Title
How much are built environments changing, and where?: Patterns of change by neighborhood sociodemographic characteristics across seven U.S. metropolitan areas

Authors
Hirsch, Jana A
Grengs, Joe
Schulz, Amy
et al.

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How Much are Built Environments Changing, and Where?: Patterns of Change by Neighborhood Sociodemographic Characteristics across Seven U.S. Metropolitan Areas

Running Title: Patterns of Change in the Built Environment

Abstract:

Investments in neighborhood built environments could increase physical activity and overall health. Disproportionate distribution of these changes in advantaged neighborhoods could inflate health disparities. Little information exists on where changes are occurring. This paper aims to 1) identify changes in the built environment in neighborhoods and 2) investigate associations between high levels of change and sociodemographic characteristics. Using Geographic Information Systems, neighborhood land-use, local destinations (for walking, social engagement, and physical activity), and sociodemographics were characterized in 2000 and 2010 for seven U.S. cities. Linear and change on change models estimated associations of built environment changes with baseline (2000) and change (2010-2000) in sociodemographics. Spatial patterns were assessed using Global Moran's I to measure overall clustering of change and Local Moran's I to identify statistically significant clusters of high increases surrounded by high increases (HH). Sociodemographic characteristics were compared between HH cluster and other tracts using Analysis of Variance (ANOVA). We observed small land-use changes but increases in the destination types. Greater increases in destinations were associated with higher percentage non-Hispanic whites, percentage households with no vehicle, and median household income. Associations were present for both baseline sociodemographics and changes over time. Greater increases in destinations were associated with lower baseline percentage over 65 but higher increases in percentage over 65 between 2000 and 2010. Global Moran's indicated changes were spatially clustered. HH cluster tracts started with a higher percentage non-Hispanic whites and higher percentage of households without vehicles. Between 2000 and 2010, HH cluster tracts experienced increases in percent non-Hispanic white, greater increases in median household income, and larger decreases in percent of households without a vehicle. Changes in the built environment are occurring in neighborhoods across a diverse set of U.S. metropolitan areas, but are patterned such that they may lead to increased health disparities over time.

Research Highlights:

- Neighborhood destinations increased, potentially promoting walkable neighborhoods
- Change in destinations occurred in advantaged neighborhoods (e.g. white, wealthier)
- Neighborhoods experienced increases in both destinations and advantage
- Neighborhood built environment changes may increase health disparities over time

Keywords:

Built Environment; Geographic Information Systems (GIS); Health Equity; Neighborhoods; Longitudinal Studies; Residence Characteristics; Walkability

Introduction

Numerous reviews have documented associations of multiple attributes of the built environment, especially neighborhood walkability (defined by residential density, proximity of shops and services, and street connectivity) with active transport and physical activity (Bauman & Bull, 2007; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Gebel, Bauman, & Petticrew, 2007; Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Rossen & Pollack, 2012; Saelens & Handy, 2008; Transportation Research Board, 2005). Investments in the built environment may be an important point of intervention for increasing physical activity and health across broad populations. Specifically, longitudinal increases in destinations to walk to or be social at have been associated with increased walking (Hirsch, Moore, Clarke, et al., 2014), higher physical activity (Ranchod, Roux, Evenson, Sánchez, & Moore, 2013), and decreased obesity (Hirsch, Moore, Barrientos-Gutierrez, et al., 2014). Indeed, since the mid-1990s a number of scientific, political, and popular movements have emerged that support change in the built environment, including the National Complete Streets Coalition (http://www.completestreets.org/), Smart Growth America (http://www.smartgrowthamerica.org/), Transportation for America (http://t4america.org/), Robert Wood Johnson Active Living Research (http://www.activelivingresearch.org/), and Bikes Belong Coalition (http://www.bikesbelong.org/). In September 2015, the U.S. Surgeon General's Call to Action, "Step It Up," identified community design and the creation of walkable communities, where physical activity is not only easier but also more engaging, as a priority for preventing chronic disease (U.S. Department of Health and Human Services, 2015). However, little information exists on how built environments may be changing or the factors associated with these changes.

Since the creation of walkable communities entails modifications of large physical structures and neighborhood layouts, this process may take a long period of time. While some changes to built environment features, such as street networks and transportation systems, require large-scale infrastructure development occurring over numerous decades, other features, such as density of destinations (e.g. places to walk to, socialize at, or exercise in) and zoning of land-uses, may be more dynamic or amenable to change. As such, these more dynamic features may reflect recent efforts by communities to increase walkability. By examining which neighborhood built environment features have experienced change in recent decades, we may gain a better understanding of how our communities are transforming into more walkable neighborhoods. Additionally, understanding whether change is occurring is important to contextualize changes we may see in physical activity and health outcomes in upcoming years.

Furthermore, identifying where change is occurring will have important implications for health promotion. Specifically, knowing the sociodemographic characteristics of neighborhoods experiencing large improvements in the built environment will allow a better comprehension of the way the built environment might play into health equity. If changes in the built environment are not implemented equally, they may have large implications for health behavior and health disparities. Neighborhood sociodemographic characteristics may influence individual behavior through unequal distribution of physical environment characteristics (Cerin, Leslie, & Owen, 2009). Some evidence supports this hypothesis, indicating low-income and minority neighborhoods have worse aesthetics or safety (Giles-Corti & Donovan, 2002; Lovasi, Hutson, Guerra, & Neckerman, 2009; Sallis et al., 2011; Zhu & Lee, 2008), and fewer opportunities for physical activity (Abercrombie et al., 2008; Estabrooks, Lee, & Gyurcsik, 2003; Gordon-Larsen, Nelson, Page, & Popkin, 2006; Powell, Slater, Chaloupka, & Harper, 2006). Little is known about whether changes in the built environment are also associated with neighborhood sociodemographic characteristics. Such associations may contribute to either equalizing conditions across neighborhoods or to magnifying existing inequalities over time.

To provide critical knowledge of where and how the built environment is changing, this paper aims to 1) identify changes in the built environment in neighborhoods and 2) investigate associations between high levels of built environment change and sociodemographic characteristics. We describe changes in the built environment using zoned land-use codes and destinations between 2000 and 2010 in a sample of neighborhoods (n=8383 census tracts) from seven U.S. metropolitan areas. Using both linear models and spatial methods, we investigate whether baseline levels of, and changes in, four neighborhood sociodemographics (percent over 65, percent Non-Hispanic white, median household income, and percent without a vehicle) are associated with changes in the built environment.

Methods

Sample

Census tracts were used to delineate neighborhoods and study boundaries were drawn based on land-use data availability by county (Supplemental Figure S1). Census tracts were excluded if they were missing information on built environment or sociodemographic variables (n=164, 1.9%). The final sample consists of 8383 census tracts from seven U.S. metropolitan areas: Los Angeles, CA (n=3325); Chicago, IL (n=1798); Baltimore, MD (n=399); St. Paul, MN (n=685); Hinds County, MS (n=63); Forsyth County, NC (n=75); and New York, NY (n=2038). Census tract boundaries are delineated to capture a set of people, so they can vary in size by population density, resulting in different number of tracts by study area. Although census tract geographies are intended to remain stable over time, physical changes in street patterns or large population growth or decline occasionally require that they be redrawn; this study uses census tract geographies from 2000 to maintain uniform boundaries across time. This accounted for the fusion and assimilation of tracts over time and reduces the potential effect of geography errors on the findings of this study (Gotway & Young, 2002).

Built Environment Measures

Neighborhoods were characterized during the Multi-Ethnic Study of Atherosclerosis (MESA) (Bild et al., 2002) and Jackson Heart Study (JHS) (Taylor Jr et al., 2005) Neighborhood ancillary studies. Information on neighborhood environments was obtained from regional governments and national commercially available business listings and then linked to 2000 census tracts using Geographic Information Systems (GIS). The following built environment measures were investigated in these analyses: percent of land-use parcels zoned as retail, percent of land-use parcels zoned as residential, count of number of destinations for social engagement (e.g. entertainment, museums, political clubs, religious locations), count of number of walking destinations (e.g. post offices, drug stores, banks, food stores), and count of number of physical activity facilities (e.g. indoor conditioning).

The land-use zoned in individual parcels was obtained from various sources including local planning departments, city governments, and regional entities (e.g. Southern California Area Governance, SCAG, for Los Angeles, CA; Metro GIS for St. Paul, MN). While the coverage of these files varied by city (some only the city boundaries, some the county, and some the region), we used parcels so as not to have variation in resolution. Attempts were made to obtain land-use files for years 2000 and 2010. When these years were not available, data was assigned by taking information from the nearest time point. Two investigators trained in urban planning and geographic information systems independently classified parcels into two mostly mutually exclusive categories (retail and residential), based on the zoned land-use codes provided for each study area. The only parcels which fell in both categories were those zoned explicitly as mixed use with residential. Three additional investigators verified the classification and resolved disagreements. ArcGIS 10.1 (ESRI, Redlands, CA) was used to calculate the percent of each census tract area zoned for retail and residential use.

Measures of access to different destinations were created using data obtained from the National Establishment Time Series (NETS) database from Walls and Associates for the years 2000-2010 (Associates, 2013). While commercial business listings such as NETS have limitations for capturing destination data (Auchincloss, Moore, Moore, & Roux, 2012; Bader, Ailshire, Morenoff, & House, 2010; Boone, Gordon-Larsen, Stewart, & Popkin, 2008; Brownson, Hoehner, Day, Forsyth, & Sallis, 2009; Forsyth, Lytle, & Van Riper, 2010; Christine M Hoehner & Schootman, 2010; Liese et al., 2010; Powell et al., 2011), the benefits of this data, including its utility for deriving historic time-varying measures have been highlighted previously (Kaufman et al., 2015; Wang, Gonzalez, Ritchie, & Winkleby, 2006). We measured social, walking, and physical activity destinations due to strong previous longitudinal evidence of associations between these features and walking, physical activity, and obesity in six of our seven cities (Hirsch, Moore, Barrientos-Gutierrez, et al., 2014; Hirsch, Moore, Clarke, et al., 2014; Ranchod et al., 2013). Social destinations were derived from 430 Standard Industrial Classification (SIC) codes selected to represent locations that facilitate social interaction and promote social engagement based on previous work (C.M. Hoehner, Brennan Ramirez, Elliott, Handy, & Brownson, 2005). These SIC codes included destinations such as beauty shops and barbers, performance-based entertainment, participatory entertainment, stadiums, amusement parks and carnivals, membership sports and recreation clubs, libraries, museums, art galleries, zoos, aquariums, civil and political clubs, religious location, and dining places. Walking destinations were also classified based on previous criteria (C.M. Hoehner et al., 2005) with 137 SIC codes for common walking destinations, including post offices, drug stores and pharmacies, banks, food stores, coffee shops, and restaurants. For physical activity facilities, 114 SIC codes were selected to represent a variety of different indoor physical activity establishments such as indoor conditioning, dance, bowling, golf, team and racquet sports, and water activities derived from lists used in previous studies (Gordon-Larsen et al., 2006; Powell, Chaloupka, Slater, Johnston, & O'Malley, 2007). For both 2000 and 2010, raw counts of destinations per census tract were calculated using ArcGIS 10.1 and area-adjusted densities were calculated by dividing raw counts by census tract land area in hectares.

Neighborhood Sociodemographics

Sociodemographic data for each census tract were collected from the Census 2000. The American Community Survey (ACS) five-year estimates for 2005-2009 were used to represent year 2010, as some sociodemographic variables did not appear in the 2010 decennial census. Sociodemographic variables were selected *a priori* to reflect age structure, racial/ethnic composition, socioeconomic status and current walkability of the neighborhoods (as represented by car ownership). Percentage over 65 years of age was used to represent age structure while percentage non-Hispanic white and inflation-adjusted median household income were used to reflect racial/ethnic composition and socioeconomic status. Although education levels, employment, poverty, and home ownership may also be associated with changes in the built environment, these were highly correlated with census tract median household income and could not be included simultaneously in analyses. Percent of total occupied housing units with no vehicle was used as a proxy for neighborhoods that are already more walkable, as low car ownership may reflect locations that have more individuals using transportation options other than driving, particularly when household income is controlled for simultaneously.

Population counts for census tracts were measured using population data from the 2000 and 2010 decennial U.S. Census blocks and allocated by the 2000 census tract boundaries. When a 2010 block was not fully contained within a 2000 census tract, its population density was assumed to be uniform within each block and was assigned in direct proportion to the area of the block contained within the census tract.

Statistical Analyses

Descriptive statistics were calculated for all neighborhood built environment and sociodemographic variables in 2000, overall and by study area. Changes in neighborhood built environment and sociodemographic variables for each tract were calculated by subtracting 2000 data from 2010 values. We also performed sensitivity analyses that examined change in the destinations using data from all years (not shown).

Linear models accounting for population in 2000, land area in hectares, and study area were used to estimate the association between baseline levels of each sociodemographic variable in 2000 and change in built environment characteristics between 2000 and 2010. Linear models of change on change, equivalent to fixed effects models (Allison, 2005), were used to estimate associations of within-census tract change between 2000 and 2010 in each sociodemographic variable with within-census tract changes between 2000 and 2010 in the built environment. These models were adjusted only for change in population because they tightly control for time-invariant characteristics (i.e. land area and study area). The association between change in a sociodemographic characteristic and change in the built environment was allowed to vary by the starting level of that sociodemographic characteristic using interaction terms and all change on change models are presented at the mean level of baseline sociodemographic characteristics. For ease of interpretation across neighborhood characteristics, all results are shown for an interquartile range (IQR) difference so estimates represent a change from the 25th to the 75th percentile. Mutually adjusted models included all four sociodemographic characteristics together.

Area-adjusted change in the built environment was mapped and spatial patterns were assessed within each study area using a first-order, row-standardized, rook contiguity neighbor definition. We ran Global Moran's I to measure overall clustering of change within each city. We then ran Local Moran's I to identify statistically significant clusters of high increases surrounded by high increases (HH). We used a common approach to evaluating the statistical significance of the Local Moran's I, with p-values presented in our results. As previous work indicates, several limitations are inherent to this metric but require a level of sophisticated analysis that is beyond the scope of most applications to public health data (Waller & Gotway, 2004). Sociodemographic characteristics were compared between HH clusters and tracts that were not in these HH clusters (including tracts in low-low, high-low, and low-high clusters) using Analysis of Variance (ANOVA) or Kruskal-Wallis as appropriate.

All spatial analyses were performed using ArcGIS 10.1 and statistical analyses using SAS version 9.2 (SAS Institute, Inc., Cary, North Carolina).

Results

Built Environment and Neighborhood Sociodemographic Characteristics

The size of census tracts varied by study area, ranging from a median of 17.7 hectares in NY to 870.6 hectares in NC, with an average of 4340 people per tract (Table 1). Across all study areas, census tracts had an average of 19.2 destinations for social engagement, 12.2 walking destinations, and 1.3 physical activity facilities in 2000. The number of all destinations increased between 2000 and 2010. Destinations for social engagement increased the most: the mean increase was 10.5 locations per tract. At baseline, the mean percent of census tract area dedicated to residential uses was 47.2%, with a low of 34.5% in MS to a high of 57.5% in NC. In all areas except NY and IL, the area zoned for residential uses decreased over time, although the magnitude of the reduction differed by site. Retail uses in 2000 were less common with a mean 6.4% and ranging from 2.4% (NC) to 8.5% (IL). Changes between 2000-2010 in zoned land-use were of very small magnitude so predictors of change in land-uses were not investigated.

Across all study areas, census tracts had a mean of 11.1% over age 65, 45.3% non-Hispanic white, 22.7% with no vehicle, and median household income of $47,900 (Table 1).

Sociodemographics varied by study area with MD and NC having higher percent over 65, MS and NY having lower percent non-Hispanic white, NY having the highest percent of households without vehicles, MS having the lowest median household income, and MN having the highest median household income. Between 2000 and 2010 (represented by 2005-2009 ACS), mean percent over 65 increased by 0.4%, while mean percent non-Hispanic white decreased by 2.9% and mean percent without a vehicle decreased by 2.5%. Median household income, adjusted for inflation, increased by a mean of $3,300. Tracts in CA, MD and NY experienced increases, IL and MN remained approximately the same, and MS and NC experienced decreases.

Associations between Neighborhood Sociodemographic Characteristics and Change in the Built Environment

Census tract sociodemographic characteristics in 2000 were associated with changes over time in the built environment (Figure 1, see supplemental material, Table S1). Adjusting for all other sociodemographic factors, metropolitan area, land area and changes in population, tracts with a higher percentage non-Hispanic white in 2000 experienced greater increases in destinations for social engagement, smaller increases in walking destinations, and greater increases in physical activity facilities. Tracts with a higher median household income in 2000 experienced greater increases in destinations for social engagement and greater increases in physical activity facilities. Tracts with a higher percentage of households without a vehicle in 2000 experienced greater increases in destinations for social engagement, smaller increases in walking destinations, and greater increases in physical activity facilities. Tracts with a higher percentage over 65 in 2000 experienced smaller increases in walking destinations and physical activity facilities. Overall, associations with change in destinations between 2000 and 2010 were stronger for percentage non-Hispanic white and percentage of households without a vehicle in 2000 than for median household income and percentage over 65 in 2000.

Within-tract changes in sociodemographic characteristics between 2000 and 2010 were associated with within-tract changes in the built environment from 2000-2010 (Figure 2, see supplemental material, Table S2). At the mean level of each sociodemographic characteristic and after adjustment for changes in population density and all other sociodemographic factors, tracts with increases in percentage non-Hispanic white between 2000 and 2010 experienced greater increases in destinations for social engagement, walking destinations, and physical activity facilities. Tracts with increases in median household income between 2000 and 2010 experienced greater increases in destinations for social engagement and physical activity facilities. Tracts with increases in percentage of households without a vehicle between 2000 and 2010 experienced greater increases in destinations for social engagement, walking destinations, and physical activity facilities. Tracts with increases in percentage over 65 between 2000 and 2010 experienced greater increases in walking destinations. With the exception of walking destinations, associations with change in destinations between 2000 and 2010 were weaker for change in percentage over 65 than for change in percentage non-Hispanic white, percentage of households without a vehicle, and median household income. There was some evidence these associations were modified by starting levels of each sociodemographic characteristic, although patterns were inconsistent as to whether higher or lower initial levels were associated with greater changes (data not shown).

Spatial Clustering of Change in the Built Environment

Positive and highly significant Global Moran's I (ranging from 0.02 to 0.62) indicated changes were more spatially clustered within each study area than would be expected if underlying spatial processes were random (results not shown). Local Moran's I identified clusters of tracts with high changes in destinations (i.e. individual tracts with high increases in destinations bordered by other tracts with high increases, when compared to the other tracts in that study area). A total of 444 census tracts were in clusters of high increases in destinations for social engagement, 261 were in clusters of high change in walking destinations, and 372 were in high clusters of change in physical activity facilities (Table 2). Census tracts that experienced the highest increases in destinations between 2000 and 2010 and were surrounded by neighbors experiencing higher increases (HH), generally had higher percentage non-Hispanic whites and higher percentage of households without vehicles than other tracts in 2000 and experienced increases in percent non-Hispanic white (as opposed to decreases), greater increases in median household income, and larger decreases in percent of households without a vehicle than other tracts between 2000 and 2010. Percent over 65 was not generally different between clusters of high change and other tracts, with the exception that tracts in clusters of high increases in walking destinations and physical activity facilities had lower percentages over 65 in 2000 than tracts in other cluster types.

Discussion

The mean number of destinations for social engagement, walking, and physical activity all increased between 2000 and 2010 in a geographically diverse sample of U.S. metropolitan areas. Change also occurred in zoned land-use categories, although they were small in magnitude. Changes in the built environment were spatially clustered and patterned by sociodemographic characteristics. Neighborhood clusters experiencing greater change had higher percent non-Hispanic white residents, higher incomes and more households without vehicles at baseline. They also tended to show greater increase in non-Hispanic white residents and income over time.

In linear regression analyses, higher initial levels and changes in percent non-Hispanic White, median household income, and percent with no vehicle were positively associated with increases in destinations between 2000 and 2010. Higher initial levels of percent over 65 were associated with decreases in destinations between 2000 and 2010. However, increases in percent over 65 between 2000 and 2010 were associated with simultaneous increases in destinations.

This study is among the first in the U.S. to examine neighborhood changes in access to destinations and land-uses. As more effort is placed on influencing the walkability of neighborhoods, it is crucial that efforts are taken to benchmark and track whether and where changes are occurring. In addition, our observation of patterning by racial composition, socioeconomic status and vehicle ownership, suggests neighborhood change over time may exacerbate existing environmental and health disparities because the benefits associated with positive change in the built environment would be experienced largely by people who already enjoy health advantages.

Our findings for neighborhoods with high percentages of the population over 65 years of age may also have important implications for understanding the health of communities. As the American population ages, the environment may play an important role in maintaining independence, mobility, and the overall ability of older adults to age in place (Michael, Green, & Farquhar, 2006). Our results showed clusters of high levels of improvement in walking destinations have a lower percent over 65 than other types of clusters. Additionally, tracts with a higher percent over 65 in 2000 were associated with decreases in walking destinations, and physical activity facilities. This may restrict access to amenities for many older adults who remain in these neighborhoods. Close destinations may be important for combining walking into daily activities and for decreasing social isolation for older adults (Michael et al., 2006; Vine, Buys, & Aird, 2012). Conversely, increases in percent over 65 were associated with increases in all built environment measures. This may potentially be reflective of older adults moving to more walkable neighborhoods. This is consistent with qualitative research on relocation motives among older adults (Oswald, Schilling, Wahl, & Gäng, 2002) and neighborhood design's role in active aging (Day, 2008; Michael et al., 2006). Age-friendly urban design will become critical for older people to successfully age in the community and it is encouraging to see that locations experiencing higher increases in percent over 65 are experiencing higher increases in destinations. However, attention should be paid to locations with higher initial percent over 65 to ensure older adults who wish to age in place have the appropriate supports to stay in their current residential location.

Our cross-sectional findings are consistent with other evidence that shows white, high-income neighborhoods are already advantaged with regards to neighborhood features (Abercrombie et al., 2008; Estabrooks et al., 2003; Giles-Corti & Donovan, 2002; Gordon-Larsen et al., 2006; Lovasi et al., 2009; Moore, Diez Roux, Evenson, McGinn, & Brines, 2008; Powell et al., 2006; Sallis et al., 2011; Zhu & Lee, 2008) and may have additional economic and political power to create positive changes in the built environment (Schulz & Northridge, 2004). Thus, our findings may illustrate the additional leverage potential of neighborhoods with higher resources at baseline. If these neighborhoods experience additional increases in destinations or favorable land-use changes, disparities in health behaviors associated with the built environment will worsen rather than improve. Efforts to improve the built environment should work to identify resource-scarce neighborhoods and to involve low-income and communities of color to work towards a more even distribution of resources associated with physical activity.

One way in which communities have worked to improve their neighborhood environments is to implement a master plan for their community targeting improvements in physical activity. One study showed locations with master plans for non-motorized transportation have similar socioeconomic characteristics as the overall U.S., it also found the diversity index among communities with plans was lower than the U.S. average (Steinman et al., 2010). Similarly, research indicates residents of counties with lower-income levels and higher proportions of non-white residents were less likely to have attributes supportive of physical activity included in their plans (Aytur, Rodriguez, Evenson, Catellier, & Rosamond, 2008). Lack of a plan may lead to a lower likelihood of positive changes in the built environment to encourage walking and cycling. While we did not have information on master plans in this work, we did find census tracts experiencing greater increases in destinations also experienced increases in percent non-Hispanic white and median household income between 2000 and 2010.

In studying change, we observed variations in changes across study areas. One possible explanation for these differences is differing levels of engagement to change the built environment. Alternatively, they could be due to different levels of political power or variations in local resources since tax collection funds some of the walkability and land-use planning projects. However, external factors, such as the economic downturn of 2008, could also be driving change. Sensitivity analyses examining change in the destinations using data from all years show a dip in 2009 but a recovery in 2010. Similarly, population growth could contribute to changes in both land-use and destinations. Another observation was changes for destinations were much larger than changes in zoned land-uses. This is not surprising given the destinations used in this study consist largely of retail and commercial business establishments that tend to open and close, or change location, more frequently than governments change zoning regulations. While land-use codes are amenable to change, these changes include numerous stakeholders and may require longer periods of time than changes in destinations. Similarly, it may take decades for a change in land-use zoning to be implemented as a physical change.

One challenge with these findings is that, in spite of longitudinal data, we do not know whether sociodemographic change preceded neighborhood changes, whether alternate processes, such as gentrification, are occurring after neighborhood resources increase or a combination of these processes. High socioeconomic status individuals may move to an area and retail may follow this new base of patrons. Alternatively, these results are potentially consistent with common patterns of expansion at the metropolitan fringe of development. Areas on the edges of metropolitan areas tend to be less dense to begin with and thus have more “room to improve.” These more suburban rings are often predominantly white, middle-class neighborhoods. Ultimately, without on-the-ground knowledge of each census tract experiencing these changes, it is hard to discuss the complex processes underlying the change. In addition, while our results indicate changes in the built environment are patterned by neighborhood sociodemographic characteristics, the ultimate impact of these changes on health disparities depends on the extent to which these built environment features are associated with health behaviors and outcomes. As stated previously, the measures used in this study have been shown to be longitudinally associated with walking (Hirsch, Moore, Clarke, et al., 2014), physical activity (Ranchod et al., 2013), and obesity

(Hirsch, Moore, Barrientos-Gutierrez, et al., 2014) within these same cities. Furthermore, in these seven cities, we observed positive changes in these built environment measures. It is worth noting, however, negative changes may also occur in neighborhoods experiencing loss of businesses, removal or closure of parks, or lapses in maintenance of existing infrastructure to the paint of disrepair. Future work should attempt to examine some of these disinvestments.

Other limitations are related to the nature of the data. First, as mentioned briefly above, NETS data are imperfect. Although we processed data based on opening and closing dates to capture the establishments that may have been present at a given year, the sensitivity and specificity of these data have been shown to be low (Bader et al., 2010; Boone et al., 2008; Brownson et al., 2009; Forsyth et al., 2010; Christine M Hoehner & Schootman, 2010; Kaufman et al., 2015; Liese et al., 2010; Powell et al., 2011; Wang et al., 2006). Furthermore, the usefulness of this dataset is likely to vary by industry, year, and geographic location. This could lead to differential misclassifications and biased estimates, especially if these patterns are linked with neighborhood level sociodemographic characteristics. Most work examining these data compare sources but do not provide the necessary details on the way these errors may be patterned to say with certainty which direction the bias would occur in this study. However, given the necessity to derive time-varying measures of historical business information and that it would be cost-prohibitive to collect the same depth of information from multiple sources or field audits (which are also impossible for the historic aspect), we felt that NETS provided the most comprehensive source for this information. Second, due to changes in the data collected for decennial census, we use ACS 2005-2009 to estimate sociodemographic characteristics for 2010. These estimates are less precise and thus may include more measurement error or potential for bias (MacDonald, 2006).

In a crude sensitivity analyses using the errors associated with each ACS estimates, some results varied between the highest and lowest confidence intervals. In general, however, sensitivity results were similar in direction and significance but not magnitude (not shown). Census tracts may not accurately reflect salient or relevant neighborhood boundaries; using a different size or scale of aggregated area may result in different results (often known as the Modifiable Areal Unit Problem) (Flowerdew, Manley, & Sabel, 2008; Haynes, Daras, Reading, & Jones, 2007; Houston, 2014; Zhang & Kukadia, 2005). In addition, combining data from multiple spatial scales (e.g. parcels and tracts) may have the potential to influence findings (Gotway & Young, 2002). Use of other geographies or methods of combination should be explored in the future. Similarly, our analysis can only provide information at the neighborhood level; extrapolating to the individual level to say that a wealthy individual or a white individual has better changes in the built environment would be an ecologic fallacy. Furthermore, exclusion of tracts missing built environment or sociodemographic data (1.9%) may create artificial boundaries or non-adjacencies, which could influence our spatial analyses. Additionally, assignment of land-use to 2000 and 2010 by closest available data may miss some changes that occur, and the use of parcel area penalizes vertical development (e.g. treats a parcel with a multi-story building the same as a parcel with a one-story building). In addition, differences in the residence rules, such as who counts in a household, and reference periods (particularly for income) could have impacted comparability between ACS 5-year estimates and Census 2000. However, the U.S. Census Bureau “recommend[s] users compare derived measures such as percent,” as was done in this study (U.S. Census Bureau, 2013). Finally, changes in the built environment may take longer than ten years or may occur in small-scale design features that are difficult to measure across multiple study areas, such as crosswalks, bicycle lanes, and sidewalks. Alternatively, trends may be different for different time periods (period effect) and we were limited to only the 2000 to 2010 period. Thus, a future examination utilizing twenty or thirty years of data would enhance our understanding of relationships between neighborhood sociodemographic characteristics and built environment change and allow for sub-analyses of different time periods.

Conclusions

Evidence from this study suggests that in these seven U.S. metropolitan areas, destinations, potentially representing walkability, are increasing. This may indicate success of recent movements to improve the neighborhood environment and could have important implications toward the realization of policies to increase physical activity such as the U.S. Surgeon General's Call to Action, "Step It Up" (U.S. Department of Health and Human Services, 2015). However, the unequal distribution of changes across neighborhood sociodemographic characteristics suggests efforts to improve the built environment may have the unintended consequence of increasing health inequality by increasing opportunities for activity only in advantaged neighborhoods. Initiatives to improve the built environment should focus on currently disadvantaged neighborhoods in order to reduce environmental and health disparities. Continued attention needs to be paid to equity in policies to change the built environment to ensure changes do not have the unintended consequence of increased health disparities.

List of Abbreviations

ACS	American Community Survey
ANOVA	Analysis of Variance
GIS	Geographic Information Systems
HH	Statistically significant cluster of high increases surrounded by high increases
IQR	Interquartile Range
NETS	National Establishment Time Series

SIC Standard Industrial Classification

Competing Interests:

The authors have no financial or competing interests to disclose.

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Table 1: Mean built environment and sociodemographic characteristics of census tracts at baseline (2000) and mean change between 2000 and 2010 for the full sample and by study area

	Overall	**CA**	**IL**	**MD**	**MN**	**MS**	**NC**	**NY**
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
N	8383	3325	1798	399	685	63	75	2038
Land Area (hectares) (median (IQR)	115.6 (260.9)	156.6 (242.4)	142.9 (329.9)	140.6 (205.4)	339.7 (534.6)	410.5 (832.5)	870.6 (1912.0)	17.7 (7.9)
Baseline (2000)								
Destinations								
Social Engagement (count)	19.2 (20.7)	21.5 (22.4)	18.4 (16.9)	18.8 (19.4)	16.6 (14.7)	26.3 (18.1)	26.9 (14.7)	16.6 (22.4)
Walking (count)	12.2 (14.7)	13.5 (14.9)	10.9 (12.4)	10.8 (14.1)	9.2 (11.7)	13.0 (11.8)	13.3 (11.7)	12.6 (16.9)
Physical Activity Facilities (count)	1.3 (1.9)	1.5 (2.0)	1.3 (1.8)	1.1 (1.5)	1.6 (1.7)	1.0 (1.2)	1.8 (1.8)	0.7 (1.7)
Zoned Land-Uses								
Percent Retail	6.4 (7.1)	5.2 (5.8)	8.5 (8.2)	8.2 (10.7)	5.2 (6.8)	2.5 (2.9)	2.4 (2.8)	6.6 (6.9)
Percent Residential	47.2 (21.1)	43.2 (19.7)	54.8 (23.8)	54.8 (25.1)	49.0 (23.0)	34.5 (15.5)	57.5 (17.8)	44.9 (16.7)
Sociodemographics								
Total Population	4340.2 (2344.6)	4883.4 (2193.2)	4454.4 (2676.6)	3505.0 (1595.5)	3853.8 (1498.4)	3981.0 (1918.5)	4080.9 (1654.3)	3700.7 (2421.1)
Percent over 65	11.1 (6.8)	10.5 (7.3)	11.0 (6.0)	14.4 (6.9)	10.0 (6.4)	11.4 (4.8)	13.3 (5.2)	11.9 (6.3)
Percent non-Hispanic white	45.3 (33.5)	40.3 (28.9)	51.4 (35.2)	53.9 (37.0)	81.5 (20.3)	33.7 (31.9)	62.3 (31.5)	33.9 (32.0)
Median Household Income (1000 USD)	47.9 (23.3)	49.9 (24.2)	51.6 (25.1)	42.3 (20.6)	55.8 (20.0)	32.9 (15.8)	42.2 (17.7)	40.4 (19.5)
Percent without a vehicle	22.7 (23.4)	10.7 (10.6)	17.6 (16.9)	23.5 (21.0)	9.1 (10.5)	12.5 (10.5)	11.3 (13.0)	51.8 (22.6)
Change (2010 level -2000 level)								
Destinations								
Social Engagement (count)	10.5 (15.6)	12.8 (18.4)	7.3 (12.5)	10.2 (11.1)	6.5 (8.0)	9.7 (10.1)	12.8 (11.2)	10.8 (15.3)
Walking (count)	1.6 (4.9)	1.4 (5.0)	0.8 (4.7)	0.1 (3.8)	0.8 (4.1)	-0.7 (4.8)	2.4 (5.2)	3.2 (5.2)
Physical Activity Facilities (count)	0.9 (2.0)	1.1 (2.2)	0.8 (1.9)	0.7 (1.4)	1.1 (2.1)	0.6 (1.3)	1.1 (1.8)	0.8 (1.6)
Zoned Land-Uses								
Percent Retail	-0.4 (4.1)	0.3 (2.8)	0.0 (1.5)	-7.3 (9.6)	-4.4 (6.4)	-0.0 (1.1)	-0.1 (1.1)	1.0 (2.2)
Percent Residential	-0.3 (7.1)	-1.5 (5.2)	0.6 (2.7)	-0.3 (11.9)	-3.1 (17.2)	-0.9 (6.1)	-12.9 (8.6)	2.2 (2.7)
Sociodemographics								
Total Population	247.4 (1511.4)	444.4 (1924.5)	120.5 (1581.7)	57.4 (717.6)	302.9 (1076.1)	-87.6 (883.9)	595.9 (1014.0)	54.0 (683.4)
Percent over 65	0.4 (3.7)	0.6 (3.1)	0.1 (4.1)	-0.8 (4.2)	0.7 (3.1)	-0.3 (2.9)	0.0 (0.0)	0.4 (4.1)
Percent non-Hispanic white	-2.9 (8.4)	-4.1 (7.1)	-3.1 (9.4)	-3.9 (7.7)	-4.1 (7.2)	-7.7 (11.7)	0.0 (2.9)	-0.1 (9.1)
Median Household Income (1000 USD)	3.3 (10.6)	4.2 (9.2)	0.7 (12.1)	3.8 (8.5)	0.1 (7.3)	-2.2 (4.9)	-1.6 (6.6)	5.5 (11.9)
Percent without a vehicle	-2.5 (7.7)	-2.8 (5.3)	-2.4 (9.2)	-3.8 (8.1)	-0.8 (4.5)	-1.1 (5.0)	-1.3 (3.5)	-2.5 (10.1)

Table 2: Comparison of sociodemographic characteristics between census tracts in clusters of high built environment change (identified using Local Moran's I) and other neighborhoods

	Social Destinations (Area Adjusted)			Walking Destinations (Area Adjusted)			Physical Activity Destinations (Area Adjusted)		
	HH	**Other**	**p-value**	**HH**	**Other**	**p-value**	**HH**	**Other**	**p-value**
N	444	7939		261	8122		372	8011	
Baseline (2000)									
Percent over 65	11.0 (6.3)	11.1 (6.8)	0.6193	8.0 (4.1)	11.2 (6.8)	<0.0001	10.4 (6.0)	11.1 (6.8)	0.0280
Percent non-Hispanic white	54.9 (29.3)	44.8 (33.7)	<0.0001	21.3 (25.1)	46.1 (33.5)	<0.0001	56.2 (27.8)	44.8 (33.7)	<0.0001
Median Household Income (1000 USD)	47.6 (27.7)	47.9 (23.1)	0.0788	28.9 (14.0)	48.5 (23.3)	<0.0001	49.1 (24.1)	47.8 (23.3)	0.1614
Percent without a vehicle	41.1 (27.9)	21.6 (22.7)	<0.0001	51.2 (25.6)	21.8 (22.8)	<0.0001	41.2 (28.9)	21.8 (22.8)	<0.0001
Change (2000 to 2010)									
Percent over 65	0.2 (3.9)	0.4 (3.7)	0.2816	0.2 (3.8)	0.4 (3.7)	0.6146	0.0 (3.4)	0.4 (3.7)	0.1035
Percent non-Hispanic white	2.7 (7.6)	-3.2 (8.3)	<0.0001	2.6 (6.6)	-3.1 (8.4)	<0.0001	3.2 (8.4)	-3.2 (8.3)	<0.0001
Median Household Income (1000 USD)	8.2 (13.5)	3.0 (10.3)	<0.0001	5.3 (8.9)	3.2 (10.6)	0.0002	9.5 (12.5)	3.0 (10.4)	<0.0001
Percent without a vehicle	-3.6 (9.1)	-2.4 (7.6)	0.0015	-4.5 (7.9)	-2.4 (7.7)	<0.0001	-3.2 (8.7)	-2.5 (7.6)	0.0854

HH=Neighborhoods (census tracts) with high values clustered with tracts with high values; Other includes: LL (Tracts with low values clustered with tracts with low values), HL/LH (discordant tracts with high values surrounded by tracts with low values or tracts with low values surrounded by tracts with high values) and NS (Not statistically significant, not in a cluster).
P-values from Analysis of Variance (ANOVA) or Wilcoxon Two-Sample Test (for Median Household Income)

Figure 1: Mean differences in change in the built environment between 2000 and 2010 associated with census tract characteristics in 2000 (estimates correspond to the mean difference in 2010-2000 change for an IQR difference of the characteristic in 2000).

Figure 2: Mean differences in change in the built environment between 2000 and 2010 associated with increases in census tract characteristics between 2000 and 2010 (estimates correspond to the mean difference in 2010-2000 change for an IQR 2010-2000 increase of the characteristic). Results displayed at the mean baseline level of each characteristic.