CLASSIFICATION OF URBAN FORMS AND THEIR RELATIONSHIP WITH VEGETATION COVER IN CACHE COUNTY, UTAH

by

Stephen J. Peaden

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Approved:

Shujuan Li, Ph.D. Major Professor	Carlos V. Licón, Ph.D. Committee Member
Joanna Endter-Wada, Ph.D. Committee Member	Richard S. Inouye, Ph.D. Vice Provost for Graduate Studies

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ABSTRACT

Classification of Urban Forms and Their Relationship with Vegetation Cover in Cache County, Utah

by

Stephen J. Peaden, Master of Landscape Architecture

Utah State University, 2019

Major Professor: Shujuan Li, Ph.D.
Department: Landscape Architecture and Environmental Planning

As residential urban development increases in the western U.S., few studies have shown how different urban forms influence vegetation cover. The two studies in this thesis examine how to define and measure residential urban forms and how they relate to vegetation cover.

The first study begins by defining urban form. Past studies showed the most essential metrics that define residential urban form are building density, centrality, connectivity, land use mix, and parcel size. Consistent definitions and methods for measuring these metrics are proposed.

Residential parcels of Cache County, Utah were measured for each metric. A K-means cluster analysis assign each parcel to one of 50 groups based on measurement similarities. The 10 most widely used groups represented distinct identifiable urban forms such as Agricultural residential, urban sprawl, historic plat patterns, and variations of each.

The second study used the metrics and groups from the first study to check for correlations with vegetation cover. A normalized difference vegetation index (NDVI) of aerial imagery of Cache County was used to classify land cover into three groups: dense vegetation, light vegetation, and no vegetation. Measurements of vegetation cover were extracted for each parcel and each urban form group. Total vegetation cover (TVC) and dense vegetation cover (DVC) measured higher in urban areas than in the county as a whole. Agricultural residential groups had among the highest TVC, but had the lowest DVC. Non-agricultural residential groups had the highest DVC as a percentage of TVC except for group 4 “Modern Suburban Sprawl” which had the lowest DVC as a percentage of TVC. Group 7 “Satellite Centers” had the highest TVC while group 3 “Dead End Semi-sprawl” had the lowest TVC but both groups had the highest DVC as a percentage of TVC.

TVC had stronger correlations than DVC with urban form metrics. Building density had the strongest correlation with TVC ($r = -0.62$, $p = 0$). Correlations with TVC were also found with Parcel size ($r = -0.23$, $p = <.001$) and centrality ($r = -0.21$, $p = <.001$). Very weak relationships with TVC were found with connectivity and land use mix.

(86 pages)

PUBLIC ABSTRACT

Classification of Urban Forms and Their Relationship with Vegetation Cover in Cache County, Utah

Stephen J. Peaden

As residential urban development increases in the western United States, few studies have shown how different urban forms influence vegetation cover. The two studies in this thesis examine how to define and measure urban form in order to understand the relationship between urban form characteristics and vegetation cover.

In the first study, urban form was defined by using past methods of identifying and measuring urban sprawl. Past studies showed the most essential metrics that define residential urban form are building density, centrality, connectivity, land use mix, and parcel size. This study reviews these metrics and proposes revised unified definitions and measurement methods. It is recommended that consistent definitions and methods be used in further research of urban form.

Cache County, Utah was used as a study area to apply these methods as a representative community of the western U.S. Residential parcels were measured for each metric. A K-means cluster analysis assign each parcel to one of 50 groups based on metric measurement similarities. The 10 most widely used groups contained 87% of the residential parcels in Cache County. These groups represented urban forms with distinct identifiable characteristics such as Agricultural residential, urban sprawl, historic plat

patterns, and evolved versions each.

The second study used the metrics and groups from the first study to check for correlations with vegetation cover. A normalized difference vegetation index (NDVI) of aerial imagery of Cache County was used to classify land cover into three groups: dense vegetation, light vegetation, and no vegetation. Measurements of vegetation cover were extracted for each parcel and each urban form group. Total vegetation cover (TVC) and dense vegetation cover (DVC) measured higher in urban areas than in the county as a whole. Agricultural residential groups had among the highest TVC, but had the lowest DVC. Non-agricultural residential groups had the highest DVC as a percentage of TVC with the exception of group 4 “Modern Suburban Sprawl” which had the lowest DVC as a percentage of TVC. Group 7 “Satellite Centers” had the highest TVC while group 3 “Dead End Semi-sprawl” had the lowest TVC. Both groups 3 and 7 had the highest DVC as a percentage of TVC.

A correlation analysis revealed that TVC had stronger correlations than DVC with urban form metrics. Building density had the strongest correlation with TVC (r = -0.62, p = 0). Correlations with TVC were also found with Parcel size (r = -0.23, p = <.001) and centrality (r = -0.21, p = <.001). Very weak relationships with TVC were found with connectivity and land use mix.

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Stephen J. Peaden

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CHAPTER 1

INTRODUCTION

Vegetation has been shown to have a positive influence on the urban environment. Past research has studied the benefits and services plants provide to humans in urban areas. Nowak, Crane, and Stevens (2006) demonstrated that trees alone remove an estimated 711,000 metric tons of air pollution in the U.S. annually. Bolund and Hunhammar (1999) reviewed described other benefits of urban vegetation including microclimate regulation, noise reduction, rainwater drainage, sewage treatment, and recreation and cultural value. Trees, have been shown to stabilize or lower landscape water consumption in some situations (Lowry, 2010). Recreational and cultural values of plants have also been demonstrated (Bolund & Hunhammar, 1999; Dwyer, Schroeder, & Gobster, 1991; Zipperer, Sisinni, & Pouyat, 1997). Since plants provide so many benefits, it is important to understand what factors influence their existence and well-being.

One factor that has an apparent influence on vegetation in the western U.S. is urban development. For example, tree canopy cover has been shown to increase with urbanization (Zipperer et al., 1997). As urban areas in the western U.S. are growing faster than other states, it is important to understand the influence it has on vegetation cover (Mackun & Wilson, 2011).

Because urban areas contain a variety of forms (Duany & Talen, 2007), this study's hypothesis is that different urban areas influence vegetation cover differently. On urban form that has been studied and measured specifically is urban sprawl. Past studies measured a variety of metrics in order to detect it, the most essential metrics being density, centrality, connectivity, land use mix, and parcel size (Alberti, 1999; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Galster et al., 2001; Hamidi & Ewing, 2014; Lowry, 2010; Song & Knaap, 2004). These metrics, however, lack consistency in their application and proposes unified methods for this and future studies. Methods used to define urban sprawl have not yet been used to identify and measure other urban forms.

Using Cache County, Utah as a study area, the first study proposes to identify the most used urban forms. It will first categorize urban forms by defining and measuring urban form metrics for individual parcels and second, sort parcels of similar characteristics into urban form groups. The results of this categorization will represent various urban form types that exist in the study area. This categorization will allow planners and researchers to objectively define neighborhoods and urban areas based on relevant physical characteristics.

The findings of Chapter 2 will then be used to study the relationship between urban form and vegetation cover in Chapter 3. Past studies have measured vegetation cover in order to compare amounts within different spatial boundaries. Nowak et al. (1996) compared vegetation across city boundaries using aerial imagery. Akbari, Rose, & Taha (2003) compared aerial imagery across zoning classifications including downtown and city center, industrial, offices, commercial, and residential. Lowry (2010) compared aerial imagery of tree canopy cover across census blocks. This study will measurements of vegetation can be compared across the spatial boundaries of urban form groups and parcels of Cache County. Urban form metrics can then be examined for correlations with vegetation cover, demonstrating what relationships exists.

The results of this study can provide city, county, and regional planners with an objective tool to evaluate and demonstrate how past development has resulted in different amounts of vegetation cover. This will allow them to make more informed planning decisions for future development. This method can also be used to measure and compare other ecological aspects as needed to better inform planners, developers, and the general public on the influence of development.

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CHAPTER 2

CLASSIFYING URBAN FORMS INTO GROUPS DEFINED BY METRICS MEASURE AT THE PARCEL LEVEL

Abstract

The purpose of this study is to define a method of identifying and classifying urban forms in an urban area. Past research showed methods of identifying urban forms measured specific metrics that ultimately allowed researchers to identify and measure urban sprawl. The most essential metrics include density, centrality, connectivity, land use mix, and parcel size. These methods, however, have not yet been used to identify and measure other urban forms. Furthermore, methods of measuring urban forms lack consistent definitions. A review of metric definitions in past research found common principles between them. This study proposes revised unified definitions and measurement methods of those metrics for this study. It is recommended that consistent definitions and methods be used in further research of urban form.

Cache County, Utah, was used as a study area to apply these methods in a representative community of the western U.S. Residential parcels were measured for each metric. A K-means cluster analysis allocated each parcel into one of 50 groups based on metric measurements. Ten of the groups contained 87% of the residential parcels in Cache County, indicating the most widely used urban forms and represented a range of urban form types. These included (1) Central Historic Plat, (2) Modern Plat, (3) Dead End Semi Sprawl, (4) Modern Suburban Sprawl, (5) Modern Modified Plat, (6)

Alternative Modern Modified Plat, (7) Satellite Centers, (8) Agricultural Residential, (9) Agricultural Residential Town Centers, and (10) Condominium. Each group is discussed individually with the context of concurrent visual observations and local development history.

Introduction

Urban development forms and typologies are often studied to gain a better understanding of the effects of past development in order to plan for future growth. With the western U.S. experiencing faster population growth than anywhere else in the country, community leaders and planners must prepare for increased growth in these areas (Mackun & Wilson, 2011). As new development occurs while existing areas age, it becomes necessary to approach urban planning differently in different areas of the city. Differences in physical characteristics require different planning approaches. An understanding of urban form and an objective method for distinguishing different forms can be helpful to planners.

In this study, “urban form” refers to the physical and spatial characteristics and patterns of aggregated human-built structures and systems. Urban forms come in a variety of arrangements. Duany and Talen (2007) demonstrated this in their study on urban transect planning. They defined different categories of urban form based on structural, spatial, and aesthetic characteristics. This conceptual framework is helpful in understanding how to appropriately differentiate between urban forms; however, planners lack the same thing that Duany and Talen lack—an objective method for defining these distinct urban areas. When faced with the task to define neighborhoods, planners often resort to methods that are more subjective in nature such as visual observations or opinion polls. Other data is useful such as zoning and land use maps, census data, and subdivision plats, but do not necessarily represent an accurate of existing physical urban forms.

In order to find a method of defining neighborhoods based on similar urban form characteristics, we can turn to past studies that sought to define a specific urban form: "Urban Sprawl." A review of literature that studied urban form revealed an array of studies focused on defining, identifying, and measuring "Urban Sprawl." Definitions and descriptions vary throughout the literature; however, there is a general consensus on what constitutes Urban Sprawl. One of the most comprehensive studies on urban sprawl was done by Burchell et al. (1998). This study reviewed much of the literature to date regarding Urban Sprawl and its impacts and derived a working definition of Urban Sprawl that included cardinal defining characteristics. These included low density, noncontiguous outward growth, abundant consumption of exurban land, and automobile dependency (Burchell et al., 1998).

Later studies attempted to quantify these characteristics using available data for the purpose of measuring the amount of urban sprawl in a given urban area. While there was some variation in the metrics used, there were common metrics that were almost always used. They included density, connectivity, centrality, and land use mix (Alberti, 1999; Ewing, Pendall, & Chen, 2003; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Galster et al., 2001; Hamidi & Ewing, 2014; Lowry, 2010; Song & Knaap, 2004). A further review of these studies will be made in a later section of this paper. As technology changes and data collection practices improve, the need for continual study and application of these metrics is imperative.

As seen in the literature, the process of identifying urban forms has been influenced by the need or desire to quantify the extent of urban sprawl. While urban sprawl has received much attention on how to identify and define it, other forms of urban development have yet to be defined and studied in such detail. As Burchell et al. (1998) observed, there is a need to “look at sprawl to determine whether an alternative to this growth pattern can be conceived, and even more importantly, whether it makes sense to pursue an alternative pattern of growth.” Using the metrics applied in identifying urban sprawl, it is possible to recognize and measure other specific urban forms that will allow planners to define neighborhoods or other urban areas and tailor planning efforts to them. Defined urban areas can also be used for research focused on their particular impacts and performance. Therefore, the purpose of this study is to define a method for identifying distinct urban form categories based on objectively measured characteristics within an urban area, demonstrating it in a sample area.

Urban Growth in the Western U.S.

Communities in the western U.S. are experiencing higher population growth than the rest of the U.S. Recent population estimates show that many of the western states had some of the highest population growth in the country. Utah’s population is estimated to have grown by 8.0% between 2010 and 2015, the 4th highest state in the country (see Table 2-1; U.S. Census Bureau, 2017).

Table 2-1

Annual Estimates of the Resident Population: April 1, 2010 to July 1, 2017 (U.S. Census Bureau, 2017)

State	2010	2015	Difference	Percent change
North Dakota	674,518	754,859	82,268	12.2
Texas	25,241,648	27,454,880	2,309,319	9.2
Colorado	5,048,029	5,440,445	411,249	8.2
Utah	2,775,260	2,984,917	221,032	8.0
Florida	18,846,461	20,268,567	1,467,257	7.8
Nevada	2,702,797	2,883,057	182,506	6.8
Arizona	6,407,002	68,022,62	410,245	6.4
Washington	6,741,386	7,152,818	428,278	6.4
South Carolina	4,635,834	4,892,423	267,059	5.8
North Carolina	9,574,247	10,041,769	506,286	5.3
Georgia	9,712,696	10,199,533	511,880	5.3
Idaho	1,570,912	1,649,324	81,742	5.2
Delaware	899,712	944,107	46,173	5.1
South Dakota	816,227	854,036	39,856	4.9
Hawaii	1,63,817	14,263,20	66,019	4.9
Oregon	3,837,073	4,016,537	185,463	4.8
California	37,327,690	39,032,444	1,778,488	4.8

This population growth trend has prompted major visioning plans across Utah. Envision Utah has been a leading organization facilitating these efforts. Envision Utah is a “unique and dynamic public/private partnership with business leaders, civic leaders, and policy-makers, working with the community to plan for future development of the Greater Wasatch Area through coordination in planning” (Envision Utah, 2003). Their planning approach includes public workshops and surveys as well as bringing residents together with “elected officials, developers, conservationists, business leaders, and other interested parties” (Envision Utah, 2016). Included among the plans facilitated by Envision Utah is “Envision Cache Valley.”

Cache Valley is located in Northern Utah and Southern Idaho, being bisected by the Utah-Idaho boundary (Figure 2-1). Much of the land in Cache Valley is used for agriculture. Several small towns exist throughout the valley. There is, however, increasing urban growth particularly on the Utah side originating from Logan City and its surrounding communities.

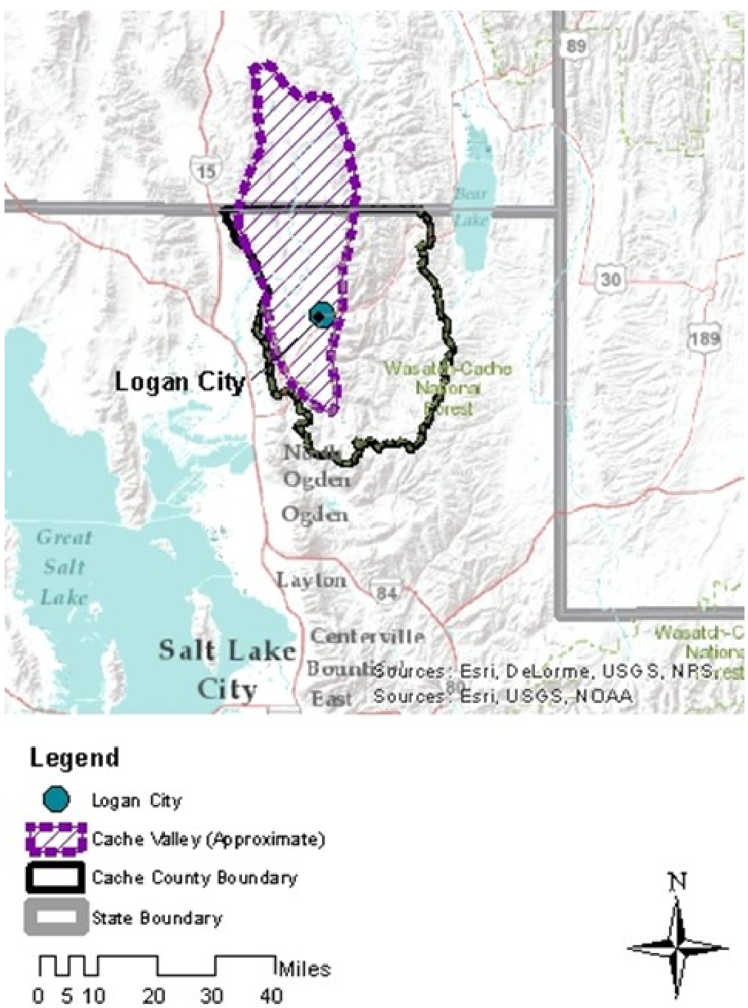

Figure 2-1. Map of Cache County location and vicinity.

Community participation in Envision Cache Valley showed that residents of the Valley are concerned about how their city and county will grow. The Envision Cache Valley study indicated that the population of Cache Valley would nearly double from 2009 to 2040. Public participation workshops held as part of the study showed residents of Cache Valley are very concerned about resulting impacts of imminent growth and development. Concerns include air quality, water quality, availability of agricultural land, potential loss of scenic beauty, housing prices, job quality, wildlife habitat, underutilized parcels, access to outdoor recreation, and traffic congestion (Envision Cache Valley, 2009). Part of the Envision Cache Valley study presented various growth scenarios each assuming development in Cache Valley followed a different pattern of urban forms. This demonstrates how determining desirable urban forms can be key to planning the future and addressing and resolving many future concerns.

Measuring Urban Form

Since urban forms take on a wide variety of arrangements it is helpful to categorize them in groups of forms with similar characteristics. Past research which focused on the urban form of "urban sprawl" attempted to measure and identify sprawl based on many defining metrics as demonstrated in Table 2-2 (Alberti, 1999; Ewing, Pendall, & Chen, 2003; Frank et al., 2005; Galster et al., 2001; Hamidi & Ewing, 2014; Huang, Lu, & Sellers, 2007; Lowry, 2010; Song & Knaap, 2004). The four most common metrics included density, connectivity, land use mix, and centrality. "Sprawl" was identified as having lower density, lower connectivity, less land use mix, and less centrality.

Table 2-2

Metrics Used in Previous Urban Form Studies

Metric	References	Number of studies
Density	Alberti, 1999; Ewing et al., 2003; Frank et al., 2005; Galster et al., 2001; Hamidi & Ewing, 2014; Huang et al., 2007; Lowry, 2010; Song & Knaap, 2004	8
Land Use Mix	Alberti, 1999; Ewing et al., 2003; Frank et al., 2005; Galster et al., 2001; Hamidi & Ewing, 2014; Lowry, 2010; Song & Knaap, 2004	7
Connectivity	Alberti, 1999; Ewing et al., 2003; Frank et al., 2005; Hamidi & Ewing, 2014; Lowry, 2010; Song & Knaap, 2004	6
Centrality	Alberti, 1999; Ewing et al., 2003; Galster et al., 2001; Hamidi & Ewing, 2014; Huang et al., 2007; Lowry, 2010	6
Proximity	Galster et al., 2001	1
Clustering	Galster et al., 2001	1
Nuclearity	Galster et al., 2001	1
Compactness/concentration	Galster et al., 2001; Huang et al., 2007	2
Continuity	Galster et al., 2001	1
Complexity	Huang et al., 2007	1
Porosity	Huang et al., 2007	1

Because these four metrics have been used consistently to identify urban sprawl, then it is possible to use the same metrics to identify other urban form categories. Despite their consistency of use, each metric varied to some degree in its application and definition in each study.

Measurements of urban form can be used to study changes over time. Song and Knaap's study on measuring urban sprawl demonstrates measuring urban form (urban sprawl in this case) for the purpose of studying its change over time (Song & Knaap,

2004) Similarly, additional urban form categories can be defined using a common categorization at various points in time to document changes in urban development. As patterns, trends, and changes are observed, it then becomes possible to discuss what caused them and how it can help communities plan for the future.

While Urban Sprawl has been a focus of many urban planners, few have recognized the significance of other urban forms. A range of urban forms were recognized by Duany and Talen (2007) in their study on "transect planning." Duany and Talen describe two contrasting urban forms: "Urban sprawl," and "the traditional neighborhood," however he acknowledged an array of urban forms through describing the urban area in a transect. This conceptual framework demonstrated a spectrum of six different urban forms ranging from the urban core to rural preserve.

Each of these studies mentioned support the idea that urban areas can be categorized into distinct subareas (or neighborhoods) based on their physical characteristics A method for defining neighborhoods that incorporates the use of urban form categories can be useful to urban planners. Urban form categories can also be useful for further research as they provide a context for comparison. Chapter 2 will initiate a study that measures urban vegetation and compare results within these urban form categories.

Methods

This study identifies groups or categories of residential urban forms with similar measures of spatial characteristics at the parcel level. Spatial characteristics were defined by measuring five primary metrics including building density, connectivity, land use mix, centrality, and parcel size. These five metrics were measured for each individual parcel in Cache County. A cluster analysis was then performed to group parcels with relatively homogenous characteristics, forming distinct groups that can be compared and studied. The resulting groups each represent a unique urban form.

Location

Cache County, Utah, was selected for this study because it is among the many western communities expected to see rapid population growth over at least the next 30 years. Cache County exhibits a wide variety of urban forms ranging from mid-nineteenth century settlement patterns and buildings to more modern development (Hamilton, 1995). At a future time, this study can be performed again to measure how this growth has altered the urban form of the County. See Figure 2-2 for map of Cache County and its municipalities.

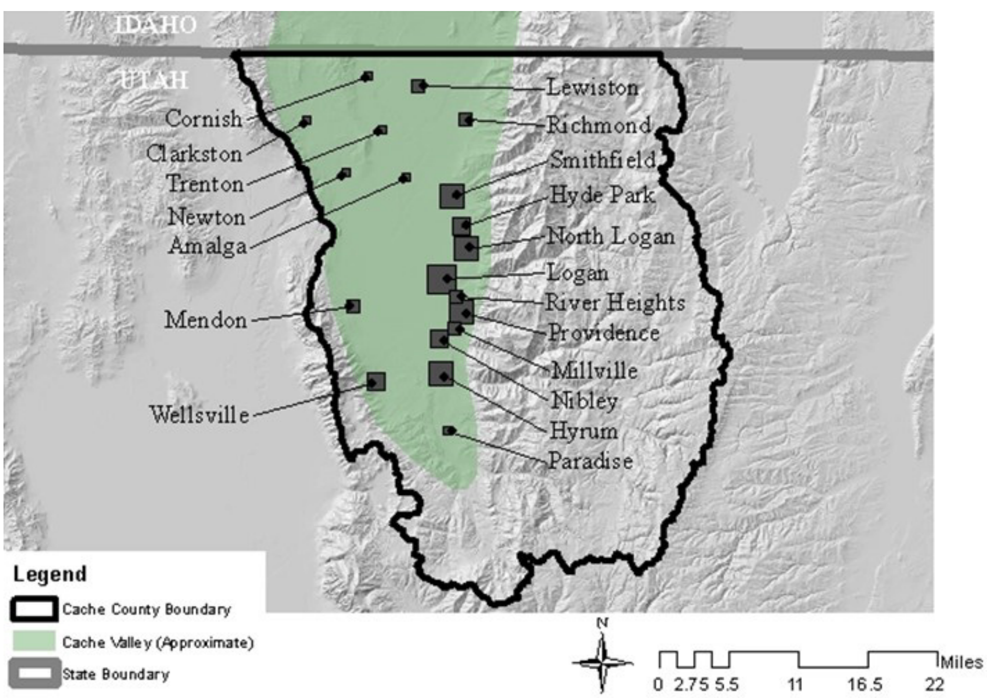

Figure 2-2. Map of Cache County showing the approximate location of each municipality.

Scale and Units

This study uses parcel-level data to form groups of parcels with similar characteristics to be studied at the city and county levels. Past studies of urban form typically used metrics measured at the census block or census block group level. While census block groups are typically fairly homogenous in their social, economic, and demographic characteristics, they do not necessarily describe the spatial and physical characteristics of the urban forms within them. In their study on measuring urban sprawl, Song and Knaap (2004) used census block data, but added a disclaimer which states “We do not argue that census blocks are the best aerial unit for measuring urban form. We only claim that it is a convenient unit that illustrates the effects we seek to capture.” In order to more accurately study urban forms, a more informative unit was required. Cache County has recorded parcel data which includes data useful in calculating these metrics. Every parcel is uniquely described in a GIS format using the same set of attributes across the county. These descriptions include: property location, parcel size, building type (use), building square footage, property value, and year built. This data allows for creating categories based on information specific to each parcel rather than a census block which can vary in size and number of parcels therein.

Metrics

Past studies have presented various methods of measuring urban form. Each used a variety of metrics to identify a particular urban form (urban sprawl). A comparison of these metrics shows that there are four primary metrics used throughout the studies. They include density, connectivity, land use mix, and centrality (Frank et al., 2005; Galster et al., 2001; Hamidi & Ewing, 2014; Huang et al., 2007; Lowry, 2010; Song & Knaap, 2004). A fifth metric (parcel size) was also identified as being critical to measuring urban form (Lowry, 2010; Song & Knaap, 2004). While these metrics were common in many of the studies, there was little consensus on the individual application of each metric. For this study, some metrics had to be adapted to better suit a parcel unit application rather than a census block group unit.

Building density. In the literature review, every study on urban form used the metric of density. Each used either population density per unit of area, number of building units per area (building density), or both. While population density likely influences urban form, it is not a direct measurement of that form. The focus of this study is measuring the physical structure of urban areas, and therefore requires a measurement of the urban forms themselves. Galster et al. (2001, pp. 687-688) noted that measuring the residential building units themselves would be a "better unit for measuring sprawl" and would be more representative of its physical condition than a population density ratio. Galster et al.'s measure of density was a ratio of the number of residential units divided by the area of developable land. While this formula may provide an improved understanding of the general density of development in an area, an additional measurement can provide an improved description of the developed density. This is accomplished by dividing the area of a building by the area of the parcel on which it resides. At the time of Galster et al.'s study, it is likely that neither the means nor the data was available to know the area of each unit in the study area. Such data is now available and Cache County provided GIS data containing both the building area and parcel area, making this calculation possible. This ratio is often termed “floor area ratio” or “lot coverage” and is used in city planning in the Cache County area (Cache County, 2019; City of Logan, 2019). For the purposes of this study, this measure will be termed “building density” and is measured by dividing the floor area by the parcel area (Figure 2-3).

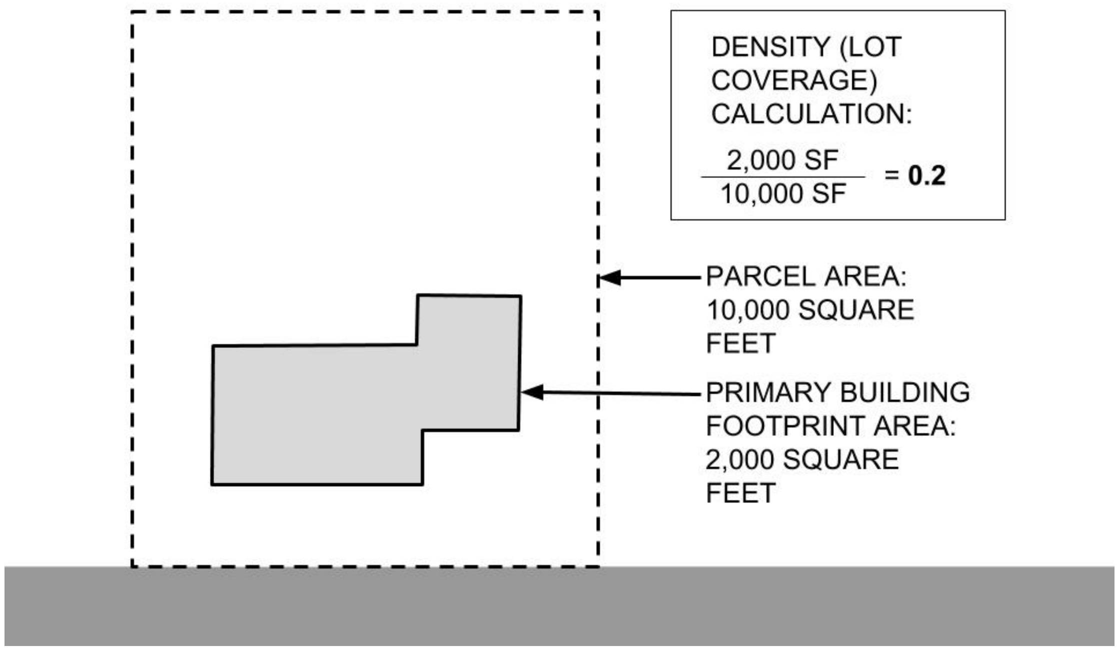

Figure 2-3. Example of building density calculation. Drawing is not to scale.

Connectivity. While connectivity is a very common metric of urban form in the literature, there is little consensus as to the most appropriate method of measuring connectivity. Studies attempted to calculate connectivity by using a wide variety of statistics such as number of intersections per kilometer (Frank et al., 2005), median block perimeter (Ewing et al., 2003; Song & Knaap, 2004), average block area (Lowry, 2010), median length of cul-de-sacs (Lowry, 2010; Song & Knaap, 2004), median distances between access points (Song & Knaap, 2004), and ratios of streets to intersections (Lowry, 2010; Song & Knaap, 2004). These examples demonstrate that what Alberti concluded in 1999 is still true— "Connectivity is an important measure of compactness of urban pattern, but a generalizable approach has been yet described for translating transportation infrastructure patterns into a quantitative measure" (p. 158).

Even with the lack of consensus on measuring connectivity, there were two principles that were common in the measurements used in these studies: number of intersections and size or dimensions of blocks. The method used for this study incorporates these principles and describes how well each parcel is connected to the road system. Connectivity was measured based on the number of options a street user is given on any given segment of road between two nodes. This is described by the number of "ways" at each end of each road segment expressed as a ratio of number of "ways" per linear mile of road. "Ways" refers to the number of directions a vehicle could go at an intersection or node. A node is a significant change in direction, an intersection, or an end point. For example, a standard four way stop intersection would have four "ways." A dead end of a street or cul-de-sac would have only one way—back the way you came. A street that has a 90-degree turn would have two ways at the turn. Each road segment has two nodes—one at each end. By adding the number of ways of each node and dividing it by the length of the road segment in miles, a value is produced for the connectivity of that segment of road. This value is then assigned to the parcels adjacent to that road segment. Figure 2-4 demonstrates how road segments, nodes, and parcels relate. Node A is a typical 3-way intersection, and therefor has 3 ways. Node B is a typical 4-way

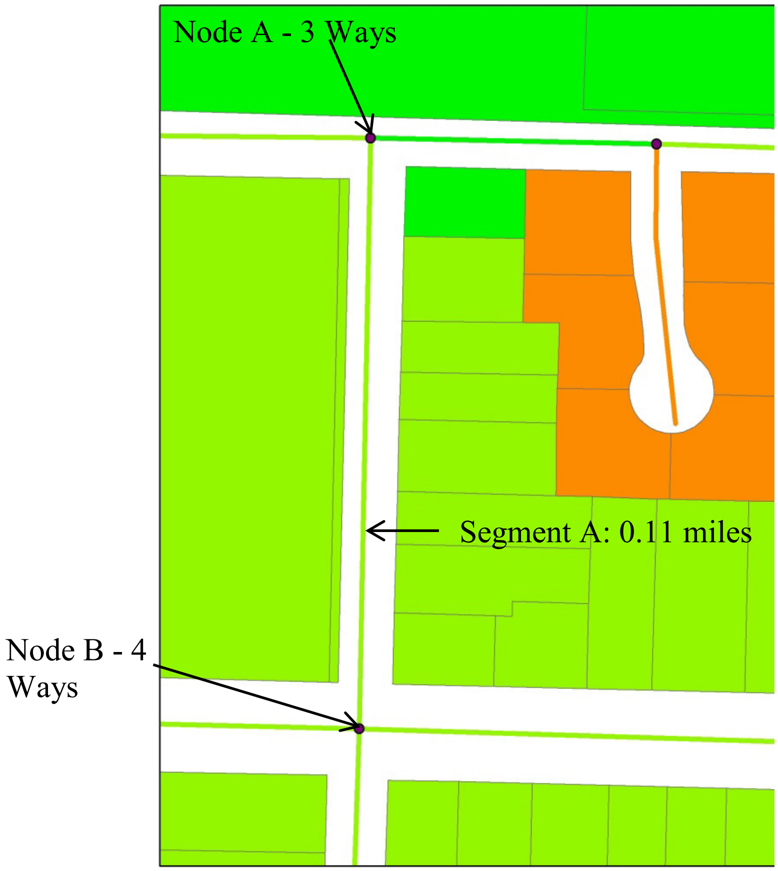

Figure 2-4. Examples of nodes and segments used in calculating the connectivity value.

intersection and, therefore, has 4 ways. Segment A is .11 miles long and stretches between node A and node B. Segment A therefore has 7 "ways." The connectivity of this road segment would be calculated as follows:

$$\frac{7}{0.11} = 63.6363$$

Road segment A therefore has a connectivity of 63.63 and thus, the adjacent parcels each have the same connectivity value. In the case where a parcel is located on the corner of two streets with differing connectivity values, the parcel would inherit the connectivity value of the road closest to it.

Land use mix. While land use mix is identified consistently in the literature as an important factor of urban form, it lacks a consistent method of measurement. It has been measured in a variety of ways including "the degree to which two different land uses exist in the same small area" (Galster et al., 2001), the number of land uses per area of land (Lowry, 2010), acres of nonresidential uses per number of housing units (Song & Knaap, 2004), and the evenness of distribution of residential and nonresidential development (Frank et al., 2005). A common concept used in among these studies included measuring the balance of different uses within a specified area such as a block, a walking distance radius, or some other defined area. The method used for this study is based on this concept and assumes the generally accepted walking distance of 1/4 mile, as did Song and Knaap (2004, p. 215). Since units such as blocks can vary in size, a standard walking distance is a better, more consistent measurement. Thus, for this study, for each parcel the numbers of residential and nonresidential uses were counted within 1/4 mile, including the parcel itself. The land use mix was then calculated by dividing the number of non-residential uses by the number of residential uses, providing a ratio of the number of commercial uses per residential use. The closer the result is to 1, the more evenly mixed the land uses. A number closer to zero would indicate a highly residential area, and very high numbers would indicate a primarily non-residential area. In this calculation, the centroid of each parcel was generated, and measurements were made from that point on each parcel. Only parcels that had centroids within the 1/4-mile radius of the subject parcel were counted. If a portion of a parcel was within the 1/4-mile radius, but its centroid was not, then it was excluded from the count. This measurement is depicted in Figure 2-5.

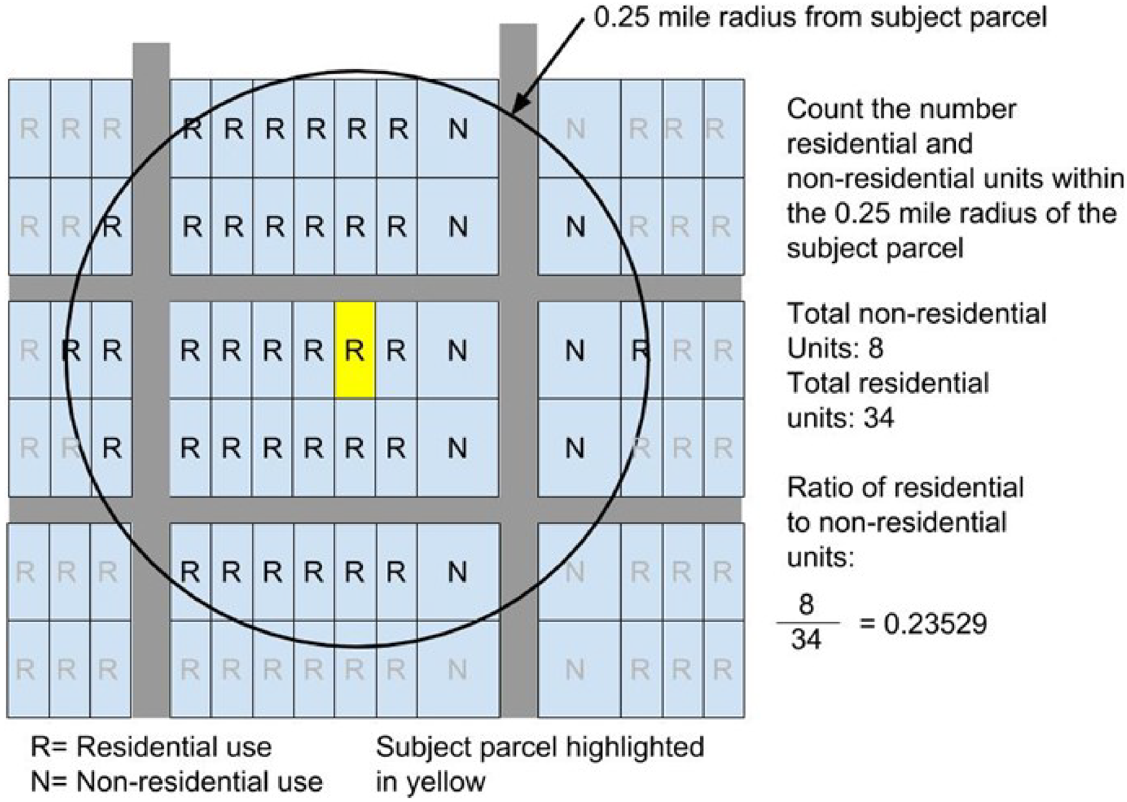

Figure 2-5. Example of land use mix ratio calculation. Drawing is not to scale.

Centrality. There was some degree of consensus in the literature on how to measure centrality. Typically, centrality refers to the influence of a central business district or other centers of activity on the entire area as a whole. The method for measuring centrality requires two steps. First, identify the central business district (CBD). Second, measure the distance from each parcel to the edge of the nearest central business district.

Because none of the studies described how a central business district or activity center was identified, we defined it as the areas of the highest density of non-residential use. Non-residential activity was measured by counting the number of non-residential parcels within walking distance (.25 miles) of each non-residential parcel, weighted by the size (acres) of those uses. A weight based on size was used because larger buildings typically provide more variety of use than smaller buildings and typically attract a larger number of people, creating a center for more activity. A department store or mall, for example, provides a larger variety of goods or services to a greater number of people than a small bakery or convenience store. The kernel density was then calculated in GIS to create a zone around the highest concentrations of those uses, representing the CBD. The distance between each parcel and the nearest CBD was then measured for the final centrality value. This measurement is depicted in Figure 2-6.

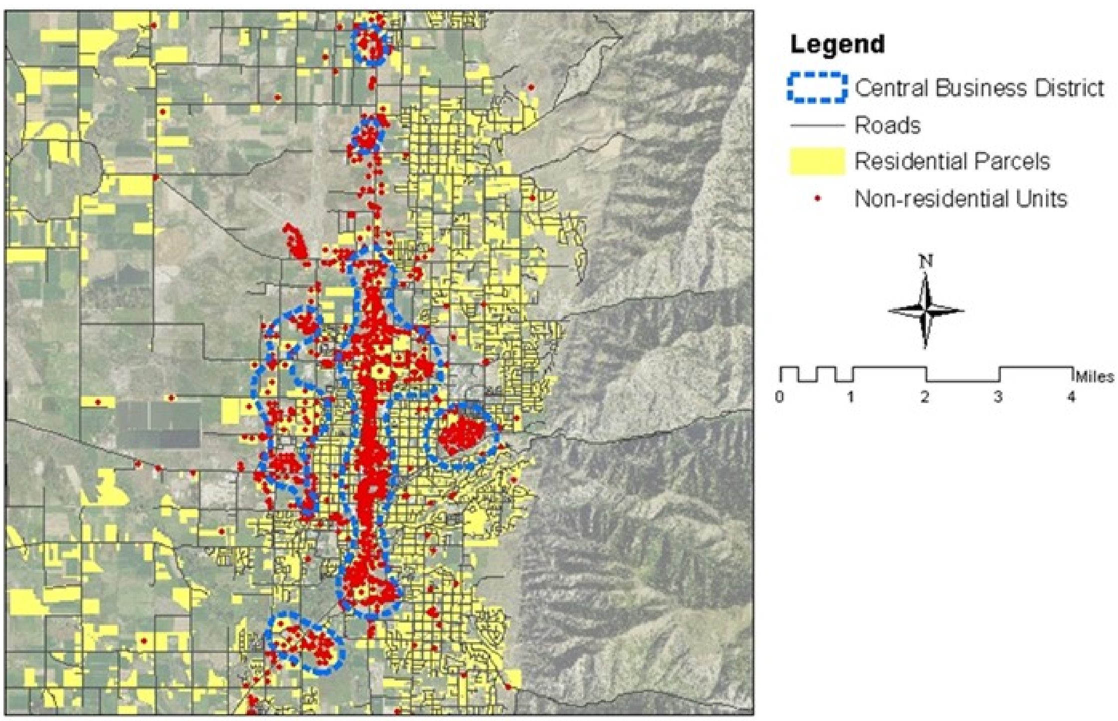

Figure 2-6. Central business district of Cache County.

Parcel size. Although not one of the most common metrics used in the literature, it was used in more recent studies as a measure of density (Lowry, 2010; Song & Knaap, 2004). While building density (building area divided by parcel area) does take parcel size into consideration, it does not account for scale. For example, a 1,400 square foot town home on a 1/10-acre lot would have a very similar building density as a 3,500 square foot home built on a 1/4-acre lot, the 3,500 square foot home. This would incorrectly give the impression that these two lots were more similar than they actually were. Including parcel size in the analysis provides more clearly defined urban form categories.

Cluster Analysis

The measurements of the 5 metrics for each parcel were then analyzed to create parcel clusters or groups. A k-means cluster analysis was performed using IBM's SPSS Statistics 24. Since the number of different possible urban form groups that might result was unknown, iterations of this process were performed to determine what number of groups separated obvious urban form differences such as single-family homes verses condos or large newer homes verses smaller historic homes into separate groups. When the analysis was performed using 5 groups, 10 groups, or 20 groups, some of the groups proved to be too general, including parcels that were only marginally similar. Those same analyses also produced other groups that only had one or a few parcels, being extreme outliers compared to the parcels in larger groups. As higher numbers of groups were used, more outlier groups with few parcels in them were formed; however, the groups with the most parcels in them became more distinguished, having more parcels with similar measurements. By using a higher number of groups such as 50, it allowed for outlier parcels to be assigned their own groups, keeping them from skewing the average measurements of the larger groups. These larger groups would be the primary urban forms found in Cache County.

Results

The 50 groups as a result of the cluster analyses were arranged and numbered in order of popularity with group 1 containing the most parcels and group 50 containing the least. Only the 10 groups with the most parcels in them were examined in this study (see Figures 2-7 and 2-8). Higher quantities of parcels in a group indicate groups of most significance to the urban form. Groups with higher quantities of parcels represent a more significant trend in development of urban forms with particular characteristics. These top 10 groups comprise 88% of the residential parcels in Cache County. While the other 40 groups still make up a significant portion of Cache County's urban form and may have unique characteristics worthy of further exploration, they will not be discussed in this paper so more attention may be given to groups that make up the greatest part of the urban area.

The distinct characteristics of each group are demonstrated by calculating averages for each metric within each group as seen in Figure 2-9. The mean "Year Built," Median "Year Built," and "parcel value per acer" were calculated for each group and are included for further comparison and discussion. "Year Built" refers to the year that the existing primary structure on the property was constructed. The property value for each parcel is the sum of the 2014 market value of the land and buildings therein as recorded by Cache County for tax purposes.

Group 1: Central Historic Plat Residential

With over 20% of the total number of residential parcels in Cache County, this

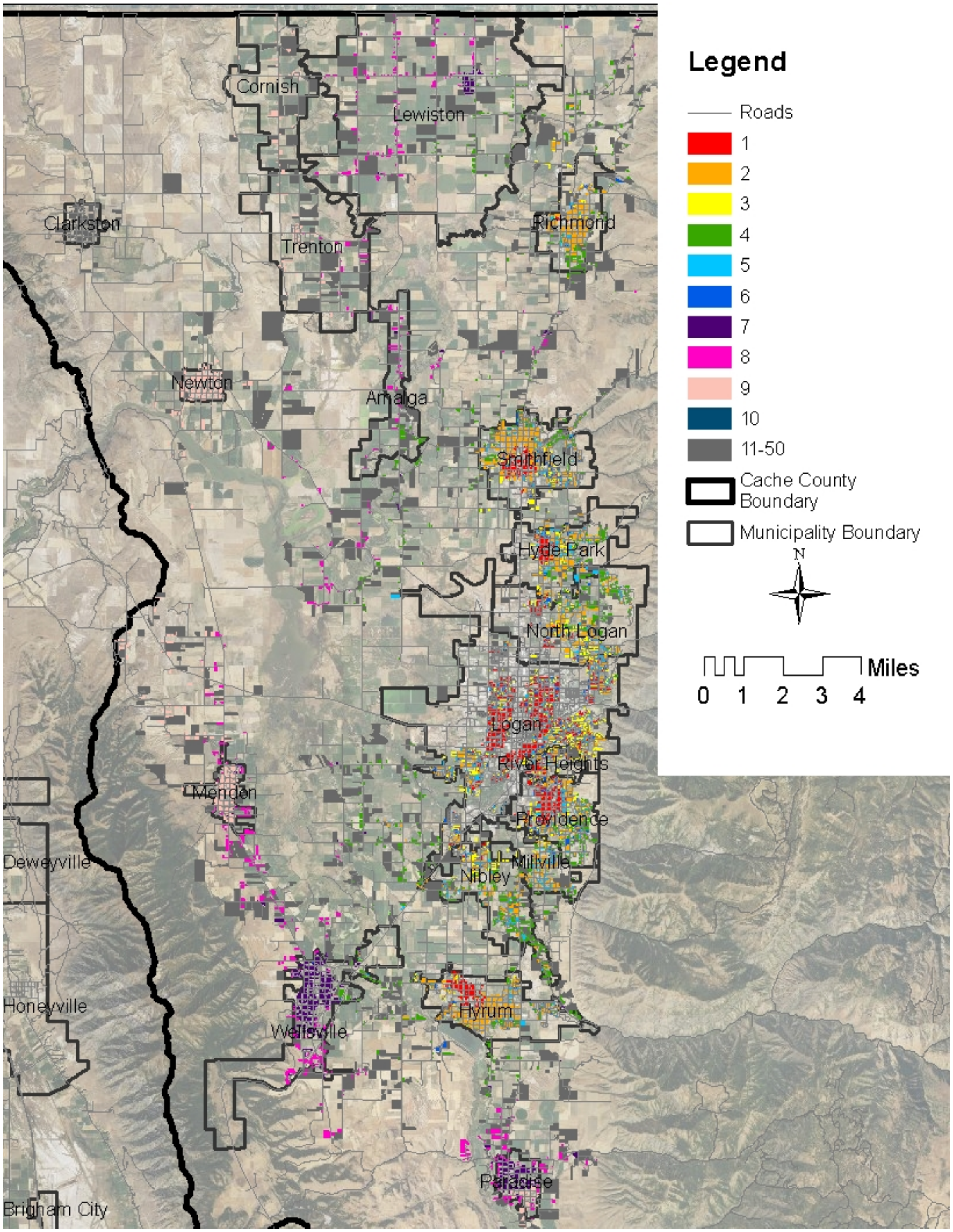

Figure 2-7. Map of urban form groups in cache county.

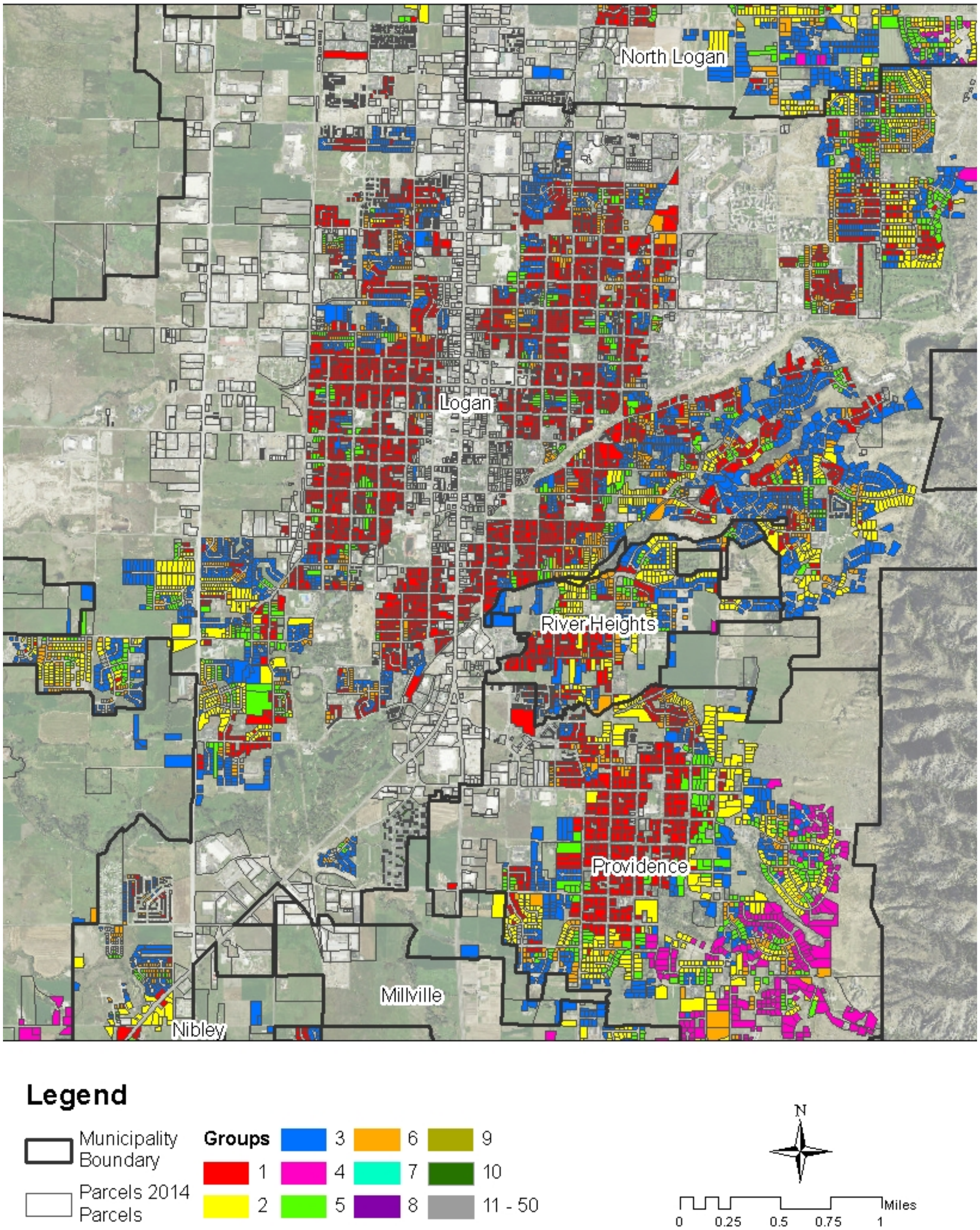

Figure 2-8. Enlargement of urban form groups.

Group Number	Number of parcels	Percent of total	Mean year built	Median year built	Parcel value per acre	Parcel size (acres)	Building density	Centrality (distance to central business district)	Connectivity	Land use mix
						5 urban form metrics				
1	5,822	20	1958	1960	$177,127.03	0.30	0.1657	1,396	48.57	0.04390
2	5,451	18	1989	1985	$194,384.41	0.53	0.0966	5,979	38.96	0.01261
3	4,203	14	1976	1994	$209,918.94	0.35	0.1722	2,778	4.06	0.02059
4	2,720	9	1998	1997	$245,420.04	0.92	0.0767	9,634	11.26	0.01055
5	2,167	7	1979	1987	$192,678.04	0.42	0.1190	4,870	66.76	0.01023
6	1,811	6	1963	1988	$186,130.89	0.31	0.1598	3,555	92.39	0.01393
7	1,240	4	1978	1975	$182,479.68	0.81	0.0674	21,005	45.64	0.02951
8	942	3	1982	1988	$233,208.79	1.82	0.0421	24,771	8.26	0.01410
9	941	3	1988	1978	$193,711.39	1.51	0.0424	37,512	33.15	0.01725
10	772	3	1966	1997	$112,180.02	0.03	1.3347	946	3.39	0.05581

Note. Darker shades indicate higher values within each column.

Figure 2-9. Metrics results of the top 10 urban form groups.

group is the largest in quantity. It has the oldest mean and median year built. Being the oldest, this group by default becomes the standard that all the other groups are compared to as development evolved over time. This group is distinguished primarily by its high land use mix, close proximity to the central business district, high connectivity, small parcel size, and high density.

Parcels in this group are located primarily in the major city centers of communities in Cache County, particularly Logan and Providence. The majority of them coincide with the historical "Plat of Zion" block layout planned by the original settlers of these communities in the mid to late 1800s (Hamilton, 1995). This explains why Group 1 has the oldest mean and median year-built dates (1958 and 1960, respectively). Group 1 parcels appear to be the most contiguous of all the groups, occurring in clusters of parcels of similar characteristics rather than scattered throughout the county. See sample image of group 1 in Figure 2-10.

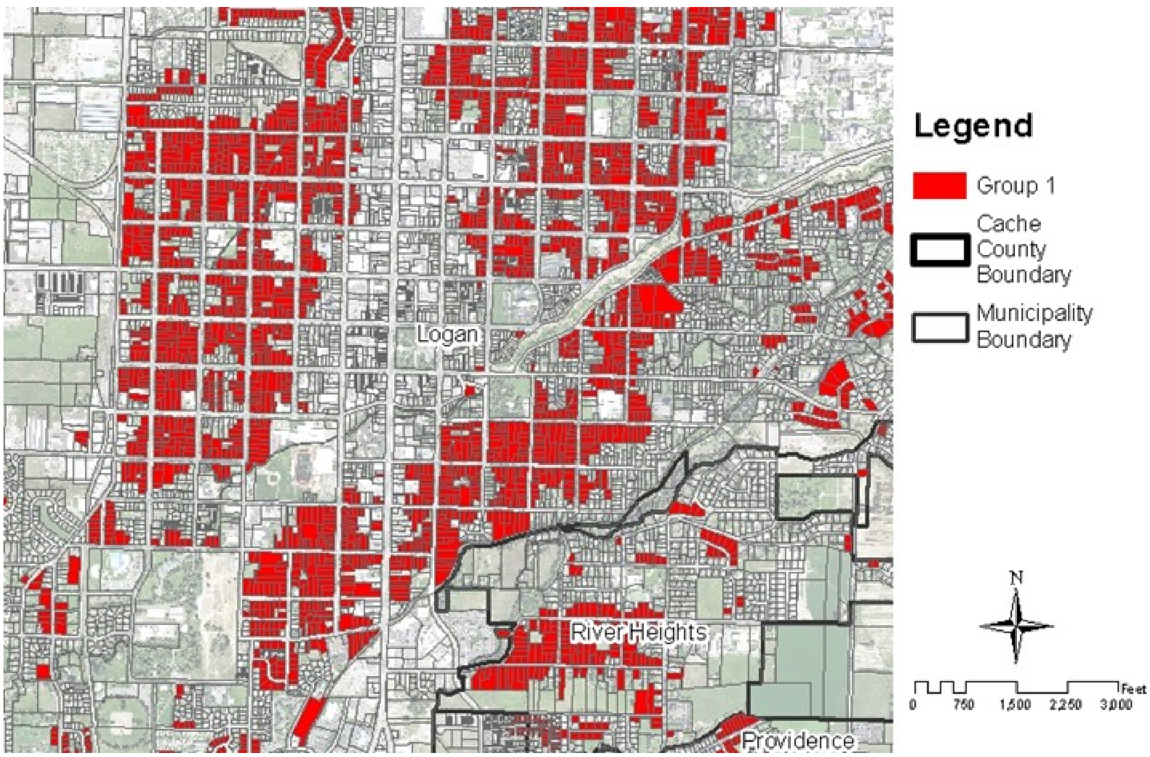

Figure 2-10. Group 1: Central historic plat residential.

Group 2: Modern Plat Residential

While many of the groups stand out due to being particularly high in one or several metrics, group 2 is distinct in that it does not stand out in any particular metric. Compared to the other 10 groups, this group tended to have lower land use mix and had buildings with a more recent average year built.

Despite its seemingly mellow results, group 2 is of interest because its general location and mean year-built date suggest it is an evolved form of another group. Group 5 is described later on as an evolved version of group 1 (the original Historic Plat Residential form). Group 2 appears to be an evolved form of group 5, as it has a mean year built that is more recent than group 5 and seem to be spreading outward from group 5 based on its higher centrality. Additionally, its parcel size is a little bigger, its distance to the central business district is further, and the connectivity is lower than group 5. These parcels lie on the outskirts of the historic grid layout and tend to reside within a range roughly between 1/3 mile and 2½ miles from the central business district. Land use mix is lower than most other groups, likely due to its greater distance from centers of commercial activity.

This group includes parcels on the central grid layout of other cities near Logan that are outside of the central business district and limited in their proximity to nonresidential uses. Many other parcels in this group were part of the original Plat of Zion grid but may not have been developed initially, existing for years as empty lots or farm land before being developed. As homes were built on these parcels, they followed the historic pattern, albeit a bit further removed from the city center and at a later date, resulting in the more recent mean year built and the lower land use mix. See sample image of group 2 in Figure 2-11.

Group 3: Semi-Sprawl Dead End

This group is distinguished by having the lowest connectivity besides group10 (4.06), the second highest building density (0.1722), and the 3rd lowest centrality (2778).

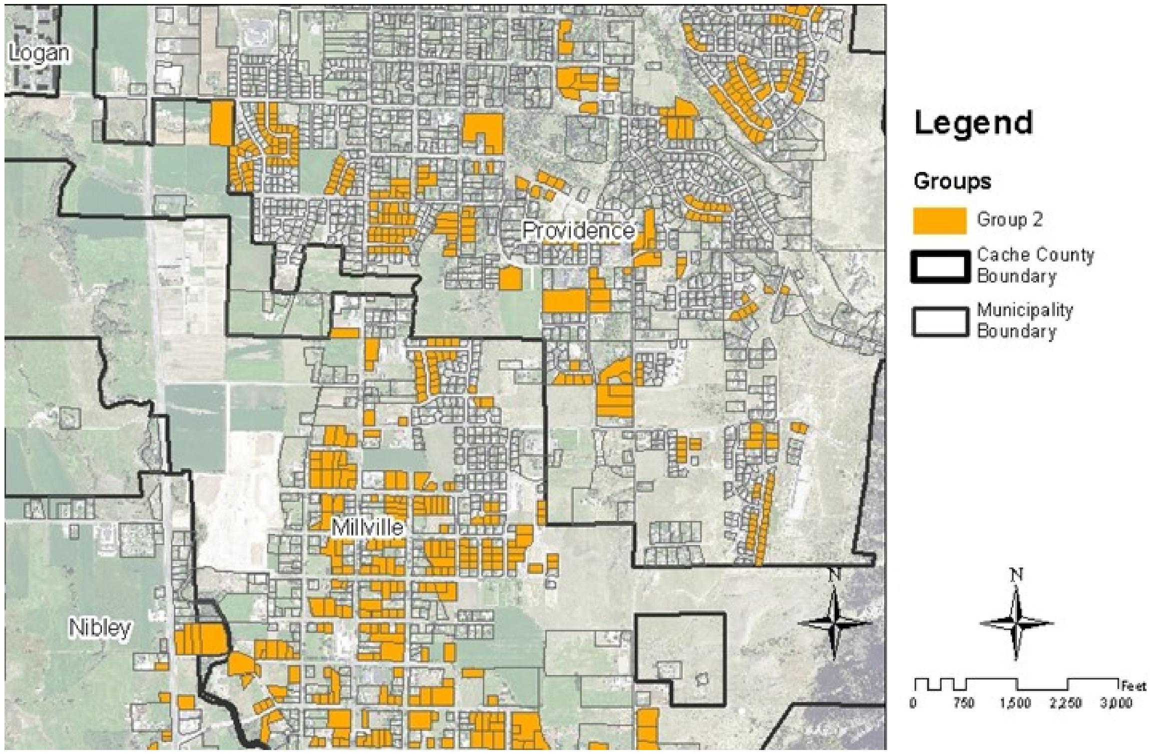

Figure 2-11. Group 2: Modern plat residential.

Although the mean year built in group 3 is 1976, the median year built for this group is 1994, indicating that the majority of buildings in this group are actually more recently built.

Parcels in this group are largely those that reside on a cul-de-sac or on a road that dead-ends, which explains why it has such low connectivity. These parcels are mostly located in developments outside of the original city grid layouts, though many are also located within the grid as infill development. As indicated in the name of this group, “semi-sprawl,” it has some sprawl-like characteristics. This type of development, compared to sprawl, swaps connectivity for building density. Rather than connecting a street through to form an intersection, it is terminated, often with a cul-de-sac. In many cases this results in more possible units for a developer. This occurs both in new subdivisions as well as infill development in the interiors of blocks. See sample image of group 3 in Figure 2-12.

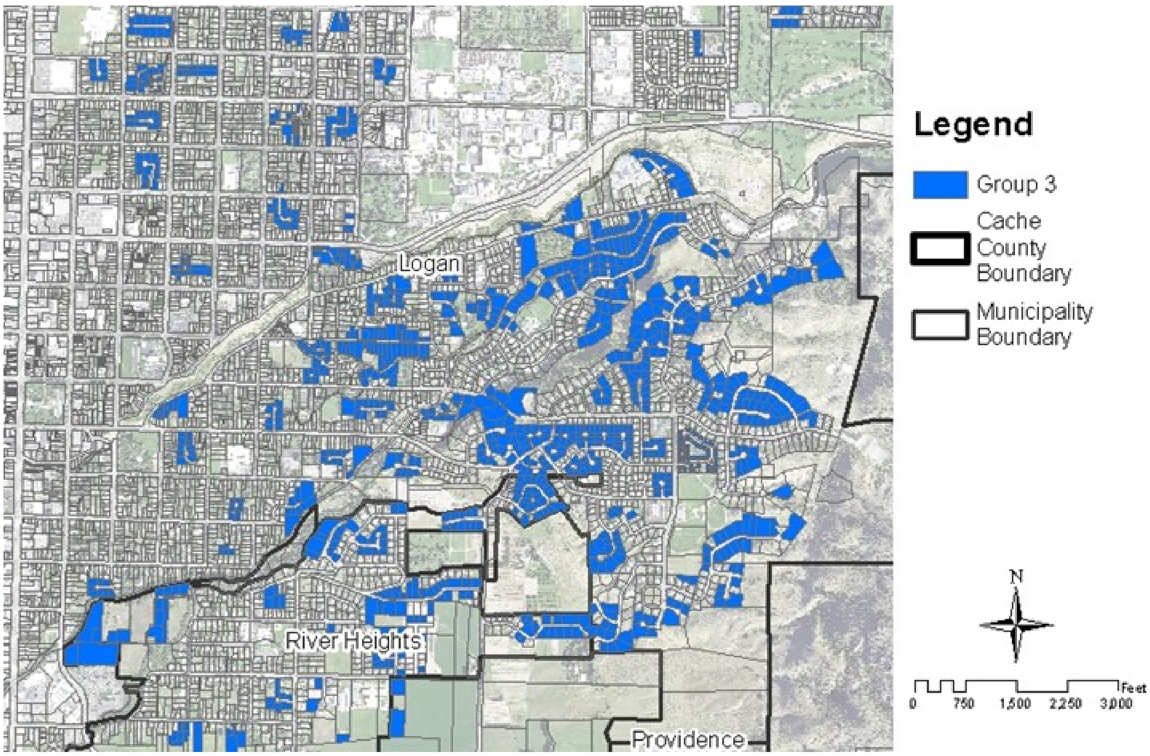

Figure 2-12. Group 3: Semi-sprawl dead end.

Group 4: Modern Suburban Sprawl

This group represents a quintessential urban sprawl form. These parcels have low land use mix, connectivity, and building density. The parcel size is the 3rd largest on average of the 10 groups at .92 acres. Centrality is moderate, indicating this type of development happens outside of the city centers, but not so far out as to be totally separated from them. It still depends on the city centers of activity to a certain extent.

These parcels have the most recent mean and median years built and the highest mean value per acre. This suggests that parcels in Group 4 were currently in higher demand in Cache County and represent the most recent trending residential urban form of those studied. See sample image of group 4 in Figure 2-13.

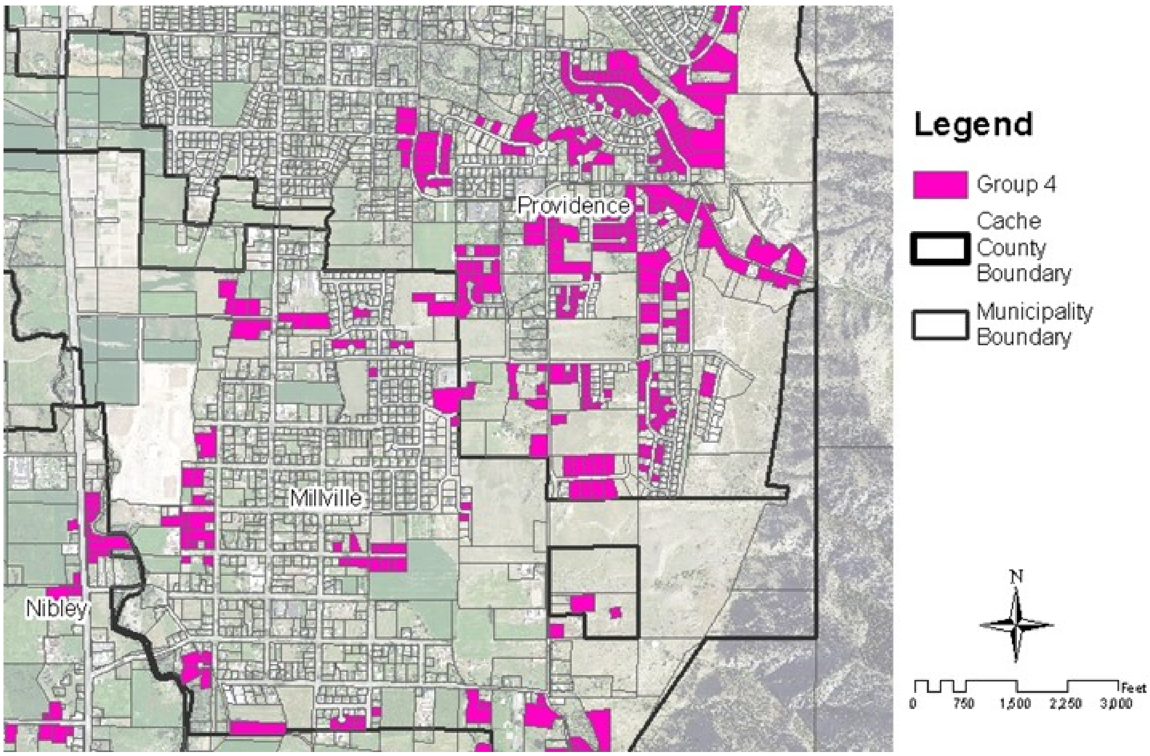

Figure 2-13. Group 4: Modern suburban sprawl.

Group 5: Modern Modified Plat Residential

Like groups 2 and 6, this group represents an evolution of the Historic Plat Residential form (group 1). This group is distinguished, though, by having very high connectivity, but very low land use mix. This suggests that this type of development maintained the connectivity characteristics that were evident in group 1, but did so with only residential use and didn't carry commercial or industrial use with it. It is moderate in all other categories It also has a larger distance to the central business district than group

1 which supports the idea that this group evolved from group 1 as it spread away from the center. See sample image of group 5 in Figure 2-14.

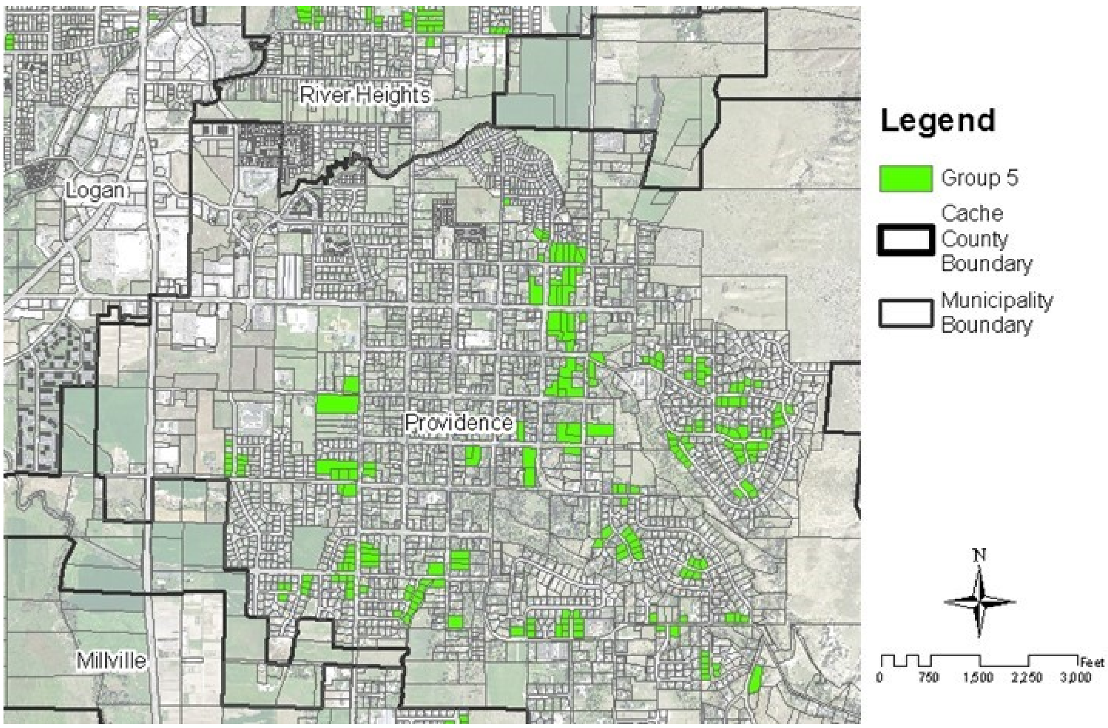

Figure 2-14. Group 5: Modern modified plat residential.

Group 5 parcels begin to break the pattern of the plat of Zion grid as they tend to lie further from business centers and on the edges and outskirts of the grids. Like group 2, parcels in this group were part of the original Plat of Zion street grid but may have existed for years as empty lots or farm land before being developed. As homes were built, they followed a similar, but more contemporary pattern, being a bit further removed from the city center and away from other land uses.

Group 6: Alternative Modern Modified Plat Residential

These parcels represent another form of development evolving from the Historic

Plat Residential form. Both groups 5 and 6 have the highest connectivity of the 10 groups. Group 6, however, clearly has the highest connectivity (92.39 compared to 66.76 for group 5). Parcel size is almost identical to group 1, signifying that as development evolved from group 1 to group 6, the parcel sizes stayed the same.

Higher connectivity and lower parcel size indicate a more compact, accessible version of the Modern Modified Plat Residential form. Although the mean year built of these parcels was 1963 (which is the second oldest), the median year built is 1988, indicating that there are more parcels with homes built during and after the 1980's than there were previous to that time. This makes the time that parcels in this group were developed nearly concurrent with group 5. See sample image of group 6 in Figure 2-15.

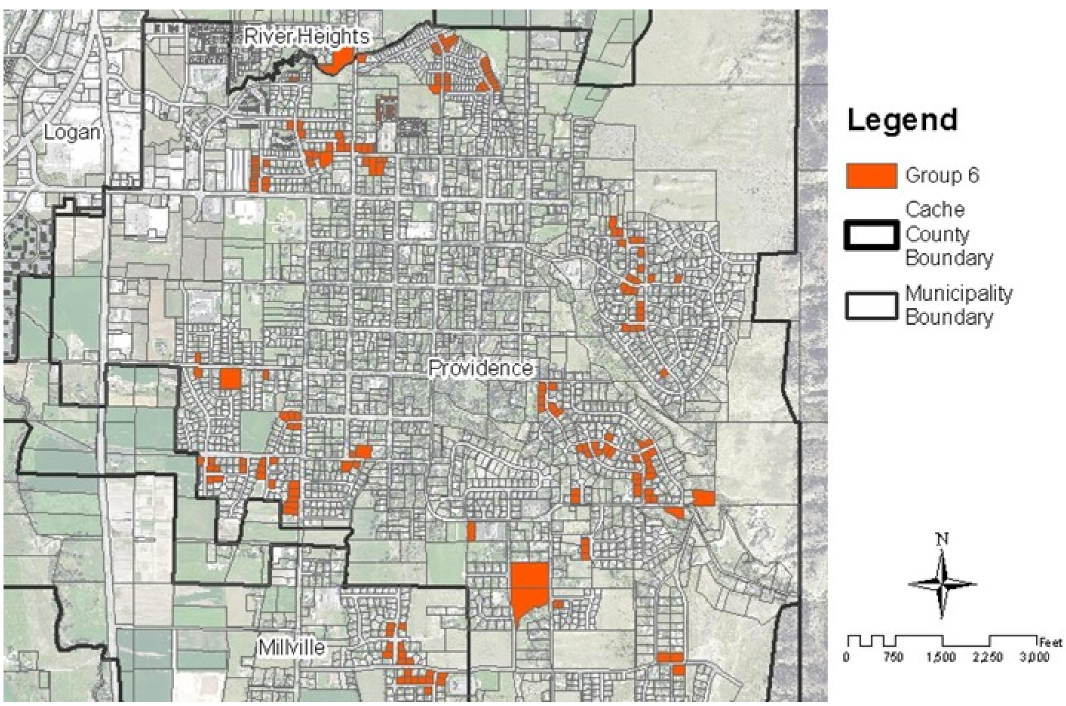

Figure 2-15. Group 6: Alternative modern modified plat residential.

Group 7: Satellite Centers

This group is unique due to its lengthy distance from the central business district, yet has the third highest land use mix value. These parcels tend to be town centers of smaller cities far removed from the more metropolitan center. High land use mix indicates that there is a significant level of commercial or industrial activity that creates small centers of business activity, but not at a density high enough to be considered part of the central business district using the method described in this study. These are important activity centers that have developed away from the main center of activity in the county. Such centers can allow residents to live away from main center of development in the valley, reducing the number of trips necessary into town and potentially allowing them to live largely independent of the main metropolitan area. See sample image of group 7 in Figure 2-16.

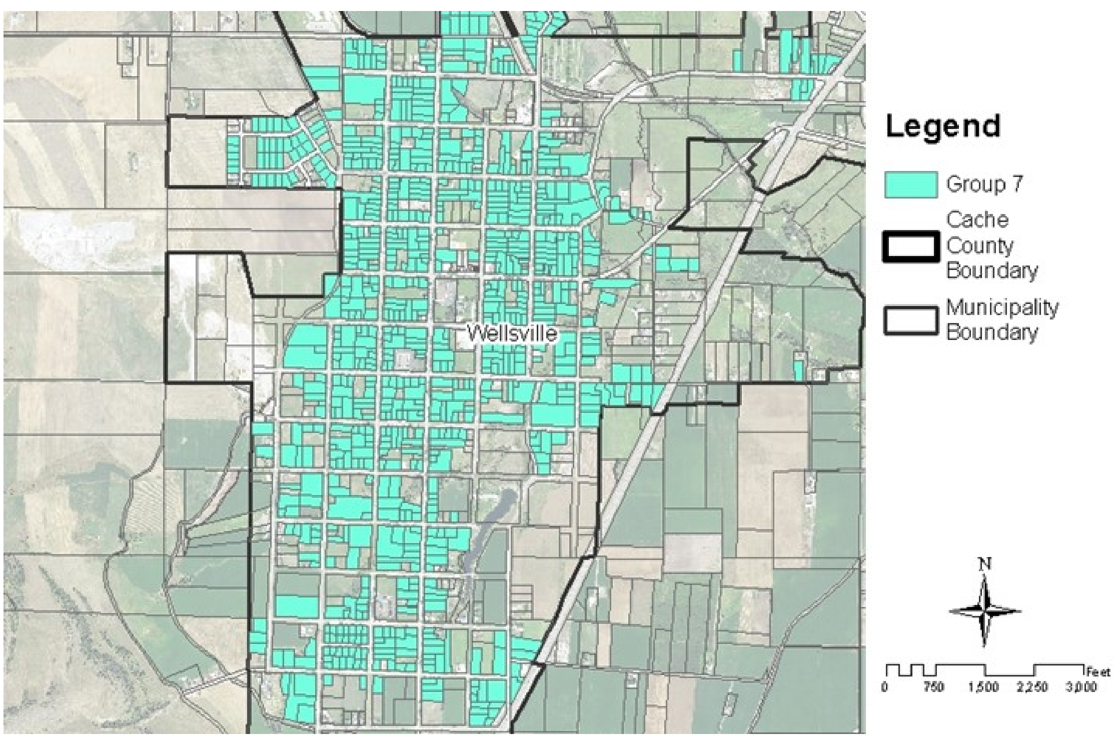

Figure 2-16. Group 7: Satellite centers.

Group 8: Agricultural Residential

This group is made up of many of the largest residential parcels. Being large, these parcels also have the lowest building density. They are far from the central business district and have very low connectivity and low land use mix.

Most of these parcels, while residential in use, are primarily agriculture related. They are farm fields with houses on them or residences on large lots with pastures or fields. Parcels in this group have the second highest mean property value per acre, indicating that they might be highly desirable to residents or developers in Cache County. See sample image of group 8 in Figure 2-17.

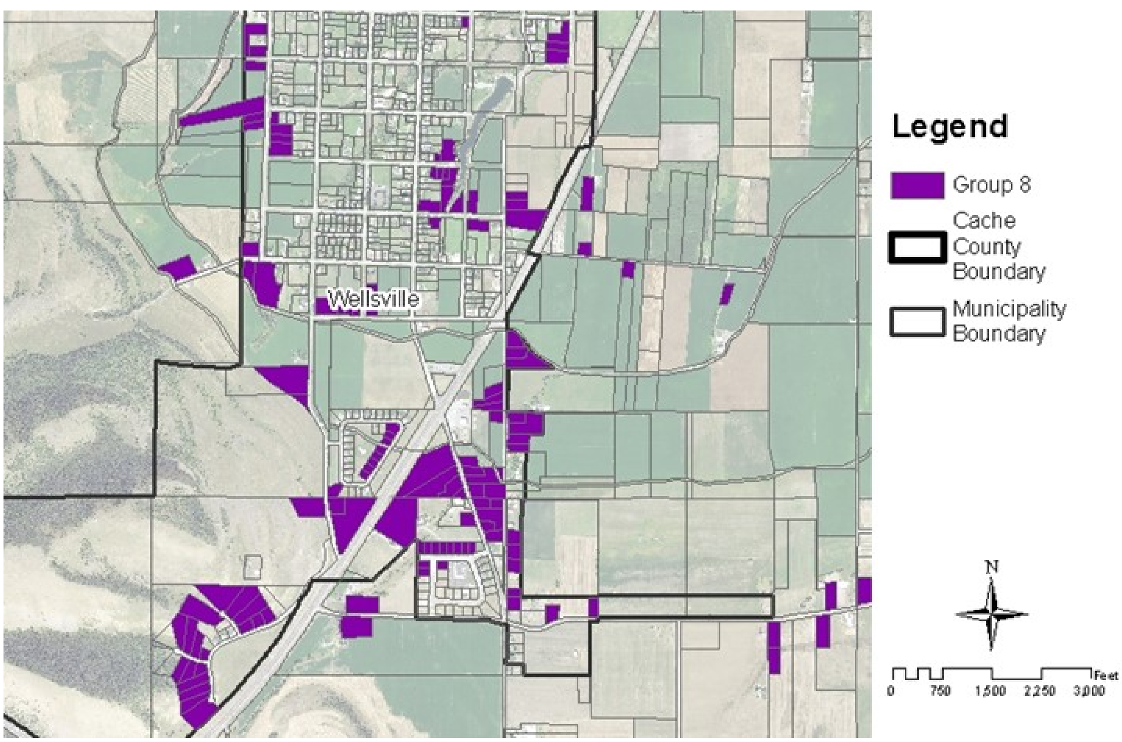

Figure 2-17. Group 8: Agricultural residential.

Group 9: Agricultural Residential Town Centers

This group is primarily composed of parcels that make up the town centers of the cities most far removed from the main urban center in Cache County. Many of the parcels in this group are laid out on a grid pattern, similar to other groups. What distinguishes these parcels from other town center parcels in the county is that these parcels appear to be less developed than other city centers, meaning there have been fewer divisions of the original historic survey blocks. As a result, many of the parcels in this grid are larger in comparison to parcels in other city grids such as Logan. See sample image of group 9 in Figure 2-18.

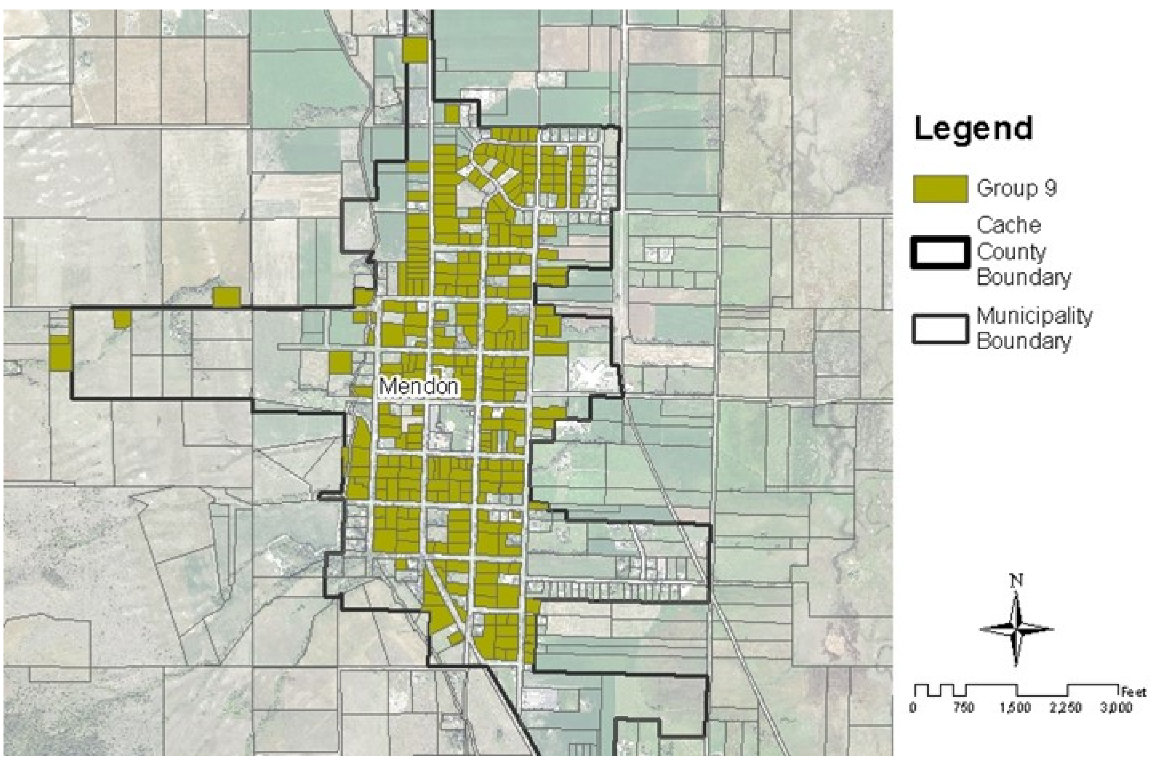

Figure 2-18. Group 9: Agricultural residential town centers.

Some parcels in group 9 are in many ways similar to group 8 parcels. They are among the furthest from the central business district, the largest residential parcels, and the lowest building density in the county. With many parcels being in city centers and part of their historic grid pattern, the connectivity is very high. A moderate degree of land use mix exists in this group due to it being so far from the central business district that it must provide some of its own business, and the proximity of many agricultural commercial uses in the vicinity. Parcel size remains large even with the grid layout, the opposite of which was seen in group 1 where parcels were smaller while on the grid layout. This suggests that group1 parcels subdivided within the grid boundaries since the initial development resulting in smaller parcels, and that this might be the fate of many of the parcels in group 9.

Group 10: Condominium

This group is strongly characterized by its small parcel size, high building density, close proximity to the central business district, high land use mix, and surprisingly low connectivity. This group also has the lowest property value per acre. All of the parcels categorized into this group are condominiums, apartments, duplexes, or townhomes where the parcel is essentially the same size or not much larger than the footprint of the residential unit itself. The clustering process effectively grouped all these types of developments into this group. See example image of group 10 in Figure 2-19.

The result for connectivity as being the lowest was surprising because of the high land use mix and how close these parcels are to the central business district. The central business district itself is a well-connected area as most of it is part of the grid layout. The reason parcels from group 10 have such low connectivity is because most of the units exist as part of a larger development that is served by a common drive way. These driveways typically were dead ends or loops. These driveways were detected as streets in the connectivity calculation and therefore each unit's parcel was given the connectivity value of the drive, rather than the public street on which the development was located. In

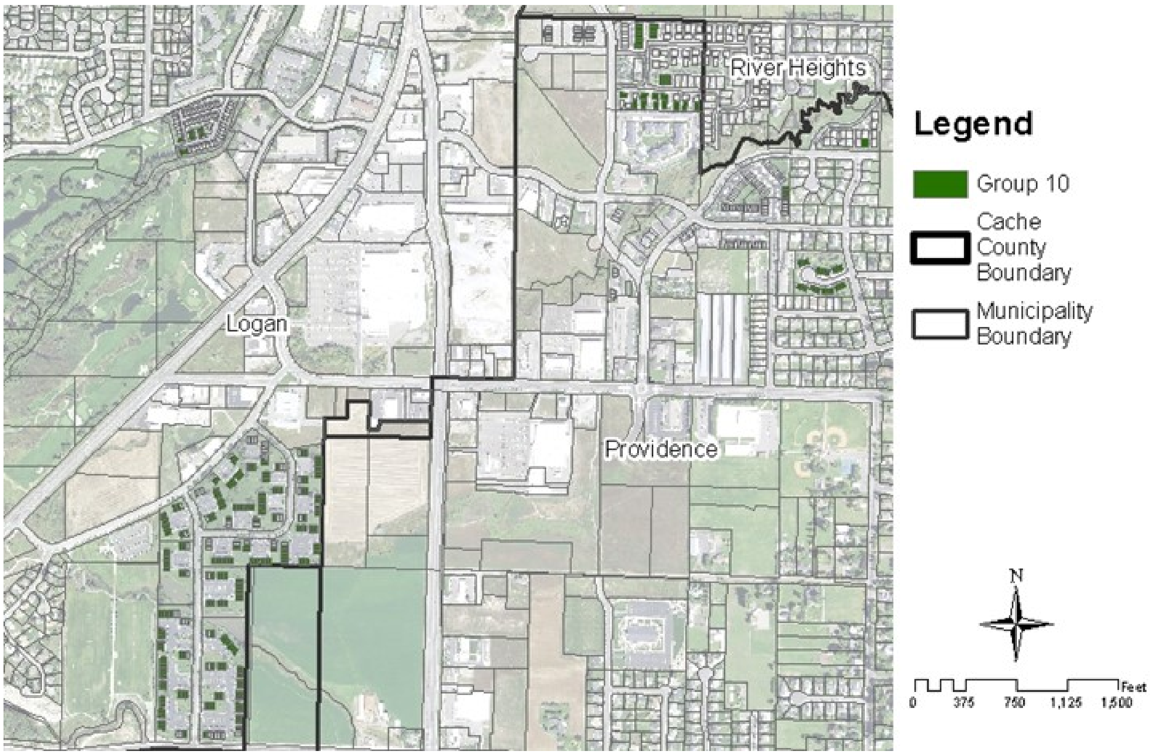

Figure 2-19. Group 10: Condominium.

practicality, these developments are more highly connected than their measurements would suggest.

Discussion and Conclusion

This study demonstrated how an urban area can be analyzed quantitatively to categorize different types of urban development based on key physical characteristics. Past studies described how to identify urban forms by identifying and quantifying urban sprawl. This study effectively demonstrated that similar methods can be used to identify a variety of other urban forms.

Like the studies reviewed, this study revealed that sprawl is the most recent trend in residential development in Cache Valley, based on the average year built of that group; however, it is still not the most dominant form of development and ranked 4th most popular urban form type. This study does not go so far as to determine whether sprawl is increasing or decreasing, much like Song and Knapp (2004) did in their study of changes in sprawl over time in Portland, but provides planners with the capability of doing such a comparison. By repeating this study at a future date, results can be compared to this study to evaluate whether certain urban forms are growing or diminishing, or whether other urban forms emerge. This was not currently possible due the lack of availability of historical data prior to 2014.

Practical Application

As planners produce general plans, visioning plans, and neighborhood specific plans, they are faced with the often-subjective task of dividing the urban area into neighborhoods in order to address the specific needs of different areas. By using this method to identify neighborhoods based on the group results, a planner may have a more quantitative, objective result that better represents the differences in physical urban characteristics and needs. It is recognized that planners must rely on their professional judgement when drawing such boundaries and would be expected to do so even with results from this type of study. The goal in using this data would be to enhance the planner's judgement and allow them to make more informed and defensible decisions. A planner might use this method in one of two potential ways.

1. Perform the urban form categorization analysis for their urban area, and then with the grouping results, identify strong clusters of parcels of different groups. Using professional judgement, neighborhoods boundaries can be drawn around these clusters and make adjustments as feedback is received from city officials and citizens.
2. Produce a preliminary neighborhood map using other data such as census bocks, citizen poles, input from city officials, zoning maps, land use plans, or past neighborhood maps. Then overlay the results of the urban form groups to compare to make informed adjustments.

One of the primary responsibilities of urban planners is to develop a code for their respective jurisdictions. City and county codes are used to control many physical characteristics of the urban form. Many planners implement form-based codes that prescribe strict physical standards for development. Codes can be developed to require standards for parcel sizes, building density, connectivity, and uses allowed. They can also define a central business district. As planners develop future plans and codes, they can demonstrate a more objective nexus between regulations and physical characteristics and needs by using this method to inform their plans.

Data derived from categorizing urban forms can also be used as an analytic tool to understand the existing development of their city or county. It provides them with measurable descriptions of existing development that can be compared with zoning and land use plans. This comparison can reveal where areas are producing development consistent or inconsistent with their zoning and land use plans, allowing for informed adjustments.

Other Applications

Quantitatively derived urban form categories can be useful in other types of studies. Measurements of other factors can be made within each group (or even within each parcel) to be able to compare the performance of different types of urban forms. Such studies could include measuring things like vegetation cover, open space, demographics, economics, access to services, and effects on other ecological factors.

Limitations

A possible limitation to this study is that the groups identified through this method in one urban area are measured and grouped relative to the characteristics of urban form in that area. Consequently, these results might not be compatible with urban form groups identified in another area. For example, the groups we identified in Cache County, Utah would be very different than groups that would be identified if this study were conducted in much more urban county such as New York County, New York.

It was evident that condominium type parcels produced results that were not consistent with other parcel types. This was due in large part to the way condominium type parcels are platted. Common or open space is a parcel separate from the dwelling units and dwelling unit parcels are essentially the shape and size of the foot print of that unit. It is recommended that when performing this method on a parcel set that such condominium parcel be separated before the analysis.

The GIS data provided by the county provided for a convenient data base that included the necessary metrics for measurement, however, such data is continually a work in progress. Additionally, data entry errors were found and excluded to the greatest extent feasible, but it is likely that errors were unavoidably included. Quality control of data was therefore in the control of the data provider and not the researcher.

Conclusion

As many urban areas in the U.S. continue to face large population growth and subsequently increased development, community planners must be able to evaluate how their urban areas have grown and decide how it should grow into the future. They must be able to make informed, defensible, and effective decisions to best allocate resources and plan for the future of their communities. This method of Categorizing urban forms provides an additional tool for solving the complexities of urban planning and research.

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CHAPTER 3

THE RELATIONSHIP BETWEEN URBAN DEVELOPMENT AND VEGETATION COVER IN CACHE COUNTY, UTAH

Abstract

The purpose of this study is to demonstrate the use of residential urban form groups as defined in Chapter 2 in studying ecological factors—in this case, vegetation cover. Results of this study are then examined in their ability to determine relationships between urban form types and vegetation cover. This study uses NAIP aerial imagery to measure dense and light vegetation cover in the main urban area of Cache County, Utah, creating a vegetation cover map. The urban form groups are overlaid on the vegetation cover map to measure the percentage of vegetation cover in each group. The metric values that created the groups are then compared to determine if they have a correlation with vegetation cover. The groups with the highest vegetation cover were those that included primarily agricultural residential uses, though dense vegetation as a percentage of total vegetation was lower in those groups. Urban Sprawl areas had moderate amounts of total vegetation, but also had the lowest dense vegetation cover of all non-agricultural groups. Results of the correlation analysis of vegetation cover and urban form metrics indicated that the most significant metric influencing vegetation cover was building density. Significant but weaker correlations were found with centrality and parcel size. The lack of a very strong correlation between vegetation cover and urban form metrics indicates that vegetation cover is not determined by any single metric alone, but likely by a combination of urban form characteristics and other factors.

Introduction

Plants are a part of nearly every ecosystem. Their presence and ability to thrive are influenced by abiotic features in their surroundings such as rocks, landforms, streams, soil, and air. In urban areas, plants are influenced by human-made abiotic factors such as roads, buildings, irrigation systems, altered soils, and polluted air. Many studies recognize urban areas as urban ecosystems and suggest studying them as such (Alberti, 1999; Bolund & Hunhammar, 1999; Hobbs et al., 2006; Lowry, 2010; Pickett et al., 1997; Talen, 2002; Zipperer, Sisinni, & Pouyat, 1997). This suggests that thy type of urban form has an influence on vegetation cover.

Past research has studied the benefits and services plants provide to humans in urban areas. Nowak, Crane, and Stevens (2006) demonstrated that trees alone remove an estimated 711,000 metric tons of air pollution annually. In addition to air filtration, Bolund and Hunhammar (1999) reviewed several other benefits of urban vegetation including microclimate regulation, noise reduction, rainwater drainage, sewage treatment, and recreation and cultural value. Some plants, particularly trees, have been shown to stabilize or lower landscape water consumption in some situations (Lowry, 2010). Recreational and cultural values of plants have also been studied and quantified to demonstrate their worth (Bolund & Hunhammar, 1999; Dwyer, Schroeder, & Gobster, 1991; Zipperer et al., 1997). Since plants provide so many benefits and services, their abundance can act as an indicator of the overall quality of the urban environment.

Urban areas have been shown to have different microclimates as a result of the different structures that exist. These have been shown to have significant differences in temperature, wind speed, and relative humidity in semi-arid ecoregions (Bonan, 2000). This supports the idea that a variety of urban ecosystems can potentially exist, each providing these benefits and services differently. These differences in urban form need further study to understand how they relate to vegetation cover. The hypothesis of this study is that each urban area has a different measurement of vegetation cover due to differences in metric measurements.

Vegetation Cover and Urbanization

While urban development has been associated with vegetation loss in areas such as Indiana (Donnelly & Evans, 2007) and other areas that were forested prior to development (Nowak et al., 1996), the influence of urban development on vegetation cover in the Western U.S. has been shown to be different. Zipperer et al. (1997) observed that in comparison to their surroundings, in "prairie/savanna and desert ecoregions, tree canopy cover actually increases with urbanization because of planting, fire suppression, and watering" (p. 236). These practices would likely have a similar effect on other plant species, meaning much of the vegetation in urban areas would not continue to exist if they were not regularly maintained by humans. Since urbanization results in increased plant cover, then it raises the question of whether different types of urban forms have different influences on the amount of urban vegetation.

Urban Forms

In order to study the relationship between vegetation and urban form, an understanding of how to measure and quantify urban form is needed. Urban form has been studied by various researchers. Each study varied in the way urban form was defined and quantified, however, common elements were found among them. Chapter 2 reviewed these methods and concluded that urban form can be defined by five key metrics: building density, land use mix, centrality, connectivity, and parcel size (Ewing, Pendall, & Chen, 2003; Galster et al., 2001; Lowry, 2010; Song & Knaap, 2004). The following is a description of these metrics as used in the chapter 2 Study.

Building density: This is defined as the floor area of a primary building divided by the area of its parcel.

Connectivity: This refers to how well a parcel is connected to the rest of the urban area through streets. It was measured by counting the number of intersection "ways" available on the street on which the parcel fronts.

Land use mix: This refers to the variety of near-by land for each parcel. This was measured by counting the number of nonresidential parcels within ¼ mile of each given parcel and dividing that by the number of residential parcels within ¼ mile. A value of 1 would indicate an equal number of residential and non-residential land uses within walking distance. I high number would indicate more non-residential uses than residential uses, and a number between 0 and 1 would indicate more residential than non-residential uses.

Centrality: This refers to how close each parcel is to the main centers of activity. A central business district was first defined by the areas of most dense non-residential parcels. The distance from the nearest central business district was measured for each parcel.

Parcel size: This refers to the area of each parcel measured in acres.

Chapter 2 demonstrated that measurements of these metrics at the parcel level can be used to categorize parcels into urban form groups with relatively similar physical and spatial characteristics.

This study resulted in 10 urban form groups with distinct average values for each metric. These results included: (1) Central Historic Plat Residential, (2) Modern Plat Residential, (3) Dead-end Semi-sprawl, (4) Modern Suburban Sprawl, (5) Modern Modified Plat Residential, (6) Alternative Modern Modified Plat Residential, (7) Satellite Centers, (8) Agricultural Residential, (9) Agricultural Town Centers, and (10) Condominium. See Table 3-1 for average metric measurements and additional statistics for each group.

This method is of interest because physically measured characteristics are more useful for studying the relationship between vegetation and urban form than politically drawn boundaries, socioeconomic boundaries such as census data, or uniformly drawn grids. With measurements of physical characteristics for each parcel, it is possible to test for correlations with vegetation cover.

Location

Cache County, Utah was selected as the study area as a representative of many western counties experiencing high growth rates in a semi-arid climate. Cache County, like many other counties in the western U.S., has limited water sources and therefore plant growth is limited unless additional irrigation is provided. This was the same location and extent as was used in Chapter 2.

						5 urban form metrics				
Group Number	Number of parcels	Percent of total	Mean year built	Median year built	Parcel value per acre	Parcel size (acres)	Building density	Centrality (distance to central business district)	Connectivity	Land use mix
1	5,822	20	1958	1960	$177,127.03	0.30	0.1657	1,396	48.57	0.04390
2	5,451	18	1989	1985	$194,384.41	0.53	0.0966	5,979	38.96	0.01261
3	4,203	14	1976	1994	$209,918.94	0.35	0.1722	2,778	4.06	0.02059
4	2,720	9	1998	1997	$245,420.04	0.92	0.0767	9,634	11.26	0.01055
5	2,167	7	1979	1987	$192,678.04	0.42	0.1190	4,870	66.76	0.01023
6	1,811	6	1963	1988	$186,130.89	0.31	0.1598	3,555	92.39	0.01393
7	1,240	4	1978	1975	$182,479.68	0.81	0.0674	21,005	45.64	0.02951
8	942	3	1982	1988	$233,208.79	1.82	0.0421	24,771	8.26	0.01410
9	941	3	1988	1978	$193,711.39	1.51	0.0424	37,512	33.15	0.01725
10	772	3	1966	1997	$112,180.02	0.03	1.3347	946	3.39	0.05581

Note. Darker shades indicate higher values within each column.

Figure 3-1. Metrics Results of the Top 10 Urban Form Groups.

Measuring Vegetation Cover

One of the most widely used methods to measure vegetation cover at the county scale is through a normalized difference vegetation index (NDVI; Akbari, Rose, & Taha, 2003; Myeong, Nowak, Hopkins, & Brock, 2001; Nowak et al., 1996; Walton, Nowak, & Greenfield, 2008). This classifies pixels of high resolution 4-band georeferenced aerial imagery based on the amount of red and near infrared light captured in the image. This has been shown to indicate chlorophyll of vegetation while minimizing the influence of shadows and topography (Mansfield, Pattanayak, McDow, McDonald, & Halpin, 2005;

Morawitz, Blewett, Cohen, & Alberti, 2006; Tucker & Sellers, 1986;). This produces an image that allows pixels to be quickly classified into categories of no vegetation, light vegetation, and dense vegetation.

Many studies have measured vegetation cover in order to compare amounts within different spatial boundaries. Nowak et al. (1996) compared vegetation across city boundaries using aerial imagery. Akbari et al. (2003) compared aerial imagery across zoning classifications including downtown and city center, industrial, offices, commercial, and residential. Lowry (2010) compared aerial imagery of tree canopy cover across census blocks. While these studies provide useful comparisons for their respective research, the spatial boundaries used are not defined by the physical characteristics of the urban form within them. They are thus limited in their ability to demonstrate relationships between specific urban forms and vegetation cover. Therefore, this study will demonstrate how urban form categories can be used to compare vegetation cover and discuss how characteristics that define urban forms are related to those results.

Methods

The urban area of Cache County, Utah was measured using high resolution 4 band satellite imagery from the National Agriculture Imagery Program (NAIP) through a NDVI in Geographic Information Systems (GIS) to produce a vegetation cover map. This map was then overlaid with the urban form groups defined in Chapter 2 and vegetation cover was calculated for each urban form group and each parcel. A correlation analysis was then used to check for correlations between urban forms and vegetation cover and for correlations between urban form metrics and vegetation cover.

The vegetation cover map was created using Esri's GIS ArcMap 10.4 using the instructions provided by the ArcGIS Resource Center (ESRI, 2019). For data management purposes, vegetation cover calculations were limited to the minimum bounding rectangle that enveloped the extents of the parcels included in the urban form groups (see Figure 3-2).

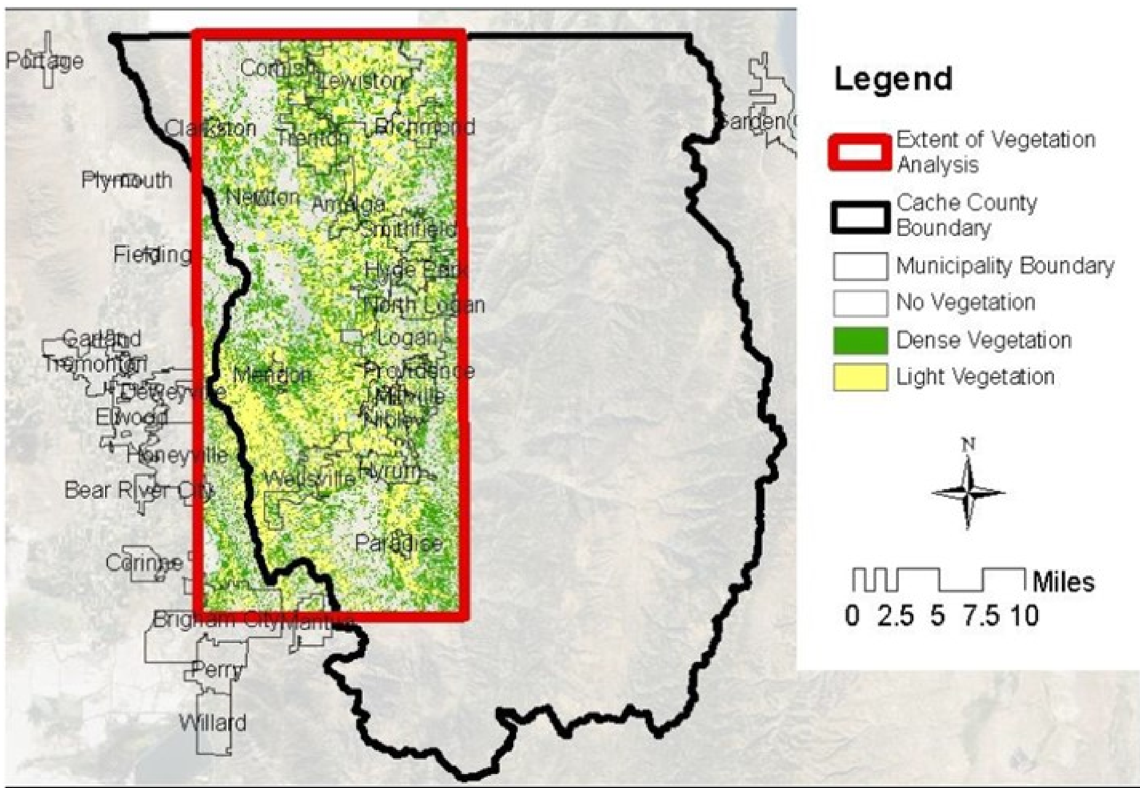

Figure 3-2. Map of minimum bounding rectangle for vegetation analysis extent.

NDVI analysis requires 4-band imagery which was acquired from Utah Automated Geographic Reference Center's (AGRC) NAIP imagery. These images were available in 1-meter pixel resolution.

The NDVI classification of the aerial imagery is calculated in using a GIS raster calculator using the following formula:

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{R})}{(\mathrm{NIR} + \mathrm{R})}$$

When this calculation is applied to the NAIP raster image it results in a new raster image that contains pixels each with a value ranging from -1 to 1. Generally, the closer the value was to 1, the more chlorophyll was present in the vegetation, indicating dense or healthy vegetation. Values of 0 or less indicate objects that were not reflecting red or near infrared light, meaning no vegetation. The (Mansfield et al., 2005; Morawitz et al., 2006; Myeong et al., 2001; Tucker & Sellers, 1986). In ArcMap 10.4, the NDVI function uses this same method, but also multiplies the values by 100 and adds 100 to create a "value range of 0–200 and fit within an 8-bit structure, which can easily be rendered with a specific color ramp or color map" (ESRI, 2019). As a result, values from 0 to 100 indicate no vegetation and values 101 to 200 indicate the existence of vegetation, the higher the number, the greener or denser the vegetation. A classification between light and dense vegetation was made by testing the value of individual pixels as they appeared over different locations of the aerial photograph. Pixels with values ranging 101 – 130 appeared to align with areas of light vegetation and pixels with values 131 – 200 appeared to align with dense vegetation. Vegetation that was considered dense included trees, green lawn, and agricultural fields. Generally, light vegetation included plants that appeared to be unirrigated, drought stressed, chlorotic, or dormant. Thus, these two classifications are termed healthy and unhealthy vegetation.

The urban form group boundaries were then overlaid with the NDVI raster image. The NDVI raster pixels were counted for each group and each parcel using the Summary

Statistics function in ArcMap 10.4, producing a table that listed each parcel with values for total vegetation area, dense vegetation area, and light vegetation area. Also included in the table were the values for each of the metrics as they resulted from the study in Chapter 2 (building density, land use mix, centrality, connectivity, and parcel size) as well as the year built and the property value. The average for these values was calculated for each urban form group. A correlation analysis was performed to detect significant statistical relationships between vegetation cover and each of these values.

Results

Vegetation Cover among Urban Form Groups

The amount of vegetation cover in each urban form group was calculated as a percentage of the total area of each group (Figure 3-3). While the vegetation cover was calculated for all 50 groups, only the first nine groups are presented here as they represent the most widely established urban forms. Although group 10 was classified and described in Chapter 2, it was excluded from this study because its parcels are all condominium type and do not include their appurtenant common area where any vegetation would occur. This made it incompatible with the first nine groups as it relates to measuring vegetation cover and is therefore excluded to avoid skewing any correlations. The results for total vegetation cover and dense vegetation as a percentage of total vegetation for these groups are displayed in Figures 3-4 and 3-5.

The nine urban form groups had an average of 66.55% vegetation cover and

Group Number	Number of parcels	Percent of total	Mean Year Built	Median Year built	Parcel Value per Acre	5 Urban Form Metrics: Parcel Size (Acres)	Building density	Centrality (Distance to Central Business District)	Connectivity	Land Use Mix	Percent Total Vegetation Cover	Percent Dense Vegetation Cover
1	5,822	20	1958	1960	$177,127.03	0.30	0.1657	1396	48.57	0.04390	61.08	41.20
2	5,451	18	1989	1985	$194,384.41	0.53	0.0966	5979	38.96	0.01261	66.75	45.15
3	4,203	14	1976	1994	$209,918.94	0.35	0.1722	2778	4.06	0.02059	59.57	41.27
4	2,720	9	1998	1997	$245,420.04	0.92	0.0767	9634	11.26	0.01055	66.42	41.56
5	2,167	7	1979	1987	$192,678.04	0.42	0.1190	4870	66.76	0.01023	65.26	44.61
6	1,811	6	1963	1988	$186,130.89	0.31	0.1598	3555	92.39	0.01393	60.00	40.71
7	1,240	4	1978	1975	$182,479.68	0.81	0.0674	21005	45.64	0.02951	75.43	52.45
8	942	3	1982	1988	$233,208.79	1.82	0.0421	24771	8.26	0.01410	71.39	42.66
9	941	3	1988	1978	$193,711.39	1.51	0.0424	37512	33.15	0.01725	73.01	42.98
10	772	3	1966	1997	$112,180.02	0.03	1.3347	946	3.39	0.05581	5.35	41.20

Figure 3-3. Percent vegetation cover and metrics results of the top 10 urban form.

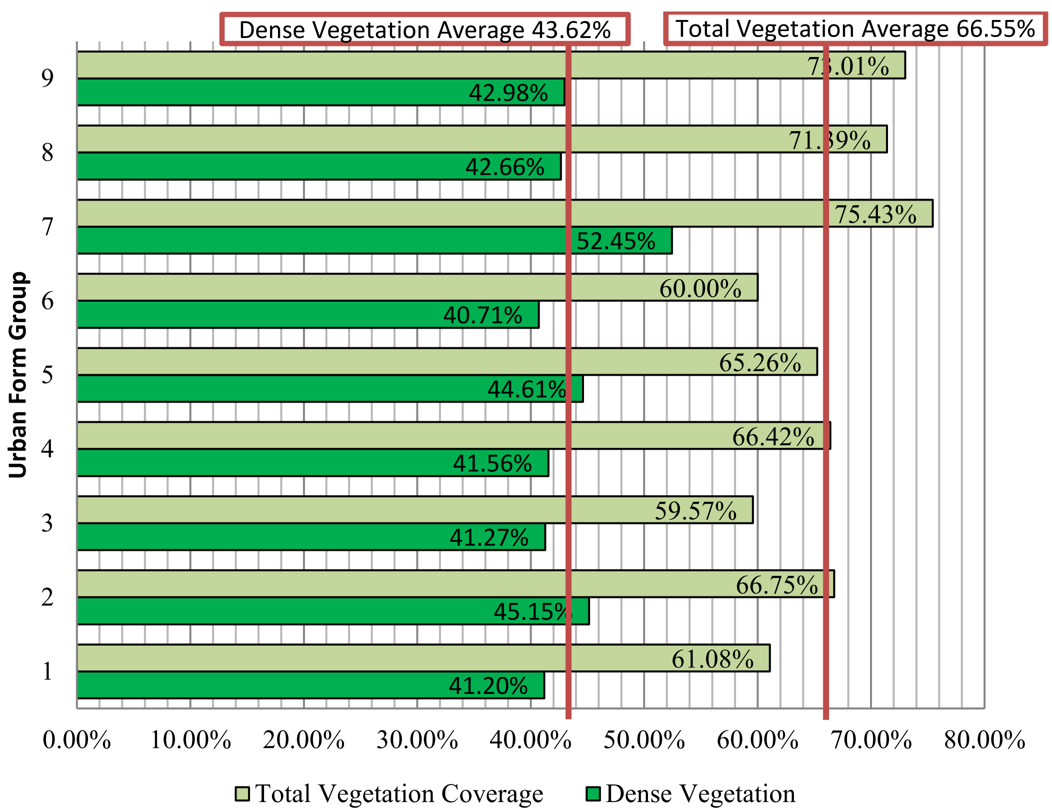

Figure 3-4. Vegetation cover results by urban form group.

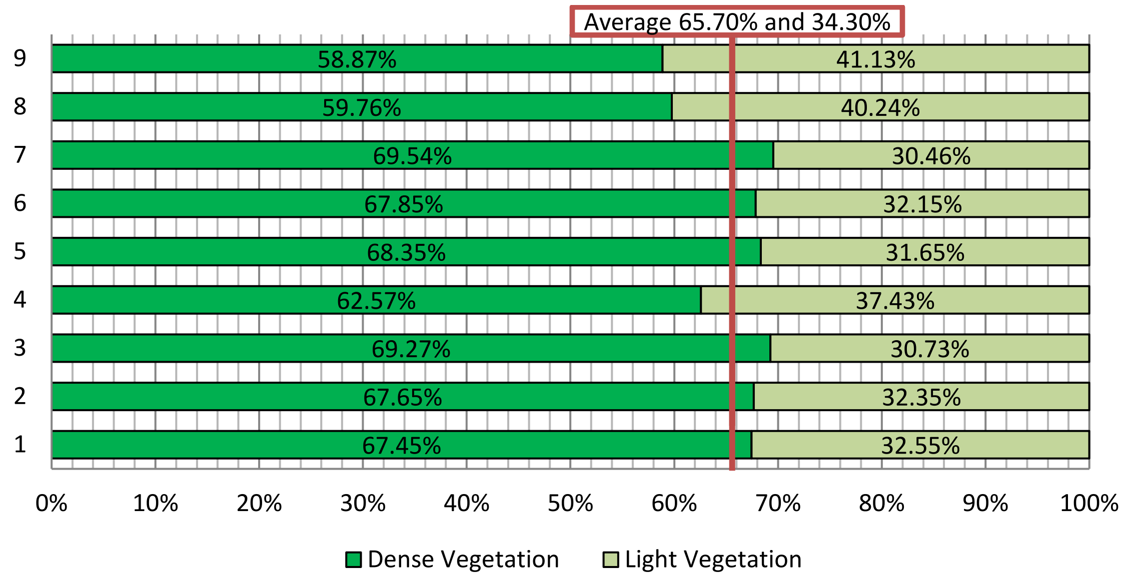

Figure 3-5. Dense and light vegetation as a percentage of total vegetation.

43.62% Dense Vegetation Cover. The average vegetation and dense vegetation coverage for the full study area (including non-urban areas) was 55.57% and 28.10%, respectively. This confirms that vegetation coverage increases with urban development as suggested by Zipperer et al. (1997). The average amount of vegetation cover differed between groups with a range of 15.86% vegetation cover between them. The group with the highest total vegetation cover was group 7 with 75.43% cover. The group with the lowest vegetation cover is group 3 with 59.57% vegetation cover.

As a percentage of total vegetation, dense and light vegetation measured an average of 65.70% and 34.30%, respectively. While each group had a different percentage of dense vegetation, groups 8, 9, and 4 had noticeably less dense vegetation than the other groups. Dense vegetation was shown to indicate areas of healthy, irrigated vegetation. Therefore, groups that show lower averages of dense vegetation likely have more areas of non-irrigated, dormant, or uncultivated vegetation. Group 8 (Agricultural

Residential) and 9 (Agricultural Residential Town Centers) are, as their names imply, largely agricultural in use. As such, a large portion of their parcels are devoted to livestock pastures which are typically unirrigated, or crop production which varies in growth stage. Due to the rotational and seasonal nature of agricultural production, many of these lots at the time the aerial imagery was photographed was at a stage where the land was recently tilled, fallow, or recently harvested. The limited actual residential use and associated landscape improvements on these properties also likely contribute to these lower dense vegetation numbers. Despite the low dense vegetation, these groups were among the highest in total vegetation cover, likely due to crop production activities.

Among the nonagricultural residential urban form groups (groups 1 – 7), the amount of dense vegetation as a percentage of total vegetation was higher than average with the exception of group 4 – Modern Suburban Sprawl. While the total vegetation average for group 4 (66.42%) was very close to the overall average of the 9 groups (66.55%), the lower ratio of dense vegetation to total vegetation suggest the quality of that vegetation was lower. This suggests that there is some factor or combination of factors in urban sprawl that limits vegetation cover compared to other urban forms that requires further research.

Group 7 had the highest total vegetation cover and highest dense vegetation cover. This group, named “Satellite Centers”, primarily included parcels that were part of city centers that were away from the main center of activity in Cache Valley, primarily the cities of Wellsville and Paradise. These city centers exhibit development patterns of the Plat of Zion, meaning many were laid out by the original settlers in the late 19th and early 20th century (Hamilton, 1995). See Figure 3-6 for enlargement of group 7 map.

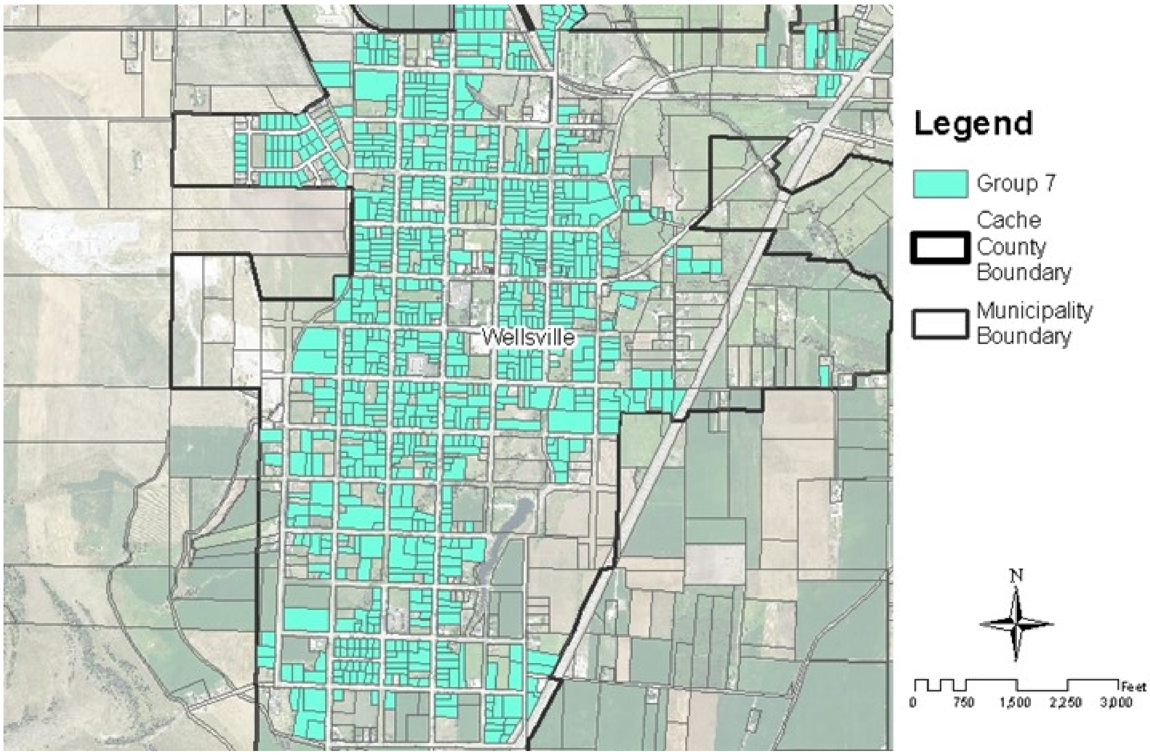

Figure 3-6. Enlargement of Group 7.

Group 7 was particularly high in dense vegetation (52.45%) compared to the other groups (the next highest being 45.15%), indicating that there is some factor or combination of factors that encourages irrigated, dense, healthy vegetation. This distinguishes group 7 from groups 8 and 9 which had similarly high total vegetation cover, which may be explained by the difference in primary land use. While groups 8 and 9 were primarily agricultural in use, group 7 was more primarily residential use and may relate more to groups 1-6 as far as urban form.

The urban form metric measurement in group 7 that distinguished it from the other non-residential groups was building density where it had the lowest value. It also had the highest centrality among nonagricultural groups, meaning parcels in this group were the furthest from the central business districts of the county. The correlation analysis confirms that these two metrics indeed relate to the higher vegetation coverage in this group.

The lowest vegetation cover was found in group 3 “Dead-end Semi Sprawl” at 59.57%. While this is not far above the average for the overall study area (55.57%), it still has much higher average dense vegetation (41.27%) than the study area average (28.10%). The dense vegetation however is among the lowest of the urban form groups. This group has the densest vegetation of the 9 groups. This group also has the lowest connectivity and is typically found as residential homes on a dead-end street. Many of these were developed as in-fill development within urban areas, which may explain the higher building density. Groups 1 and 6, which had similarly low total vegetation, also had similarly high amounts of dense vegetation.

Correlation Analysis

With the appearance of a relationship between building density and vegetation cover, a correlation analysis was performed to study whether there were any significant statistical relationships. The urban form metrics (building density, land use mix, centrality, connectivity, and parcel size) were all tested for correlations with vegetation cover. In addition, ‘Year built’ and ‘property value’ were also tested for correlations with vegetation cover for further discussion. The coefficient of correlation (*r* value) and the significance level (*p* value) were calculated for each metric for both total vegetation and dense vegetation.

The *r* value and *p* value results are listed in Table 3-1. An *r* value closer to 1 or -1 indicates a stronger correlation and 0 indicates no correlation. A *p*-value maximum threshold of .05 is used to establish significance.

Table 3-1

Correlation Analysis Results of Total Vegetation Cover and Dense Vegetation Cover for Groups 1-9

	Total vegetation		Dense vegetation	
Metric	coefficient *r*	*p* value	coefficient *r*	*p* value
Parcel size	0.23	< .001	-0.02	0.010
Connectivity	0.00	0.528	0.03	< .001
Land use mix	-0.05	< .001	-0.05	< .001
Centrality	0.21	< .001	0.05	< .001
Building density	-0.62	0	-0.35	0
Property value	-0.11	< .001	-0.09	< .001
Year built	-0.27	0	-0.12	0

Given that there are many factors that influence vegetation growth, a very strong correlation was not expected from any one metric. The strongest correlation found was between building density and total vegetation cover (r = -0.62, p = 0). The correlation between building density and dense vegetation cover was the next strongest (r = -0. 35, p = 0). Building density, in both cases, displayed an inverse relationship with vegetation cover. This makes sense as more area is used for buildings, less space is available for plants to grow. One reason why this relationship might not be stronger could be that at a certain size, plants (particularly trees) can overlap and cover buildings as was observed in the aerial imagery. Another factor limiting the relationship could be that as building density decreases due to an increase in parcel size, the amount of money per acre the land owner is willing to spend for improving and irrigating the land is spread thin, while land owners with less land and higher building density are less financially restrained.

Significant correlations with total vegetation were found, though weaker, with Parcel size ($r = 0.23$, $p = 0$) and centrality ($r = 0.21$, $p = < .001$). While total vegetation correlated with parcel size and centrality, dense vegetation had very little correlation with them, meaning that larger parcels did not necessarily have more or less vegetation than smaller parcels, and parcels far from the central business district had similar vegetation compared to those near the central business district.

Weak, but significant correlations were observed for total vegetation with property value ($r = -0.11$, $p = <.001$) and year built ($r = -0.27$, $p = 0$). These inverse relationships suggest that property value increases somewhat with lower total vegetation cover – the opposite of what was expected. This also suggests that newer homes have less total vegetation than older homes. These findings may be partly explained by Cache County's recent increased population growth discussed earlier. As newer homes are built, new vegetation has not yet had time to mature as would more likely be found with older homes. A correlation analysis between year built and property value reveals a weak but significant relationship ($r = 0.20$, $p = <.001$), which indicates that as year built increases, property value increases.

Very weak correlations were found for total vegetation with land use mix or connectivity. These findings were expected since no past studies indicated any reason to believe they might have any relationship.

Generally, dense vegetation had weaker correlations with urban form metrics than did total vegetation. Dense vegetation displayed a moderate relationship with building density ($r = -0.35$, $p = 0$). A weak correlation was observed for year built ($r = -0.12$, $p = 0$). Only very weak correlations were found with parcel size, connectivity, land use mix, centrality, or property value. These findings indicate that dense vegetation might tend to occur in less dense areas and around older homes.

Though many of the correlations were weak, these results establish that a portion of vegetation cover in urban areas is related to urban form. It is also clear that there is not one single factor that determines the amount of vegetation cover. It is likely a multitude of factors play a role in determining urban vegetation cover including urban form characteristics socioeconomics, culture, land use, and ecology.

Discussion

This study found that there is a relationship between the physical form of an urban area and the amount of vegetation within it. The results clearly showed the strongest relationship that exists between urban form and vegetation cover is with building density. These results, however acknowledge that there is more to understanding the existence, quantity, and quality of vegetation cover than was covered in this study.

The varying amounts of vegetation cover measured in each urban form group strengthen the assertion that a variety of urban ecosystems can potentially exist due to the various forms that urban areas can take. These variations in urban form appear to represent an urban ecosystem where different arrangements of abiotic components result in different arrangements of biotic components. Further ecological study is required to truly understand what these ecosystems are and how they function.

Urban form groups as described in Chapter 2 proved useful to a certain extent in studying the relationship between urban form and vegetation cover. They provided an appropriate context for comparison as their composition was meaningful – being derived from physical measurements. The vegetation cover results for each group provided useful preliminary results that directed and supported the study through further analysis of individual metrics. As the vegetation cover results for the urban form groups were analyzed, it became apparent that building density was a key factor in understanding urban vegetation before the correlation analysis was performed.

The descriptions of each urban form group added further value to understanding vegetation that could not have been derived from measurements alone. A greater understanding of why and how vegetation came to be what it is now can be gained through knowing the historical background of how parcels were laid out and what the primary land uses are.

Limitations

While the results of this study provide some useful insights, the topic of urban vegetation might be too broad of a category, and might benefit with the study of more specific categories. Light and dense vegetation are useful categories to study in a preliminary extent, but in order to provide more useful analysis for planners and researchers, the ability to measure more specific categories such as tree canopy cover is needed. Measuring tree canopy cover was explored as an option for this study, but was not pursued due to the lack of data required for such an analysis. Discerning trees from other vegetation using NDVI color categories as outlined in this study proved unreliable. A more accurate and efficient method for measuring tree canopy at the county scale is using airborne laser scanning (LIDAR) data, which provides vertical measurements allowing for 3-dimensional differentiation between vegetation (Andersen, 2005). Such data was not currently publicly available in Cache County.

Another limitation of this study included the limited and incomplete availability of GIS data provided by government jurisdictions. GIS data are relatively new when compared to the lifespan of most cities and compiling it is often a work in progress. Urban form groups are only as accurate as the data they were formed by.

High resolution NAIP imagery is also limited in its availability. It can be found for the entire state of Utah as well as most other states, but is only available for certain years. Such imagery is also subject to differences in the vegetation cover captured due to the timing of the imagery. Even a difference of several weeks can significantly change the measured vegetation cover, especially as was seen in the case of agricultural lands where the vegetation is continually being changed.

Technology and data availability are continually evolving and quickly growing. If not available now, it will likely be only a matter of time before the necessary data and methods are available in most, if not all, counties.

This study was intentionally limited to studying residential urban forms which were the product of the Chapter 2 study. While these results demonstrate some relationships between residential urban form and vegetation cover, these results may not necessarily apply in other land uses such as institutional, commercial, industrial, or open space. Additional research is advised to expand the understanding of urban forms and vegetation cover. It is also acknowledged that there are likely many other factors beyond urban forms in such fields as ecology, socioeconomics, and anthropology that influence vegetation cover that warrant further research.

Recommendations and Conclusion

The methods used for measuring vegetation in this study are not new, however the context of urban form groups provides a unique perspective in understanding what aspects of urban form influence or relate to vegetation cover such as building density, parcel size, and centrality, as well as which aspects do not, such as connectivity and land use mix. The findings of this study allow planners to evaluate how past, current, and future development and municipal codes might influence the existence and quality of urban vegetation.

The findings in this study that indicate an inverse relationship between vegetation cover and building density implore further investigation. It is recommended that this relationship be studied in greater detail and that planners use strategies to increase vegetation cover in areas where building density is higher. Focusing on maximizing tree canopy cover in these areas is likely the best way to deter diminishing vegetation cover in areas of high building density.

The methods described in this study, including the use of urban form groups as a context are recommended to be used more for preliminary study to direct efforts for further studies. While this study demonstrated that certain urban forms have higher vegetation cover than others and that there is a relationship to urban form, it was also determined that there are likely factors beyond urban form characteristics that influence vegetation cover that should be studied. It is recommended that all other factors should be studied before applying these results in practice.

By focusing on urban form characteristics and their relationship to vegetation, we can see the results of our community decisions on the environment around us. As urban areas are recognized as urban ecosystems that support important services throughout the community, the relationship between urban form and vegetation cover becomes critical. The benefits plants provide are well recognized and as planners seek to develop plans and codes that encourage urban vegetation cover, an understanding of all the factors that influence vegetation cover will benefit future planning.

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CHAPTER 4

RESULTS AND CONCLUSION

The purpose of this thesis was to examine the relationship between the physical structure of urban forms and vegetation cover through the use of categorized urban form groups. A study was first done (Chapter 2) to establish the defining physical characteristics that constitute urban areas and proposed a method of classifying these areas into groups of similar characteristics. In Chapter 3, these urban form groups and their defining characteristics were then used with measurements of urban vegetation cover to search for correlations that might indicate a relationship between urban form and vegetation cover. Chapter 4 discusses the results of both studies and their merits.

Categorizing Urban Forms

The purpose of Chapter 2 was to establish defined measurements and definitions of urban form in order to study vegetation cover and its relationship to urban form. Two important findings resulted. The first finding was the establishment of defining characteristics of urban form. Past research showed there were essentially 5 metrics that define urban form: building density, centrality, connectivity land use mix, and parcel size. With conflicting and differing definitions of these metrics among these studies, common principles were found and a unified definition and method of measurement was proposed. Building density was measured as the floor area ratio – a ratio of building square footage divided by the parcel area, or the floor area ratio. Centrality was defined as the distance a parcel was from a central business district. Connectivity was defined by the number of intersection ways per mile of road for each road segment. Parcels were given a connectivity value of the street segment it fronted. Land use mix was defined as the ratio of residential to nonresidential parcels within walking distance of a given parcel. Parcel size was simply a measure of the area of a parcel in acres. Consistent definitions and methods of measuring urban forms is clearly needed in urban studies.

The second finding was that these measurements could be applied to individual parcels of a county which could then be classified into groups of similar characteristics. 50 urban form groups were formed using parcels in Cache County, Utah. 87% of the parcels fell within the first 10 groups, each possessing at least 3% of the total parcel count. These 10 groups represent the most widely used residential urban forms in Cache County. These groups were each named based on their observed characteristics and historical development and included Central Historic Plat Residential, Modern Plat Residential, Dead End Semi-sprawl, Modern Modified Plat Residential, Alternative Modern Modified Plat Residential, Satellite Centers, Agricultural Residential, Agricultural Town Centers, and Condominium.

The results of the urban form classification demonstrate how methods for identifying urban sprawl in past studies can be used to identify a variety of urban forms. These groups provide a context for further studies such as measuring vegetation cover to find whether different amounts exist in different groups and whether there is a relationship between certain urban characteristics and vegetation cover.

Comparing Vegetation Cover across Urban Form Groups

The purpose of Chapter 3 was to use urban form metrics and classifications to examine relationships between vegetation cover and urban forms by comparing measurements of vegetation cover between groups. Vegetation cover was measured for the same urban area as Chapter 2, using an NDVI classification of 4-band aerial imagery. Results included measurements of light and dense vegetation cover for each group. Vegetation cover results were extracted for each parcel and for each urban form group.

Each urban form group had a different percentage of vegetation cover. This confirms that each urban form allows and prohibits vegetation growth differently. Correlation analysis between vegetation cover and the urban form metrics showed several relationships exist. The strongest correlation found was between total vegetation cover and building density ($r^2 = 0.384266$, $p = 0$). For dense vegetation this was also the strongest correlation, although somewhat weaker ($r^2 = 0.123775$, $p = 0$). This makes sense as buildings get larger and closer together less space is available for plants to grow. Results for parcel size ($r^2 = 0.052625$, $p = 2.50\text{E-}299$) and centrality ($r^2 = 0.045812$, $p = 6.10\text{E-}260$) indicate they have a small level of influence on vegetation cover. Correlations proved stronger with measurements of total vegetation than with dense vegetation. No correlation with vegetation cover was found with connectivity or land use mix.

Limitations

It is important to note that the method described in Chapter 2 for categorizing urban forms is relative to the study area. The results produce a unique, customized classification of urban forms in the study area that cannot necessarily be imposed on another urban area.

As with all studies that use on GIS data, the availability and accuracy of the collected data can limit where this method can be applied. Within this study, errors and incomplete data were found in the GIS data provided due to it being a continual work in process to keep it up to date. Such errors and incompletions were omitted from the study.

Comparing urban forms can only reasonably be done within a similar category of land use. For this reason, only residential urban forms were studied. It was found that even within residential uses there were certain results that need to be separated out, such as multi-family and condominium type parcels.

Similar limitations exist in the methods used for analyzing vegetation cover. The availability of recent NAIP aerial imagery is often limited as not taken every year. The time of year that the imagery is taken can also influence the vegetation cover results. Even a difference of a few weeks can make a significant difference, especially in the case of agricultural areas. The use of vegetation cover as a factor to measure may be limiting itself as it is a very broad category. Vegetation could mean trees, lawn, and shrubs, but it can also mean weeds, native plants, and crops. The influence of urban forms on different types of vegetation would be more informative and might have more conclusive correlation results.

Conclusion

The findings of this study conclude that categorizing urban forms into groups based on similar and consistent metrics is useful for studying urban development patterns and defining distinct urban forms. These groups can potentially benefit land planners by providing an objective and quantifiable method of dividing the urban area into neighborhoods for planning purposes. It encourages the discussion of how past development has shaped the urban area into what it currently is. Understanding how the past has influenced the present is key to envisioning the future and knowing how to plan for it.

Urban form metrics and classified groups proved useful in studying relationships between urban development and vegetation cover. Measuring and comparing vegetation cover across urban form groups illustrates how biotic factors of ecosystems can be studied in the context of an urban area to find relationships with urban forms. As data quality and technology advance, these studies can be improved to be performed more efficiently and accurately. As many urban areas continue to increase development, planners and leaders must have tools that allow them to examine what past development has produced in order to determine the best future for their respective areas.