The Vertical Space Problem: Rethinking Population Visualizations in Contemporary Cities

Nicholas A. Perdue, University of Oregon: perdue@uoregon.edu

ABSTRACT

The conventional population density metric is insufficient for accurately representing population patterns in contemporary urban environments, which contain vertical residential structures distributed across the horizontal extent of the city, producing volumetric living spaces. The flatness of conventional population density creates representations of city space that confuse the concepts of density and crowdedness, a confusion I call the vertical space problem. Drawing on existing dasymetric approaches, this paper introduces the building footprint technique to provide an alternative visualization of how people vertically inhabit the city of Chicago. The resulting cartographies juxtapose conventional population density metrics with a new Personal Space Metric (PSM), revealing a nuanced picture of contemporary building and living spaces. The PSM overcomes the vertical space problem and provides a new way to calculate and visualize how much space individual people have within the residential buildings of the city. This paper concludes by arguing that new methodologies which visualize the increasingly-prominent verticality of cities facilitate discourse about, and greater understanding of, the geopolitical, social, structural, and personal geographies of the city.

INTRODUCTION

The relationship between visual representations and human experiences of space has long been an area of interest in the field of human geography. While recognition does exist of the differences between spatial patterns of population density and the human experience of crowdedness, the two terms are often confused in geographic literature and cartographic applications. As Yi-Fu Tuan states, "space and spaciousness are closely related terms, as are population density and crowding; but ample space is not always experienced as spaciousness, and high-density does not necessarily mean crowding" (1977, 51). Although the confusion between population density and crowdedness may be the unintended consequence of conceptual misuse and map design, a critical examination of the conventional population density metric itself illustrates how it is fundamentally flawed for contemporary urban population analytics and visualizations.

While conventional population density (e.g., persons per square mile) effectively characterizes the number of people residing within a given geographic extent, it is limited in its ability to capture settlement patterns within contemporary vertical urban environments. Applied to urban spaces, it assumes both the uniform distribution of individuals as well the uniform distribution of vertical residential structures across the bounded spatial unit. A common visualization of conventional population density, the choropleth map, represents these data as zones of unique values abruptly ending at defined borders. Consequently, conventional population density metrics and subsequent cartographies fall short in illustrating a contemporary urban pattern of individuals distributed within the vertical landscape of buildings. To understand the spatial occupancy within this vertical landscape and, thus, to begin to shed light on the lived experiences of crowdedness in cities, a new visualization technique is needed.

The need for alternative techniques to analyze and represent populations in cities is essential, as over half of the world's population now lives in urbanized spaces (United Nations 2012). Furthermore, the manner in which people are settling within the urban landscape is changing; in many urbanized areas, residential patterns are rapidly transforming away from sprawling suburban developments towards centralized, revitalized, and integrated residential spaces accommodating institutional pressures on resources and infrastructure (Kern 2007). Increasingly, a higher proportion of urban residents are living in stratified vertical landscapes unevenly distributed across the city. With this growing urban verticality, conceptualizations of urban design, social interaction, political power, and human experiences of space must also mature in order to overcome the unintended consequences arising from the flatness of conventional metrics (Jones et al. 2007; Graham and Hewitt 2013).

Additionally, societal functions such as environmental risk planning, crime analysis, public health resources, emergency response, and spatial interaction modeling will benefit considerably from increased insight into both where and how people live in the urban space (Chen 2002; Langford 2006; Mennis 2009). Visualizations that move beyond conventional population density are essential in these rapidly growing, recentralizing, vertical urban spaces. Current cartographic approaches capture a picture of the urban space that excludes this verticality, and as a result, the ubiquitous choropleth population maps of cities show little about how populations actually live in cities.

Conventional visualizations of population within the vertical landscapes of contemporary cities produce unintended confusion between population rates and individual experiences. Moving forward, I will refer to this confusion as the vertical space problem. The primary goal of this paper is to develop a straightforward and accessible methodology to reduce the prominence of the vertical space problem in visualizations of urban populations. Chicago, with a large population and an abundance of vertical residential environments across an expansive geographic area, serves as the study area to explore the relationship between people, built environments, and perceptions of space.

By exploring the vertical space problem across the landscape of Chicago, I develop herein the Personal Space Metric (PSM), an extension of dasymetric techniques to conceptualize and represent living spaces across the extent of a contemporary city. The PSM works to minimize the confusion of the vertical space problem and to facilitate a more nuanced understanding of the complex residential urban landscape. This alternative technique characterizes how urban verticality produces unmeasured population space and provides insight into the primary question of this paper: how does the flatness of conventional population density visualizations confuse our understanding of contemporary urban settlements? To answer this question, this paper first explores the limitations of conventional population density and the choropleth map in the context of the contemporary vertical city. Drawing from dasymetric techniques, I demonstrate a straightforward technique to measure, visualize, and understand how people vertically inhabit the city of Chicago. The resulting metric, when visually juxtaposed with conventional population metrics, reveals a more refined picture of the contemporary urban residential landscape. I conclude by arguing how new techniques to represent the increasingly prominent verticality of cities facilitate a greater understanding of the political, social, and institutional landscape of the contemporary city, which is masked by the flat discourse of conventional population density approaches.

THE LIMITATIONS OF POPULATION DENSITY AND ALTERNATIVE APPROACHES

Before illustrating an alternative approach, it is important to consider how visualizations of conventional population density influence and limit understandings of population distributions. Population density is the number of people per unit of ground space and is most commonly visualized with a choropleth map. Standardizing total population by ground area helps to eliminate misrepresentative comparisons of populations across differently-sized geographies (Openshaw 1983). A well-designed choropleth map assigns each polygon a different lightness, illustrating population density in a sequential visualization across administrative geographic space (Slocum et al. 2009). Though populations are more appropriately conceptualized as a continuous phenomenon, the choropleth design breaks populations into discrete classes with differences defined abruptly at administrative boundaries (Holt et al. 2004). Though administrative boundaries rarely reflect natural breaks, and changes in population are typically more gradual, choropleth maps give the impression of abrupt changes at the boundaries of geographic units (Eicher and Brewer 2001). Additionally, choropleth maps imply a homogenous distribution of population across the extent of each unit (Maantay et al. 2007). In reality, urban populations are often clustered and stacked in buildings, not distributed uniformly across administrative spaces. A well-designed choropleth map, though useful for many applications, is not suited to detailed urban population mapping.

Langford and Unwin (1994), recognizing the limitations of choropleth maps and striving to refine the accuracy of population visualizations, "developed a novel mapping method based on remote sensing, dasymetric mapping, and generalization" (Slocum et al. 2009, 278). A dasymetric approach is an alternative population mapping technique utilizing ancillary data to allocate populations into smaller more appropriate spatial units. Though dasymetric techniques are over a hundred years old (Petrov 2008) and were utilized in early population research (Wright 1936), they had yet to be comprehensively developed and standardized prior to Langford and Unwin's study (Eicher and Brewer 2001). By utilizing modern remotely-sensed data, raster-based GIS data structures, and raw census populations, Langford and Unwin were able to illustrate how "representation of spatial discontinuities in the data is divorced from the boundaries of the collection unit" (1994, 23).

As Maantay et al. (2007) note, contemporary developments in dasymetric technique have been expansive and diverse in approach and scale. These approaches include: a binary method (Eicher and Brewer 2001; Poulsen and Kennedy 2004), an areal interpolation method (Langford et al. 1991; Goodchild et al. 1993; Eicher and Brewer 2001; Holt et al. 2004), a three class and limiting variable method (Eicher and Brewer 2001; Liu et al. 2006), a land use/land cover as ancillary data approach (Langford and Unwin 1994; Mennis 2003; Sleeter 2004), an image texture method (Liu et al. 2006), regression and kernel density-based approaches (Flowerdew and Green 1994; Goodchild et al. 1993; Martin et al. 2000; Langford 2006), a heuristic sampling method (Mennis 2003), and a street-weighted interpolation method (Reibel and Bufalino 2005). As demonstrated by the extent of methodological development in the past twenty years, a dasymetric approach clearly has advantages in painting a more precise picture of where people actually live within administrative spaces, by allowing the reconfiguration and segmentation of bounded administrative units into smaller zones of population suitability (Maantey et al. 2007).

Recently, scholars have recognized the need to disaggregate census data into the smallest residential units possible: the individual buildings (Lwin and Murayama 2009; Lwin and Murayama 2011; Ural et al. 2011). Recent volumetric dasymetric methods illustrating the importance of micro-scale urban analysis have significantly contributed to ideas of urban verticality, residential density, and mapping crowdedness. These studies, however, are limited to the scale of neighborhoods or campuses, employ expensive geocomputational processes, and often rely on lidar and Object-Based Image Analysis (OBIA) derived datasets. Consequently, though urban volumetric analysis is conceptually impressive, the methods are not suitable for large scale projects at this time. To map the residential distribution and the personal spaces of individuals in a city the size of Chicago, a conceptually equivalent but computationally less demanding dasymetric technique is needed. Building

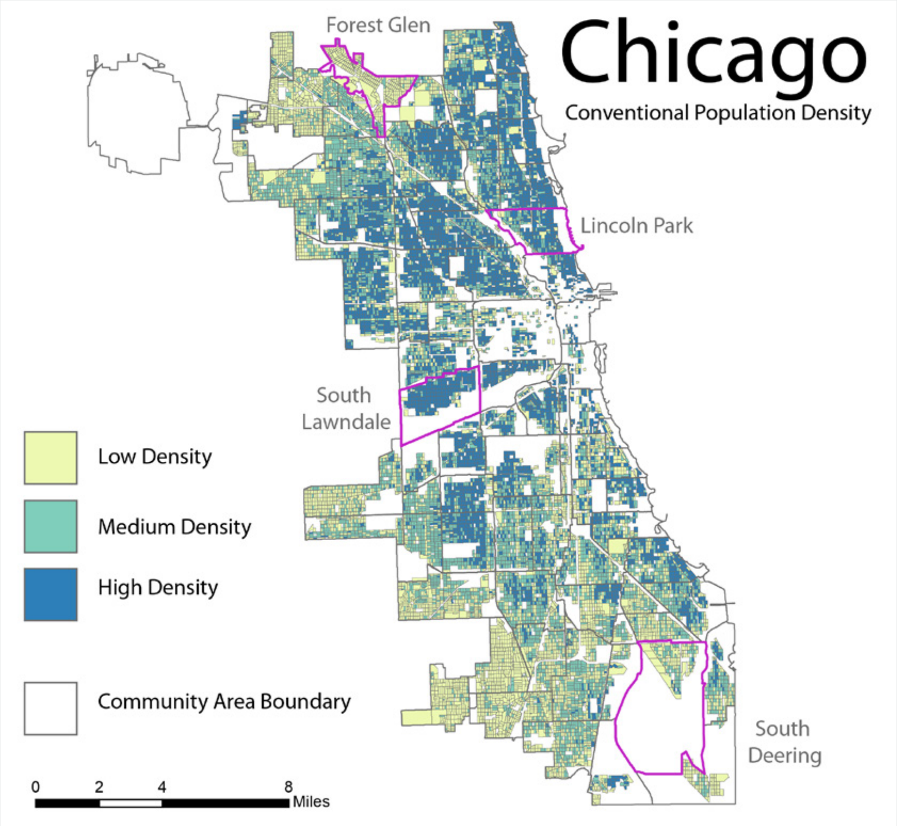

Figure 1: A choropleth map of conventional population density in Chicago at the census block geographic unit. Data provided by United States Census Bureau, Chicago Metro Agency of Planning, and the City of Chicago GIS Department.

on volumetric cartographies (Lwin and Murayama 2009), this paper introduces an alternative dasymetric approach called the building footprint technique.

THE VERTICAL CITY

Many previous micro-scale dasymetric map projects, especially those utilizing residential buildings to map detailed residential patterns, have been relatively small in scope. Chicago, with 2.7 million residents distributed across 17,665 census blocks residing in over 500,000 structures, is too large and complex for many of the established volumetric techniques. To understand the micro-scale human patterns over such a large spatial extent, a visualization technique is needed that is straightforward in approach but as conceptually robust as existing methods. Before delving into specific data and methodology, however, it is important to consider the ways in which Chicago illustrates the larger need for tools that expand our understanding of the verticality of contemporary cities.

First consider Figure 1, a choropleth population density map of Chicago. Four community areas are highlighted, two with predominately high-density census blocks (Lincoln Park and South Lawndale) and two with predominately low-density (Forest Glen and South Deering). This map suggests the community areas of Lincoln Park and South Lawndale, both consisting of primarily high-density census blocks, are similar or related to each other. Representing two places with the same symbol for one attribute suggests that they are similar in additional attributes not explicitly represented in the map (Crampton 2004). For example, two spaces shown as having equal rates of population density may also be assumed by readers to be similar in other community features, including social mobility, cultural identity, political affiliation, racial and ethnic distribution, and power structures (Lamont and Molnar 2002).

The fundamental limitation of the conventional population density metric is that it restricts populations to a flat two-dimensional space, neglecting the built verticality ubiquitous in contemporary cities. Figure 2, a photograph looking north along the lakeshore of Chicago, illustrates the vertical residential environment of the city and clearly demonstrates why new cartographies of population spaces are needed: disregarding the vertical spaces in visualizations of residential environments is quite problematic. Conversely, a photograph of the residential environment of South Lawndale (Figure 3) shows a residential environment with the same conventional density but a vastly different built environment and type of residential space. The contrast between the two images is striking; it is clear these two parts of Chicago have drastically different residential environments, yet conventional metrics imply that they are similar and likely related to each other. Jones et al. recognize the "widespread confusion over the relationship between vertically stratified scales and horizontally extensive spaces" (2007, 265) and how this asymmetrical relationship between the two axes influences conceptualizations of space. Simplifying the complex vertical spaces of contemporary cities down to the flatness of conventional techniques leads to incomplete comprehensions of urban spaces and inaccurate discernments between crowdedness and density. Verticality—how people occupy the built spaces above the ground—is an essential component in the host of ways materiality, imaginaries, experiences, and power intersect across the horizontal expanses of contemporary urban space (Graham and Hewitt 2012). The cartographic technique introduced in this paper contributes an alternative visualization to the growing theoretical conceptualizations of verticality in cities.

Chicago, in addition to geographic size, serves as the study area for this project due to the strong architectural tradition of vertical structures (Kaufman 1969), drastic socioeconomic delineations between neighborhoods (Rankin 2010), and widespread redevelopment initiatives geared at the recentralization of artistic, culturally-vibrant, upper middle class neighborhoods pervasive to many American

Figure 2: The view from the John Hancock Tower looking north along the Lake Michigan coast, including the community areas of Lakeview, Lincoln Park, and Uptown. The vertical residential structure of the city is evident in the apartment and condominium structures of this part of the city. Photo by author, 2011.

Figure 3: Row houses in South Lawndale, typical of many of the high-density community areas on the South Side and West Side of the city. The flat residential structures of this community area have similar population density rates to the vertical residential environments of the Near North, though the built environment is vastly different. Photo by author, 2011.

cities (Solnit and Schwartzenberg 2000; Ley 2003; Lees 2003; Lees et al. 2008; Slater et al. 2012). This verticality, neighborhood divisions, and changing urban spaces in Chicago allow for the drawing out of the distinct differences between density and crowdedness across the city.

The exclusion of vertical space in conventional techniques produces confusion between the metric of density and the experience of crowdedness. Altman (1975) describes crowdedness as an individual perception of higher social contact than desired. Gifford (2007) connects increasing population density rates with heightened negative social feelings of individual crowdedness. Social science literature has persistently confused density and crowdedness, equating increased population density with the loss of individual control (Jain 1987; Kaya and Erkip 2001; Yeh and Yuen 2011), feelings of aggression (Freedman et al. 1972; Novelli et al. 2010; Watve 2013), and social withdrawal (Sundstrom 1978; Winkel et al. 2009). Boyko and Cooper (2011) point out that the measurement of density is a nebulous spatial concept with various combinations of units, calculations, and metrics, depending on professional discipline and intended use. In contemporary cities, density should be conceptualized as external space density and personal space density (Yeh and Yuen 2011). People experience crowdedness through increases in personal space density, not through the increased vertical stratifications of individuals within an external unit. But much of the social science literature increasingly treats conventional conceptions of external space density and personal space crowdedness as synonymous and interchangeable terms.

The confusion of density and crowdedness has additional unintended consequences in the understanding of urban spaces. Research has shown that the contrast between spaciousness and crowdedness serves as a demarcation between radically different experiences of place (Tuan 1977), quality of life (Schmidt et al. 1979), and levels of personal satisfaction (Kearney 2006). The persistence of this confusion and the potential for misleading representations of people in space clearly illustrates an overarching need to parse out the different types of personal spaces that are included within greater conventional high-density or low-density zones. Conventional population density is not the same as crowdedness; rather crowdedness is the amount of personal space an individual has within the residential environment of a place relative to others within a similar socially-constructed boundary. For this project, I consider crowdedness in Chicago to be the amount of personal space an individual has within the home compared to people in the rest of Chicago.

THE PERSONAL SPACE METRIC

As illustrated above, the vertical residential environment of Chicago creates a spatial dimension not characterized by the flatness of conventional population density metrics. Residential buildings are both horizontally arranged and vertically stratified across the surface of the city, creating three-dimensional living spaces. The building footprint dasymetric technique presented in this research requires three inputs—census data, zoning codes, and building footprints with number of floors—to calculate the Personal Space Metric (PSM). This extension of

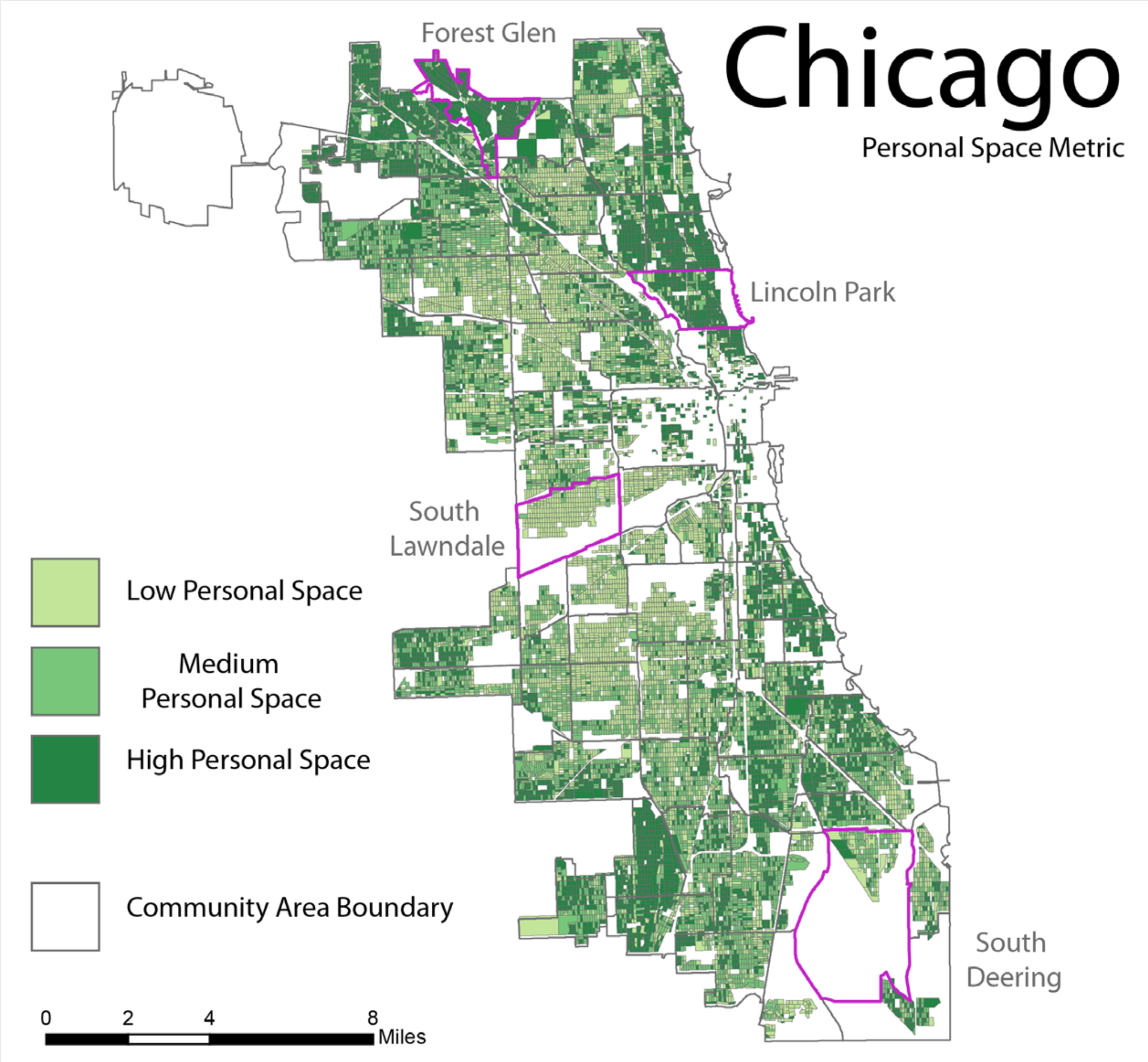

Figure 4: The PSM, a calculation of how much space each person has within the vertical residential environment of the city, shown at the census block level. Data source: United States Census Bureau, Chicago Metro Agency of Planning, and the City of Chicago GIS Department.

volumetric dasymetric cartographies provides a new technique for visualizing the amount of space each resident of Chicago has within the built residential environment of the city.

The first step in the building footprint technique is to separate residential from nonresidential structures throughout the city using a binary dasymetric approach. This method masks out all of the buildings in the city in which people do not live (Maantay et al. 2007) and allocates all residential buildings in the city as the places of residential suitability. Certainly it will miss a small percentage of the population living in non-residential buildings (residential motels, homeless, squatters, etc.), though it is unlikely this sector of the population was tabulated by the 2010 Census. Mixed-use buildings, with both commercial and residential zoning designations, add an additional layer of complexity to a traditional binary analysis. During this first step of the analysis, all mixed-use buildings are assigned as suitable residential living spaces. The limitations imposed by administrative demarcations are offset by assigning only specific buildings within the larger boundary areas as suitable living spaces.

The second step is to calculate the total available living space for each residential building using the product of the square footage of the building footprint and the number of stories of that building. While building datasets with this level of detail—provided for this research by the Chicago Metro Agency of Planning—are not universal, similar official datasets were easily found for the cities of Boston, New York, Washington, Portland, Denver, Seattle, San Francisco, Los Angeles and Minneapolis. As mentioned, mixed-use buildings add additional complexity to this approach. To this point, mixed-use and residential have been treated equally. To parse out the portion of a mixed-use building dedicated to residential housing, I utilized a model based on urban development simulation experiments, assigning 60% of the total space to residential and 40% to non-residential (Waddell et al. 2003; Waddell et al. 2007). Due to the degree of variation in the zoning of mixed-use and the fluidity of occupancy and ownership, the 60/40 estimator is appropriate for delineations between residential and non-residential (Talen 2006). As only 4.81% of the buildings in Chicago are zoned mixed-use, potential misrepresentations from this estimator are minimal over the extent of the city. At this point in the building footprint technique, each building in the city has a designation of residential suitability and a total available living space.

The final step is to populate the buildings with census data using a simple areal interpolation approach, which allows for the transformation of a source data set into a target data set (Langford et al. 1991; Goodchild et al. 1993; Mennis 2003. Though studies utilizing this approach are often criticized for assuming that population is homogeneously distributed across the target zone (Maantay et al. 2007), this limitation is overcome by the scale of our target data. The PSM technique does not delineate interior building spaces, treating each individual residential building in Chicago as a small homogeneous zone. The interpolation is straightforward: each building receives the percentage of the census block population equal to its percentage of total residential space within than same block. For example, if one building accounts for 25% of the total living space of a census block, 25% of the population is allocated to that specific building. Simple areal interpolation is a straightforward, computationally light approach that is suitable for this project based on the scale of the data and the extent of the study area.

The initial uncertainty in the development of the PSM was the inclusion of common spaces inherent to multi-family residential structures that vary by the design of each individual building. Step two in the building footprint technique calculates the total amount of floor space in each building. This total includes all common areas inside the building: hallways, laundry facilities, storage rooms, foyers, etc. During the third step, census totals are allocated to a total including this not-quite-residential space. As a result, a varying percentage of the PSM, depending on architectural design, is not explicitly individual space. With this approach, a boundary is effectively drawn separating personal and public spaces. Common spaces inside the building are a part of the PSM, common space outside the building is not, and is classified as public. This organization reveals a conceptual taxonomy of spaces in contemporary cities. In the urban environment, there are private, semi-private, semi-public, and public spaces. Private and semi-private are spaces within the residential structures. They are places removed from the public entanglements of social interaction (Blunt 2005), and are instead places of security (Tuan 1977), and of companionship (Tuan 2004a). Though much work done has been done on the ways the state intrudes into private spaces (Hyndman 2008; Dittmer and Dodds 2008), the emergence of technological surveillance (Chun 2006; Goodchild 2007; Elwood 2010), the redefining of privacy (Elwood and Leszczynski 2011), and the prominence of exclusionary architectural designs that work to blur the boundary between public and private life (Fincher 2004; Gandy 2005), there is a materiality to the idea that the inside/outside worlds drive fundamentally different social experiences. The private or home space "is a place that offers security, familiarity, and nurture" (Tuan 2004b, 164). By entering the interior of a multi-unit residential building—whether one is checking the mail, locking up a bike, or casually chatting with a neighbor on the way to the individual unit—a vital transformation in movements, experiences, and security between the exterior public and the interior personal occurs. Personal space is thus the coupling of private and semi-private spaces; while the semi-private spaces may not be explicitly residential, they are personal in nature.

The PSM provides an effective new visualization for overcoming the flatness of conventional population density and understanding the vertically-produced residential spaces in contemporary cities. The PSM classifies all public, semi-public, commercial, industrial, natural, and infrastructural spaces as non-residential and then allocates the entire city population into the personal spaces of the three-dimensional residential environment. This dasymetric approach moves beyond the planar cartographic imagination inherited from conventional political spatialities (Elden 2013) and builds upon the verticality of existing dasymetric techniques. The PSM facilitates new ways of rendering and understanding the dimensionality of the building space and population concentrations. Referring back to Figure 1, the community areas of Lincoln Park and South Lawndale appear to be similar, as both are high-density spaces. Accounting for the vertical residential environment, however, illustrates the fact that these two areas of Chicago have drastically different amounts of personal space (Figure 3). Similarly, the community areas of Forest Glen and South Deering, in the far north and south of the city respectively, have similar conventional population density rates but very different levels of personal space. With this map, questions begin to emerge of what socioeconomic and political factors produce personal spaces asymmetrically across a landscape.

The building footprint dasymetric technique calculates the amount of personal space each individual in the city has within each residential structure, recognizing the verticality of the urban landscape and circumventing the vertical space problem. It assigns every residential structure in the city an amount of personal space using three inputs: census data, zoning codes, building footprints. This approach is designed to be easily repeatable with accessible data and minimal computational expense across different geographies and scales.

A BIVARIATE POPULATION MAP OF CHICAGO

The primary goal of this research is to better understand how the flatness of conventional population density confuses visualizations of human settlement patterns in contemporary, vertical urban space. A bivariate classification with conventional population density on the y-axis and PSM on the x-axis was used to compare the two metrics. Each was classified into three quantiles, creating an index of high, medium, and low values across the extent of Chicago.

A quantile classification has three clear advantages for this project. First, census block units are roughly the same size and thus, each of the nine classifications in the bivariate population map will have roughly the same map area (Slocum et al. 2009). Similarly-sized population units allow for more insightful comparisons across the spaces of the city. Secondly, quantile classification is naturally suited for ordinal level data. The ranges of the data are easily separated into rankings of high, medium, and low density or personal space and juxtaposed with each other on a three by three bivariate grid. Finally, a quantile data classification allows for the range of the data in both variables to determine the class breakpoints. There is not an absolute threshold in which a place becomes crowded or spacious; crowdedness is deeply embedded in the individual experience of a person and the geographic context of the space (Tuan 1977). The ranges of population densities and personal spaces will vary drastically depending on place; perceptions of space in Chicago will certainly be different than those in other cities. What may be average in Chicago could be incredibly crowded in Denver or incredibly spacious in New York. A quantile data classification recognizes the fluidity of socially-constructed perceptions of crowdedness and allows for the range of the data within the analyzed city to drive the classification. High personal space in Chicago, for example, is classified as such by being in the upper third of the range of personal spaces available across the entire residential environment of Chicago.

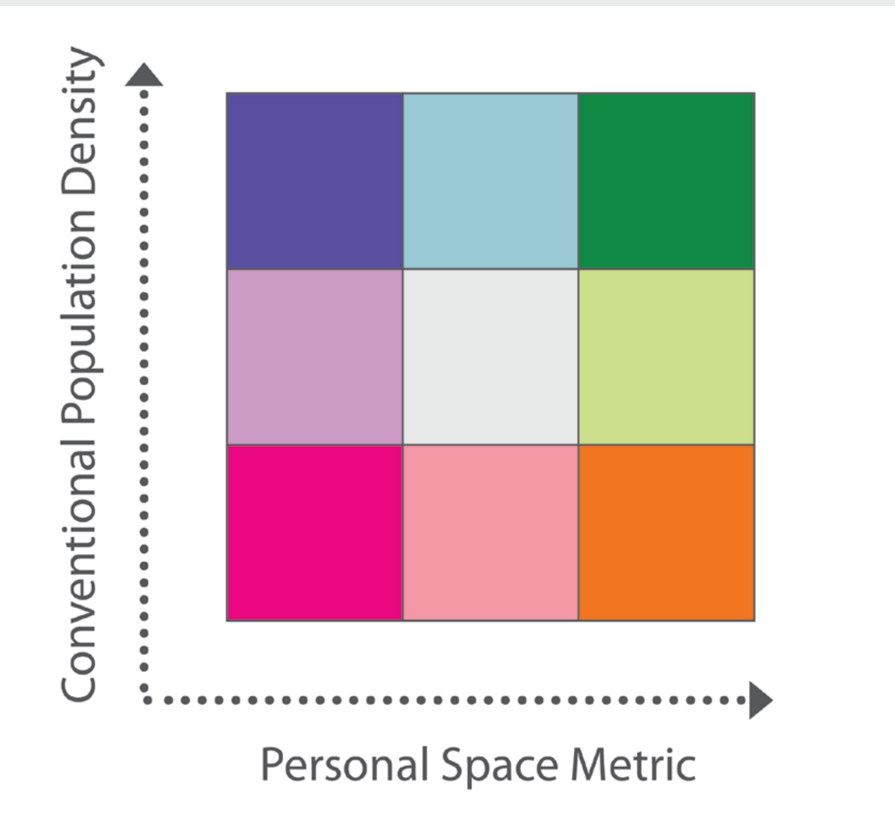

Figure 5: The bivariate legend illustrates the spaces where population density inaccurately characterizes the spaciousness or crowdedness of the residential environment. It uses a diverging color scheme on both axes to emphasize the corner classifications.

Combining the PSM and conventional population density on a three by three grid, symbolized with a diverging color scheme, highlights how the relationship of the two metrics unfolds over space (Brewer 1994). The diverging color scheme enables the high/low interactions of the two measurements to be emphasized in the four corners of the bivariate legend (Figure 5). The census blocks of Chicago with a low conventional population density and a low PSM are highlighted in pink, while those areas with a high conventional population density and a high PSM are shown in green. Illustrating the frequent confusion of high-density as crowded and low-density as spacious, the pink and the green classifications clearly highlight the places in Chicago where conventional population density does not capture an experience of crowded personal space.

Conversely, the other two corners of the legend, the purple upper left and the orange lower right, indicate the spaces where a conventional population density approach is a relatively accurate descriptor of personal spaces. Unfortunately, due to the overall complexity of urban housing environments, there is no clean taxonomy of neighborhood environments discretely falling into each of the nine classifications.

The four corners of the bivariate classification grid, however, illustrate strikingly different urban landscapes and significant spatial variations across the city of Chicago (Figure 6). The green classification, dominating the northeastern spaces of the city, is characterized by a vertical urban landscape with high-rise buildings and tightly-packed, redeveloped vertical living spaces. The purple classification indicates short, tightly-packed small urban homes and apartments on small properties, primarily in western Chicago. The orange classification denotes two distinctly different types of landscapes. The first is a suburban form with large houses on large plots of land along the northern and western edges of city; the second is one of emerging gentrification, unused commercial and industrial infrastructure being redeveloped into residential spaces in the center and near south of the city. Both types of spaces in the orange classification have relatively few people per census block and high personal space, but are drastically different types of built environments. The pink classification signifies a fragmented landscape,

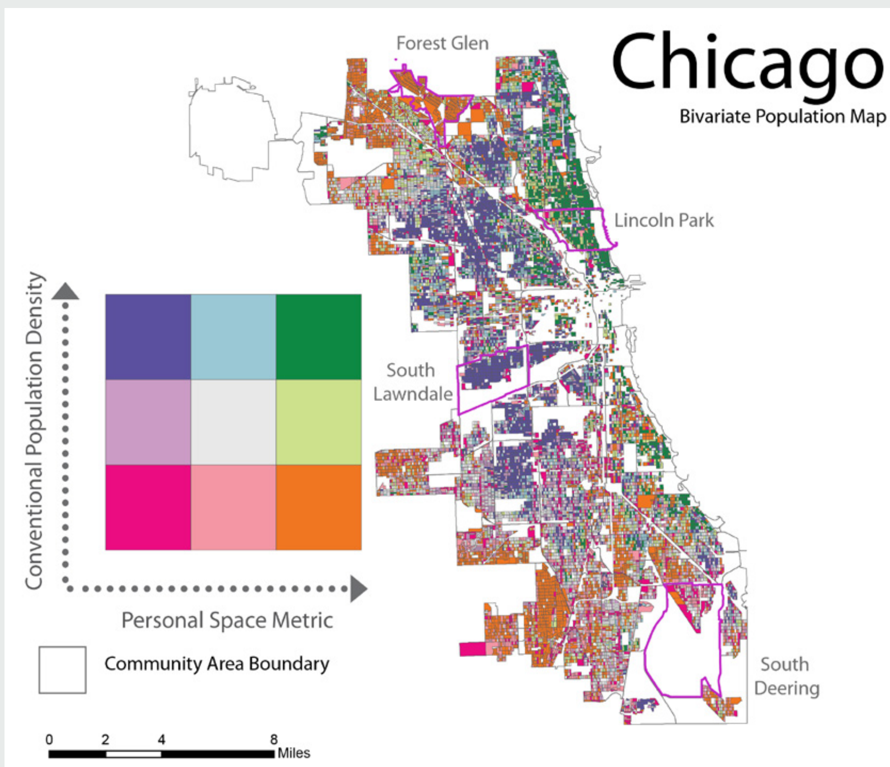

Figure 6: The bivariate map, at the census block geography, compares conventional population density and the PSM. The four corners of the legend employ higher saturation to highlight where the highs and lows of the two metrics intersect. Data source: United States Census Bureau, Chicago Metro Agency of Planning, and the City of Chicago GIS Department.

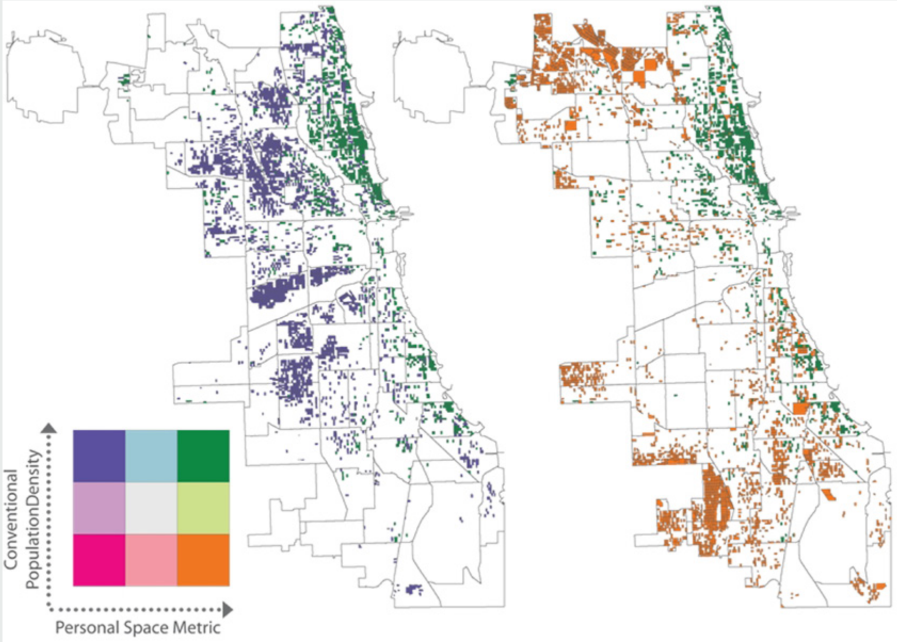

Figure 7: These maps show the green classification (high-density, high PSM) compared to the purple classification (high-density low PSM) on the left and the orange classification (low-density, high PSM) on the right. They clearly show the spatial variations in census blocks that share one of the two variables on the bivariate grid. Data source: United States Census Bureau, Chicago Metro Agency of Planning, and the City of Chicago GIS Department.

with small housing complexes surrounded by mostly industrial land uses. These four types of spaces illustrate the unique social, structural, and spatial residential patterns that are masked by the flatness of conventional population density.

Visualizing both the PSM and conventional population density in a single map highlights the regions of comparable value combinations (Olson 1981), and reveals the geographic variations of places which share of the two attributes (Monmonier 2006). In Figure 7, the green class (high PSM, high conventional population density) is the constant variable. In the left map, it is contrasted with the purple class. Both classes share the same conventional population density but are on opposite sides of the PSM spectrum. In the map on the right, the green class is contrasted with the orange class. Both share similar PSM values but are on opposite ends of the conventional population density range. Clearly there are significant spatial variations in census blocks sharing one of the two measures.

In theorizing about the production of urban spaces, Maciones and Parrillo argue that "people organize their daily lives and actions—whether cultural, economic, educational, or social—within constraints or opportunities of the built environment" (2004, 250). Indeed, the patterned relationship between the built environment, human experience, and representation is unevenly distributed across the city (McFarlane and Rutherford 2008). Emerging research on urban socioeconomic variability, governmentality, infrastructure, and human experience needs reimagined visualizations of population space to more carefully characterize human interaction with the urban environment. The approach outlined in this research calls to attention the verticality of cities and provides a unique visual alternative to move beyond the limitations and unintended consequences of conventional population density.

CONCLUSION

The flatness of conventional population density standardizes and characterizes space with metrics which facilitate comparative analysis between different geographies. Conventional cartographic approaches, however, fail to address confusions associated with the vertical space problem. Contemporary cities produce volumetric space in the form of discrete structures built vertically across the horizontal extent. The flatness of conventional methods propagates the vertical space problem through cartographic projects and affects representations in unpredictable ways. The building footprint dasymetric technique recognizes this verticality and provides an alternative approach and visualization technique which transcends the limitations of conventional population imaginaries and facilitates new vertical urban inquiry. The PSM, when juxtaposed with conventional population density, produces new cartographies of Chicago that illustrate the limitations of conventional population density for urban analytics and stressing the importance of developments in three-dimensional methods. Crowdedness is a socially-constructed experience that cannot be indiscriminately substituted with conventional geographic population density metrics. A personal space metric allows for greater insight into both where and how people live in the urban space. Recognizing the verticality of contemporary cities and visualizing unexplored residential spaces will lead to greater insights into the asymmetrical geopolitical, social, structural, and personal geographies of contemporary cities.

Both conventional population density and PSM tell a story about the geographic variations and similarities of spaces and places across the contemporary city. Neither metric can tell the whole story by itself; rather it is through the relationship of the metrics that we can begin to understand the interplay of spaciousness and crowdedness both inside and outside the home and its effect on the urban experience. Visualizing PSM and conventional population density simultaneously establishes a powerful distinction between crowdedness and density in the city space. Assumptions of crowdedness inferred solely from conventional population density are partial; there is a larger narrative of urban living spaces that can only be understood by shifting our fixation from the surface of the Earth upwards to the vertical structures that tower over us.

REFERENCES

Altman, I. 1975. *The Environment and Social Behavior*. Monterey, CA: Brooks/Cole.

Blunt, A. 2005. "Cultural Geography: Cultural Geographies of Home." *Progress in Human Geography* 29 (4): 505–515.

Boyko, C. and R. Cooper. 2011. "Clarifying and re-conceptualizing Density." *Progress in Planning* 76 (1): 1–61.

Brewer, C. 1994. "Color Use Guidelines for Mapping and Visualization." *Visualization in Modern Cartography* 2: 123–148.

Chen, K. 2002. "An Approach to Linking Remotely Sensed Data and Areal Census Data." *International Journal of Remote Sensing* 23 (1): 37–48.

Chun, W. 2006. *Control and Freedom: Power and Paranoia in the Age of Fiber Optics*. Cambridge, MA: MIT Press.

Crampton, J. 2004. "GIS and Geographic Governance: Reconstructing the Choropleth Map." *Cartographica* 39 (1): 41–53.

Dittmer, J. and K. Dodds. 2008. "Popular Geopolitics Past and Future: Fandom, Identities and Audiences." *Geopolitics* 13 (3): 437–457.

Eicher, C. and C. Brewer. 2001. "Dasymetric Mapping and Areal Interpolation: Implementation and Evaluation." *Cartography and Geographic Information Science* 28 (2): 125–138.

Elden, S. 2013. "Secure the Volume: Vertical Geopolitics and the Depth of Power." *Political Geography* 34: 35-51.

Elwood, S. 2010. "Geographic Information Science: Emerging Research on the Societal Implications of the Geospatial Web." *Progress in Human Geography* 34 (3): 349–357.

Elwood, S. and A. Leszczynski. 2011. "Privacy, Reconsidered: New Representations, Data Practices, and the Geoweb." *Geoforum* 42 (1): 6–15.

Fincher, R. 2004. "Gender and Life Course in the Narratives of Melbourne's High-rise Housing Developers." *Australian Geographical Studies* 42 (3): 325–338.

Flowerdew, R. and M. Green. 1994. "Areal Interpolation and Types of Data." In: S. Fotheringham and P. Rogerson (eds), *Spatial Analysis and GIS.* London: Taylor and Francis. 121-145.

Freedman, J., A. Levy, R. Buchanan, and J. Price. 1972. "Crowding and Human Aggressiveness." *Journal of Experimental Social Psychology* 8 (6): 528–548.

Gandy, M. 2005. "Cyborg Urbanization: Complexity and Monstrosity in the Contemporary City." *International Journal of Urban and Regional Research* 29 (1): 26–49.

Gifford, R. 2007. *Environmental Psychology: Principles and Practice*. Colville, WA: Optimal Books.

Goodchild, M. F., L. Anselin, and U. Deichmann. 1993. "A Framework for the Areal Interpolation of Socioeconomic Data." *Environment and Planning A* 25 (3): 383–397.

Goodchild, M. F. 2007. "Citizens as Sensors: The World of Volunteered Geography." *GeoJournal* 69 (4): 211–221.

Graham, S. and L. Hewitt. 2012. "Getting Off the Ground: On the Politics of Urban Verticality." *Progress in Human Geography*.

Holt, J. B., C. P. Lo, and T. W. Hodler. 2004. "Dasymetric Estimation of Population Density and Areal Interpolation of Census Data." *Cartography and Geographic Information Science* 31 (2): 103–121.

Hyndman, J. 2008. "Towards a Feminist Geopolitics." *The Canadian Geographer/Le Geógraphe Canadien* 45 (2): 210–222.

Jain, U. 1987. "Effects of Population Density and Resources on the Feeling of Crowding and Personal Space." *The Journal of Social Psychology* 127 (3): 331–338.

Jones, J. P., K. Woodward, and S. A. Marston. 2007. "Situating Flatness." *Transactions of the Institute of British Geographers* 32 (2): 264–276.

Kaufman, M. D. 1969. *Father of Skyscrapers: A Biography of Louis Sullivan*. New York: Little, Brown.

Kaya, N. and F. Erkip. 2001. "Satisfaction in a Dormitory Building the Effects of Floor Height on the Perception of Room Size and Crowding." *Environment and Behavior* 33 (1): 35–53.

Kearney, A. R. 2006. "Residential Development Patterns and Neighborhood Satisfaction Impacts of Density and Nearby Nature." *Environment and Behavior* 38 (1): 112–139.

Kern, L. 2007. "Reshaping the Boundaries of Public and Private Life: Gender, Condominium Development, and the Neoliberalization of Urban Living." *Urban Geography* 28 (7): 657–681.

Lamont, M. and F. Molnar. 2002. "The Study of Boundaries in the Social Sciences." *Annual Review of Sociology* 28: 167–195.

Langford, M. 2006. "Obtaining Population Estimates in Non-census Reporting Zones: An Evaluation of the 3-class Dasymetric Method." *Computers, Environment and Urban Systems* 30 (2): 161–180.

Langford, M., D. J. Maguire, and D. J. Unwin. 1991. "The Areal Interpolation Problem: Estimating Population Using Remote Sensing in a GIS Framework." In: I. Masser and M.B. Blakemore (eds), *Handling Geographical Information: Methodology and Potential Applications*: Essex, U.K.: Longman Scientific & Technical. 55–77.

Langford, M. and D. J. Unwin. 1994. "Generating and Mapping Population Density Surfaces within a Geographical Information System." *The Cartographic Journal* 31 (1): 21–26.

Lees, L. 2003. "Super-gentrification: The Case of Brooklyn Heights, New York City." *Urban Studies* 40 (12): 2487–2509.

Lees, L., T. Slater, and E. K. Wyly. 2008. *Gentrification*. New York: Routledge.

Ley, D. 2003. "Artists, Aestheticisation and the Field of Gentrification." *Urban Studies* 40 (12): 2527–2544.

Liu, X., K. Clarke, and M. Herold. 2006. "Population Density and Image Texture: A Comparison Study." *Photogrammetric Engineering and Remote Sensing* 72 (2): 187.

Lwin, K. K. and Y. Murayama. 2009. "A GIS Approach to Estimation of Building Population for Micro-spatial Analysis." *Transactions in GIS* 13 (4): 401–414.

———. 2011. "Estimation of Building Population from LIDAR Derived Digital Volume Model." *Spatial Analysis and Modeling in Geographical Transformation Process*: 87–98.

Maantay, J. A., A. R. Maroko, and C. Herrmann. 2007. "Mapping Population Distribution in the Urban Environment: The Cadastral-based Expert Dasymetric System (CEDS)." *Cartography and Geographic Information Science* 34 (2): 77–102.

Macionis, J. J. and V. N. Parrillo. 2004. *Cities and Urban Life*. New York: Pearson Education.

Martin, D. 2006. "Last of the Census? The Future of Small Area Population Data." *Transactions of the Institute of British Geographers* 31 (1): 6-18.

Martin, D., N. J. Tate, and M. Langford. 2000. "Refining Population Surface Models: Experiments with Northern Ireland Census Data." *Transactions in GIS* 4 (4): 343–360.

McFarlane, C. and J. Rutherford. 2008. "Political Infrastructures: Governing and Experiencing the Fabric of the City." *International Journal of Urban and Regional Research* 32 (2): 363–374.

Mennis, J. 2003. "Generating Surface Models of Population Using Dasymetric Mapping." *The Professional Geographer* 55 (1): 31–42.

———. 2009. "Dasymetric Mapping for Estimating Population in Small Areas." *Geography Compass* 3 (2): 727–745.

Monmonier, M. 2006. "Cartography: Uncertainty, Interventions, and Dynamic Display." *Progress in Human Geography* 30 (3): 373–381.

Novelli, D., J. Drury, and S. Reicher. 2010. "Come Together: Two Studies Concerning the Impact of Group Relations on Personal Space." *British Journal of Social Psychology* 49 (2): 223–236.

Olson, J. M. 1981. "Spectrally Encoded Two-variable Maps." *Annals of the Association of American Geographers* 71 (2): 259–276.

Openshaw, S. 1983. *The Modifiable Areal Unit Problem*. Vol. 38. Norwich, NY: Geo Books.

Petrov, A. N. 2008. "Setting the Record Straight: On the Russian Origins of Dasymetric Mapping." *Cartographica* 43 (2): 133–136.

Poulsen, E. and L. W. Kennedy. 2004. "Using Dasymetric Mapping for Spatially Aggregated Crime Data." *Journal of Quantitative Criminology* 20 (3): 243–262.

Rankin, W. 2010. "Cartography and the Reality of Boundaries." *Perspecta 42*, 42–45.

Reibel, M. and M. E. Bufalino. 2005. "Street-weighted Interpolation Techniques for Demographic Count Estimation in Incompatible Zone Systems." *Environment and Planning A* 37 (1): 127–139.

Schmidt, D. E., R. D. Goldman, and N. R. Feimer. 1979. "Perceptions of Crowding Predicting at the Residence, Neighborhood, and City Levels." *Environment and Behavior* 11 (1): 105–130.

Slater, T., W. Curran, and L. Lees. 2012. "Gentrification Research: New Directions and Critical Scholarship." *Environment and Planning A* 36 (7): 1141–1150.

Sleeter, R. 2004. "Dasymetric Mapping Techniques for the San Francisco Bay Region, California." In *Urban and Regional Information Systems Association Annual Conference Proceedings*, 7–10.

Slocum, T. A., R. B. McMaster, F. C. Kessler, and H. H. Howard. 2009. *Thematic Cartography and Geovisualization.* New Jersey. Prentice-Hall, Inc.

Solnit, R. and S. Schwartzenberg. 2000. *Hollow City: Gentrification and the Eviction of Urban Culture*. London: Verso.

Sundstrom, E. 1978. "Crowding as a Sequential Process: Review of Research on the Effects of Population Density on Humans." *Human Response to Crowding*: 31–116.

Talen, E. 2006. "Design for Diversity: Evaluating the Context of Socially Mixed Neighborhoods." *Journal of Urban Design* 11 (1): 1–32.

Tuan, Y. 1977. *Place and Space: The Perspective of Experience*. Minneapolis: University of Minnesota Press.

———. 2004a. "Cultural Geography: Glances Backward and Forward." *Annals of the Association of American Geographers*, *94*(4), 729–733.

———. 2004b. "Home." In S. Harrison and N. Thrift (eds), *Patterned Ground: The Entanglements of Nature and Culture*. London: Reaktion Books. 164-165.

"United Nations Population Division | Department of Economic and Social Affairs." 2013. Accessed February 8. **http://www.un.org/en/development/desa/population/**.

Ural, S., E. Hussain, and J. Shan. 2011. "Building Population Mapping with Aerial Imagery and GIS Data." *International Journal of Applied Earth Observation and Geoinformation* 13 (6): 841–852.

Waddell, P., A, Borning, M. Noth, N. Freier, M. Becke, and G. Ulfarsson. 2003. "Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim." *Networks and Spatial Economics* 3 (1): 43–67.

Waddell, P., F. Gudmundur, G. Ulfarsson, J. P. Franklin, and J. Lobb. 2007. "Incorporating Land Use in Metropolitan Transportation Planning." *Transportation Research Part A: Policy and Practice* 41 (5): 382–410.

Watve, M. 2013. "Why Population Density Matters." *Doves, Diplomats, and Diabetes: A Darwinian Interpretation of Type 2 Diabetes and Related Disorders*. New York: Springer. 185–202.

Winkel, G., S. Saegert, and G. W. Evans. 2009. "An Ecological Perspective on Theory, Methods, and Analysis in Environmental Psychology: Advances and Challenges." *Journal of Environmental Psychology* 29 (3): 318–328.

Wright, J. K. 1936. "A Method of Mapping Densities of Population: With Cape Cod as an Example." *Geographical Review* 26 (1): 103–110.

Yeh, A. and B. Yuen. 2011. "Tall Building Living in High-Density Cities: A Comparison of Hong Kong and Singapore." In A. Yeh and B. Yuen (eds) *High-Rise Living in Asian Cities*, 9–23. Amsterdam: Springer.