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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

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1How Much are Built Environments Changing, and Where?: Patterns of Change by 2Neighborhood Sociodemographic Characteristics across Seven U.S. Metropolitan Areas

3**Running Title:** Patterns of Change in the Built Environment

4**Abstract:**

5Investments in neighborhood built environments could increase physical activity and overall
6health. Disproportionate distribution of these changes in advantaged neighborhoods could inflate
7health disparities. Little information exists on where changes are occurring. This paper aims to 1)
8identify changes in the built environment in neighborhoods and 2) investigate associations
9between high levels of change and sociodemographic characteristics. Using Geographic
10Information Systems, neighborhood land-use, local destinations (for walking, social engagement,
11and physical activity), and sociodemographics were characterized in 2000 and 2010 for seven
12U.S. cities. Linear and change on change models estimated associations of built environment
13changes with baseline (2000) and change (2010-2000) in sociodemographics. Spatial patterns
14were assessed using Global Moran's I to measure overall clustering of change and Local Moran's
15I to identify statistically significant clusters of high increases surrounded by high increases (HH).
16Sociodemographic characteristics were compared between HH cluster and other tracts using
17Analysis of Variance (ANOVA). We observed small land-use changes but increases in the
18destination types. Greater increases in destinations were associated with higher percentage non-
19Hispanic whites, percentage households with no vehicle, and median household income.
20Associations were present for both baseline sociodemographics and changes over time. Greater
21increases in destinations were associated with lower baseline percentage over 65 but higher
22increases in percentage over 65 between 2000 and 2010. Global Moran's indicated changes were
23spatially clustered. HH cluster tracts started with a higher percentage non-Hispanic whites and
24higher percentage of households without vehicles. Between 2000 and 2010, HH cluster tracts
25experienced increases in percent non-Hispanic white, greater increases in median household
26income, and larger decreases in percent of households without a vehicle. Changes in the built
27environment are occurring in neighborhoods across a diverse set of U.S. metropolitan areas, but
28are patterned such that they may lead to increased health disparities over time.

29**Research Highlights:**

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

34**Keywords:**

35Built Environment; Geographic Information Systems (GIS); Health Equity; Neighborhoods;
36Longitudinal Studies; Residence Characteristics; Walkability

37

38Introduction

39Numerous reviews have documented associations of multiple attributes of the built environment,
40especially neighborhood walkability (defined by residential density, proximity of shops and
41services, and street connectivity) with active transport and physical activity (Bauman & Bull,
422007; Frank, Schmid, Sallis, Chapman, & Saelens, 2005; Gebel, Bauman, & Petticrew, 2007;
43Owen, Humpel, Leslie, Bauman, & Sallis, 2004; Rossen & Pollack, 2012; Saelens & Handy,
442008; Transportation Research Board, 2005). Investments in the built environment may be an
45important point of intervention for increasing physical activity and health across broad
46populations. Specifically, longitudinal increases in destinations to walk to or be social at have
47been associated with increased walking (Hirsch, Moore, Clarke, et al., 2014), higher physical
48activity (Ranchod, Roux, Evenson, Sánchez, & Moore, 2013), and decreased obesity (Hirsch,
49Moore, Barrientos-Gutierrez, et al., 2014). Indeed, since the mid-1990s a number of scientific,
50political, and popular movements have emerged that support change in the built environment,
51including the National Complete Streets Coalition (<http://www.completestreets.org/>), Smart
52Growth America (<http://www.smartgrowthamerica.org/>), Transportation for America
53(<http://t4america.org/>), Robert Wood Johnson Active Living Research
54(<http://www.activelivingresearch.org/>), and Bikes Belong Coalition
55(<http://www.bikesbelong.org/>). In September 2015, the U.S. Surgeon General’s Call to Action,
56“Step It Up,” identified community design and the creation of walkable communities, where
57physical activity is not only easier but also more engaging, as a priority for preventing chronic
58disease (U.S. Department of Health and Human Services, 2015). However, little information
59exists on how built environments may be changing or the factors associated with these changes.

60

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

72

73 Furthermore, identifying where change is occurring will have important implications for health
74 promotion. Specifically, knowing the sociodemographic characteristics of neighborhoods
75 experiencing large improvements in the built environment will allow a better comprehension of
76 the way the built environment might play into health equity. If changes in the built environment
77 are not implemented equally, they may have large implications for health behavior and health
78 disparities. Neighborhood sociodemographic characteristics may influence individual behavior
79 through unequal distribution of physical environment characteristics (Cerin, Leslie, & Owen,
80 2009). Some evidence supports this hypothesis, indicating low-income and minority
81 neighborhoods have worse aesthetics or safety (Giles-Corti & Donovan, 2002; Lovasi, Hutson,
82 Guerra, & Neckerman, 2009; Sallis et al., 2011; Zhu & Lee, 2008), and fewer opportunities for
83 physical activity (Abercrombie et al., 2008; Estabrooks, Lee, & Gyurcsik, 2003; Gordon-Larsen,

84 Nelson, Page, & Popkin, 2006; Powell, Slater, Chaloupka, & Harper, 2006). Little is known
85 about whether changes in the built environment are also associated with neighborhood
86 sociodemographic characteristics. Such associations may contribute to either equalizing
87 conditions across neighborhoods or to magnifying existing inequalities over time.

88

89 To provide critical knowledge of where and how the built environment is changing, this paper
90 aims to 1) identify changes in the built environment in neighborhoods and 2) investigate
91 associations between high levels of built environment change and sociodemographic
92 characteristics. We describe changes in the built environment using zoned land-use codes and
93 destinations between 2000 and 2010 in a sample of neighborhoods (n=8383 census tracts) from
94 seven U.S. metropolitan areas. Using both linear models and spatial methods, we investigate
95 whether baseline levels of, and changes in, four neighborhood sociodemographics (percent over
96 65, percent Non-Hispanic white, median household income, and percent without a vehicle) are
97 associated with changes in the built environment.

98

99 **Methods**

100 ***Sample***

101 Census tracts were used to delineate neighborhoods and study boundaries were drawn based on
102 land-use data availability by county (Supplemental Figure S1). Census tracts were excluded if
103 they were missing information on built environment or sociodemographic variables (n=164,
104 1.9%). The final sample consists of 8383 census tracts from seven U.S. metropolitan areas: Los
105 Angeles, CA (n=3325); Chicago, IL (n=1798); Baltimore, MD (n=399); St. Paul, MN (n=685);
106 Hinds County, MS (n=63); Forsyth County, NC (n=75); and New York, NY (n=2038). Census

107tract boundaries are delineated to capture a set of people, so they can vary in size by population
108density, resulting in different number of tracts by study area. Although census tract geographies
109are intended to remain stable over time, physical changes in street patterns or large population
110growth or decline occasionally require that they be redrawn; this study uses census tract
111geographies from 2000 to maintain uniform boundaries across time. This accounted for the
112fusion and assimilation of tracts over time and reduces the potential effect of geography errors on
113the findings of this study (Gotway & Young, 2002).

114

115***Built Environment Measures***

116Neighborhoods were characterized during the Multi-Ethnic Study of Atherosclerosis (MESA)
117(Bild et al., 2002) and Jackson Heart Study (JHS) (Taylor Jr et al., 2005) Neighborhood ancillary
118studies. Information on neighborhood environments was obtained from regional governments
119and national commercially available business listings and then linked to 2000 census tracts using
120Geographic Information Systems (GIS). The following built environment measures were
121investigated in these analyses: percent of land-use parcels zoned as retail, percent of land-use
122parcels zoned as residential, count of number of destinations for social engagement (e.g.
123entertainment, museums, political clubs, religious locations), count of number of walking
124destinations (e.g. post offices, drug stores, banks, food stores), and count of number of physical
125activity facilities (e.g. indoor conditioning).

126

127The land-use zoned in individual parcels was obtained from various sources including local
128planning departments, city governments, and regional entities (e.g. Southern California Area
129Governance, SCAG, for Los Angeles, CA; Metro GIS for St. Paul, MN). While the coverage of

130these files varied by city (some only the city boundaries, some the county, and some the region),
131we used parcels so as not to have variation in resolution. Attempts were made to obtain land-use
132files for years 2000 and 2010. When these years were not available, data was assigned by taking
133information from the nearest time point. Two investigators trained in urban planning and
134geographic information systems independently classified parcels into two mostly mutually
135exclusive categories (retail and residential), based on the zoned land-use codes provided for each
136study area. The only parcels which fell in both categories were those zoned explicitly as mixed
137use with residential. Three additional investigators verified the classification and resolved
138disagreements. ArcGIS 10.1 (ESRI, Redlands, CA) was used to calculate the percent of each
139census tract area zoned for retail and residential use.

140

141Measures of access to different destinations were created using data obtained from the National
142Establishment Time Series (NETS) database from Walls and Associates for the years 2000-2010
143(Associates, 2013). While commercial business listings such as NETS have limitations for
144capturing destination data (Auchincloss, Moore, Moore, & Roux, 2012; Bader, Ailshire,
145Morenoff, & House, 2010; Boone, Gordon-Larsen, Stewart, & Popkin, 2008; Brownson,
146Hoehner, Day, Forsyth, & Sallis, 2009; Forsyth, Lytle, & Van Riper, 2010; Christine M Hoehner
147& Schootman, 2010; Liese et al., 2010; Powell et al., 2011), the benefits of this data, including
148its utility for deriving historic time-varying measures have been highlighted previously
149(Kaufman et al., 2015; Wang, Gonzalez, Ritchie, & Winkleby, 2006). We measured social,
150walking, and physical activity destinations due to strong previous longitudinal evidence of
151associations between these features and walking, physical activity, and obesity in six of our
152seven cities (Hirsch, Moore, Barrientos-Gutierrez, et al., 2014; Hirsch, Moore, Clarke, et al.,

1532014; Ranchod et al., 2013). Social destinations were derived from 430 Standard Industrial
154Classification (SIC) codes selected to represent locations that facilitate social interaction and
155promote social engagement based on previous work (C.M. Hoehner, Brennan Ramirez, Elliott,
156Handy, & Brownson, 2005). These SIC codes included destinations such as beauty shops and
157barbers, performance-based entertainment, participatory entertainment, stadiums, amusement
158parks and carnivals, membership sports and recreation clubs, libraries, museums, art galleries,
159zoos, aquariums, civil and political clubs, religious location, and dining places. Walking
160destinations were also classified based on previous criteria (C.M. Hoehner et al., 2005) with 137
161SIC codes for common walking destinations, including post offices, drug stores and pharmacies,
162banks, food stores, coffee shops, and restaurants. For physical activity facilities, 114 SIC codes
163were selected to represent a variety of different indoor physical activity establishments such as
164indoor conditioning, dance, bowling, golf, team and racquet sports, and water activities derived
165from lists used in previous studies (Gordon-Larsen et al., 2006; Powell, Chaloupka, Slater,
166Johnston, & O'Malley, 2007). For both 2000 and 2010, raw counts of destinations per census
167tract were calculated using ArcGIS 10.1 and area-adjusted densities were calculated by dividing
168raw counts by census tract land area in hectares.

169

170 ***Neighborhood Sociodemographics***

171 Sociodemographic data for each census tract were collected from the Census 2000. The
172 American Community Survey (ACS) five-year estimates for 2005-2009 were used to represent
173 year 2010, as some sociodemographic variables did not appear in the 2010 decennial census.
174 Sociodemographic variables were selected *a priori* to reflect age structure, racial/ethnic
175 composition, socioeconomic status and current walkability of the neighborhoods (as represented

176by car ownership). Percentage over 65 years of age was used to represent age structure while
177percentage non-Hispanic white and inflation-adjusted median household income were used to
178reflect racial/ethnic composition and socioeconomic status. Although education levels,
179employment, poverty, and home ownership may also be associated with changes in the built
180environment, these were highly correlated with census tract median household income and could
181not be included simultaneously in analyses. Percent of total occupied housing units with no
182vehicle was used as a proxy for neighborhoods that are already more walkable, as low car
183ownership may reflect locations that have more individuals using transportation options other
184than driving, particularly when household income is controlled for simultaneously.

185

186Population counts for census tracts were measured using population data from the 2000 and 2010
187decennial U.S. Census blocks and allocated by the 2000 census tract boundaries. When a 2010
188block was not fully contained within a 2000 census tract, its population density was assumed to
189be uniform within each block and was assigned in direct proportion to the area of the block
190contained within the census tract.

191

192*Statistical Analyses*

193Descriptive statistics were calculated for all neighborhood built environment and
194sociodemographic variables in 2000, overall and by study area. Changes in neighborhood built
195environment and sociodemographic variables for each tract were calculated by subtracting 2000
196data from 2010 values. We also performed sensitivity analyses that examined change in the
197destinations using data from all years (not shown).

198

199 Linear models accounting for population in 2000, land area in hectares, and study area were used
200 to estimate the association between baseline levels of each sociodemographic variable in 2000
201 and change in built environment characteristics between 2000 and 2010. Linear models of
202 change on change, equivalent to fixed effects models (Allison, 2005), were used to estimate
203 associations of within-census tract change between 2000 and 2010 in each sociodemographic
204 variable with within-census tract changes between 2000 and 2010 in the built environment.
205 These models were adjusted only for change in population because they tightly control for time-
206 invariant characteristics (i.e. land area and study area). The association between change in a
207 sociodemographic characteristic and change in the built environment was allowed to vary by the
208 starting level of that sociodemographic characteristic using interaction terms and all change on
209 change models are presented at the mean level of baseline sociodemographic characteristics. For
210 ease of interpretation across neighborhood characteristics, all results are shown for an
211 interquartile range (IQR) difference so estimates represent a change from the 25th to the 75th
212 percentile. Mutually adjusted models included all four sociodemographic characteristics together.
213
214 Area-adjusted change in the built environment was mapped and spatial patterns were assessed
215 within each study area using a first-order, row-standardized, rook contiguity neighbor definition.
216 We ran Global Moran's I to measure overall clustering of change within each city. We then ran
217 Local Moran's I to identify statistically significant clusters of high increases surrounded by high
218 increases (HH). We used a common approach to evaluating the statistical significance of the
219 Local Moran's I, with p-values presented in our results. As previous work indicates, several
220 limitations are inherent to this metric but require a level of sophisticated analysis that is beyond
221 the scope of most applications to public health data (Waller & Gotway, 2004). Sociodemographic

222 characteristics were compared between HH clusters and tracts that were not in these HH clusters
 223 (including tracts in low-low, high-low, and low-high clusters) using Analysis of Variance
 224 (ANOVA) or Kruskal-Wallis as appropriate.

225

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

228

229 **Results**

230 ***Built Environment and Neighborhood Sociodemographic Characteristics***

231 The size of census tracts varied by study area, ranging from a median of 17.7 hectares in NY to
 232 870.6 hectares in NC, with an average of 4340 people per tract (Table 1). Across all study areas,
 233 census tracts had an average of 19.2 destinations for social engagement, 12.2 walking
 234 destinations, and 1.3 physical activity facilities in 2000. The number of all destinations increased
 235 between 2000 and 2010. Destinations for social engagement increased the most: the mean
 236 increase was 10.5 locations per tract. At baseline, the mean percent of census tract area dedicated
 237 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
 238 except NY and IL, the area zoned for residential uses decreased over time, although the
 239 magnitude of the reduction differed by site. Retail uses in 2000 were less common with a mean
 240 6.4% and ranging from 2.4% (NC) to 8.5% (IL). Changes between 2000-2010 in zoned land-use
 241 were of very small magnitude so predictors of change in land-uses were not investigated.

242

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

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

253 ***Associations between Neighborhood Sociodemographic Characteristics and Change in the***
254 ***Built Environment***

255 Census tract sociodemographic characteristics in 2000 were associated with changes over time in
256 the built environment (Figure 1, see supplemental material, Table S1). Adjusting for all other
257 sociodemographic factors, metropolitan area, land area and changes in population, tracts with a
258 higher percentage non-Hispanic white in 2000 experienced greater increases in destinations for
259 social engagement, smaller increases in walking destinations, and greater increases in physical
260 activity facilities. Tracts with a higher median household income in 2000 experienced greater
261 increases in destinations for social engagement and greater increases in physical activity
262 facilities. Tracts with a higher percentage of households without a vehicle in 2000 experienced
263 greater increases in destinations for social engagement, smaller increases in walking destinations,
264 and greater increases in physical activity facilities. Tracts with a higher percentage over 65 in
265 2000 experienced smaller increases in walking destinations and physical activity facilities.
266 Overall, associations with change in destinations between 2000 and 2010 were stronger for
267 percentage non-Hispanic white and percentage of households without a vehicle in 2000 than for
268 median household income and percentage over 65 in 2000.

269

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

288 ***Spatial Clustering of Change in the Built Environment***

289 Positive and highly significant Global Moran's I (ranging from 0.02 to 0.62) indicated changes
290 were more spatially clustered within each study area than would be expected if underlying spatial
291 processes were random (results not shown). Local Moran's I identified clusters of tracts with

292high changes in destinations (i.e. individual tracts with high increases in destinations bordered by
293other tracts with high increases, when compared to the other tracts in that study area). A total of
294444 census tracts were in clusters of high increases in destinations for social engagement, 261
295were in clusters of high change in walking destinations, and 372 were in high clusters of change
296in physical activity facilities (Table 2). Census tracts that experienced the highest increases in
297destinations between 2000 and 2010 and were surrounded by neighbors experiencing higher
298increases (HH), generally had higher percentage non-Hispanic whites and higher percentage of
299households without vehicles than other tracts in 2000 and experienced increases in percent non-
300Hispanic white (as opposed to decreases), greater increases in median household income, and
301larger decreases in percent of households without a vehicle than other tracts between 2000 and
3022010. Percent over 65 was not generally different between clusters of high change and other
303tracts, with the exception that tracts in clusters of high increases in walking destinations and
304physical activity facilities had lower percentages over 65 in 2000 than tracts in other cluster
305types.

306

307**Discussion**

308The mean number of destinations for social engagement, walking, and physical activity all
309increased between 2000 and 2010 in a geographically diverse sample of U.S. metropolitan areas.
310Change also occurred in zoned land-use categories, although they were small in magnitude.
311Changes in the built environment were spatially clustered and patterned by sociodemographic
312characteristics. Neighborhood clusters experiencing greater change had higher percent non-
313Hispanic white residents, higher incomes and more households without vehicles at baseline.
314They also tended to show greater increase in non-Hispanic white residents and income over time.

315In linear regression analyses, higher initial levels and changes in percent non-Hispanic White,
316median household income, and percent with no vehicle were positively associated with increases
317in destinations between 2000 and 2010. Higher initial levels of percent over 65 were associated
318with decreases in destinations between 2000 and 2010. However, increases in percent over 65
319between 2000 and 2010 were associated with simultaneous increases in destinations.

320

321This study is among the first in the U.S. to examine neighborhood changes in access to
322destinations and land-uses. As more effort is placed on influencing the walkability of
323neighborhoods, it is crucial that efforts are taken to benchmark and track whether and where
324changes are occurring. In addition, our observation of patterning by racial composition,
325socioeconomic status and vehicle ownership, suggests neighborhood change over time may
326exacerbate existing environmental and health disparities because the benefits associated with
327positive change in the built environment would be experienced largely by people who already
328enjoy health advantages.

329

330Our findings for neighborhoods with high percentages of the population over 65 years of age
331may also have important implications for understanding the health of communities. As the
332American population ages, the environment may play an important role in maintaining
333independence, mobility, and the overall ability of older adults to age in place (Michael, Green, &
334Farquhar, 2006). Our results showed clusters of high levels of improvement in walking
335destinations have a lower percent over 65 than other types of clusters. Additionally, tracts with a
336higher percent over 65 in 2000 were associated with decreases in walking destinations, and
337physical activity facilities. This may restrict access to amenities for many older adults who

338 remain in these neighborhoods. Close destinations may be important for combining walking into
339 daily activities and for decreasing social isolation for older adults (Michael et al., 2006; Vine,
340 Buys, & Aird, 2012). Conversely, increases in percent over 65 were associated with increases in
341 all built environment measures. This may potentially be reflective of older adults moving to more
342 walkable neighborhoods. This is consistent with qualitative research on relocation motives
343 among older adults (Oswald, Schilling, Wahl, & Gäng, 2002) and neighborhood design's role in
344 active aging (Day, 2008; Michael et al., 2006). Age-friendly urban design will become critical for
345 older people to successfully age in the community and it is encouraging to see that locations
346 experiencing higher increases in percent over 65 are experiencing higher increases in
347 destinations. However, attention should be paid to locations with higher initial percent over 65 to
348 ensure older adults who wish to age in place have the appropriate supports to stay in their current
349 residential location.

350

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

361resource-scarce neighborhoods and to involve low-income and communities of color to work
362towards a more even distribution of resources associated with physical activity.

363

364One way in which communities have worked to improve their neighborhood environments is to
365implement a master plan for their community targeting improvements in physical activity. One
366study showed locations with master plans for non-motorized transportation have similar
367socioeconomic characteristics as the overall U.S., it also found the diversity index among
368communities with plans was lower than the U.S. average (Steinman et al., 2010). Similarly,
369research indicates residents of counties with lower-income levels and higher proportions of non-
370white residents were less likely to have attributes supportive of physical activity included in their
371plans (Aytur, Rodriguez, Evenson, Catellier, & Rosamond, 2008). Lack of a plan may lead to a
372lower likelihood of positive changes in the built environment to encourage walking and cycling.
373While we did not have information on master plans in this work, we did find census tracts
374experiencing greater increases in destinations also experienced increases in percent non-Hispanic
375white and median household income between 2000 and 2010.

376

377In studying change, we observed variations in changes across study areas. One possible
378explanation for these differences is differing levels of engagement to change the built
379environment. Alternatively, they could be due to different levels of political power or variations
380in local resources since tax collection funds some of the walkability and land-use planning
381projects. However, external factors, such as the economic downturn of 2008, could also be
382driving change. Sensitivity analyses examining change in the destinations using data from all
383years show a dip in 2009 but a recovery in 2010. Similarly, population growth could contribute

384to changes in both land-use and destinations. Another observation was changes for destinations
385were much larger than changes in zoned land-uses. This is not surprising given the destinations
386used in this study consist largely of retail and commercial business establishments that tend to
387open and close, or change location, more frequently than governments change zoning
388regulations. While land-use codes are amenable to change, these changes include numerous
389stakeholders and may require longer periods of time than changes in destinations. Similarly, it
390may take decades for a change in land-use zoning to be implemented as a physical change.

391

392One challenge with these findings is that, in spite of longitudinal data, we do not know whether
393sociodemographic change preceded neighborhood changes, whether alternate processes, such as
394gentrification, are occurring after neighborhood resources increase or a combination of these
395processes. High socioeconomic status individuals may move to an area and retail may follow this
396new base of patrons. Alternatively, these results are potentially consistent with common patterns
397of expansion at the metropolitan fringe of development. Areas on the edges of metropolitan areas
398tend to be less dense to begin with and thus have more “room to improve.” These more suburban
399rings are often predominantly white, middle-class neighborhoods. Ultimately, without on-the-
400ground knowledge of each census tract experiencing these changes, it is hard to discuss the
401complex processes underlying the change. In addition, while our results indicate changes in the
402built environment are patterned by neighborhood sociodemographic characteristics, the ultimate
403impact of these changes on health disparities depends on the extent to which these built
404environment features are associated with health behaviors and outcomes. As stated previously,
405the measures used in this study have been shown to be longitudinally associated with walking
406(Hirsch, Moore, Clarke, et al., 2014), physical activity (Ranchod et al., 2013), and obesity

407(Hirsch, Moore, Barrientos-Gutierrez, et al., 2014) within these same cities. Furthermore, in
408these seven cities, we observed positive changes in these built environment measures. It is worth
409noting, however, negative changes may also occur in neighborhoods experiencing loss of
410businesses, removal or closure of parks, or lapses in maintenance of existing infrastructure to the
411point of disrepair. Future work should attempt to examine some of these disinvestments.

412

413Other limitations are related to the nature of the data. First, as mentioned briefly above, NETS
414data are imperfect. Although we processed data based on opening and closing dates to capture
415the establishments that may have been present at a given year, the sensitivity and specificity of
416these data have been shown to be low (Bader et al., 2010; Boone et al., 2008; Brownson et al.,
4172009; Forsyth et al., 2010; Christine M Hoehner & Schootman, 2010; Kaufman et al., 2015;
418Liese et al., 2010; Powell et al., 2011; Wang et al., 2006). Furthermore, the usefulness of this
419dataset is likely to vary by industry, year, and geographic location. This could lead to differential
420misclassifications and biased estimates, especially if these patterns are linked with neighborhood
421level sociodemographic characteristics. Most work examining these data compare sources but do
422not provide the necessary details on the way these errors may be patterned to say with certainty
423which direction the bias would occur in this study. However, given the necessity to derive time-
424varying measures of historical business information and that it would be cost-prohibitive to
425collect the same depth of information from multiple sources or field audits (which are also
426impossible for the historic aspect), we felt that NETS provided the most comprehensive source
427for this information. Second, due to changes in the data collected for decennial census, we use
428ACS 2005-2009 to estimate sociodemographic characteristics for 2010. These estimates are less
429precise and thus may include more measurement error or potential for bias (MacDonald, 2006).

430In a crude sensitivity analyses using the errors associated with each ACS estimates, some results
431varied between the highest and lowest confidence intervals. In general, however, sensitivity
432results were similar in direction and significance but not magnitude (not shown). Census tracts
433may not accurately reflect salient or relevant neighborhood boundaries; using a different size or
434scale of aggregated area may result in different results (often known as the Modifiable Areal Unit
435Problem) (Flowerdew, Manley, & Sabel, 2008; Haynes, Daras, Reading, & Jones, 2007;
436Houston, 2014; Zhang & Kukadia, 2005). In addition, combining data from multiple spatial
437scales (e.g. parcels and tracts) may have the potential to influence findings (Gotway & Young,
4382002). Use of other geographies or methods of combination should be explored in the future.
439Similarly, our analysis can only provide information at the neighborhood level; extrapolating to
440the individual level to say that a wealthy individual or a white individual has better changes in
441the built environment would be an ecologic fallacy. Furthermore, exclusion of tracts missing
442built environment or sociodemographic data (1.9%) may create artificial boundaries or non-
443adjacencies, which could influence our spatial analyses. Additionally, assignment of land-use to
4442000 and 2010 by closest available data may miss some changes that occur, and the use of parcel
445area penalizes vertical development (e.g. treats a parcel with a multi-story building the same as a
446parcel with a one-story building). In addition, differences in the residence rules, such as who
447counts in a household, and reference periods (particularly for income) could have impacted
448comparability between ACS 5-year estimates and Census 2000. However, the U.S. Census
449Bureau “recommend[s] users compare derived measures such as percent,” as was done in this
450study (U.S. Census Bureau, 2013). Finally, changes in the built environment may take longer
451than ten years or may occur in small-scale design features that are difficult to measure across
452multiple study areas, such as crosswalks, bicycle lanes, and sidewalks. Alternatively, trends may

453be different for different time periods (period effect) and we were limited to only the 2000 to
 4542010 period. Thus, a future examination utilizing twenty or thirty years of data would enhance
 455our understanding of relationships between neighborhood sociodemographic characteristics and
 456built environment change and allow for sub-analyses of different time periods.

457

458**Conclusions**

459Evidence from this study suggests that in these seven U.S. metropolitan areas, destinations,
 460potentially representing walkability, are increasing. This may indicate success of recent
 461movements to improve the neighborhood environment and could have important implications
 462toward the realization of policies to increase physical activity such as the U.S. Surgeon General’s
 463Call to Action, “Step It Up” (U.S. Department of Health and Human Services, 2015). However,
 464the unequal distribution of changes across neighborhood sociodemographic characteristics
 465suggests efforts to improve the built environment may have the unintended consequence of
 466increasing health inequality by increasing opportunities for activity only in advantaged
 467neighborhoods. Initiatives to improve the built environment should focus on currently
 468disadvantaged neighborhoods in order to reduce environmental and health disparities. Continued
 469attention needs to be paid to equity in policies to change the built environment to ensure changes
 470do not have the unintended consequence of increased health disparities.

471**List of Abbreviations**

472ACS	American Community Survey
473ANOVA	Analysis of Variance
474GIS	Geographic Information Systems
475HH	Statistically significant cluster of high increases surrounded by high increases
476IQR	Interquartile Range
477NETS	National Establishment Time Series

478SIC Standard Industrial Classification
479

480Competing Interests:

481The authors have no financial or competing interests to disclose.

482

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483

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621

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)							
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)								
<i>Destinations</i>								
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)
<i>Zoned Land-Uses</i>								
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)
<i>Sociodemographics</i>								
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)								
<i>Destinations</i>								
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)
<i>Zoned Land-Uses</i>								
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)
<i>Sociodemographics</i>								
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)

622

623

624 Figure 1: Mean differences in change in the built environment between 2000 and 2010 associated
625 with census tract characteristics in 2000 (estimates correspond to the mean difference in 2010-
626 2000 change for an IQR difference of the characteristic in 2000).

627

628Figure 2: Mean differences in change in the built environment between 2000 and 2010 associated
629with increases in census tract characteristics between 2000 and 2010 (estimates correspond to the
630mean difference in 2010-2000 change for an IQR 2010-2000 increase of the characteristic).

631Results displayed at the mean baseline level of each characteristic.

632