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Street life and the built environment in an auto-oriented US region

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ABSTRACT

Urban planners and designers believe that the built environment at various geographic scales affects pedestrian activity, but have limited empirical evidence at the street scale, to support their claims. We are just beginning to identify and measure the qualities that generate active street life, and this paper builds on the first few studies to do so. This study measures street design qualities and surrounding urban form variables for 881 block faces in Salt Lake County, Utah, and relates them to pedestrian counts. This is the largest such study to date and includes suburbs as well as cities. At the neighborhood scale, we find that D variables – development density, accessibility to destinations, and distance to transit – are significantly associated with the pedestrian activity. At the street scale, we find significant positive relationships between three urban design qualities – imageability, human scale, and complexity – and pedestrian counts, after controlling for neighborhood-scale variables. Finally, we find that pedestrian counts are positively associated with seven of twenty streetscape features – historic buildings, outdoor dining, buildings with identifiers, less sky view, street furniture, active uses, and accent building colors. This study provides implications for streetscape projects that aim to create walkable places in typical auto-oriented, medium-sized cities.

1. Introduction

Streets are important economically as movement corridors and loci of commerce. In contrast to private spaces, streets are open to everyone regardless of income, social class, and ethnicity. They are gathering places for everyone. After years of inattention to streets as public space, now more than ever, people around the world are becoming interested in the multiple purposes of streets. Recent trends include new urbanism, transit-oriented developments (TOD), tactical urbanism, complete streets, to name a few (Cervero, 2004; LaPlante & McCann, 2008; Leccese & McCormick, 2000; Lydon & Garcia, 2015). Not only urban researchers, but also property owners, street vendors, local governments, and the general public are re-discovering ‘streets,’ emphasizing the association of streets with the quality of public life (Frank et al., 2010; Gehl, 2013; Jackson, 2003; Mehta, 2013; Patterson & Chapman, 2004).

In the planning and transportation literature, travel behavior, including walking, has been related to the built environment measured in terms of the ‘D’ variables—e.g., density, diversity, design, destination accessibility, and distance to transit (Ewing & Cervero, 2010). These are gross qualities of the urban environment. Using one or more of the D variables, over 200 studies have sought to explain household travel outcomes such as trip frequencies, mode choices, trip distances, or overall vehicle miles traveled (see Ewing & Cervero, 2010 for a meta-analysis on this subject). A large subset of studies explains walking frequency, or pedestrian traffic volume, in terms of the D variables.

The urban design literature shows that subtler urban design qualities may influence walking as well (Ameli, Hamidi, Garfinkel-Castro, & Ewing, 2015; Ewing & Clemente, 2013; Maxwell, 2016), which is a significant proportion of an individual's daily travel, particularly in developing cities (Mateo-Babiano, 2016). The experience of walking down a street may have less to do with gross qualities such as intersection density than streetscape features themselves. While urban designers presume that these features are important for active street life, there is limited empirical evidence to support the claim.

Based on a comprehensive literature review and expert opinion, Ewing and Handy (2009) provide qualitative definitions of five urban design qualities:

- Imageability is the quality of a place that makes it distinct, recognizable and memorable.
- Enclosure refers to the degree to which streets and other public

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spaces are visually defined by buildings, walls, trees and other vertical elements.
- Human scale refers to a size, texture, and articulation of physical elements that match the size and proportions of people and, equally important, correspond to the speed at which people walk.
- Transparency refers to the degree to which people can see or perceive what lies beyond the edge of a street and, more specifically, the degree to which people can see or perceive human activity beyond the edge of a street.
- Complexity refers to the visual richness of a place. Complexity is related to the number noticeable differences to which a viewer is exposed per unit time.

These urban design qualities have been shown to predict pedestrian activity in a handful of studies (Ameli et al., 2015; Ewing & Clemente, 2013; Ewing, Hajrasouliha, Neckerman, Purciel-Hill, & Greene, 2016; Hamidi & Moazzeni, 2018; Maxwell, 2016). Some studies further find that pedestrian volumes are associated with individual streetscape features (e.g., street furniture, the proportion of windows, etc.) (Ewing et al., 2016; Rodríguez, Brisson, & Estupiñán, 2009). Ewing and Clemente (2013) specifically sought to validate the urban design metrics against pedestrian counts in the context of New York City (NYC), one of America's most walkable cities. Ameli et al. (2015) measured urban design qualities and validated them against pedestrian counts on 179 block faces in downtown Salt Lake City, Utah, a more typical auto-oriented city. Their study found that imageability in addition to transparency adds significantly to street vitality (Ameli et al., 2015). The same two urban design qualities were found to have significant relationships to pedestrian activity in Downtown Dallas (Hamidi & Moazzeni, 2018) and Glasgow, Scotland (Maxwell, 2016). In a new town in Iran, Bahrainy and Khosravi (2013) concluded that complexity, human scale, and continuity and cohesion—defined as "the appropriate integration of elements and permeability" (p.23)—are the three urban design qualities that affect walkability.

Existing studies, however, have limited their spatial scope to specific location types such as central cities (Ameli et al., 2015; Ewing et al., 2016; Ewing & Clemente, 2013; Hamidi & Moazzeni, 2018; Maxwell, 2016) or station areas (Rodríguez et al., 2009). This makes it difficult for planners and designers to apply the study results to their cities because most cities are still dominated by automobiles, and thus their sidewalks are almost empty or even do not exist (Moudon, Hess, Snyder, & Stanilov, 1997). Studies have shown less walking in suburban areas than urban neighborhoods (Gallimore, Brown, & Werner, 2011; Moudon et al., 1997; Rodríguez, Khattak, & Evenson, 2006), but few studies provide empirical evidence relating pedestrian volume to environmental design attributes.

The Wasatch Front Regional Council (WFRC) in Salt Lake City, Utah, is a Metropolitan Planning Organization (MPO) consisting of four counties – Salt Lake, Utah, Davis, and Weber Counties – in the Wasatch Front region. The transport system of this region, like many metropolitan areas, has become increasingly multimodal. The present study utilizes pedestrian and urban design data collected by WFRC. The Salt Lake region is typical of western metropolitan areas of medium-size and a high degree of automobile dependence. A 2012 Utah travel survey (RSG Inc., 2013) shows that in this region, 78.5% of respondents drive alone to work, which is comparable to the national average (76.6% in 2015; U.S. Census Bureau, 2015). The walk share of work trips in this region is 3.1%, also similar to the national average, 2.8%. Also, the Salt Lake region's size and urban form represent typical auto-dependent, medium-sized cities. The *Costs of Sprawl* (Ewing & Hamidi, 2017) finds that Salt Lake City MSA (metropolitan statistical area) ranked 94 out of 221 MSAs in the U.S. with a sprawl index of 106.96, close to the average index, 100.

This paper is distinguishable from the travel literature in that it relates pedestrian volumes to both conceptual urban design qualities and specific streetscape features while controlling for neighborhood-scale built environmental variables. By doing so, this study adds to our understanding of how both neighborhood- and street-scale built environment characteristics are related to walkability, measured by pedestrian traffic volumes. It thereby has practical implications for urban planners and designers.

2. Methodology

2.1. Study area

To measure urban design qualities of streets, WFRC conducted field work in over 1200 blocks throughout the Wasatch Front in 2015. The Wasatch Front ranges from south of Provo and Orem in Utah County to north of Ogden in Weber County in Utah. Salt Lake City falls near the middle of the Wasatch Front, and is the largest jurisdiction in Salt Lake County, our study area. WFRC selected streets that are of key interest, exemplary, or generally representative of the region. Streets were also selected if they fell within designated centers in the Wasatch Choice for 2040 Vision. Like many metropolitan planning organizations, WFRC envisions a region with a hierarchy of mixed-use centers connected by high-quality transit.

Like many mid-sized cities, the study area consists of a small, dense downtown and widespread suburban areas. The downtown Salt Lake City area is dense, mixed-use, and well-connected through transit, distinctive from the rest of the region. Pedestrians are most prevalent in the downtown area. As mentioned above, this study is unique in that the study area includes these two distinct development patterns. At the same time, like other typical U.S. regions, the Salt Lake region is automobile-oriented, partially due to large blocks and wide roads.

Block face, the frontage on one side of a block, is our unit of observation. If a block was too long, it was divided into walkable subsections. For each block face, streetscape features were measured and pedestrians were counted by WFRC. Observation protocols of Ewing and Clemente (2013) were used, as explained in the next section. The methodology and resulting interactive maps can be found at a WFRC ArcGIS website (https://wfrcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=7d1b1df5686c41b593d1e5ff5539d01a).

For this study, out of over 1200 block faces surveyed across the region, 881 segments within Salt Lake County were selected based on other data availability such as parcel-level land use data (Fig. 1).

2.2. Pedestrian activity

We are modeling the average number of pedestrians encountered on four passes up and down a given block. The four passes were averaged to obtain a representative number of pedestrians for each block, and this was rounded to the nearest integer.

All fieldwork was conducted between 10 am and 5 pm on weekdays. Pedestrian counts were taken during the whole year of 2015. The distribution and descriptive statistics of pedestrian counts are presented in Fig. 2.

2.3. Urban design measures and streetscape features

Since the five urban design qualities defined above are conceptual, Ewing and Handy (2009) operationalized them in terms of 20 streetscape features based on expert panel ratings of the qualities and content analyses of video clips (see Table 1). The expert panel consisted of 10 leading urban designers/planners who were asked to rate 48 video clips in terms of the five qualities, and then the streetscape features were estimated for each clip by independent raters. The streetscape features were combined into indices based on the coefficients in Table 1. *p*-Values of the individual variables contributing to the urban design qualities are also presented in Table 1.

Imageability is a linear function of seven streetscape variables, enclosure a linear function of five streetscape variables, human scale a

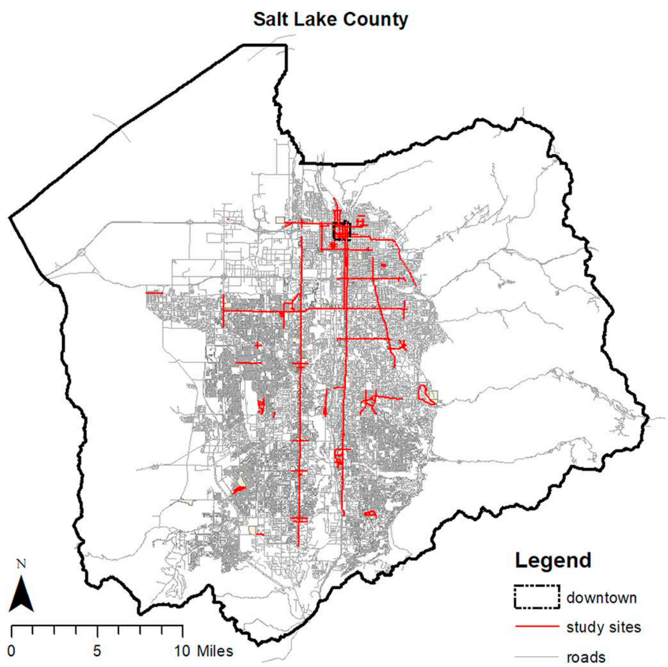

Fig. 1. Study sites (881 block faces).

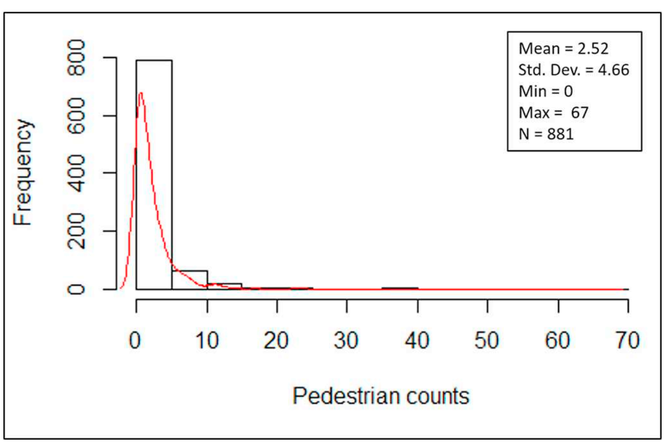

Fig. 2. Frequency distribution and descriptive statistics of pedestrian counts.

linear function of five streetscape variables, transparency a linear function of three streetscape variables, and complexity a linear function of five streetscape variables. See Ewing and Handy (2009) for a detailed description of how these composite functions were derived.

2.4. "D" variables

For neighborhood-level built environment variables, we drew on characterizations of D variables from Ewing and Cervero (2010). GIS data were acquired from the Salt Lake County Assessor's Office, 2010 Decennial Census, and Tiger 2010 Census Block shapefiles.

D variables were computed for the quarter-mile buffer around each street segment. A quarter mile was selected as a standard walking distance beyond which walk frequency drops off rapidly (Ewing & Clemente, 2013). One density variable is the average floor area ratio (FAR), computed as the total building floor area for all parcels within the buffer, divided by the total area of tax lots. The other is the average net population density, computed as the population of all census blocks whose centroids fall within the buffer divided by the total area of residential tax lots whose centroids fell within the buffer, measured in 1000 residents per square mile.

Table 1
Streetscape features contributing to urban design qualities.
(Adapted from Ewing & Handy, 2009).

Urban design quality	Significant physical features	Coefficients	*p*-Value
Imageability	People (#)[a]	0.024	< 0.001
	Proportion of historic buildings	0.970	< 0.001
	Courtyards/plazas/parks (#)	0.414	< 0.001
	Outdoor dining (y/n)	0.644	< 0.001
	Buildings with non-rectangular silhouettes (#)	0.080	0.036
	Noise level (rating)	−0.183	0.045
	Major landscape features (#)	0.722	0.049
	Buildings with identifiers (#)	0.111	0.083
Enclosure	Proportion street wall—same side	0.716	0.001
	Proportion street wall—opposite side	0.940	0.002
	Proportion sky across	−2.193	0.021
	Long sight lines (#)	−0.308	0.035
	Proportion sky ahead	−1.418	0.055
Human scale	Long sight lines (#)	−0.744	< 0.001
	All street furniture and other street items (#)	0.036	< 0.001
	Proportion first floor with windows	1.099	< 0.001
	Building height—same side	−0.003	0.033
	Small planters (#)	0.050	0.047
Transparency	Proportion first floor with windows	1.219	0.002
	Proportion active uses	0.533	0.004
	Proportion street wall—same side	0.666	0.011
Complexity	People (#)[a]	0.027	< 0.001
	Buildings (#)	0.051	0.008
	Dominant building colors (#)	0.177	0.031
	Accent colors (#)	0.108	0.043
	Outdoor dining (y/n)	0.367	0.045
	Public art (#)	0.272	0.066

Note: [a]Excluded from the models in this research because the number of people on the street is our dependent variable.

Diversity was measured by an entropy variable, which is related to the number of different land uses within the quarter-mile buffer and the degree to which they were balanced in floor area. Entropy was computed with the formula:

$$\text{entropy} = -[\text{residential share} * \ln(\text{residential share}) + \text{retail share} * \ln(\text{retail share}) + \text{office share} * \ln(\text{office share})] / \ln(3)$$

where ln refers to the natural logarithm of the share of floor area and the shares were computed based on floor area of each use for tax lots within the buffer. Mixed-use areas would be expected to generate more pedestrian activity than single-use residential or office areas (entropy scores > 0 would be expected to generate more pedestrian activity than entropy scores of 0). We are measuring entropy in terms of three uses—residential, retail, and office—that might be expected, when in balance, to generate interchanges of trips (per Chapter 7 of the *ITE Trip Generation Handbook; Institute of Transportation Engineers, 2008*). In addition, the percent of retail uses in the quarter-mile catchment area is added as a control variable as additional retail may induce pedestrians.

Gross measures of street network design were computed with GIS. Intersection density, a measure of the block size, was computed as the number of intersections within the quarter mile buffer divided by the gross area of the buffer in square miles. The proportion of four-way intersections, a measure of street connectivity, was computed as the number of four-way intersections divided by the total number of intersections within the buffer area.

Destination accessibility was represented by two variables – Walk Scores® and job accessibility. Walk Score® rates the walkability of a specific address on a numeric scale from 0 to 100, by compiling the number of nearby stores and amenities within one and a half miles. The 13 amenity categories are grocery stores, coffee shops, restaurants, bars, movie theaters, schools, parks, libraries, bookstores, fitness centers, drug stores, hardware stores and clothing/music stores (Carr, Dunsiger, & Marcus, 2010). Amenities within 0.25 miles receive maximum points, and no points are awarded for amenities farther than one and a half miles from the address.

Regional job accessibility is another important measure of destination accessibility, defined as the percentage of jobs that can be reached within 10-minutes by automobile, which tends to be highest at central locations and lowest at peripheral ones (Ewing & Cervero, 2010). Different ranges – 20-minute and 30-minute – were also tested, but the 10-minute extent was chosen for its highest correlation with our dependent variable, pedestrian counts. We used travel time skims and employment data at the TAZ (traffic analysis zone) level acquired from WFRC. Distance to transit was measured as the street network distance from the block face center point to the nearest rail station. Another transit variable is transit stop density, measured as the number of stops per square mile.

Two demographic variables were also included. One is the average household size for blocks whose centroids fall within the quarter mile buffer around each block face. Household size is positively associated with pedestrian traffic volume in the literature (Ameli et al., 2015; Ewing et al., 2016). The other is median household income, hypothesizing that residents in more affluent neighborhoods might walk less and drive more (Ewing et al., 2015; Owen et al., 2007). Other evidence suggests that walking may be less common in deprived areas (see Dalton, Jones, Panter, & Ogilvie, 2013Fishman, Böcker, & Helbich, 2015). Block-group-level median household incomes were gathered from the American Community Survey (2012 5-year estimates) and assigned to the ¼-mile buffers based on the relative areas of the census block groups (i.e., the spatial apportioning technique).

At the block level, we estimated additional D variables: average floor area ratio (FAR) for the block face, computed as the total building floor area for parcels abutting the street, divided by the total area of tax lots; an entropy measure based on floor area for parcels abutting the street, computed with the formula above; and proportion of retail frontage along the block face, on the assumption that retail frontage generates more pedestrian activity than other types of frontage. The length of each block face was also included as a control variable because after controlling for other influences, the longer the block, the more pedestrians will be present on it at any given time.

Three additional site conditions relevant to walking and pedestrian volume were also accounted for: 1) sidewalk coverage as a ratio of sidewalk length to block face length; 2) car traffic volume measured as Annual Average Daily Traffic (AADT), and 3) a downtown dummy variable, coding 1 for the downtown Salt Lake City area. The defining boundary of downtown Salt Lake City is a downtown 'Free Fare Zone' (629 acres) in which Utah Transit Authority (UTA) allows transit riders to board at no cost.

One final control variable was the month when the fieldwork was conducted. An analysis of variance showed that there was a statistically significant association between observation months and pedestrian counts, and a Tukey's post-hoc test shows that pedestrian counts are significantly higher only in October compared to the other months at the 0.05 significance level. Thus, October was used as a reference group in a dummy 'month' variable.

All variables used in this study and their summary statistics are presented in Table 2. We expect positive relationships between D variables and the pedestrian counts, except for three variables – distance to rail station, median household income, and car traffic volume (i.e., longer distance to rail station, higher neighborhood income, and more car traffic would be negatively associated with pedestrian traffic volume).

3. Analyses

3.1. Negative binomial regression

Our dependent variable, the average number of pedestrians counted by the observer within a block, is expected to have many zero or low values and a few high values, as in similar studies (Ameli et al., 2015; Ewing et al., 2016; Ewing & Clemente, 2013). When the dependent variable is a count with many small values and few large ones, two regression methods, Poisson and negative binomial, are applicable (Dumbaugh & Rae, 2009; Marshall & Garrick, 2011). If the dependent variable is over-dispersed, that is, the variance of counts is greater than the mean, negative binomial regression is appropriate. In this study, counts range from 0 to 67, with a mean value of 2.5 and a standard deviation of 4.7 (Fig. 2). We found over-dispersion in Poisson models using a *dispersion test* in R 3.4.0 software, and the negative binomial model is, therefore, more appropriate.

We used the software package R 3.4.0 and *glm.nb* function to estimate three negative binomial models of pedestrian counts. Model 1 contains the standard D variables without any street-level variables. Model 2 includes the five urban design quality metrics in addition to the D variables, and Model 3 includes the streetscape variables in addition to the same D variables.

3.2. Spatial filtering

The pedestrian count data in this study could create an issue of spatial autocorrelation (Anselin, 1988; Anselin, Florax, & Rey, 2004), meaning that the pedestrian volume in one sampled block is highly correlated with those in nearby sampled blocks. This is true for many reasons – walk trips that extend from one block to the next, similar demographics or urban form characteristics, or a large-scale destination in one block (e.g., convention center, theater, plaza). Moran's I spatial statistic is a commonly used measure to check for spatial autocorrelation. The null hypothesis of Moran's I is that the variable is randomly distributed among the observations in the study area. Moran's I for pedestrian counts in this study is 5.840 ($p < 0.001$) indicating a strongly positive spatial relationship.

An important assumption of regression models is that residuals are independent of each other and randomly distributed (i.e., homoscedastic). Any spatial pattern in the residuals violates this assumption and the model lacks validity. Before controlling for spatial autocorrelation, the Model 1 residuals' Moran's I is 0.119 and marginally significant ($p = 0.067$). Similarly, both Model 2 and Model 3 have spatial autocorrelation issues on their residuals slightly (Moran's Is are 0.138 and 0.103, respectively).

As a robust tool to deal with the spatial autocorrelation issue in regression, spatial filtering separates spatial and non-spatial effects of a variable (Griffith, 2013). This study employs the spatial eigenvector mapping technique based on the eigenvector analysis of the spatial lag operator. During the analysis, eigenvectors that are most effective at reducing spatial autocorrelation in the residuals are chosen and added to the regression as additional control variables (Dormann et al., 2007). The advantage of this approach is that when adding spatial predictors to the regression model, the coefficients of the independent variables do not change. The R 3.4.0 software has a function called *ME* (the Moran Eigenvector function) in the *spdep* package. The *ME* is appropriate for removing spatial autocorrelation from the residuals of generalized linear models, including negative binomial regression. After the spatial filtering was applied, the Moran's I of residuals for the adjusted Model 1 indicates no spatial autocorrelation (Moran's $I = 0.071$; $p = 0.193$). Likewise, the adjusted Model 2 and Model 3 have no spatial autocorrelation in their residuals (Moran's Is are 0.027 and 0.033, respectively). Also, ANOVA tests show that all three spatial filtering models

Table 2
Descriptive statistics (n = 881 block faces).

Category	Variable	Mean	Median	Min.	Max.	Std. dev.
Outcome	Pedestrian count	2.5	1.0	0.0	67.0	4.7
D variables	FAR	0.4	0.3	0.0	4.4	0.5
(1/4-mile buffer)	Population density	22.9	14.3	0.0	285.0	28.7
	Entropy	0.6	0.7	0.0	1.0	0.2
	% retail	0.2	0.2	0.0	0.7	0.1
	Intersection density	105.7	103.2	12.1	265.0	44.2
	% 4-way	30.8	25.8	0.0	96.2	19.9
	Walk score	64.8	66.0	6.0	98.0	16.3
	% jobs within 10-min by car	13.3	12.7	0.8	27.6	6.0
	Distance to rail	1.5	0.9	0.0	8.8	1.5
	Stop density	37.0	33.2	0.0	114.3	22.7
	Household size	1.9	2.0	0.0	4.1	0.8
	Median household income ($1000)	53.5	48.5	0.0	199.5	24.4
D variables (block)	Block FAR	0.4	0.3	0.0	7.3	0.8
	Block entropy	0.2	0.0	0.0	1.0	0.3
	% block retail	0.3	0.2	0.0	1.0	0.3
	Block length	871.6	797.6	320.4	1948.0	228.4
	AADT (log-transformed)	9.6	9.8	7.6	12.3	0.8
	Side coverage (%)	0.8	0.9	0.0	1.0	0.3
	Downtown (y/n)	0.1	0.0	0.0	1.0	0.3
Time	Month (October)	0.2	0.0	0.0	1.0	0.4
Urban design qualities	Imageability	4.0	3.8	1.6	13.4	1.3
	Enclosure	1.3	1.2	−0.2	4.2	0.8
	Human scale	2.6	2.2	0.4	20.4	2.0
	Transparency	2.3	2.2	1.7	4.0	0.4
	Complexity	5.4	5.2	3.1	15.0	1.3
Streetscape features	% historic buildings	0.1	0.0	0.0	0.9	0.1
	Parks/plazas (#)	0.7	0.0	0.0	5.0	1.0
	Outdoor dining (yes/no)	0.3	0.0	0.0	7.0	0.7
	Buildings with non-rectangular shapes (#)	9.3	9.0	0.0	37.0	5.7
	Noise level (rating)	3.4	3.5	1.3	5.0	0.7
	Major landscape features (#)	0.2	0.0	0.0	4.0	0.6
	Building w/identifiers (#)	6.0	5.0	0.0	27.0	4.8
	% street wall (same side)	0.3	0.1	0.0	1.0	0.3
	% street wall (other side)	0.2	0.1	0.0	1.0	0.3
	% sky across	0.2	0.3	0.0	0.5	0.1
	Long sight lines (#)	2.3	2.0	0.0	3.0	0.8
	% sky ahead	0.3	0.3	0.0	0.5	0.1
	% 1st floor w/windows	0.1	0.0	0.0	0.9	0.2
	Building height	19.4	20.0	0.0	100.0	10.6
	Small planters (#)	1.0	0.0	0.0	82.0	4.1
	Street furniture (#)	40.0	31.0	0.0	334.0	34.0
	% of active uses	0.6	0.7	0.0	1.0	0.3
	Buildings (#)	6.3	6.0	0.0	20.0	2.5
	Dominant building color (#)	5.3	5.0	1.0	12.0	1.9
	Accent colors (#)	6.2	6.0	0.0	12.0	2.1
	Public art (#)	1.1	0.0	0.0	20.0	2.2

outperform their counterparts – non-spatial models ($p < 0.001$).

4. Results

Three negative binomial models of pedestrian counts are presented in Table 3. All three models have highly significant likelihood ratio chi-squares, indicating a good fit to the data compared with a null model. The likelihood ratio chi-square of model 2 relative to model 1—141.7 with 9 degrees of freedom—indicates that the fit is significantly better for model 2 at the 0.001 probability level. Likewise, the likelihood ratio chi-square of model 3 relative to model 1—198.8 with 22 degrees of freedom—indicates that model 3 has a significantly better fit. The Akaike information criterion (AIC) is lower in model 3 than in model 2, demonstrating a relatively better quality of model 3.

Then we tested for multicollinearity. The highest variance inflation factor (VIF) values are found in FAR variables in all three models – 5.58 in Model 1, 7.97 in Model 2, and 8.21 in Model 3, all of which are below the standard ceiling value for multicollinearity of 10.0 (Hair, Black, Babin, & Anderson, 2009). These results show that there is likely no multicollinearity among predictors in all models and based on these results, we believe our coefficients are efficient and unbiased.

In all models, the floor area ratio (FAR), transit stop density, proportion of block retail, household size, and median household income are significantly related to pedestrian counts at the 0.05 probability level. Intersection density is also significant in all models but has unexpected negative sign. A measure of destination accessibility, the percentage of jobs within 10-minutes by car, is significant in Model 1 and 3. Likewise, block length and average car traffic volume (AADT) are significant only in Models 1 and 3.

Of the remaining D variables, the measures of amenity accessibility (i.e., Walk Score®) is only significant in Model 1, and becomes insignificant when either urban design qualities or streetscape features are included (Models 2 and 3). The downtown variable is only significant in Model 2. Sidewalk coverage is not significant in any model, which may be attributed to the fact that 96% of street segments in the study area have a sidewalk on the sample side of the street.

We would particularly note that the two entropy variables are not significant in any of the models. Entropy is the most commonly used measure of land use diversity in built environment-travel literature (Ewing & Cervero, 2010), and therefore is appropriately tested in this study. Yet, our two entropy variables are not significant, while our block-level retail proportion variable is significant. So having an exact

Table 3
Negative binomial regression models of pedestrian counts (n = 881 block faces).

Variable		Model 1: base model		Model 2: urban design quality		Model 3: streetscape features	
		Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Intercept		0.400	0.554	−0.882	0.595	−0.877	0.575
D variables	FAR	0.553***	0.098	0.225**	0.101	0.225**	0.094
(1/4-mile buffer)	Population density	0.001	0.001	0.001	0.001	0.000	0.001
	Entropy	0.055	0.176	0.213	0.171	0.027	0.181
	% retail use	−0.533*	0.321	−0.320	0.308	−0.210	0.299
	Intersection density	−0.003***	0.001	−0.002***	0.001	−0.003***	0.001
	% 4-way	0.001	0.002	0.001	0.002	0.005**	0.002
	Walk score	0.010***	0.003	0.004	0.003	0.004	0.003
	% jobs within 10-min by car	0.023***	0.009	0.014	0.008	0.030***	0.008
	Distance to rail	−0.010	0.034	−0.016	0.031	−0.016	0.031
	Stop density	0.005**	0.002	0.004**	0.002	0.005***	0.002
	Household size	0.221***	0.057	0.215***	0.055	0.222***	0.054
	Median household income ($1000)	−0.006***	0.002	−0.008***	0.002	−0.005**	0.002
D variables	Block FAR	−0.078*	0.045	−0.034	0.044	−0.002	0.046
(block face)	Block entropy	0.075	0.108	−0.132	0.102	0.011	0.100
	% block retail	0.684***	0.1106	0.414***	0.1054	0.3261***	0.1094
	Block length	0.0004***	0.000	0.000	0.000	0.000**	0.000
	AADT (log)	−0.147***	0.050	−0.060	0.048	−0.128**	0.052
	Side coverage	−0.139	0.132	−0.049	0.126	−0.207*	0.124
	Downtown (y/n)	0.145	0.185	0.400**	0.176	0.044	0.168
Time	Month (October)	0.052	0.080	−0.068	0.078	−0.015	0.080
Urban design qualities	Imageability			0.137***	0.034		
	Enclosure			−0.151**	0.061		
	Human scale			0.036	0.026		
	Transparency			0.092	0.122		
	Complexity			0.108***	0.039		
Streetscape features	% historic buildings					0.771**	0.307
	Parks/plazas (#)					0.048	0.036
	Outdoor dining (yes/no)					0.216***	0.040
	Buildings with non-rectangular shapes (#)					−0.027***	0.008
	Noise level (rating)					0.082	0.058
	Major landscape features (#)					−0.066	0.063
	Building w/identifiers (#)					0.021**	0.011
	% street wall (same side)					−0.185	0.186
	% street wall (other side)					0.034	0.137
	% sky across					0.643*	0.352
	Long sight lines (#)					0.132**	0.055
	% sky ahead					−0.848**	0.376
	% 1st floor w/windows					−0.175	0.282
	Building height					0.000	0.003
	Small planters (#)					−0.014**	0.006
	Street furniture (#)					0.004***	0.001
	% of active uses					1.093***	0.158
	Buildings (#)					0.021	0.013
	Dominant building color (#)					−0.060**	0.028
	Accent colors (#)					0.056**	0.026
	Public art (#)					0.033*	0.019
Spatial filtering eigenvector	Fitted (ME) (1)	3.625***	0.933	3.663***	0.846	−1.504**	0.726
	Fitted (ME) (2)	−2.420***	0.651	3.861***	0.999	2.967***	0.857
	Fitted (ME) (3)	–	–	2.298***	0.643	2.112***	0.665
	Fitted (ME) (4)	–	–	−1.263*	0.760	–	–
	Fitted (ME) (5)	–	–	1.413**	0.716	–	–
	Fitted (ME) (6)	–	–	−1.153	0.838	–	–
Sample size			881		881		881
2 * log-likelihood (df)			−3161.2 (858)		−3019.5 (849)		−2962.4 (836)
AIC			3209		3085		3054

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

balance of the uses, and an entropy score of 1, does not appear to be as conducive to pedestrian activity as having a disproportionate amount of retail frontage.

After controlling for the D variables, we next focus on the five urban design quality variables in Model 2. Imageability and complexity are positively related to pedestrian counts at the 0.01 probability level. Enclosure is also significant, but the sign is unexpectedly negative. Urban design qualities as a group add significantly to the explanatory power of the pedestrian activity model.

The seven streetscape variables that proved significant at the 0.05 probability level with expected signs, in combination with the standard D variables, are the proportion of historic buildings, the presence of outdoor dining along the block face, the number of buildings with identifiers, the proportion of sky ahead, the number pieces of street furniture, the proportion of active uses, and the number of accent building colors. There are four significant variables that show an unexpected sign – the number of buildings with non-rectangular shapes, the number of long sight lines, the number of small planters, and the number of dominant building colors. As a whole, the streetscape variables improved the fit of the model.

Furthermore, we partitioned the dataset to distinguish downtown from suburbs, and to see if correlates with street life are the same for the two. Because of the small sample size of downtown street segments ($n = 62$), only a suburban model is considered valid and analyzed (results are not presented in a table). Being consistent with the overall model, the suburban model shows that multiple built environment and sociodemographic variables—job accessibility, transit stop density, intersection density, household size, household income, the proportion of block retail, block length—are associated with the pedestrian volume at $p < 0.05$ significance level. On the other hand, population density, % 4-way intersection, and car traffic volume (AADT) become not statistically significant.

Interestingly, human scale (B = 0.07; $p = 0.04$), in addition to imageability, enclosure, and complexity, turns out to be associated with pedestrian volume in the suburban-only model. Among streetscape features (Model 3), percentage of historic buildings and buildings with identifiers become not significant in the suburban model while outdoor dining (B = 0.26, $p < 0.01$), street furniture (B = 0.27, $p < 0.01$), long sight line (B = 0.12, $p = 0.04$), street furniture (B = 0.004, $p = 0.02$), active uses (B = 0.94, $p < 0.01$), and accent building colors (B = 0.06, $p = 0.04$) remain positively related to the number of pedestrians.

5. Discussion and conclusions

This study explains pedestrian counts on 881 block faces in Salt Lake County, Utah in terms of surrounding built environment characteristics – D variables at the neighborhood scale and urban design qualities and streetscape features at the street scale.

The first implication for planning practice is that context is important, particularly development density. Municipalities can amend zoning or adopt a form-based code to achieve high values of floor area ratio or population density. In addition, streets need to have more retail frontage. Access to jobs, amenities, or rail transit service is also important but might be less so than specific streetscape features. Land use diversity and street network variables are not significant in most models. In particular, street design might be better explained by subtler urban design qualities than a gross measure of intersection density or proportion of four-way intersections.

Among five urban design qualities, significant measures vary among studies. Table 4 shows a comparison of five urban design quality models in five different studies, including Model 2 in this study. The significance levels demonstrate the significant association of specific D variables and urban design qualities with pedestrian activity.

In this study, two out of five urban design qualities were found to be significant for more pedestrians on street: imageability and complexity. Imageability proves important in three out of four studies, including the current one (Table 4). It is described as the quality of a place that makes it distinctive, recognizable, and memorable (Ewing & Handy, 2009). Interestingly, human scale is positively associated with pedestrian volume only in suburban areas. These results may reflect that even in an auto-oriented place, more place-making features and comfortable-scale streetscape would encourage people to choose the route.

The non-significance of transparency is contradictory to the other four studies conducted in NYC (Ewing & Clemente, 2013), downtown Salt Lake City (Ameli et al., 2015), downtown Dallas (Hamidi & Moazzeni, 2018), and central street segments in Glasgow, Scotland (Maxwell, 2016) (Table 4). In the equation for urban design qualities (Table 1), transparency mainly depends on the proportion of the first floor with windows. While it can range from 0 to 1 theoretically, that feature is not highly variable in this study, with a mean of 0.11, median of 0, and standard deviation of 0.20 (Table 2). This might imply that transparency, the degree to which people can see what lies beyond the edge of a street (Ewing & Handy, 2009), is more relevant in highly urban places such as downtowns than lower-density suburbs. On the other hand, in lower density areas with streets like those in this study, improving imageability, complexity, and human scale might be more conducive to street walkability.

Out of 20 streetscape features that were found to have a relationship to urban design qualities (Ewing, Handy, Brownson, Clemente, & Winston, 2006), this study could identify seven significant streetscape features that are associated with pedestrian volumes. The first three features are the number of historic buildings, the presence of outdoor dining, and the number of buildings with identifiers. The building identifier is defined as clear signs or universal symbols that reveal a building's street-level use – for example, a steeple for a church, tables and chairs for a restaurant, or clear words like "Joe's Pub" (Ewing & Clemente, 2013). These two variables are important elements of imageability. The presence and arrangement of outdoor dining and identifiers would capture visitors' attention and create a lasting impression.

The fourth significant feature is the percentage of sky ahead, or frame of vision. This variable is negatively associated with pedestrian counts, implying that more enclosed streets might generate more pedestrians. However, in the urban design quality model (Model 2), enclosure was not positively related to pedestrian volume. Thus, in the typical mid-size city having wide-open streets, enclosure might be less important than imageability or complexity. From observation in many American cities, great streets do not always have continuous building facades of roughly comparable height that bound space and create an outdoor room. They tend to have these in older European cities, but not so much in the United States. In the book *Pedestrian- and Transit-Oriented Design*, Ewing and Bartholomew (2013) categorized the "street wall" effect, described above, as a worthwhile addition to a street rather than an essential feature of a great street.

The fifth feature is the number of pieces of street furniture or other street items (e.g., tables, benches, vendors, trash cans, bike racks, street lights, etc.). Providing street furniture and specifically outdoor seating is a common recommendation for activating public spaces, and this study supports this recommendation. The seventh feature is the percentage of active uses, defined as shops, restaurants, public parks, and other uses that generate significant pedestrian traffic. Inactive uses include blank walls, driveways, parking lots, vacant lots, abandoned buildings, and offices with no apparent activity. A lesson from this finding is to monitor the use of street frontage before investing in streetscape projects. For example, a corridor that is losing its commercial identity to inactive uses may not be a priority for streetscape improvements.

The last feature is the number of accent building colors, an important element that provides a street with complexity (Table 1). More complex streets have higher levels of visual richness, which then creates visual interest for pedestrians. Compared to the New York study (Ewing et al., 2016), diverse building colors might be helpful in low- to medium-density cities where visual enclosure is not achieved.

In this study, we found several variables showing unexpected signs – intersection density (in all models), enclosure (in model 2), and the number of buildings with non-rectangular shapes (in model 3). Compared to the previous downtown-focused studies, these three variables having unexpected signs can be explained by the unique landscape of Salt Lake region. These results could be, however, applied to other cities with similar size and urban form.

Pedestrians are most prevalent in the downtown Salt Lake City area where blocks are long (i.e., intersection density is low) and most buildings are rectangular. On the other hand, more intersections and more non-rectangular buildings can be found in single-family residential neighborhoods having fewer pedestrians. This difference would yield negative relationships between the intersection density or the non-rectangular-shape buildings and pedestrian counts. Thus, street design might be better described by subtler urban design qualities than a gross measure of intersection density or proportion of four-way intersections. Also, while the other factors such as outdoor dining or building identifiers are related to better imageability and more

Table 4
Comparison on statistical significance of D variables and urban design qualities in five studies.

Category	Variable	Ewing & Clemente, 2013 (New York, USA)	Ameli et al., 2015 (Salt Lake City, USA)	Maxwell, 2016 (Glasgow, Scotland)	Hamidi & Moazzeni, 2018 (Dallas, USA)	This study (Model 2) (Salt Lake County, USA)
Density	FAR	***	*	***	**	***
	Population density	***	***	–	–	n.s.
	Block FAR	***	n.s.	–	–	n.s.
Diversity	Entropy	n.s.	***	n.s.	–	n.s.
	Block entropy	n.s.	n.s.	–	**	n.s.
Design	Intersection density	n.s.	n.s.	n.s.	***	*** (Unexpected sign)
	% 4-way	n.s.	n.s.	n.s.	–	n.s.
Destination accessibility	Walk score	n.s.	n.s.	***	–	n.s.
	Job accessibility	–	–	–	–	n.s.
Distance to transit	Distance to rail	***	***	***	***	n.s.
	Stop density	–	–	–	–	**
Demographics	Household size	***	***	**	n.s.	***
	Median hh income	–	–	–	–	***
Others	% block retail	***	n.s.	–	–	***
	Block length	***	**	***	n.s.	n.s.
Urban design qualities	Imageability		***	***	**	***
	Enclosure	* (Unexpected sign)	n.s.	n.s.	n.s.	** (Unexpected sign)
	Human scale	*	n.s.	n.s.	n.s.	** (Only in suburban areas)
	Transparency	***	***	***	***	n.s.
	Complexity	n.s.	n.s.	n.s.	n.s.	***

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.
n.s.: not significant.
–: not included in the study.

pedestrians, the number of buildings with non-rectangular shapes would not be an important streetscape feature for pedestrian experience in a smaller region.

In the case of the enclosure, in a city with homogenous sprawled landscapes, the higher level of enclosure might actually detract from the pedestrian experience by, for example, blocking sunlight. Table 4 shows that none of the previous studies including the current one found a positive relationship between enclosure and pedestrian counts (Ameli et al., 2015; Ewing & Clemente, 2013; Maxwell, 2016). It may be that, after controlling for such attributes as FAR and population density, enclosure is not an important urban design quality for pedestrians.

In sum, there are some takeaways for medium-size cities and 'non-downtown' neighborhoods. A local government might focus streetscape investments in areas that have active uses. Also, it might focus less on enclosure and transparency, and more on historic buildings, outdoor dining, seating, adding identifiers to the buildings, and varying building colors. These features are found in many European cities which have car-free streets throughout the city, with many people enjoying the outdoor social and cultural activities (European Commission, 2004). If we provide memorability and visual richness, people might walk more, even in the suburbs. This result delivers a positive, empowering message – you don't have to rebuild everything completely; focus on enhancing what you have.

Limitations of this study relate to both in validity and in reliability. In terms of the external validity of our findings, cities in Salt Lake County do not represent the variety of cities in the United States, cities in other developed nations, and cities in the developing world. Nevertheless, many cities in developed and developing countries are also dominated by personal cars (Appleyard, 1983; Castillo-Manzano, Lopez-Valpuesta, & Asencio-Flores, 2014; Liu, He, Wu, & Webster, 2010). In fact, the emerging pattern of results from such studies is complex and challenging to synthesize. A future study could repeat this validation study in multiple cities characterized by more diverse built environments.

In terms of internal validity, while our models include comprehensive measures of built environments such as D variables, urban design qualities, and streetscape features, there could be missing variables that are also correlated with pedestrian counts. For example, pedestrian safety, a significant predictor of pedestrian traffic volume, could be measured in more precise ways than with vehicle traffic volume or AADT, used in this study (Boarnet, Forsyth, Day, & Oakes, 2011; Landis, Vattikuti, Ottenberg, McLeod, & Guttenplan, 2001; Miranda-Moreno, Morency, & El-Geneidy, 2011; Rodríguez et al., 2009).

Also with respect to internal validity, a strong association has been shown to exist between the built environment and travel in dozens of studies, even those that control for self-selection (Ewing & Cervero, 2010). The consistency of these findings, in so many different settings, is evidence of so-called environmental determinism, that the environment in fact affects travel behavior. Association is one of the necessary conditions for causal inference. However, it is only one condition and causation could be in the reverse direction. It is certainly possible that heavy pedestrian traffic has caused developers to put windows on the street or the city to install street furniture as opposed to windows and street furniture causing pedestrian traffic to increase. At the very least, both could be true.

Finally, in terms of significant associations, the model with the most independent variables has 45 of them (see Table 3, column 3). It is certainly possible, at the 0.05 significance level, that two or even three of the variables that appear significant really are not. This type 1 error is always a threat when there are many independent variables in a multi-variate analysis. Having said that, we wanted to depict the effect size and significance level of each predictor in order to help policy makers have more complete understanding about each discussed feature of streets.

A threat to the reliability of our results is the limited counts done on each block face. Each block face was observed four times as an observer walked up and down the block face. The days and times of the counts were variable. Field counts during lunch hours or after 4 pm might be higher than those at other times of a day. Our second research recommendation would be to collect the data for a longer period at consistent times of day on each street segment or to use automated pedestrian counters. For example, Ameli et al. (2015) conducted half hour counts in standardized time periods to minimize sampling error. One of the new automated pedestrian counters such as passive infrared counters, micro radar sensors, or portable fisheye cameras will probably need to be employed for studies of this type in the future. For example, a surveyor could place the counter at midblock and then measure urban design qualities while the counts are underway, so as not to lose this time. With the advancement of methodology and reliable and valid empirical evidence, this study and its progeny will provide urban planners and designers with a more compelling guidance for streetscape projects that aim to create walkable places and vibrant street life.

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