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Operationalizing the neighborhood effects of the built environment on travel behavior

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ABSTRACT

Evidence of a connection between the built environment and individual travel behavior is substantiated by multidisciplinary research. In general, compact development patterns exhibiting high concentrations of activity locations and a traditional street design support sustainable travel. However, uncertainty in the magnitude of this connection remains due to how the built environment has been operationalized, usually at a geographic boundary chosen out of convenience. This Portland, Oregon study uses household travel survey data to systematically examine variation in the magnitude of this association when measuring land development pattern, urban design, and transportation system features at various scales. Specifically, this study measures 57 built environment features describing an individual's trip origin and destination at 12 combinations of zonal systems and spatial extents, and assesses their effect on home-based mode choice. First, correlations between individual- and household-level walking behaviors and each combination of indicator and geographic boundary were measured to examine scaling and zoning effects associated with the modifiable areal unit problem (MAUP). These sensitivity test results informed the specification of home-based work and non-work multinomial logit models estimating the effect of sociodemographic, economic, and built environment features on mode choice. Our study findings offer new insight into the MAUP's scaling effect on measuring smart growth indicators and their connection to sustainable travel behavior.

1. Introduction

The transportation-land use connection has an extensive evidence base, with public health research more recently investigating the influence of the built environment on walking or transportation-related physical activity (Saelens and Handy 2008). Early transportation-land use research almost exclusively studied auto-related travel with regional built environment measures; however, the current of practice is to also adopt neighborhood-level indicators to evaluate environmental connections to all transportation modes. A shift largely attributed to the advent of geographic information systems and the pairing of disaggregate land use and household travel diary data (Boarnet 2011). These measurement advancements, coupled with this ascribed multidisciplinary interest, have guided the growth of integrated transportation-land use programs aimed at creating walkable, activity-friendly communities.

Policies and programs that facilitate active transportation or physical activity are generally place-dependent and therefore linked to a person's physical surroundings (Sallis 2009). Yet, conceptualizing the built environment with a set of key indicators reflecting land development pattern, urban design, and the transportation system (Frank and Engelke 2001) remains a complicating factor in quantifying the strength of this stated connection. Although improvements in data integrity and availability support this nontrivial task, many measures remain inadequate for understanding how changes to different built environment dimensions can moderate more sustainable travel behaviors. While reflecting the built environment is an ongoing and challenging endeavor, past studies generally reveal a significant association between the built environment and travel (Ewing and Cervero 2010). However, given the variation in spatial boundaries chosen to operationalize these myriad measures, the extent of any environmental association with mode choice is still somewhat unclear (Clark and Scott 2014).

Inconsistencies in the modeled neighborhood effects of the built environment on travel behavior resulting from measuring a traveler's environmental context with dissimilar spatial boundaries is defined as

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the modifiable areal unit problem (MAUP) (Hess et al. 2001). A methodological issue, arising from representing different measures with varying aggregation levels and zoning systems, which has received inadequate attention in the transportation-land use evidence base (Kwan and Weber 2008). This prospect for scale-related decisions to distort the significance or degree of any theorized interaction also confounds any understanding of how the physical context near each trip end effects an individual's travel behavior.

While recent health-related studies have investigated the impact of the MAUP on connections between walkability indicators and walking behaviors, transportation research has given less attention to the requisite decision of geographic scale selection. Despite a recognition that the likelihood of the MAUP affecting study findings—and therefore creating uncertainty in any modeled relationship—increases with the continued variation in scale and spatial extents (Clark and Scott 2014). In response, a pair of notable studies (Mitra and Buliung 2012; Clark and Scott 2014) started to consider the implications of scale and zoning effects on recognized transportation-land use connections. Extending these efforts, our study seeks to assess the impact of the MAUP in the connection between the built environment and pedestrian travel. Specifically, our study operationalizes an extensive list of built environment measures with a wide range of zonal systems to (a) analyze the connection between travel mode choice and the built environment at varying fixed and sliding scales, and (b) investigate the contribution of the built environment at each trip end for adult travel to work and nonwork locations.

2. Literature review

Selecting a spatial scale to represent the built environment is inherent to studies of the transportation-land use connection (Hess et al. 2001). Contextual impacts on travel behavior often stretch continuously across areas, presenting a challenge in dividing its spatial effect into distinct, overlapping, or multilevel analytic units (Openshaw 1983; Kwan 2012). Research has investigated the built environment's impact on travel with measures operationalized with assorted spatial scales (Handy et al. 2002), with few studies experimenting with scale variation (Boarnet 2011). An inattention to scale choice in context measurement may lead to inconsistent study findings and policy implications.

This sensitivity of empirical results to the definition of spatial units for collecting and quantifying these neighborhood effects is termed the MAUP (Fotheringham and Wong 1991). The MAUP has two components, scale and zoning effects, describing the subjective decisions of boundary delineation in reporting contextual effects. Scale effect is the sensitivity of built environment measures to changes in the size of the geographic unit of analysis (Gehlke and Biehl 1934; Openshaw 1983). Therefore, variation in a stated transportation-land use connection may simply be an artifact of adopting smaller or larger scales to reflect land use. Zoning effects arise from the many ways to configure a spatial boundary at each level of aggregation (Jelinski and Wu 1996). This review, structured by measurement of the built environment with fixed or sliding scales (Guo and Bhat 2007; Gehrke and Clifton 2016), describes studies of the built environment determinants of travel that have explored boundary variation.

2.1. Fixed geographic scales

Describing a built environment aspect within a predefined set of distinct, adjoining boundaries represents the application of a fixed geographic scale. Implementation of a fixed zonal system to operationalize built environment measures is typically due to analytical convenience, data availability, and the attractiveness of prevailing hierarchical structures (Kwan and Weber 2008). Fixed zonal systems include administrative, statistical, and artificial boundaries (Gehrke and Clifton 2016). The use of statistical boundaries (e.g., census units) to outline the local environment is pervasive in travel behavior research because of the availability of socioeconomic data at this boundary (Guo and Bhat 2007) and its approximation of a neighborhood unit (Manaugh and Kreider 2013). However, variation in the spatial scale of contiguous statistical boundaries has led an increased adoption of artificial boundaries (e.g., grid cells) that assess the built environment's neighborhood effect by generating a uniformed, synthetic zoning system (Krizek 2003).

Zhang and Kukadia (2005) used three statistical and five artificial zoning systems to operationalize the built environment around an individual's residence to assess its impact on mode choice. Considering three common measures, the authors noted tractable and stable estimates of home-based travel when operationalizing the built environment with artificial boundaries. In an active travel study, Clark and Scott (2014) compared the adoption of statistical and artificial boundaries to operationalize five development pattern, urban design, and transportation system features of the traveler's residential environment. Corroborating the prior study, the authors suggested the MAUP significantly influenced the relationship between the built environment and active travel. Other studies outside the United States (Duncan et al. 2010; Learnihan et al. 2011; Mitra and Buliung 2012) similarly employed statistical boundaries to understand the impact of their adoption for quantifying the neighborhood effect of the built environment on physical activity. Investigating land use mix, Duncan et al. (2010) measured development patterns at four census scales and found adjusting for scaling effects improved the phenomenon's association with walk trip duration. Learnihan et al. (2011) examined the impact of four walkability indicators near the residence on walking for transport and recreation; whereas, Mitra and Buliung (2012) considered the influence of a greater set of contextual indicators near the home location and destination on school-related active travel. Houston (2014) found evidence of zoning effects by using three artificial boundaries to estimate the effects of five environmental measures at home and non-home locations on moderate and physical activity bouts.

Studies examining the MAUP by adopting fixed scales confirm the existence of scaling and zoning effects. Zoning effects result from the seemingly arbitrary placement of a trip end, which may be near the center or perimeter of the partitioned space, inside the unit of analysis (Oliver et al. 2007; Mitra and Buliung 2012). For this reason and the availability of detailed data reducing the scaling effect (Clark and Scott 2014), recent studies have also generally operationalized the built environment with sliding scales.

2.2. Sliding geographic scales

Measuring an individual's contextual surroundings at a given activity location by using objective distance- or time-related boundaries indicates the adoption of a sliding geographic scale (Guo and Bhat 2007; Gehrke and Clifton 2014). Sliding scales offer an individual-centric operationalization of the neighborhood concept that seeks to explain the built environment aspects most likely to affect travel decisions (Gehrke and Clifton 2016). The creation of areal buffers extending from an activity location, a sliding scale application, permits the formation of overlapping spatial boundaries that enable variation in neighborhood delineations. Yet, the assumption that the environment in this circular-unit representation is equally consequential in all directions to the decision-making process and its insensitivity to the physical access constraints presented by nearby natural and artificial boundaries limits the appeal of areal buffers (Guo and Bhat 2007). Network bands, confining the neighborhood boundary to include only the area that an individual can hypothetically travel to along a street network, reflect a more nuanced way to operationalize the built environment with a sliding geographic scale (Frank et al. 2008).

Applying areal buffers and network bands at four extents, Forsyth et al. (2008) found modest relationships between physical activity and housing, population, employment, and activity density at the home location. Operationalizing population density as well as business intensity and intersection density with four areal buffer extents, Boone-Heinonen et al. (2010) revealed higher physical activity levels were generally associated with the latter two aspects at smaller spatial extents. Berke et al. (2007) modeled a significant association between increased walking for exercise in older adults and a walkability index comprised of eight features including housing and retail store density, across three areal buffers. Kerr et al. (2014) echoed this finding in a study of physical activity in older women but acknowledged small effect sizes. That study, like others by Forsyth et al. (2008) and Learnihan et al. (2011), used network bands to assess the impact of scaling effects on the relationship between the residential environment and walking. Studying travel mode choice and land use mixing, Gehrke and Clifton (2014) explored the scaling and zoning effects of seven land use composition measures operationalized at the trip origin and destination with two statistical boundaries and two network bands. In their study, land use diversity at the trip destination had a positive relationship with walking and bicycling when calculated at larger spatial extents.

Sliding scale representations provide a methodological and conceptual improvement over fixed scaled delineations of the neighborhood concept. Foremost, by only measuring the built environment that immediately extends from a given location, areal buffers and networks bands place an individual at the neighborhood's center and avoid statistical biases linked to placement near another spatial unit. Second, by eliminating physical barriers and limiting space by network access, the application of objective network bands helps to guide MAUP-related research closer to the ideal application of perceptive scales such as mental maps (Fig. 1). Considering the many limitations in data availability and the dynamic nature of perceived geographic scales (Arentze and Timmermans 2005), their adoption in the literature is uncommon.

3. Methods

3.1. Travel behavior data

This study used transportation data provided by an activity-travel survey of 46,414 individuals from 19,932 randomly sampled households in Oregon between 2009 and 2012. The Oregon Household Activity Survey was a one-day diary of weekday travel reported by a chosen household member who detailed information on the activity locations (trip destinations), trip purposes, and modes of all out-of-home travel conducted by their household as well as socioeconomic characteristics of the household and its members. The geographic coordinates of all activity locations were provided in the data set; permitting measurement of the built environment at each trip end (origin and destination). However, the actual route taken between origin and destination was not recorded in the data set. In this study, the travel behaviors of a subsample of respondents, who resided in the City of Portland and conducted a home-based trip to a destination inside of the three-county metro region, were analyzed.

3.2. Built environment data and measurement

To supplement these characteristics of the traveler and their home-based travel behavior, information describing the land development patterns, urban design, and transportation systems near an individual's residence and their destination were collected. Land development patterns denote both the density of activities within a neighborhood and their composition or spatial configuration in terms of land use mixing (Gehrke and Clifton 2019). Reduced trip lengths and subsequent increases in travel mode availability are posited to be associated with an intensification in the diversity and interspersion of local activities or land uses (Frank and Engelke 2001). Consequently, walking has been positively related to a greater balance of land uses and increase in the number of destinations near a traveler's home (Ewing and Cervero 2010). Urban design, on the other hand, describes the arrangement and appearance of various environmental features; whereas, the transportation system details the physical infrastructure and performance of the various systems presented to the traveler (Saelens and Handy 2008). Features in the former dimension describe the desirability for travel and are more likely to affect walking and cycling in which a person moves through a setting at a slower rate, while transportation systems are integral to providing connections between trip origins and destinations (Frank and Engelke 2001). Accordingly, improvements in transportation network connectivity have been found to decrease commute travel times and auto mode shares (Levinson 2012), while increased sidewalk availability is correlated with a higher propensity for walking to work or school (Rodriguez and Joo 2004).

A range of indicators for each of these dimensions was measured for this study (Table 1). These 57 variables were calculated with data provided by the 2011 Portland Metro Regional Land Information System, 2010 US Census, 2014 Longitudinal Employer-Household Dynamics (LEHD) Program, and 2010 Topologically Integrated Geographic Encoding and Referencing files. Further variable details are provided elsewhere (Gehrke and Clifton 2017).

To recognize the potential impact of the MAUP, built environment indicators were calculated at the residence and trip destination using 12 combinations of zonal systems and scale extents. The first pair of geographies are statistical zonal systems measuring the context with spatial extents at the US Census block group (BG) and tract (CT). Adopting another pair of fixed scales, the built environment was also measured using artificial boundaries where grid cell systems of one-quarter-

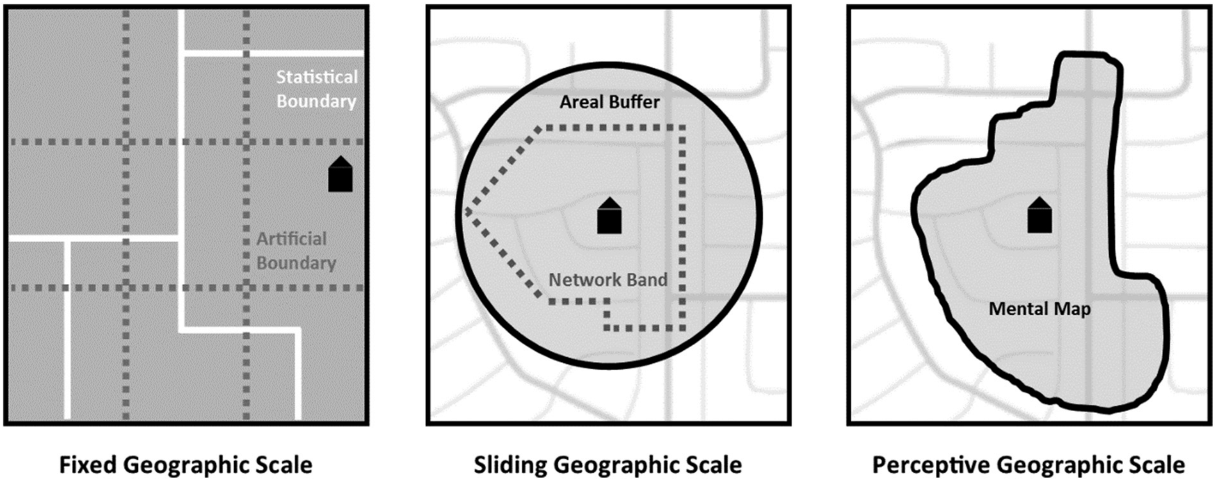

Fig. 1. Classification of zonal systems for representing the neighborhood effects of the built environment.

Table 1

Description of built environment indicators.

Variable name	Description	Data
Land development patterns: density		
Housing density	Number of housing units per acre	C
Persons density	Number of persons per acre	C
Jobs density	Number of jobs per acre	L
Activity density	Sum of persons and jobs per acre	C, L
Retail jobs density	Number of retail jobs per acre	L
Office jobs density	Number of office jobs per acre	L
Industrial jobs density	Number of industrial jobs per acre	L
Service jobs density	Number of service jobs per acre	L
Entertainment jobs density	Number of entertainment jobs per acre	L
Land development patterns: land use mix, composition		
Jobs-housing balance	Ratio of jobs-to-housing units	C, L
Employment entropy	Entropy index based on five job sub-categories	L
Land use percent: residential	Percent of land area classified as residential	R
Land use percent: retail	Percent of land area classified as retail	R
Land use percent: manufacturing	Percent of land area classified as manufacturing	R
Land use percent: utilities	Percent of land area classified as utilities	R
Land use percent: entertainment	Percent of land area classified as entertainment	R
Land use percent: education	Percent of land area classified as education	R
Land use percent: construction	Percent of land area classified as construction	R
Land use percent: extraction	Percent of land area classified as extraction	R
Land use percent: agricultural	Percent of land area classified as agricultural	R
Land use entropy index 1 [a]	Diversity amongst nine land uses	R
Land use entropy index 2 [a]	Diversity amongst five land uses: Residential, retail, entertainment, education, and other	R
Land use balance 1[b]	Evenness in spatial footprint of nine land uses	R
Land use balance 2[b]	Evenness in spatial footprint of five land uses: Residential, retail, entertainment, education, and other	R
Activity-related complementarity 1 [c]	Balance in nine land uses based on activity participation	O, R
Activity-related complementarity 2 [c]	Balance in five land uses based on activity participation: Residential, retail, entertainment, education, and other	O, R
Land use patches: residential	Percent of landscape patches classified as residential	R
Land use patches: retail	Percent of landscape patches classified as retail	R
Land use patches: manufacturing	Percent of landscape patches classified as manufacturing	R
Land use patches: utilities	Percent of landscape patches classified as utilities	R
Land use patches: entertainment	Percent of landscape patches classified as entertainment	R
Land use patches: education	Percent of landscape patches classified as education	R
Land use patches: construction	Percent of landscape patches classified as construction	R
Land use patches: extraction	Percent of landscape patches classified as extraction	R
Land use patches: agricultural	Percent of landscape patches classified as agricultural	R
Land developments: land use mix, configuration		
Maximum patch size: residential	Percent of land area covered by largest landscape patch classified as residential	R
Maximum patch size: retail	Percent of land area covered by largest landscape patch classified as retail	R
Maximum patch size: manufacturing	Percent of land area covered by largest landscape patch classified as manufacturing	R
Maximum patch size: utilities	Percent of land area covered by largest landscape patch classified as utilities	R
Maximum patch size: entertainment	Percent of land area covered by largest landscape patch classified as entertainment	R
Maximum patch size: education	Percent of land area covered by largest landscape patch classified as education	R
Maximum patch size: construction	Percent of land area covered by largest landscape patch classified as construction	R
Maximum patch size: extraction	Percent of land area covered by largest landscape patch classified as extraction	R
Maximum patch size: agricultural	Percent of land area covered by largest landscape patch classified as agricultural	R
Maximum patch size	Percent of land area covered by largest landscape patch	R
Urban design and transportation system		
Average street block size	Average size of street blocks in acres	T
Alpha index [d]	Ratio of observed circuits to maximum number of circuits	T
Beta index [d]	Ratio of street links to all intersections	T
Cyclomatic index [d]	Ratio of 3- and 4-way intersections to all intersections	T
Gamma index [d]	Ratio of observed street links to maximum number of street links	T
Intersection density	Number of 3- and 4-way intersections per acre	T
Intersection proportion	Proportion of 3- and 4-way intersections	T
Cul-de-sac density	Number of cul-de-sacs per acre	T
Street density	Length of street network in feet per acre	T
Percent of local roads	Percent of local roads	T
Percent of primary roads	Percent of primary roads	T
Sidewalk coverage	Percent of observed sidewalks to potential existence of sidewalks along roads	T

Notes: Land use type taxonomy adopted from American Planning Association's Land-Based Classification Standards. Data abbreviations: (C) 2010 US Census Bureau, (L) 2014 US Census Longitudinal Employer-Household Dynamic, (O) 2011 Oregon Household Activity Survey, (R) 2011 Portland Metro Regional Land Information System, and (T) 2010 US Census Topologically Integrated Geographic Encoding and Referencing. Numerical superscripts (^{n}) source relevant studies using built environment indices.

[a] Cervero (1989).

[b] Bhat and Gossen (2004).

[c] Gehrke and Clifton (2019).

[d] Dill (2004).

(G025) and one-mile (G100) edges were casted over the study area. For both fixed scale strategies, the home and destination were assigned built environment attributes of the statistical or artificial boundary in which they were located. A second measurement strategy used two sliding geographic scales, areal buffers and network bands, to measure the built environment around the trip origin and destination at one-quarter- (AB025, NB025), one-half- (AB050, NB050), three-quarter- (AB075, NB075), and one-mile (AB100, NB100) spatial extents. Disaggregate data were summarized to the geography of interest; whereas, data from the US Census and LEHD were provided at the block-level and aggregated to the respective neighborhood representation using a proportional split method. Utilizing the smallest spatial unit limits MAUP-related sensitivity by assuming a uniform dispersion of all attributes in the selected boundary (Schlossberg 2003).

3.3. Analytic strategy

The analytic strategy has two components. First, the impact of the MAUP on the association between the built environment at each trip end and walking is investigated. A second analysis utilizes these findings to inform the estimation of two mode choice models assessing the role of the built environment at each trip end on work and non-work travel.

The scale effects of the MAUP on the built environment at an individual traveler's residence and trip destination were investigated by performing zero-order correlation analyses. At the trip origin, the point-biserial correlation coefficient between the household-level decision to perform at least one daily trip via walking and each combination of contextual indicator and geography was calculated. Likewise, a correlation analysis between a binary variable of the individual-level decision to participate in a walk trip and each combination of indicator and boundary was conducted to describe the MAUP's scaling effect on the built environment near the trip destination. The outcome of this analysis offers insight into the scale effect by identifying visual trends in the statistical significance and magnitude of these 1368 associations. The zoning effects of the built environment connection with active travel was investigated by assessing these associations at each trip end across comparable spatial extents but different zonal systems (i.e., one-mile areal buffer versus one-mile network band). The indicator and geographic boundary pair at each trip end with the strongest absolute magnitude was then selected for testing in the mode choice models.

Discrete choice modeling (DCM) is an established strategy for examining the relative importance of individual and alternative characteristics in travel mode choice (Cervero 2002; Li and Zhao 2015). In this framework, the mode choice set considered by a decision-maker comprises an exhaustive, finite list of four mutually exclusive alternatives: auto, transit, bicycle, and walk.

The utility of a traveler choosing mode *m* amongst the choice set—auto, transit, bicycle, and walk—for trip *i* can be represented by:

$$U_{im} = V_{im} + \varepsilon_{im} \tag{1}$$

$$V_{im} = \alpha_m T_i + \beta_m X_{im} + \gamma_m BE_i \tag{2}$$

where U_{im} is utility of the traveler choosing mode *m* for trip *i*. V_{im} is a vector of the deterministic components of U_{im} and ε_{im} is a vector of unobserved errors. Following the specification of a multinomial logit model (Ben-Akiva and Lerman, 1985), the deterministic components are assumed linear-in-parameters with independent variables in the model. α_m, β_m, and γ_m are coefficients to be estimated. T_i is a vector of the socioeconomic characteristics of a traveler making trip *i*, including both personal and household characteristics related to travel mode choice; X_{im} is a vector of the attributes of trip *i,* such as travel time and cost; while BE_i is a vector of the built environment measures for trip *i.* Since coefficients are allowed to vary by mode, auto was chosen as the reference alternative to make the model identifiable. Adoption of disaggregate DCM offers the ability to represent changes in mode behavior related to varying individual, alternative, and contextual features and modify the choice set to only include alternatives available to an individual (Train 2009).

Travel time, measured in minutes, was calculated using 2010 travel skims modeled by Portland Metro at the traffic analysis zone (TAZ). Midday and peak period travel times for each feasible alternative were determined by matching each trip end to its respective TAZ and linking the trip departure times to the appropriate time-of-day skim. The feasible choice set was defined by the following assumptions. Since no distinction was made between auto-related travel as a driver or passenger, the only restriction for this alternative was that the licensed drivers per household vehicle ratio must exceed zero. For transit, which entailed bus and rail-based modes, availability was predetermined for each TAZ geography in the modeled skims. Bicycling and walking were considered as available modes if the individual's trip could be conducted in 2 h with an average travel speed of 9.0 and 3.5 miles per hour, respectively. Whalen et al. (2013) previously noted the importance in reducing the feasible choice set for active transportation modes based on trip duration. Bicycle mode availability was constrained if the number of household bikes was zero. Travel costs were assumed to be zero for active travel modes, while auto and transit costs were modeled using previous assumptions (Singleton and Wang 2014).

The application of this DCM framework enabled a cumulative strategy for assessing how land development pattern, urban design, and transportation system features at the trip origin and destination affect home-based modal decisions for work and non-work travel. Built environment measurement at both trip ends was noted by Ewing et al. (2015) as a methodological advancement for studies of household travel behavior data exploring the transportation-land use connection. First, a base model was estimated using individual- and household-level attributes of the traveler and alternative-specific characteristics of the trip. Second, built environment features measured at the residence were tested. These indicators, operationalized at a boundary determined by the earlier MAUP-related analysis, were added to the base model in a forward selection process where the log-likelihood of the newly-specified model was tested against the base model's fit. The variable that produced an expanded model with the best fit was retained. This iterative process continued until adding an environmental variable measured at the home location no longer produced a significant improvement per a log-likelihood ratio test. The full model specification was determined by repeating this step for all features measured at the trip destination. Base and full models of mode choice for HBW and HBNW trip purposes were estimated.

4. Results

4.1. Study sample

The travel behaviors and patterns of a sample of 3139 adults from 1912 home locations in the City of Portland, who performed 4745 home-based trips to a destination inside the three-county metro region, were analyzed in this study (Table 2). Of these home-based unlinked trips, most individuals traveled to their activity location in a private vehicle (77%), while other travelers selected a more active mode such as walking (12%) or bicycling (8%). Nearly one-half (47%) of out-of-home trips were to conduct subsistence activities such as commuting to work or school, while the remaining non-work trips were related to conducting travel for mandatory (e.g., shopping) or discretionary (e.g., recreation) purposes. The average distances for home-based work (HBW) and home-based non-work (HBNW) trips were 4.70 and 2.41 miles, respectively. This relationship was consistent across different travel modes, with an average HBW trip distance of 6.76 miles for individuals riding transit, 5.09 miles for automotive travel, 2.79 miles for bicyclists, and 0.64 miles for pedestrians. As for non-work trips, on average, an individual traveled 4.35 miles using transit, 2.78 miles when driving, 1.54 miles when bicycling, and 0.33 miles

Table 2
Descriptive statistics of the study sample.

Variable name	n	%	Mean	St. Dev.	Min	Max
Individual characteristics (n = 3139)						
Gender: female	1704	54	–	–	0.00	1.00
Age: 16–29 years old	339	11	–	–	0.00	1.00
Age: 30–44 years old	764	25	–	–	0.00	1.00
Age: 45–64 years old	1472	48	–	–	0.00	1.00
Age: 65 years or older	521	17	–	–	0.00	1.00
Education: high school diploma or less	494	16	–	–	0.00	1.00
Education: associate degree or credits	657	21	–	–	0.00	1.00
Education: bachelor's degree	985	32	–	–	0.00	1.00
Education: graduate degree	989	32	–	–	0.00	1.00
Employed: part- or full-time	2193	70	–	–	0.00	1.00
Student: part- or full-time	314	10	–	–	0.00	1.00
Disability affecting travel	202	6	–	–	0.00	1.00
Driver's license	2878	92	–	–	0.00	1.00
Parking provided at no charge by employer	1621	68	–	–	0.00	1.00
Transit pass	629	20	–	–	0.00	1.00
Transit pass provided at no charge by employer	293	12	–	–	0.00	1.00
Bike	1248	40	–	–	0.00	1.00
Household characteristics (n = 1912)						
Number of children under 6 years old	–	–	0.13	0.42	0.00	4.00
Number of children 6 to 15 years old	–	–	0.25	0.62	0.00	4.00
Number of adults	–	–	1.85	0.73	1.00	7.00
Number of part- or full-time workers	–	–	1.84	0.69	1.00	7.00
Non-related household	69	4	–	–	0.00	1.00
Annual income: under $25,000	247	14	–	–	0.00	1.00
Annual income: $25,000 to $49,999	381	22	–	–	0.00	1.00
Annual income: $50,000 to $99,999	696	40	–	–	0.00	1.00
Annual income: $100,000 or more	431	25	–	–	0.00	1.00
Oldest adult: 16 to 29 years old	63	3	–	–	0.00	1.00
Oldest adult: 30 to 44 years old	399	21	–	–	0.00	1.00
Oldest adult: 45 to 64 years old	962	51	–	–	0.00	1.00
Oldest adult: 65 years or older	467	25	–	–	0.00	1.00
Highest education: high school diploma or less	148	8	–	–	0.00	1.00
Highest education: associate degree	340	18	–	–	0.00	1.00
Highest education: bachelor's degree	595	31	–	–	0.00	1.00
Highest education: graduate degree	826	43	–	–	0.00	1.00
Household vehicles per licensed driver	–	–	0.92	0.48	0.00	3.00
Household transit passes per adult	–	–	0.20	0.34	0.00	1.00
Household bikes per person 6 years or older	–	–	0.64	0.76	0.00	13.00

when walking from their residence to an out-of-home location.

4.2. Scale and zoning effects

The magnitude and direction of the relationship between the 57 built environment features measured at 12 geographies and pedestrian travel were investigated to assess MAUP-related effects. Inspection of the scale effect of the built environment at the trip origin is guided by the results of the correlation analysis in Fig. 2. Looking at the set of density measures, a consistently positive association was found between the household decision to conduct at least one walk trip and an increased intensity in activities within a residential neighborhood. Within sliding scale zonal systems, the strength of the point-biserial correlation coefficient remained above 0.10 at each of the four spatial extents. Similar findings occurred within the two scale extents for the statistical and artificial boundaries; however, operationalizing density measures with a grid cell revealed a small and counterintuitive connection to the household-level walking behavior.

Comparing land use mix measures operationalized with fixed scales, the effect size and direction of correlation coefficients generally remained unchanged at the two spatial extents. Consistency was also exhibited when maximum patch size was measured using areal buffers or network bands. Composition measures, however, showed scaling effects when assessed at these two sliding scale representations. Using areal buffers, both versions of the land use entropy index and activity-related complementarity measure had strong, positive associations with walking at the smaller spatial extents, but this effect size decreased as zoning size increased. Interestingly, adoption of network bands to represent street network connectivity revealed two instances where this relationship was contradicted. The association between a household-level decision to walk and the alpha and gamma indices strengthened as extent increased.

Scale effects of built environment measurement at the destination were also examined (Fig. 3), but relationships between these measures and the individual-level decision to walk were not as robust. Housing and office or entertainment employment density exhibited scaling effects when operationalized with artificial boundaries. Land use entropy and maximum residential patch size were also impacted by increased aggregation levels when measured with areal buffers. The former mix indicator also had scaling effects when operationalized using grid cells or network bands. In contrast, the percent of residential or retail land uses in neighborhoods defined by areal buffers had a diminishing strength of relationship with walking as spatial extent increased. As with the origin analysis, several connectivity indices demonstrated an increased strength of relationship with walking as the spatial extent of the areal buffer increased.

While visual inspection can deliver insight into zoning effects, a more definitive assessment of the impact of zoning systems across fixed geographic extents would involve comparing different orientations of the same zoning system (Clark and Scott 2014). In this assessment, zoning effects were not apparent for density indicators measured at either trip end. Comparing mix measures operationalized with areal buffers to network bands, in turn, showed more instances of zoning effects. Measured at the home location, several composition indicators were impacted by zoning system selection, including the land use and employment entropy indices, activity-related complementarity, and jobs-housing balance measures. Two configuration measures describing the maximum size of a residential or retail landscape patch in the neighborhood encircling the destination also displayed zoning effects. As for the other built environment dimensions, the average city block size, alpha index, and gamma index were all impacted by zonal configuration decisions at both trip ends.

4.3. Travel mode choice

Applying these MAUP-related findings, a second analysis was performed to understand the neighborhood effects of the built environment at each trip end on mode choice. Adding this second component provided behavioral complexity by accounting for individual, household, and transportation characteristics that may confound any observed active transportation-land use connection and refining an individual's choice set to only consider realistic alternatives. For parsimony and a desire to select the geography best operationalizing the built environment's connection to walking, the contribution of each feature to mode choice was only investigated at the indicator-scale pairing with the strongest correlation. Table 3 describes the built environment indicators at each trip end tested in the multinomial logistic regression models of work and non-work travel.

To examine the additive contribution of the built environment on HBW mode choice, a reduced model with alternative-specific travel time and cost attributes as well as statistically significant individual-specific attributes was first estimated. This base model produced a log-likelihood estimation of -806.56 and an adjusted McFadden's R^2 value of 0.32 (results not shown). A full model with built environment attributes was then estimated (Table 4). Accounting for built environment features at the HBW trip origin and destination significantly improved the final model's fit ($\chi^2 = 222.17$, $p < 0.001$). Increase in the density

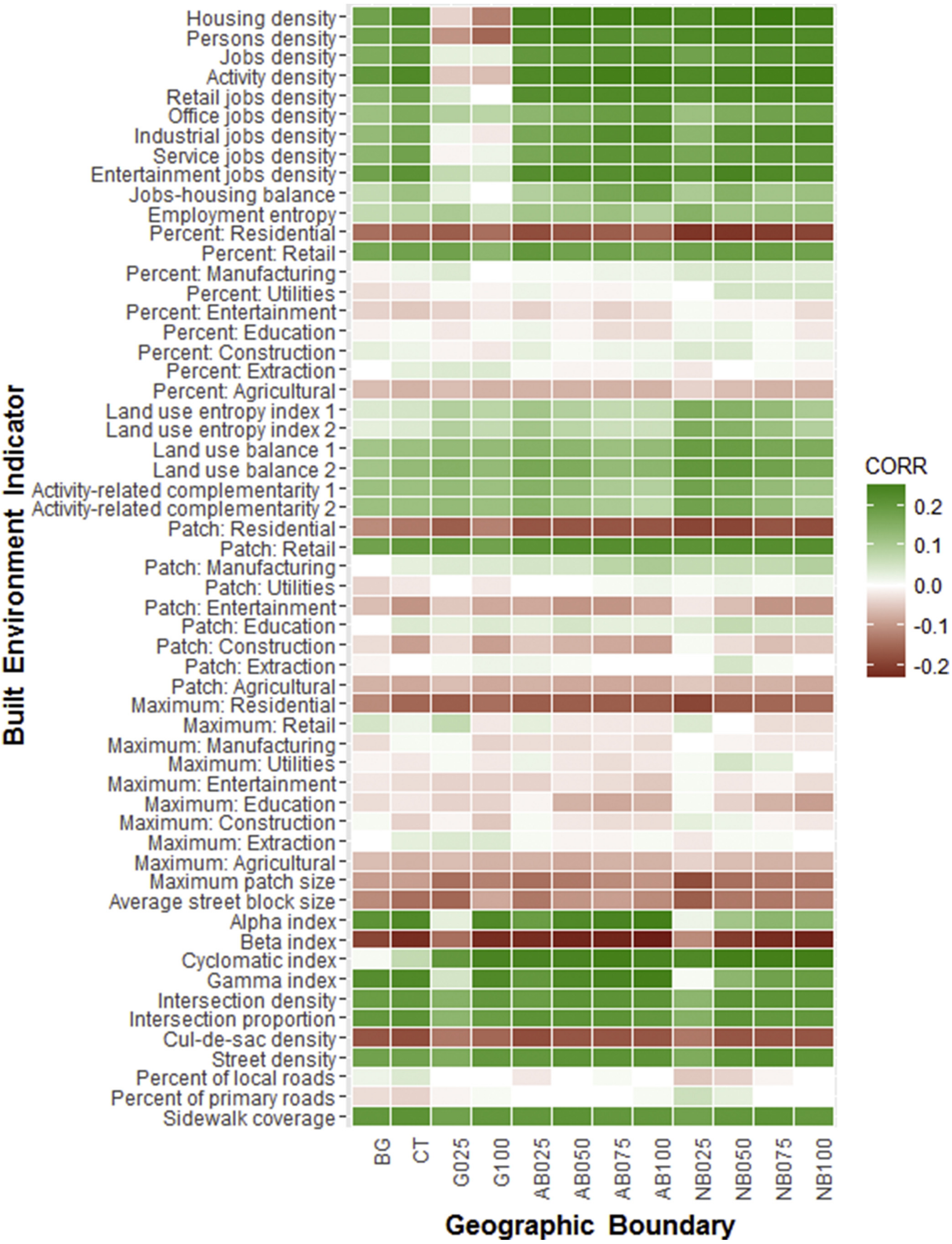

Fig. 2. Zero-Order Correlation between Walking and Built Environment at Trip Origin (Household Level, $N = 1912$).

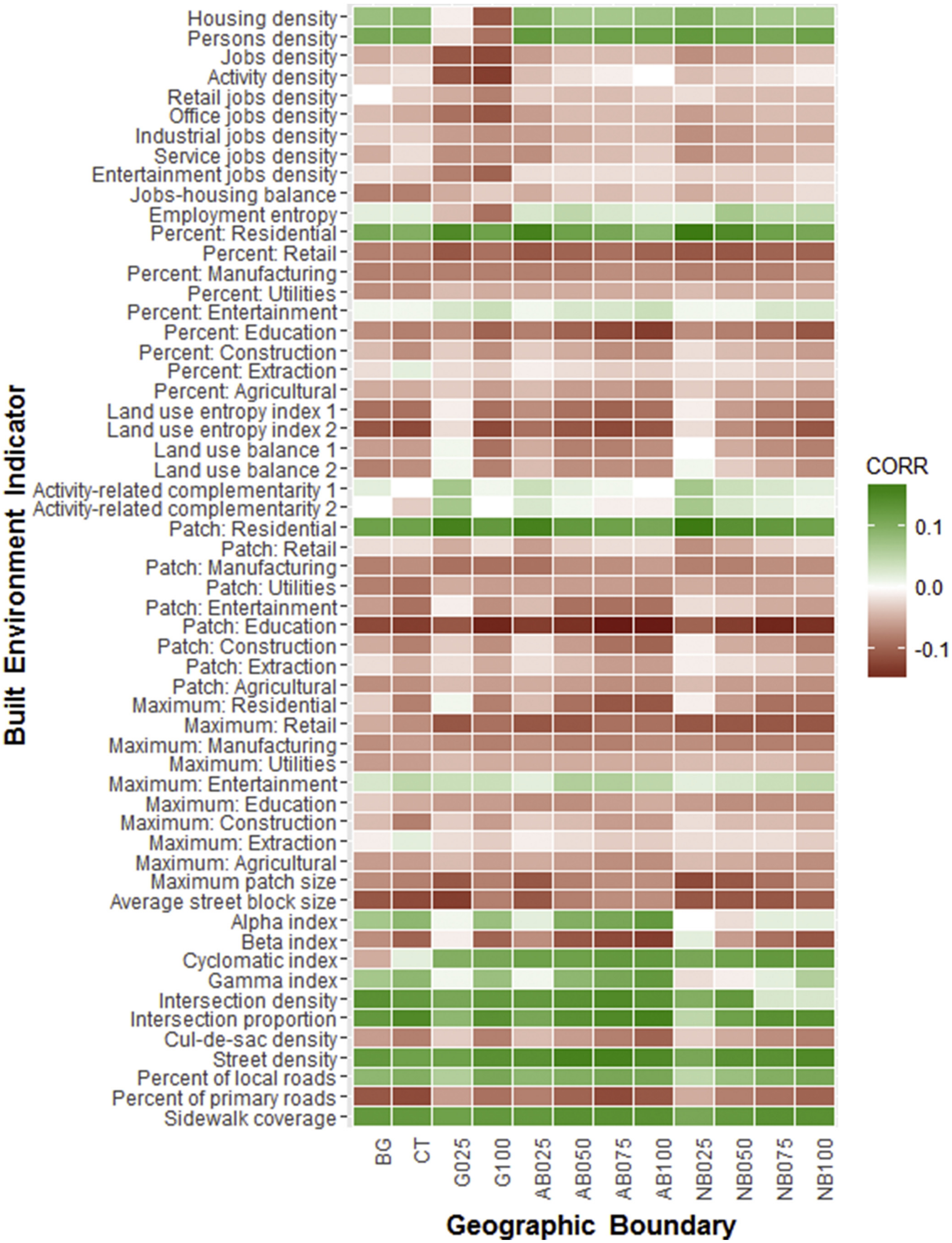

Fig. 3. Zero-Order Correlation between Walking and Built Environment at Trip Destination (Trip Level, $N = 4745$).

Table 3
Descriptive statistics of built environment at sampled trip-ends.

Variable name	Origin (n = 1912)				Destination (n = 4745)			
Land development patterns: density	Scale[a]	CORR[b]	Mean	SD	Scale[a]	CORR[c]	Mean	SD
Housing density	NB075	0.26	5.47	11.94	G100	−0.11	0.05	0.06
Persons density	NB050	0.24	11.94	5.19	NB025	0.13	11.46	9.32
Jobs density	AB100	0.23	6.00	9.37	G100	−0.12	0.24	0.46
Activity density	AB100	0.23	15.88	11.40	G100	−0.13	0.37	0.50
Retail jobs density	NB100	0.23	0.60	0.82	G100	−0.08	0.02	0.06
Office jobs density	AB100	0.21	1.23	3.22	G100	−0.11	0.03	0.05
Industrial jobs density	AB100	0.23	0.86	1.11	G100	−0.07	0.06	0.23
Service jobs density	NB100	0.21	2.74	4.60	G025	−0.07	2.67	9.31
Entertainment jobs density	NB050	0.24	0.90	2.14	G100	−0.10	0.02	0.03
Land development patterns: land use mix, composition								
Jobs-housing balance	AB100	0.19	1.05	1.05	BG	−0.08	7.73	23.76
Employment entropy	NB025	0.15	0.56	0.26	G100	−0.09	0.59	0.24
Land use percent: residential	NB050	−0.21	0.54	0.15	NB025	0.16	0.31	0.23
Land use percent: retail	AB025	0.20	0.07	0.09	NB050	−0.10	0.16	0.13
Land use percent: manufacturing	NB050	0.05	0.01	0.04	G100	−0.08	0.05	0.09
Land use percent: utilities	NB075	0.05	0.00	0.01	BG	−0.07	0.02	0.07
Land use percent: entertainment	CT	−0.05	0.06	0.08	G100	0.04	0.05	0.07
Land use percent: education	AB100	−0.03	0.05	0.02	AB100	−0.13	0.06	0.03
Land use percent: construction	NB050	0.04	0.00	0.00	G100	−0.07	0.00	0.00
Land use percent: extraction	G100	0.04	0.00	0.00	G100	−0.03	0.00	0.01
Land use percent: agricultural	AB050	−0.07	0.01	0.03	AB100	−0.07	0.01	0.04
Land use entropy index 1	NB025	0.16	0.35	0.15	CT	−0.09	0.60	0.12
Land use entropy index 2	NB025	0.16	0.26	0.11	G100	−0.12	0.43	0.10
Land use balance 1	NB050	0.19	0.38	0.13	G100	−0.09	0.50	0.15
Land use balance 2	NB050	0.20	0.32	0.10	G100	−0.08	0.41	0.11
Activity-related complementarity 1	NB025	0.18	0.77	0.14	NB025	0.07	0.82	0.18
Activity-related complementarity 2	NB025	0.18	0.77	0.14	NB025	0.07	0.82	0.17
Land use patches: residential	NB050	−0.19	0.69	0.17	NB025	0.17	0.47	0.27
Land use patches: retail	NB100	0.22	0.22	0.10	NB025	−0.07	0.32	0.21
Land use patches: manufacturing	AB100	0.10	0.03	0.04	G100	−0.09	0.06	0.09
Land use patches: utilities	BG	−0.04	0.01	0.02	CT	−0.09	0.02	0.03
Land use patches: entertainment	AB075	−0.10	0.02	0.02	AB075	−0.09	0.03	0.03
Land use patches: education	NB050	0.07	0.06	0.04	AB100	−0.16	0.08	0.04
Land use patches: construction	AB100	−0.09	0.01	0.01	AB100	−0.10	0.01	0.01
Land use patches: extraction	NB050	0.05	0.00	0.00	AB100	−0.06	0.00	0.00
Land use patches: agricultural	CT	−0.08	0.01	0.03	AB100	−0.07	0.01	0.02
Land developments: land use mix, configuration								
Maximum patch size: residential	NB025	−0.19	0.11	0.11	AB100	−0.11	0.02	0.02
Maximum patch size: retail	G025	0.07	0.03	0.05	AB025	−0.11	0.05	0.08
Maximum patch size: manufacturing	G100	−0.04	0.01	0.02	AB050	−0.08	0.02	0.04
Maximum patch size: utilities	NB050	0.05	0.00	0.01	BG	−0.06	0.01	0.06
Maximum patch size: entertainment	AB100	−0.05	0.03	0.04	AB075	0.06	0.02	0.03
Maximum patch size: education	NB100	−0.09	0.02	0.02	NB100	−0.07	0.02	0.04
Maximum patch size: construction	G100	−0.05	0.00	0.00	CT	−0.08	0.00	0.00
Maximum patch size: extraction	G100	0.04	0.00	0.00	AB100	−0.03	0.00	0.01
Maximum patch size: agricultural	AB050	−0.08	0.00	0.02	AB100	−0.07	0.00	0.02
Maximum patch size	NB025	−0.18	0.13	0.11	NB025	−0.12	0.16	0.18
Contagion index	G025	−0.14	0.65	0.09	G025	−0.04	0.59	0.11
Urban design and transportation system								
Average street block size	NB025	−0.16	7.76	7.88	G025	−0.13	10.44	12.40
Alpha index	AB100	0.25	0.31	0.10	AB100	0.13	0.33	0.11
Beta index	AB100	−0.24	0.63	0.09	AB100	−0.13	0.62	0.09
Cyclomatic index	NB050	0.25	96.51	55.98	NB100	0.13	352.95	215.20
Gamma index	AB100	0.25	0.54	0.07	AB100	0.13	0.55	0.07
Intersection density	AB050	0.21	0.32	0.12	AB075	0.15	0.31	0.13
Intersection proportion	CT	0.21	0.86	0.11	AB100	0.16	0.84	0.11
Cul-de-sac density	CT	−0.18	0.05	0.03	AB100	−0.10	0.05	0.03
Street density	NB075	0.22	227.30	51.19	AB075	0.16	204.01	62.03
Percent of local roads	NB025	−0.05	0.95	0.09	AB075	0.11	0.89	0.06
Percent of primary roads	NB025	0.06	0.01	0.03	CT	−0.12	0.04	0.05
Sidewalk coverage	CT	0.21	0.69	0.31	AB075	0.14	0.73	0.25

[a] Scale abbreviations: AB025 (areal buffer, 0.25-mile), AB050 (areal buffer, 0.50-mile), AB075 (areal buffer, 0.75-mile), AB100 (areal buffer, 1.00-mile), NB025 (network buffer, 0.25-mile), NB050 (network buffer, 0.50-mile), NB075 (network buffer, 0.75-mile), NB100 (network buffer, 1.00-mile), BG (Census block group), CT (Census tract), G025 (grid cell, 0.25-mile), G100 (grid cell, 1.00-mile).

[b] Point-biserial correlation with binary variable of household decision to participate in ≥1 walk trip.

[c] Point-biserial correlation with binary variable of individual trip-level decision to walk.

Table 4
Multinomial logistic regression model results for home-based work travel.

Variable name	Travel mode alternative [a]					
	Public transit		Bicycle		Walk	
	B	SE	B	SE	B	SE
Intercept	−1.66	1.05	−3.60	1.58*	1.09	1.80
Travel time (minutes)	−0.038	0.01***	−0.004	0.01	−0.122	0.01***
Cost (US$)	−0.27	0.12*	−0.27	0.12*	−0.27	0.12*
Individual characteristics						
Gender: female	−0.71	0.20***	0.18	0.29	−0.23	0.30
Education: high school diploma/ less [b]						
Education: associate degree	0.40	0.50	−0.41	0.45	−0.17	0.57
Education: bachelor's degree	1.37	0.46**	−0.44	0.43	0.79	0.52
Education: graduate degree	1.78	0.46***	−1.06	0.49*	0.96	0.54
Driver's license	−2.22	0.52***	−2.72	0.54***	−2.61	0.54***
Household characteristics						
Oldest adult: 16 to 29 years old [b]						
Oldest adult: 30 to 44 years old	−0.91	0.50	0.64	0.88	−1.11	0.98
Oldest adult: 45 to 64 years old	−1.25	0.49*	−0.46	0.84	−0.97	0.95
Oldest adult: 65 years or older	−2.58	0.65***	−0.53	0.93	−1.85	1.09
Household vehicles per driver	−1.65	0.31***	−0.49	0.40	−1.34	0.40***
Built environment (residence)						
Housing density	0.11	0.07	−0.16	0.13	0.14	0.08
Jobs density	−0.12	0.03***	−0.03	0.06	−0.03	0.03
Land use balance 2	2.70	0.99**	−1.38	1.45	1.26	1.49
Alpha index	3.51	1.44*	−5.22	2.08*	−0.11	3.97
Built environment (destination)						
Housing density	1.05	2.67	7.07	3.00*	16.85	5.20**
Land use percent: education	8.00	3.90*	18.76	4.24***	−1.54	8.70
Land use patches: entertainment	8.22	2.67**	16.35	3.18***	−0.28	10.06
Alpha index	4.73	1.24***	13.19	1.91***	7.81	3.93*
Model statistics						
Log-likelihood	−695.47					
McFadden's R^2 (adjusted)	0.41					

[a] Base alternative = personal vehicle.
[b] Reference category.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

of housing units (Walk: B = 16.85, $p < 0.01$; Bicycle: B = 7.07, $p < 0.05$) and ratio of observed to possible route alternatives (alpha index) (Walk: B = 7.81, $p < 0.05$; Bicycle: B = 13.19, $p < 0.001$) at the destination had a positive effect on the decision to select an active mode rather than ride in a private vehicle. An increase in the percentage of educational land uses (Public Transit: B = 8.00, $p < 0.05$; Bicycle: B = 18.76, $p < 0.001$) and landscape patches related to an entertainment land use (Public Transit: B = 8.22, $p < 0.01$; Bicycle: B = 16.35, $p < 0.001$) had a positive impact on the decision to ride transit or cycle when compared to the base case of auto travel.

Fewer built environment features had a significant contribution to the full HBNW choice model (Table 5); yet, their addition offered a statistically significant expansion ($\chi^2 = 103.37$, $p < 0.001$) to the base model which produced a log-likelihood estimation of −1037.10 and an adjusted McFadden's R^2 value of 0.40. An adult was more likely to walk than ride in a vehicle if their residential environment had a higher housing unit density (B = 0.14, $p < 0.001$) or activity-related complementarity of residential, retail, entertainment, education, and other land uses (B = 1.63, $p < 0.05$). Expectedly, the presence of a large retail landscape patch (e.g., big box store, shopping mall) at a trip destination (B = −5.88, $p < 0.01$) was a significant predictor of the decision to use a private vehicle rather walk for HBNW travel.

5. Discussion and conclusions

This study explored the neighborhood effects of the built environment on travel mode choice by analyzing the MAUP-related impacts of scale selection and zonal configuration. Examining variation in the scale extent chosen to reflect the built environment's connection to walking, this study found evidence of scale effects in development pattern, urban design, and transportation system measures. Land use composition indices were affected by the subjective decision of boundary delineation and exhibited a stronger association with walking at a smaller spatial extent. A flattening relationship from increased aggregation levels was found at each trip end and shown by several configuration measures, which has been noted elsewhere in the literature (Zhang and Kukadia 2005; Mitra and Buliung 2012; Clark and Scott 2014) and suggests that studies of pedestrian travel should operationalize land use mix at a disaggregate scale. By adding complexity in land use composition and configuration, the feasibility of walking is improved by bringing residential and non-residential activities in closer proximity.

In general, density and network connectivity indices, when observed at the trip origin, displayed a stronger association with walking as spatial scale increased. For planners interested in walkability, this discovery could be the result of micro-level urban design features having a greater effect on walking when connectivity extends, consequently increasing the feasibility and attractiveness of longer walking trips. Importantly for researchers, this result also highlights a prospect that different spatial extents or zoning schemes may be more suitable when measuring the various contextual influences of pedestrian travel and that a more aggregate spatial extent may be sufficient in assessing this connection for connectivity or density measures. Zoning effects, which are likely more meaningful in fixed scale systems, were found to influence sliding scale neighborhood representations and were most prominent at the destination when analyzing neighborhood effects of the built environment on walking. In all, three suggestions regarding the operationalization of built environment determinants of walking are informed by this MAUP analysis:

- Sliding geographic scales should be adopted for built environment measurement when possible.
- Measurement near origin should be prioritized but will not provide complete travel picture.
- Calculate land use mix measures at a more disaggregate spatial extent than other indicators.

Subsequent examination of the neighborhood effects of the built environment on mode choice at the home location for work and nonwork travel found that the built environment at each trip end significantly explained mode choice for both trip purposes. The physical context around an individual's work or school location explained greater variation in home-based mode choice than their residential environment. An individual was more likely to walk or bicycle to work or school if the environment around their destination had more nearby residences and a traditional street network design; highlighting an association between walkable environments and walking behaviors. Unsurprisingly, destinations in neighborhoods with a higher percent of education land uses and intensity of retail establishments—proxies for schools and job centers, respectively—were more likely to produce bicycling and transit trips for subsistence activities. Supported by the

Table 5
Multinomial logistic regression model results for home-based non-work travel.

Variable name	Travel mode alternative [a]					
	Public transit		Bicycle		Walk	
	B	SE	B	SE	B	SE
Intercept	−4.65	1.11***	5.20	2.76	0.77	0.73
Travel time (minutes)	−0.113	0.01***	−0.113	0.01***	−0.113	0.01***
Cost (US$)	−0.90	0.13***	−0.90	0.13***	−0.90	0.13***
Individual characteristics						
Driver's license	−1.34	0.45**	−2.44	1.06*	−1.67	0.34***
Bike	3.87	0.54***	−0.07	0.79	0.42	0.15**
Household characteristics						
Annual income: under $25,000 [b]						
Annual income: $25,000–$49,999	0.15	0.47	0.17	1.16	−0.15	0.28
Annual income: $50,000–$99,999	0.08	0.43	−0.55	1.18	−0.30	0.26
Annual income: $100,000 or more	0.17	0.44	−1.06	1.43	−0.36	0.27
Household vehicles per driver	−0.63	0.27*	−0.99	0.95	−0.51	0.20*
Built environment (residence)						
Housing density	−0.07	0.06	−0.57	0.28*	0.14	0.04***
Activity-related complementarity 2	−1.35	1.07	1.05	2.86	1.63	0.73*
Land use patches: retail	5.87	1.69***	−7.92	6.43	−0.32	1.23
Built environment (destination)						
Maximum patch size: retail	1.76	2.05	−32.97	19.07	−5.88	1.84**
Cyclomatic index	0.01	0.01***	0.01	0.01	−0.01	0.00
Model statistics						
Log-likelihood	−985.39					
McFadden's R^2 (adjusted)	0.43					

[a] Base alternative = personal vehicle.
[b] Reference category.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

literature (Brownson et al. 2009; Ewing and Cervero 2010), our study also found that land development pattern, urban design, and transportation system characteristics mattered in the choice to perform non-work travel via more sustainable modes, with land development patterns at each trip end exhibiting the greatest effect on the choice to walk rather than drive. However, the context surrounding the residence exhibited a stronger role on non-work travel, which includes discretionary trips for recreation or social activities that are typically not routine. In example, an individual was more likely to walk for non-work trips if the environment around their home was characterized by a balanced spatial distribution of land uses but increased housing density. This positive association between walk mode choice for home-based non-work travel and a neighborhood offering an assortment of out-of-home activity locations (e.g., retail, entertainment) offers further evidence of how physical contexts reflecting smart growth principles may facilitate healthy, active travel decisions.

Our study also has implications for transportation-land use research. First, greater deliberation should be given to geographic boundary choice when measuring the built environment. As demonstrated, increasing scale extent can produce an amplified or waning importance for certain determinants of active travel. Relatedly, the neighborhood effect of the built environment should not be standardized using one spatial extent or zoning system when evaluating different dimensions. By using disaggregate data and testing the sensitivity of applying different aggregation levels, researchers can identify the boundaries at which contextual factors exert their actual or strongest influence on the individual behaviors being studied (Kwan 2012). In this study, the specification of built environment indicators based on the strength of their association to walking emphasized the significance of isolating the physical context at each trip end on an individual's mode choice. Since most travel decisions are context-dependent, future transportation-land use studies must clearly distinguish the role of the built environment at each trip end on travel decisions for work and non-work activities.

Future efforts should address the following limitations and extend this study's contributions to research and practice. Foremost, due to limitations in our travel behavior data, a node-based analysis of the transportation-land use connection was performed by measuring the built environment around each sampled trip end. Measurement of the built environment along an observed route would be preferable and address possible measurement overlap for shorter trips in our analysis. While the average sampled trip was 2.41 miles for HBNW travel and nearly twice that for HBW trips, a potential to double-count some of the neighborhood effect of the built environment on mode choice exists in a node-based analysis, with shorter walking trips likely to be most susceptible. However, any route-level mode choice analysis of self-reported travel survey data would rely heavily on the assumptions of shortest network path, with methodologic consequences. Recent studies (Guo and Loo 2013; Broach et al. 2012) have shown that pedestrians and cyclists routinely deviate from the shortest network path for a host of reasons related to the built environment and not. Thus, assigning the shortest network path for chosen and alternative (non-chosen) travel modes and then measuring the route-level built environment following this path may be problematic. With current advancements in travel survey methods, the adoption of route-level measures of the built environment in mode choice studies may be more suitable but a reasonable analysis would require a more sophisticated model structure that incorporates route choice.

Second, the contextual features in the choice models were operationalized based on associations with walking; however, the appropriate spatial extent for studying this transportation-land use connection is likely to vary with travel speed. Pedestrians, who travel at slower speeds, have a greater ability to process the complexity of their immediate setting, so a suitable scale to measure the built environment's effect on walking is expected to be smaller than users of faster modes

(Frank and Engelke 2001). As such, the built environment connection to mode choice should be modeled by concurrently testing auto- and pedestrian-oriented spatial extents of the same indicator. Third, the phenomenon of residential self-selection warrants further attention in the mode choice analysis since decisions involving residential neighborhood and, to a lesser extent, workplace may have a confounding role in the mode used to perform HBW travel. Finally, given that travel time was a significant deterrent to walking for work and non-work trips, an exciting contribution to the evidence base would be an inspection of scaling and zoning effects of the built environment's connection to destination choice for walking (Clifton et al. 2016). In all, this study's systematic assessment of the impact of geographic scale on understanding the complex interactions between the built environment and travel behavior provides new insights and prospects for future study.

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