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Comparing spatial metrics that quantify urban form

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ABSTRACT

Measuring and characterizing urban form is an important task for planners and policy analysts. This paper compares eighteen metrics of urban form for 542 neighborhoods in Salt Lake County, Utah. The comparison was made in the context of characterizing three neighborhood types from different time periods: pre-suburban (1891–1944), suburban (1945–1990), and late-suburban (1990–2007). We used correlation analysis, within and across time periods, to assess each metric's ability to uniquely characterize urban form; and we used linear regression to assess the ability to distinguish neighborhood type. Three of the metrics show redundancy and two did not capture differences in urban form for the case study. Based on our findings, we recommend thirteen of the eighteen metrics for planners and policy analysts who want to quantify urban form using spatial data that are commonly available. Furthermore, our case study shows that despite policy efforts to encourage "smart growth," urban neighborhoods in Salt Lake County continue to exhibit characteristics of "sprawl." These findings suggest the effectiveness of smart growth policies in Salt Lake County have had limited effect.

1. Introduction

The spatial structure of cities, also called "urban form," has changed dramatically over the last century (Garreau, 1991; Jackson, 1985). Cities at the beginning of the century were relatively compact and densely populated, with transportation primarily by foot, wagon, or trolley. By the end of the twentieth century the defining characteristic of most U.S. cities was, and still is, a heavy reliance on the automobile for transportation. The urban form of many modern cities can be characterized as low-density, sprawling development.

A wide variety of spatial metrics have been created to characterize and quantify urban form (Ewing, Pendall, & Chen, 2002; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Glaser, Kahn, & Chu, 2001; Song & Knaap, 2004; Theobald, 2002; Torrens, 2000; Weston, 2002). Urban scientists use spatial metrics to gain understanding about the evolving landscape in which we live. Planners and policy analysts use spatial metrics to evaluate and promote policies concerning land use and urban development. The increased use and growing demand for spatial metrics is due in part because of the availability of commercial and open source computing tools, such geographic information systems (GIS) that can store and analyze large amounts of spatial data, and the increased availability of spatial data in the public domain (Kerski & Clark, 2012).

This paper presents a study comparing 18 spatial metrics that are simple to compute and require commonly available GIS data. Our aim was to evaluate the metrics' relative effectiveness in capturing four dimensions of urban form: density, centrality, accessibility, and neighborhood mix (Ewing et al., 2002). Using Salt Lake County, Utah as our study area we assigned each of 542 neighborhoods to one of three neighborhood types based on the era during which they were developed: pre-suburban era (1891–1945), suburban era (1945–1990), and late-suburban era (1990–2007). Given the recognized differences in neighborhood design following World War II and the subsequent era of suburbanization, we wished to evaluate the relative ability of these metrics to capture differences in the four dimensions of urban form. To evaluate possible redundancy among metrics we use linear regression and correlation analysis, within and across neighborhood types, to assess each metric's ability to uniquely characterize urban form. We include the late suburban era neighborhood type in order to compare our results in Salt Lake County with a similar case study carried out in Portland, Oregon (Song & Knapp, 2004).

The next section provides background on urban form research and introduces various spatial metrics. Section 3 describes the case study community and the data used for this project. Sections 4 and 5 present the analysis method and a discussion of the results, respectively. Section 6 provides conclusions about the particular case study and offers recommendations for practitioners and researchers.

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2. Background

2.1. Urban form research

Often the motivation to quantify urban form is to evaluate policies and strategies aimed at managing urban sprawl (Herold, Couclelis, & Clarke, 2005). In the 1990s the American Planning Association (APA) began promoting the concept of "smart growth" as a strategy for controlling sprawl (Knapp, 2005). Smart growth principals include encouraging mixed land uses, developing walkable neighborhoods, promoting public transportation, and fostering communities with a strong sense of place. Related to smart growth, are the ideals espoused by the philosophy of "New Urbanism" (Leccese, McCormick, Davis, & Poticha, 2000). Proponents of New Urbanism advocate an urban form reminiscent of residential development before World War II—in other words, compact, pedestrian friendly neighborhoods, mixed land uses, and easy access to public transit and activity centers.

A number of studies have used spatial metrics to evaluate smart growth policies and measure urban sprawl. For example, recently in this journal Liu and Shen (2011) used spatial metrics to analyze the influence of urban form on household travel and energy consumption in Baltimore, Maryland. Early and influential studies of spatial metrics include Galster et al. (2001) who used eight spatial metrics to characterize the amount of sprawl for 13 U.S. Urban Areas, and Ewing et al. (2002) who used 22 sprawl metrics to derive "sprawl rankings" for 83 U.S. cities. Weston (2002) used four spatial metrics to characterize urban form in Austin, Texas to assess the feasibility of retrofitting current residential neighborhoods to New Urbanist ideals. An important conclusion from Weston's work is that if planners with New Urbanist ideals hope to encourage re-development of existing neighborhoods they must first know, in a quantitative fashion, how far off those neighborhoods are from the ideal.

Finally, an important study, relevant to our work, was carried out by Song and Knapp (2004) who sought to quantitatively measure urban form across three different time periods of development in Portland, Oregon. Song and Knaap's motivation was to determine whether spatial measures of urban form offer empirical evidence that urban form changes over time. They found that starting in the 1990s several measures of sprawl had changed. For example, on average newer residential neighborhoods were better connected and more pedestrian friendly (Song & Knapp, 2004).

2.2. Spatial metrics

We compared 18 spatial metrics that are simple, straightforward, and require commonly available GIS data. We selected these metrics from eight previous case studies (Ewing et al., 2002; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Glaser et al., 2001; Song & Knapp, 2004; Theobald, 2002; Torrens & Alberti, 2000; Weston, 2002).

Following Ewing et al. (2002) we organize the metrics into four urban form categories: *density*, *centrality*, *accessibility*, and *neighborhood mix* (see Table 1). Churchman (1999) suggests *density* is the most intuitive characteristic of urban form and it is often considered the most indicative of "sprawl" (Galster et al., 2001). Smart growth advocates argue that living in low-density neighborhoods increases dependence on automobiles with potentially adverse health and environmental effects (Johnson, 2001). *Centrality* metrics seek to quantify the separation between where people live and where they must go for common daily activities (Song & Knapp, 2004). These measure the strength of activity centers, such as the central business district or other commercial centers (Ewing et al., 2002). *Accessibility* is a related concept, but with greater focus on the ability to access destinations (a neighborhood might have high centrality, i.e. near key activity centers, but poor accessibility because of missing street connections to the activity centers). Critics of sprawling suburban development contend that neighborhoods with winding dendritic streets, large residential blocks, and cul-de-sacs are not pedestrian friendly (Jin and White, 2012). Consequently, accessibility metrics seek to quantify street pattern and network connectivity (Ewing et al., 2002; Song & Knapp, 2004). *Neighborhood mix* refers to land use and demographic heterogeneity. It has been argued that zoning restrictions following World War II encouraged segregating residential subdivisions from commercial activities, and also encouraged (either intentionally or unintentionally) social and economic segregation (Lindsrom & Bartling, 2003). We include three metrics aimed at quantifying land use heterogeneity and two concerned with demographic heterogeneity. Unlike the other sixteen metrics, these three involve calculating an index (see Appendix A).

Table 1
Selected spatial metrics that use commonly-available GIS data.

Urban form category	Spatial metric (units)	GIS data	Earlier case study[a]
Density	1. Median single family residential lot size (acres)	Parcels	4, 7
	2. Housing density (housing units/sq. km.)	Census, Parcels	2, 5, 7
	3. Median number of rooms (#)	Census	7
	4. Population density (pop./sq. km.)	Census, Parcels	4, 8
	5. Average household size (people/housing unit)	Census	7
Centrality	6. Mean distance to commercial zone (km)	Streets, Parcels	2, 7
	7. Mean distance to public parks (km)	Streets, Parcels	7
	8. Mean distance to K-12 schools (km)	Streets, Parcels	
	9. Mean distance to transit bus stops (km)	Streets, Bus Stops	6, 7
Accessibility	10. Street connectivity (ratio streets to intersections)	Streets, Parcels	6, 7
	11. Median perimeter of residential blocks (m)	Parcels	7
	12. Dendritic street pattern (ratio cul-de-sacs to streets)	Streets, Parcels	6
	13. Median length of cul-de-sacs (m)	Streets, Parcels	7
Neighbor-hood mix	14. Land use contiguity (Juxtapose Interspersion Index)	Parcels	1
	15. Land use richness (Patch Richness)	Parcels	8
	16. Land use diversity (Simpsons Diversity Index)	Parcels	6, 8
	17. Pop. working outside city of residence (proportion)	Census	4, 3
	18. Renter–owner balance (ratio renters to owners)	Census	1

[a] 1 – Torrens and Alberti (2000), 2 – Galster et al. (2001), 3 – Glaser et al. (2001), 4 – Ewing et al. (2002), 5 – Theobald (2002), 6 – Weston (2002), 7 – Song and Knapp (2004), 8 – Frenkel and Ashkenazi (2008).