a city from a biological perspective, not necessarily motivated from a resource-efficiency perspective. In contrast, this paper considers the patterns that emerge as a result of analyzing cities while considering LEED-ND metrics. The goal of this paper aims to assist with identifying the functional form of these parameters and highlights what planners and policy-makers can do to ensure that their city can be as resource efficient as possible.

2. Background to LEED-ND

The Leadership in Energy and Environmental Design (LEED) group of rating systems is an internationally recognized certification framework that verifies the use of building design and construction strategies for improved environmental performance. LEED was developed by the U.S. Green Building Council (USGBC), and provides specific guidelines for identifying and implementing practical green building design, construction, operations and maintenance measures [REF]. However, the original *LEED for New Construction* rating system did not place an emphasis on building location or the effect of location on the resources and transportation energy required for the occupants to use the building and satisfy their other daily needs. The LEED-ND rating system was then developed to address this issue, and extends beyond individual buildings to integrate the principles of smart growth, new urbanism and green building into the choices regarding a development's location and design. LEED-ND surveys aspects of a neighborhood with the goal of reaching a certain level of environmental performance and to achieve credits toward certification [REF].

These credits can be viewed as a type of sustainability indicator, which serve as 'distance-to-target' measures; they are actionable strategies that have been set for advancing toward the community's sustainability goals. As such, it is possible to apply portions of the LEED-ND checklist to existing cities to determine their performance with respect to particular sustainable development goals. Similar to many sustainability plans being developed and implemented in cities throughout the world, LEED-ND is a 'checklist' of topic areas with key issues, for which data is collected in order to arrive at credit values for the locality. These types of findings provide a static, snapshot view of the area's performance.

3. Urban Patterns in Industrialized Countries

To achieve ecological sustainability, it is necessary to consider economics, as this is one of the main driving forces of growth within cities. However, neoclassical economics is only one way of valuing growth; it is also necessary to integrate social and ecological considerations when making investment and policy decisions. There are many historic examples exist of cities that declined or collapsed when environmental considerations were not taken into account (Diamond, 2005) [REF: girabet].

Urban economics is a field of study that developed in the late 1950's, with the major stimulus for the field being traffic congestion [REF: small]. Planners realized that complex statistical models of traffic did not consider the system as a whole, and failed to consider the integrated effects of land use and transportation. Evans [REF] considers the formation of cities to be dependent upon the fact that agricultural surpluses exist, thereby making it possible to sustain a city with no internal food production of its own. Furthermore, cities exist because production of goods varies among different cities, and comparative advantage between regions makes trade advantageous. In addition, agglomeration economics in production result in firms clustering in cities.

There is a need to move from focusing on economics as being the sole criterion and explanatory framework for location choices, and to promote alternative ways of thinking about this. For example, the myopic, economically rational household wants to purchase as large a house with as much land as possible. In a city where wages are low, but land is abundant, this would result in a city which is sprawling. However if the externalities of development location decisions are considered (material to provide the infrastructure and energy usage to live), not to mention poor community life, we would try and encourage higher-density dwellings. Our goal is to provide a holistic estimate of what the difference between a high-density urban dweller and a low-density suburban household is from a systems perspective.

4. LEED-ND Criteria

Three quantitative criteria from the section Smart Location & Linkage were considered in this analysis. These criteria are used to assess that a development is in an appropriate location, according to the goals that LEED-ND aims to assist with the implementation of. In this paper, three criteria are examined, as many of these criteria could not be calculated at a city scale for the following reasons:

some measures are site-specific, (e.g. number of jobs provided on the development) and some were not included (bicycle lanes) as there is not enough data at the city scale. For some categories (water and wastewater systems), the data is not publicly available at a city scale. It is assumed that if the project does not satisfy the pre-requisite criteria, that it would be difficult to achieve LEED accreditation.

The following three metrics that have been calculated from the Smart Location & Linkage (SLL) section:

4.1. SLL Prerequisite 1: Smart Location

These criteria specifies that the project be located on an infill site; or with a certain level of connectivity (measured in street network intersections); or near a transit route or corridor; or hat it be near a certain number of services. This considers one of the four options, 'OPTION 4. Sites with Nearby Neighborhood Assets'. As stated in the guidelines, the projects geographic center should be within a 1/2-mile walk distance of at least seven diverse uses or within a 1/4-mile walk distance of at least five diverse uses. The diverse use categories are listed in Table 3.

4.2. SLL Credit 3: Preferred Location

This criterion specifies that the urban form should have a certain level of road density in the surrounding area. 'Calculate the street grid density (in street centerline miles per square mile) within a 1 mile radius from the perimeter of the site boundary'. The site is required to have roads with a density level between 10 - 40 centerline miles per square mile, or greater, within one mile (Table 1). In addition, it should be a development with an existing community. Street density is a measure of permeability and circulation, and can be used as a proxy for measuring openness. *[Note: this measure has been removed from the final version of the LEED guidelines - they now use a measure of intersections per area]*

Table 1: Road density measures

Centre-lines/square mile	Credit Points
10 - 19	2
20 - 29	5
30 - 39	10
>40	20

4.3. NPD Credit 15: Neighborhood Schools

This criterion requires that the site be within a 1/2 mile walking distance of an existing or planned school.

5. Methodology

In this analysis 21 cities were analyzed (Table 2). These cities are almost all inland, with few geographical constraints to prevent them from spreading outwards, Minneapolis-St.Paul, Detroit and Houston being the exceptions. The data used was from the 2000 Census, and all Census calculations were performed at either the block, or block group level. The population density was calculated for each census block, and cities were identified based on clusters, where a minimum of 386 people/km^2 was the minimum density. This criteria (386 people/km^2) is a US Census categorization for 'urban areas' (US Census 2000)[REF].

Table 2: Cities analyzed *(Data: US Census 2000)*

City	Pop.[10^6]	Radius[km]	Dens.[$Per./km^2$]
Minneapolis-St.Paul	2.4	34	674.6
Kansas City	1.5	30	520.5
St Louis	2.2	38	477.9
Dallas	4.2	51	517.2
Houston	4.1	50	522.7
Atlanta	3.7	51	447.3
Indianapolis	1.2	26	550.5
Pittsburgh	2.0	45	316.4
Phoenix-Mesa	2.9	38	649.9
Memphis	0.9	26	444.6
San Antonio	1.3	24	744.4
Detroit	4.5	64	350.0
Columbus	1.2	25	613.5
Cincinatti	1.6	36	401.0
Orlando	1.4	30	486.5
Nashville	0.8	27	342.3
Oklahoma	0.8	26	378.0
Denver	2.0	26	929.9
Charlotte-Gastonia	1.3	41	249.3
Louisville	0.9	23	531.1
Richmond-Petersburg	0.8	25	389.5

5.1. Boundary of City

Political or census boundaries of cities were not used in this work. The center of the city was defined as the point with the highest density of services. Using this center point, the population was calculated for concentric rings, and a cutoff threshold of 100 people/km^2 was used to define the outer boundary. Using this approach the radii of all cities is given in Table 2. The cities were of varying sizes with total population ranging from 4.5 million (Detroit), to 0.8 million (Nashville, Oklahoma and Richmond-Petersberg) when the boundary is defined using the above cut-off.

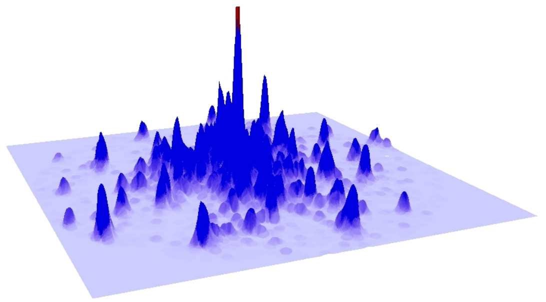

Figure 1: Service density for Atlanta; the highest value is illustrated in red.

The North American Industrial Classification System (NAICS) was used for classifying services. ESRI Business Analyst data [REF] was used to identify the location of each service. This data is more recent than the 2000 Census Data, however, the goal is to illustrate the relationship between population densities and LEED-ND patterns, rather than making policy conclusions so it was considered appropriate for this purpose. It is included to show how the population density gradient results in a distribution of infrastructure and services from an urban center.

The analysis was conducted using ESRI ArcMap. Rasters with a cell size of 200m were generated for all cities and the map projection used was Albert Equal Area. Standard raster geoprocessing techniques were used to analyze the data with python scripting. Theses scripts have been packages together into an ArcGIS toolbox that is freely available for download and modification [REF].

5.2. Trip frequency calculation

The American Time Use Survey (ATUS) from 2003-2008 was used to estimate the weekly frequency at which average urban dwellers make trips to the 19 services listed by LEED-ND [REF]. In ATUS, respondents are interviewed about how they spent their time on the previous day. Particular individuals are assigned to respond regarding each day of the week. The survey also provides information on the amount of time (in number of minutes) that people spend in travel associated with their activities, such as religious activities, education, and shopping, among others. Demographic information, including urban or rural residence is also collected for each respondent.

Because travel times are associated in the survey with particular activities, we were also able to associate them with particular destinations comprising the 19 services that are listed in LEED-ND. We then assumed that the median travel time of all respondents for each day represented the length of one trip to a particular destination. By dividing the average travel time per day of all respondents by the median travel time (assumed length of a single trip), we were able to estimate the number of trips per respondent per day to each of the 19 destinations. Then, summing over all 7 weekdays gave us the weekly trip frequency to each service.

Table 3: List of Services that are considered 'Diverse Uses' *(Data: LEED-ND)* and Frequency of visit per week *(Data: US Transportation Survey*

Service	Frequency [Visits/week]
Bank	0.370
Child care facility	0.382
Community/Civic center	1.078
Convenience store	2.556
Hair care	0.151
Hardware Store	1.379
Health club/Rec. facility	0.957
Laundry/dry cleaner	0.056
Library	0.254
Medical/Dental office	0.706
Pharmacy	2.044
Place of worship	0.900
Police/Fire station	0.002
Post Office	0.488
Restaurant	7.553
School	1.298
Senior care facility	0.204
Supermarket	1.173
Theater	0.823

6. Relationship of LEED-ND Metrics with Resource Consumption

To provide some background context to this study, two other emergent properties of cities are discussed. The first, the population density gradient, is one that has been widely observed (Clark, 1951). The second, examining the distances to services as a function of distance from city-center (or population density), is most relevant to this LEED-ND analysis as it illustrates quantitatively what the difference of achieving a certain level of population density is in terms of energy consumption. By exploring how population density changes from the city-center outwards, and where services are located. this illustrates how far people need to travel to access the 19 services that LEED considers necessary to achieve a good community.

6.1. Population Density

The population density falls as the radius increases, and follows a logarithmic pattern, which was first observed by Clark (1951). The structure of this relationship is

$$y = Ae^{xb}$$

where y is the population density, x is the distance from the urban center, and A and b are parameters for each city. These values are given in Table 4, and the associated R-squared, p-value and t-statistic are also listed for each city. This relationship appears to hold for all 20 cities in this study, with Memphis being the exception (Adjusted-R^2 = 0.15). The highest population density at the center is in Denver while the lowest is in Memphis. The reason for this could be due to the the highest service density not occurring near the center (this is illustrated in Figure 3).

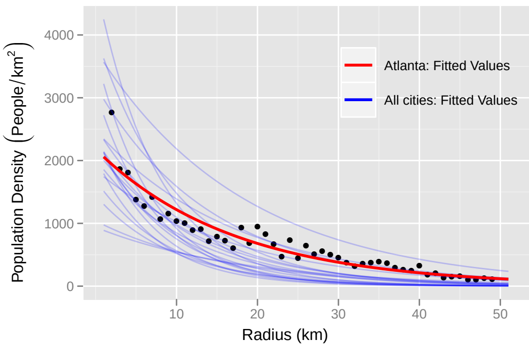

Figure 2: Population density gradient for Atlanta

The results from Table 4 are illustrated in Figure 2 with Atlanta's population density gradient visualized in 3-D (Figure 4).

6.2. Distance Traveled to Services per week

Using ESRI Business Analyst data, the distance to 19 services was calculated from each raster-cell.

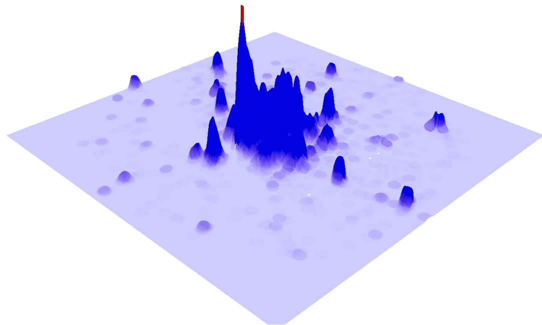

Figure 3: Service density for Memphis, with highest service density level colored red

Table 4: Population Density Gradient *(Data: US Census Data)*

NAMES	A	b	Adj.-R-Sq.	p-value	t-stat.
Minneapolis-St.Paul	4,006.22	-0.100	0.926	0.0000	-19.69
Kansas City	2,025.04	-0.087	0.828	0.0000	-11.44
St Louis	2,536.78	-0.084	0.850	0.0000	-14.13
Dallas	2,485.34	-0.058	0.872	0.0000	-18.09
Houston	3,191.46	-0.070	0.871	0.0000	-17.83
Atlanta	2,181.01	-0.058	0.931	0.0000	-25.42
Indianapolis	2,297.95	-0.105	0.825	0.0000	-10.44
Pittsburgh	2,172.37	-0.080	0.888	0.0000	-18.23
Phoenix-Mesa	1,849.18	-0.059	0.353	0.0001	-4.48
Memphis	938.30	-0.055	0.154	0.0329	-2.28
San Antonio	3,703.01	-0.139	0.815	0.0000	-9.67
Detroit	3,765.87	-0.054	0.914	0.0000	-25.42
Columbus	3,113.18	-0.134	0.868	0.0000	-12.06
Cincinatti	2,341.61	-0.089	0.915	0.0000	-18.92
Orlando	2,379.71	-0.115	0.737	0.0000	-8.75
Nashville	1,443.50	-0.102	0.821	0.0000	-10.52
Oklahoma	1,688.85	-0.110	0.698	0.0000	-7.36
Denver	4,838.83	-0.130	0.730	0.0000	-7.95
Charlotte-Gastonia	1,038.70	-0.063	0.756	0.0000	-10.90
Louisville	2,444.26	-0.135	0.772	0.0000	-8.28
Richmond-Petersburg	2,052.46	-0.136	0.854	0.0000	-11.41
Mean	2,499.70	-0.094	0.780	-	-
Standard Deviation	978.13	0.030	0.190	-	-

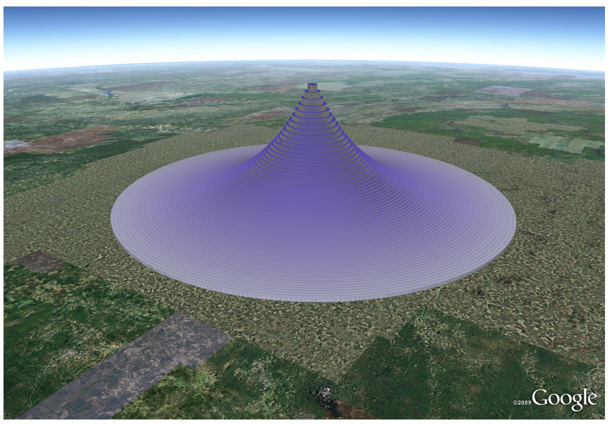

Figure 4: Geovisualization of Atlanta's population density gradient using Google Earth

Then, summing these values together, weighted by the frequency of visiting each service during one week provided an estimate of the total distance travelled. Similar to the equation used to describe population density, the structure of this relationship was

$$y = Ae^{xb}$$

where y is the distance travelled per week by one household, x is the distance from the urban center, and A and b are parameters for each city. A linear regression model was used to estimate this relationship, and the results are summarized in Table 5. From this calculation, a lower bound of the amount of energy required a household to operate, as a function of distance from city center can be estimated (based on a Joules/km conversion). This measure is a lower-bound estimate as it is just a measure of straight line distance, and does not consider commuting to work or other modes of transportation, aside from autos.

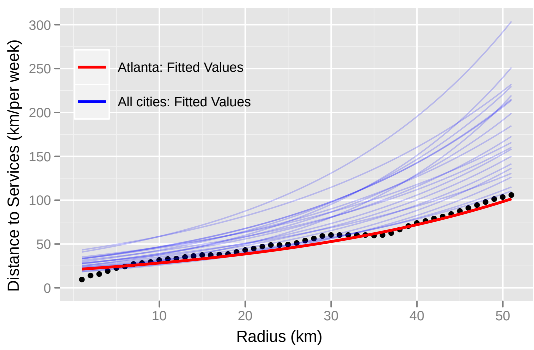

Figure 5: Estimated distance traveled by one household to services, during one week, based on the location of the household as a distance from the city center.

6.3. LEED-ND Measures

This method of analysis, where a parameter is examined as a function of the distance from the city-center, is then applied to the three LEED-ND measures previously described. This illustrates how other patterns, including these LEED criteria, exist as a function of population density from the city center.

6.3.1. SLL Prerequisite 1: Smart Location

Figure 6 illustrates the areas within the Atlanta metro area that satisfy the criteria of being with

Table 5: Distance to Services *(Data: US Census Data, US Time Use Survey)*

Names	A	b	Adj.-R-Sq.	p-value	t-stat.
Minneapolis-St.Paul	17.66	0.039	0.922	0.0000	27.58
Kansas City	24.48	0.037	0.917	0.0000	26.69
St Louis	21.66	0.037	0.938	0.0000	31.13
Dallas	20.65	0.034	0.957	0.0000	37.71
Houston	18.15	0.040	0.978	0.0000	52.91
Atlanta	20.76	0.031	0.935	0.0000	30.24
Indianapolis	26.92	0.036	0.904	0.0000	24.63
Pittsburgh	22.69	0.031	0.871	0.0000	20.81
Phoenix-Mesa	23.82	0.046	0.963	0.0000	40.95
Memphis	41.87	0.034	0.776	0.0000	14.91
San Antonio	28.53	0.041	0.866	0.0000	20.32
Detroit	39.26	0.040	0.838	0.0000	18.22
Columbus	30.43	0.033	0.797	0.0000	15.89
Cincinatti	23.14	0.037	0.880	0.0000	21.73
Orlando	26.25	0.040	0.886	0.0000	22.37
Nashville	34.08	0.031	0.782	0.0000	15.19
Oklahoma	32.34	0.037	0.865	0.0000	20.29
Denver	19.13	0.048	0.926	0.0000	28.32
Charlotte-Gastonia	27.40	0.031	0.848	0.0000	18.95
Louisville	32.19	0.034	0.803	0.0000	16.16
Richmond-Petersburg	31.98	0.037	0.870	0.0000	20.74
Mean	26.83	0.037	0.882	-	-
Standard Deviation	6.71	0.005	0.060	-	-

a half-mile of six or more services. Figure 7 illustrates this measure radially, calculated as a function from the city center.. The fitted curve follows a clear pattern of behavior that is similar for all other cities examined, with the estimated curve for Atlanta highlighted in red. The form of this curve is:

$$y = A \times ln(x) + b$$

and the statistical analysis for this curve summarized in Table 6.

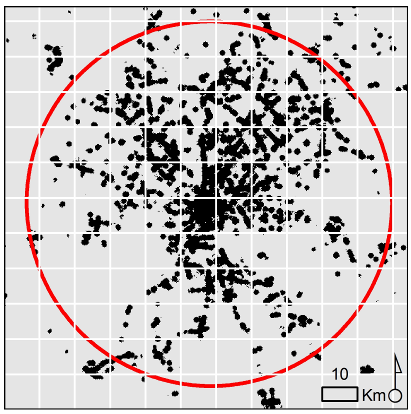

Figure 6: Plan view of Atlanta, illustrating areas close to 6 or more services (colored black)

6.3.2. SLL Credit 3: Preferred Location

Similar to the previous two examples, Figure 8 illustrates that the fraction of area that satisfies

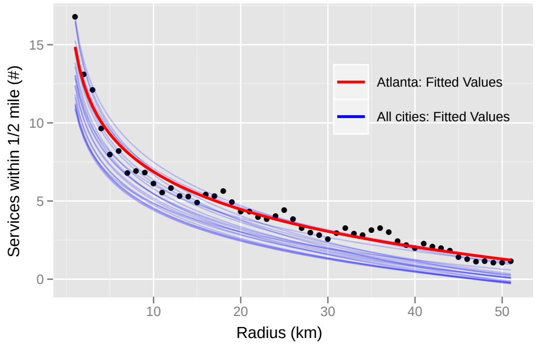

Figure 7: Mean value of number of services within a half-mile concentric ring

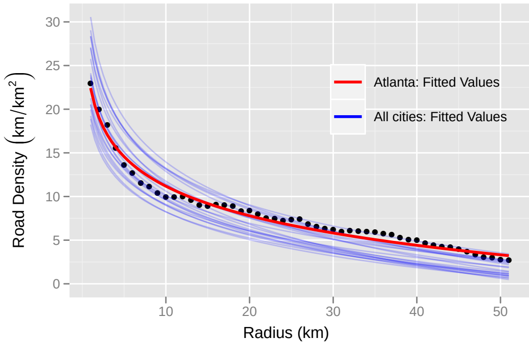

Figure 8: SLL Credit 3:Road density

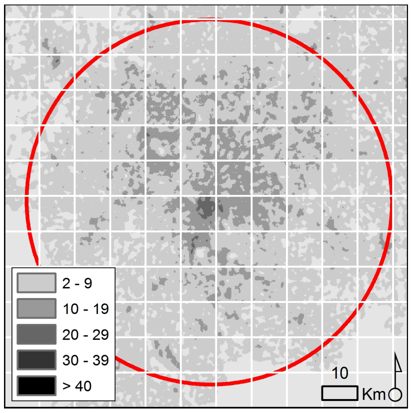

Figure 9: Road density of Atlanta

Table 6: Services within a half-mile *(Data: US Census Data, ESRI Business Analyst)*

NAMES	A	b	Adj.-R-Sq.	p-value	t-stat.
Minneapolis-St.Paul	0.04	2.872	0.922	0.0000	27.58
Kansas City	0.04	3.198	0.917	0.0000	26.69
St Louis	0.04	3.075	0.938	0.0000	31.13
Dallas	0.03	3.028	0.957	0.0000	37.71
Houston	0.04	2.899	0.978	0.0000	52.91
Atlanta	0.03	3.033	0.935	0.0000	30.24
Indianapolis	0.04	3.293	0.904	0.0000	24.63
Pittsburgh	0.03	3.122	0.871	0.0000	20.81
Phoenix-Mesa	0.05	3.171	0.963	0.0000	40.95
Memphis	0.03	3.735	0.776	0.0000	14.91
San Antonio	0.04	3.351	0.866	0.0000	20.32
Detroit	0.04	3.670	0.838	0.0000	18.22
Columbus	0.03	3.415	0.797	0.0000	15.89
Cincinatti	0.04	3.142	0.880	0.0000	21.73
Orlando	0.04	3.268	0.886	0.0000	22.37
Nashville	0.03	3.529	0.782	0.0000	15.19
Oklahoma	0.04	3.476	0.865	0.0000	20.29
Denver	0.05	2.951	0.926	0.0000	28.32
Charlotte-Gastonia	0.03	3.310	0.848	0.0000	18.95
Louisville	0.03	3.472	0.803	0.0000	16.16
Richmond-Petersburg	0.04	3.465	0.870	0.0000	20.74
Mean	0.04	3.261	0.882	-	-
Standard Deviation	0.00	0.245	0.060	-	-

this criteria diminishes with a curve of the following shape (similar to the population density gradient):

$$y = A \times ln(x) + b$$

where y is the road density and x is the distance from the urban center, and A and b are parameters for each city. The parameters for these curves are shown in Table 7.

6.3.3. SLL Credit 7: School Proximity

Figure 11 illustrates the areas that satisfy the criteria of being within $\frac{1}{2}$ mile of a school. Similar to the previous two measures, Figure 10 illustrates the fraction of area that satisfies this criteria diminishes with a curve of the following shape:

$$y = A \times ln(x) + b$$

The values for these curves are shown in Table 8.

7. Observations

Using a radial measure to approximate the average behavior of a city is a general approach, as it does not take into account local spatial patterns. The purpose of this approach is to highlight how the cities change, moving from the city center outwards. In this way the boundary of a city could be defined to maximize efficiency, and perhaps to encourage those who live outside, it to move closer when the resources required are illustrated. One of the limitations of using average values from concentric circles is illustrated in Figure 6 as there is a different pattern of behavior on the north side of the city when compared to the south side. However, there is a high level of statistical significance

Table 7: Road density parameters *(Data: US Tiger line files)*

Names	A	b	Adj.-R-Sq.	p-value	t-stat.
Minneapolis-St.Paul	-6.61	28.341	0.962	0.0000	27.58
Kansas City	-6.08	25.761	0.951	0.0000	26.69
St Louis	-5.44	23.874	0.936	0.0000	31.13
Dallas	-5.99	26.995	0.984	0.0000	37.71
Houston	-7.21	30.561	0.990	0.0000	52.91
Atlanta	-4.88	22.424	0.981	0.0000	30.24
Indianapolis	-5.86	24.112	0.976	0.0000	24.63
Pittsburgh	-6.57	28.379	0.930	0.0000	20.81
Phoenix-Mesa	-4.54	20.526	0.776	0.0000	40.95
Memphis	-4.62	18.891	0.924	0.0000	14.91
San Antonio	-6.76	27.089	0.926	0.0000	20.32
Detroit	-5.33	23.638	0.961	0.0000	18.22
Columbus	-5.51	22.296	0.929	0.0000	15.89
Cincinatti	-5.66	23.195	0.951	0.0000	21.73
Orlando	-5.45	22.345	0.969	0.0000	22.37
Nashville	-4.34	18.237	0.908	0.0000	15.19
Oklahoma	-5.06	21.254	0.941	0.0000	20.29
Denver	-7.02	29.039	0.932	0.0000	28.32
Charlotte-Gastonia	-4.40	19.226	0.958	0.0000	18.95
Louisville	-4.79	20.003	0.926	0.0000	16.16
Richmond-Petersburg	-5.00	20.550	0.941	0.0000	20.74
Mean	-5.58	23.654	0.940	-	-
Standard Deviation	0.88	3.634	0.044	-	-

between the distance from city-center and the number of services that are nearby.

As population density is related to distance from city center using the following relationship:

$$y = Ae^{xb}$$

and all LEED-ND measures are described using

$$y = A \times ln(x) + b$$

population density and LEED-ND measures can be directly correlated, with a high level of statistical significance. Using this relationship the probability of an area satisfying LEED-ND criteria can be estimated based on its location from the city-center.

Distance based accessibility measures have been criticized (Handy and Clifton, 2001), as they do not consider people's preferences or more more qualitative considerations. In this case, the analysis is abstract and high-level, so individual decisions or choices are not considered to be important. The goal is to estimate what the minimum transportation energy for a city to function based on resident location, and to consider how LEED-ND measures are distributed throughout the city, and there are definite patterns that can be observed.

Based on this analysis, it is suggested that ensuring that there is a minimum level of population density, could result in the types of development that LEED strives to achieve. This approach does

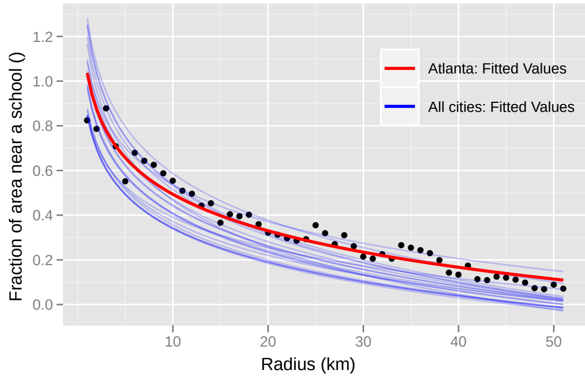

Figure 10: Fraction of area that satisfies SLL Credit 7

Table 8: Fraction of area near schools *(Data: ESRI Business Analyst)*

Names	A	b	Adj.-R-Sq.	p-value	t-stat.
Minneapolis-St.Paul	-0.31	1.250	0.940	0.0000	27.58
Kansas City	-0.26	1.038	0.943	0.0000	26.69
St Louis	-0.30	1.203	0.950	0.0000	31.13
Dallas	-0.24	1.085	0.899	0.0000	37.71
Houston	-0.30	1.282	0.940	0.0000	52.91
Atlanta	-0.24	1.036	0.949	0.0000	30.24
Indianapolis	-0.25	0.986	0.935	0.0000	24.63
Pittsburgh	-0.27	1.098	0.942	0.0000	20.81
Phoenix-Mesa	-0.20	0.847	0.718	0.0000	40.95
Memphis	-0.22	0.842	0.910	0.0000	14.91
San Antonio	-0.30	1.166	0.915	0.0000	20.32
Detroit	-0.23	1.031	0.942	0.0000	18.22
Columbus	-0.25	0.975	0.913	0.0000	15.89
Cincinatti	-0.26	1.046	0.940	0.0000	21.73
Orlando	-0.24	0.967	0.928	0.0000	22.37
Nashville	-0.22	0.846	0.879	0.0000	15.19
Oklahoma	-0.23	0.878	0.921	0.0000	20.29
Denver	-0.31	1.254	0.898	0.0000	28.32
Charlotte-Gastonia	-0.22	0.871	0.893	0.0000	18.95
Louisville	-0.22	0.850	0.891	0.0000	16.16
Richmond-Petersburg	-0.22	0.850	0.902	0.0000	20.74
Mean	-0.25	1.019	0.912	-	-
Standard Deviation	0.04	0.148	0.049	-	-

not take into account that as part of a development, more services could be constructed that would increase the number the site is near and this would enable it to become feasible. LEED-ND specifically considers this as being part of the development plans.

8. Conclusions

The goal of this work was to quantitatively analyze a sample of US cities using some quantitative criteria from LEED-ND. In addition, the resource consumption coefficients were estimated so that these patterns could be converted into units of energy and material. The principles espoused in

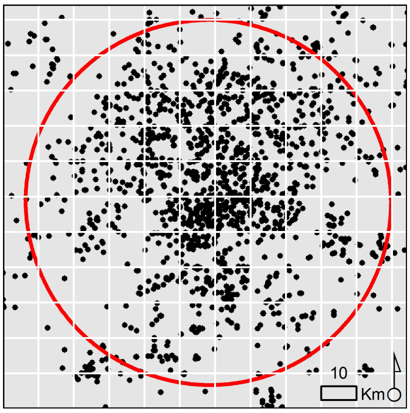

Figure 11: Area near schools that satisfies SLL Credit 7

LEED-ND are difficult criteria for many US cities to achieve. The current form of the US cities is a result of the quasi-equilibrium between many forces in the economy. To move US cities from their current state to one, which satisfies more of these criteria, it is necessary for either strong planning legislation, or for another exogenous forces such as an increase in energy prices.

However, an optimistic view is that the market would drive such behavior. A recent study using Walkscore (WalkScore, 2009) data which illustrated the correlation between property value and walkability (Cortright, 2009) suggests that such qualities are reflected in their market value. If a similarly strong correlation can be identified between neighborhoods and LEED-ND certification, it is possible that the market will move towards an urban form that results in a better quality of life.

While LEED-ND is a much needed step in the right direction, it is a criteria that would not be possible to achieve on a wider scale within many of the cities examined here due to the necessity of having higher densities than currently exist in urban areas, as it relies on there already existing a pre-requirement of high-density settlements. Ideally the

It is necessary to look at infrastructure changes, that result in different neighborhoods being formed rather than assuming that the private sector will be able to change the overall patterns of development on a large scale.

Another consideration, is that LEED-ND could be a catalyst for nodes of high density development. In this way, as the population density and services diminish from the center, if each node was sufficiently close the tail of the distribution would not fall off as dramatically. In a free market economy, it seems inevitable that this pattern will form, so policy-makers should attempt to make it as steep as possible, to minimize the area that the city takes up.

Defining the functional parameters of the city provides a new way of describing and comparing the relative performance of cities. This provisional work does not consider a sufficient number of factors to enable judgements to made about the relative performance, but illustrates an approach that is rooted in objectivity and replicability.

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