

1 **Street Life and the Built Environment in an Auto-oriented US Region**

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30 **Abstract**

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

46

47 **Keywords**

48 Pedestrian volume, Streetscape Features, Urban Design Measures, Walkability, Spatial
49 filtering

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52 **Introduction**

53 Streets are important economically as movement corridors and loci of commerce. In contrast
54 to private spaces, streets are open to everyone regardless of income, social class, and ethnicity.
55 They are gathering places for everyone. After years of inattention to streets as public space,
56 now more than ever, people around the world are becoming interested in the multiple purposes
57 of streets. Recent trends include new urbanism, transit-oriented developments (TOD), tactical
58 urbanism, complete streets, to name a few (Cervero, 2004; LaPlante & McCann, 2008; Leccese,
59 2000, Lydon & Garcia, 2015). Not only urban researchers, but also property owners, street
60 vendors, local governments, and the general public are re-discovering ‘streets,’ emphasizing
61 the association of streets with the quality of public life (Frank et al., 2010; Gehl, 2013; Jackson,
62 2003; Mehta, 2013; Patterson and Chapman, 2004).

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

71 The urban design literature shows that subtler urban design qualities may influence walking as
72 well (Ameli et al., 2015; Maxwell, 2016; Ewing and Clemente, 2013), which is a significant
73 proportion of an individual's daily travel, particularly in developing cities (Mateo-Babiano,
74 2016). The experience of walking down a street may have less to do with gross qualities such
75 as intersection density than streetscape features themselves. While urban designers presume

76 that these features are important for active street life, there is limited empirical evidence to
77 support the claim.

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

- 80 • Imageability is the quality of a place that makes it distinct, recognizable and
81 memorable.
- 82 • Enclosure refers to the degree to which streets and other public spaces are visually
83 defined by buildings, walls, trees and other vertical elements.
- 84 • Human scale refers to a size, texture, and articulation of physical elements that match
85 the size and proportions of people and, equally important, correspond to the speed at
86 which people walk.
- 87 • Transparency refers to the degree to which people can see or perceive what lies beyond
88 the edge of a street and, more specifically, the degree to which people can see or
89 perceive human activity beyond the edge of a street.
- 90 • Complexity refers to the visual richness of a place. Complexity is related to the number
91 noticeable differences to which a viewer is exposed per unit time.

92 These urban design qualities have been shown to predict pedestrian activity in a handful of
93 studies (Ameli et al., 2015; Ewing and Clemente, 2013; Ewing et al., 2016; Maxwell, 2016;
94 Hamidi and Moazzeni, 2018). Some studies further find that pedestrian volumes are associated
95 with individual streetscape features (e.g., street furniture, the proportion of windows, etc.)
96 (Ewing et al., 2016; Rodríguez et al., 2009). Ewing and Clemente (2013) specifically sought to
97 validate the urban design metrics against pedestrian counts in the context of New York City
98 (NYC), one of America's most walkable cities. Ameli et al. (2015) measured urban design
99 qualities and validated them against pedestrian counts on 179 block faces in downtown Salt

100 Lake City, Utah, a more typical auto-oriented city. Their study found that imageability in
101 addition to transparency adds significantly to street vitality (Ameli et al., 2015). The same two
102 urban design qualities were found to have significant relationships to pedestrian activity in
103 Downtown Dallas (Hamidi and Moazzeni, 2018) and Glasgow, Scotland (Maxwell, 2016). In
104 a new town in Iran, Bahrainy and Khosravi (2013) concluded that complexity, human scale,
105 and continuity and cohesion—defined as “the appropriate integration of elements and
106 permeability” (p.23)—are the three urban design qualities that affect walkability.

107 Existing studies, however, have limited their spatial scope to specific location types such as
108 central cities (Ameli et al., 2015; Ewing and Clemente, 2013; Ewing et al., 2016; Hamidi and
109 Moazzeni, 2018; Maxwell, 2016) or station areas (Rodríguez et al., 2009). This makes it
110 difficult for planners and designers to apply the study results to their cities because most cities
111 are still dominated by automobiles, and thus their sidewalks are almost empty or even do not
112 exist (Moudon et al., 1997). Studies have shown less walking in suburban areas than urban
113 neighborhoods (Gallimore et al., 2011; Moudon et al., 1997; Rodriguez, Khattak, & Evenson,
114 2006), but few studies provide empirical evidence relating pedestrian volume to environmental
115 design attributes.

116 The Wasatch Front Regional Council (WFRC) in Salt Lake City, Utah, is a Metropolitan
117 Planning Organization (MPO) consisting of four counties – Salt Lake, Utah, Davis, and Weber
118 Counties – in the Wasatch Front region. The transport system of this region, like many
119 metropolitan areas, has become increasingly multimodal. The present study utilizes pedestrian
120 and urban design data collected by WFRC. The Salt Lake region is typical of western
121 metropolitan areas of medium-size and a high degree of automobile dependence. A 2012 Utah
122 travel survey (RSG inc., 2013) shows that in this region, 78.5% of respondents drive alone to
123 work, which is comparable to the national average (76.6% in 2015; U.S. Census Bureau, 2015).
124 The walk share of work trips in this region is 3.1 percent, also similar to the national average,

125 2.8%. Also, the Salt Lake region's size and urban form represent typical auto-dependent,
126 medium-sized cities. The *Costs of Sprawl* (Ewing and Hamidi, 2017) finds that Salt Lake City
127 MSA (metropolitan statistical area) ranked 94 out of 221 MSAs in the U.S. with a sprawl index
128 of 106.96, close to the average index, 100.

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

135 **Methodology**

136 *Study Area*

137 To measure urban design qualities of streets, WFRC conducted field work in over 1,200 blocks
138 throughout the Wasatch Front in 2015. The Wasatch Front ranges from south of Provo and
139 Orem in Utah County to north of Ogden in Weber County in Utah. Salt Lake City falls near
140 the middle of the Wasatch Front, and is the largest jurisdiction in Salt Lake County, our study
141 area. WFRC selected streets that are of key interest, exemplary, or generally representative of
142 the region. Streets were also selected if they fell within designated centers in the Wasatch
143 Choice for 2040 Vision. Like many metropolitan planning organizations, WFRC envisions a
144 region with a hierarchy of mixed-use centers connected by high-quality transit.

145 Like many mid-sized cities, the study area consists of a small, dense downtown and widespread
146 suburban areas. The downtown Salt Lake City area is dense, mixed-use, and well-connected
147 through transit, distinctive from the rest of the region. Pedestrians are most prevalent in the
148 downtown area. As mentioned above, this study is unique in that the study area includes these

149 two distinct development patterns. At the same time, like other typical U.S. regions, the Salt
150 Lake region is automobile-oriented, partially due to large blocks and wide roads.

151 Block face, the frontage on one side of a block, is our unit of observation. If a block was too
152 long, it was divided into walkable subsections. For each block face, streetscape features were
153 measured and pedestrians were counted by WFRC. Observation protocols of Ewing and
154 Clemente (2013) were used, as explained in the next section. The methodology and resulting
155 interactive maps can be found at a WFRC ArcGIS website
156 ([https://wfrcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=7d1b1df5686c41b593d1](https://wfrcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=7d1b1df5686c41b593d1e5ff5539d01a)
157 [e5ff5539d01a](https://wfrcgis.maps.arcgis.com/apps/MapSeries/index.html?appid=7d1b1df5686c41b593d1e5ff5539d01a)).

158 For this study, out of over 1,200 block faces surveyed across the region, 881 segments within
159 Salt Lake County were selected based on other data availability such as parcel-level land use
160 data (Figure 1).

161 “Figure 1 here”

162 *Pedestrian Activity*

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

166 All fieldwork was conducted between 10 a.m. and 5 p.m. on weekdays. Pedestrian counts were
167 taken during the whole year of 2015. The distribution and descriptive statistics of pedestrian
168 counts are presented in Figure 2.

169 “Figure 2 here”

170 *Urban design measures and streetscape features*

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

179 “Table 1 here”

180 Imageability is a linear function of seven streetscape variables, enclosure a linear function of
181 five streetscape variables, human scale a linear function of five streetscape variables,
182 transparency a linear function of three streetscape variables, and complexity a linear function
183 of five streetscape variables. See Ewing and Handy (2009) for a detailed description of how
184 these composite functions were derived.

185 *“D” Variables*

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

189 D variables were computed for the quarter-mile buffer around each street segment. A quarter
190 mile was selected as a standard walking distance beyond which walk frequency drops off
191 rapidly (Ewing and Clemente, 2013). One density variable is the average floor area ratio (FAR),
192 computed as the total building floor area for all parcels within the buffer, divided by the total
193 area of tax lots. The other is the average net population density, computed as the population of

194 all census blocks whose centroids fall within the buffer divided by the total area of residential
195 tax lots whose centroids fell within the buffer, measured in 1,000 residents per square mile.

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

198 Entropy was computed with the formula:

$$199 \quad \text{entropy} = -[\text{residential share} * \ln(\text{residential share}) + \text{retail share} * \ln(\text{retail share}) + \\ 200 \quad \text{office share} * \ln(\text{office share})] / \ln(3)$$

201 where \ln refers to the natural logarithm of the share of floor area and the shares were computed
202 based on floor area of each use for tax lots within the buffer. Mixed-use areas would be
203 expected to generate more pedestrian activity than single-use residential or office areas
204 (entropy scores greater than 0 would be expected to generate more pedestrian activity than
205 entropy scores of 0). We are measuring entropy in terms of three uses—residential, retail, and
206 office—that might be expected, when in balance, to generate interchanges of trips (per Chapter
207 7 of the *ITE Trip Generation Handbook*). In addition, the percent of retail uses in the quarter-
208 mile catchment area is added as a control variable as additional retail may induce pedestrians.

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

214 Destination accessibility was represented by two variables – Walk Scores® and job
215 accessibility. Walk Score® rates the walkability of a specific address on a numeric scale from
216 0 to 100, by compiling the number of nearby stores and amenities within one and a half miles.

217 The 13 amenity categories are grocery stores, coffee shops, restaurants, bars, movie theaters,
218 schools, parks, libraries, bookstores, fitness centers, drug stores, hardware stores and

219 clothing/music stores (Carr et al. 2011). Amenities within 0.25 miles receive maximum points,
220 and no points are awarded for amenities farther than one and a half miles from the address.

221 Regional job accessibility is another important measure of destination accessibility, defined as
222 the percentage of jobs that can be reached within 10-minutes by automobile, which tends to be
223 highest at central locations and lowest at peripheral ones (Ewing et al., 2015). Different ranges
224 – 20-minute and 30-minute – were also tested, but the 10-minute extent was chosen for its
225 highest correlation with our dependent variable, pedestrian counts. We used travel time skims
226 and employment data at the TAZ (traffic analysis zone) level acquired from WFRC. Distance
227 to transit was measured as the street network distance from the block face center point to the
228 nearest rail station. Another transit variable is transit stop density, measured as the number of
229 stops per square mile.

230 Two demographic variables were also included. One is the average household size for blocks
231 whose centroids fall within the quarter mile buffer around each block face. Household size is
232 positively associated with pedestrian traffic volume in the literature (Ameli et al., 2015; Ewing
233 et al., 2016). The other is median household income, hypothesizing that residents in more
234 affluent neighborhoods might walk less and drive more (Ewing et al., 2014; Owen et al., 2007).
235 Other evidence suggests that walking may be less common in deprived areas (see Dalton et al.,
236 2013 and Fishman et al., 2015). Block-group-level median household incomes were gathered
237 from the American Community Survey (2012 5-year estimates) and assigned to the ¼-mile
238 buffers based on the relative areas of the census block groups (i.e., the spatial apportioning
239 technique).

240 At the block level, we estimated additional D variables: average floor area ratio (FAR) for the
241 block face, computed as the total building floor area for parcels abutting the street, divided by
242 the total area of tax lots; an entropy measure based on floor area for parcels abutting the street,
243 computed with the formula above; and proportion of retail frontage along the block face, on

244 the assumption that retail frontage generates more pedestrian activity than other types of
245 frontage. The length of each block face was also included as a control variable because after
246 controlling for other influences, the longer the block, the more pedestrians will be present on
247 it at any given time.

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

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

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

264 "Table 2 here"

265 **Analyses**

266 *Negative binomial regression*

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

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

281 *Spatial filtering*

282 The pedestrian count data in this study could create an issue of spatial autocorrelation (Anselin,
283 1988; Anselin, Florax, and Rey, 2004), meaning that the pedestrian volume in one sampled
284 block is highly correlated with those in nearby sampled blocks. This is true for many reasons
285 – walk trips that extend from one block to the next, similar demographics or urban form
286 characteristics, or a large-scale destination in one block (e.g., convention center, theater, plaza).
287 Moran's I spatial statistic is a commonly used measure to check for spatial autocorrelation. The
288 null hypothesis of Moran's I is that the variable is randomly distributed among the observations

289 in the study area. Moran's I for pedestrian counts in this study is 5.840 ($p < 0.001$) indicating
290 a strongly positive spatial relationship.

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

297 As a robust tool to deal with the spatial autocorrelation issue in regression, spatial filtering
298 separates spatial and non-spatial effects of a variable (Griffith, 2003). This study employs the
299 spatial eigenvector mapping technique based on the eigenvector analysis of the spatial lag
300 operator. During the analysis, eigenvectors that are most effective at reducing spatial
301 autocorrelation in the residuals are chosen and added to the regression as additional control
302 variables (Dormann et al., 2007). The advantage of this approach is that when adding spatial
303 predictors to the regression model, the coefficients of the independent variables do not change.
304 The R 3.4.0 software has a function called *ME* (the Moran Eigenvector function) in the *spdep*
305 package. The *ME* is appropriate for removing spatial autocorrelation from the residuals of
306 generalized linear models, including negative binomial regression. After the spatial filtering
307 was applied, the Moran's I of residuals for the adjusted Model 1 indicates no spatial
308 autocorrelation (Moran's I = 0.071; $p = 0.193$). Likewise, the adjusted Model 2 and Model 3
309 have no spatial autocorrelation in their residuals (Moran's Is are 0.027 and 0.033, respectively).
310 Also, ANOVA tests show that all three spatial filtering models outperform their counterparts
311 – non-spatial models ($p < 0.001$).

312 Results

313 Three negative binomial models of pedestrian counts are presented in Table 3. All three models
314 have highly significant likelihood ratio chi-squares, indicating a good fit to the data compared
315 with a null model. The likelihood ratio chi-square of model 2 relative to model 1—141.7 with
316 9 degrees of freedom—indicates that the fit is significantly better for model 2 at the 0.001
317 probability level. Likewise, the likelihood ratio chi-square of model 3 relative to model 1—
318 198.8 with 22 degrees of freedom—indicates that model 3 has a significantly better fit. The
319 Akaike information criterion (AIC) is lower in model 3 than in model 2, demonstrating a
320 relatively better quality of model 3.

321 “Table 3 here”

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

327 In all models, the floor area ratio (FAR), transit stop density, proportion of block retail,
328 household size, and median household income are significantly related to pedestrian counts at
329 the 0.05 probability level. Intersection density is also significant in all models but has
330 unexpected negative sign. A measure of destination accessibility, the percentage of jobs within
331 10-minutes by car, is significant in Model 1 and 3. Likewise, block length and average car
332 traffic volume (AADT) are significant only in Models 1 and 3.

333 Of the remaining D variables, the measures of amenity accessibility (i.e., Walk Score®) is only
334 significant in Model 1, and becomes insignificant when either urban design qualities or
335 streetscape features are included (Models 2 and 3). The downtown variable is only significant
336 in Model 2. Sidewalk coverage is not significant in any model, which may be attributed to the

337 fact that 96% of street segments in the study area have a sidewalk on the sample side of the
338 street.

339 We would particularly note that the two entropy variables are not significant in any of the
340 models. Entropy is the most commonly used measure of land use diversity in built
341 environment-travel literature (Ewing and Cervero, 2010), and therefore is appropriately tested
342 in this study. Yet, our two entropy variables are not significant, while our block-level retail
343 proportion variable is significant. So having an exact balance of the uses, and an entropy score
344 of 1, does not appear to be as conducive to pedestrian activity as having a disproportionate
345 amount of retail frontage.

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

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

359 Furthermore, we partitioned the dataset to distinguish downtown from suburbs, and to see if
360 correlates with street life are the same for the two. Because of the small sample size of
361 downtown street segments ($n=62$), only a suburban model is considered valid and analyzed

362 (results are not presented in a table). Being consistent with the overall model, the suburban
363 model shows that multiple built environment and sociodemographic variables—job
364 accessibility, transit stop density, intersection density, household size, household income, the
365 proportion of block retail, block length—are associated with the pedestrian volume at $p<.05$
366 significance level. On the other hand, population density, % 4-way intersection, and car traffic
367 volume (AADT) become not statistically significant.

368 Interestingly, human scale ($B=0.07$; $p=.04$), in addition to imageability, enclosure, and
369 complexity, turns out to be associated with pedestrian volume in the suburban-only model.
370 Among streetscape features (Model 3), percentage of historic buildings and building with
371 identifiers become not significant in the suburban model while outdoor dining ($B=0.26$, $p<.01$),
372 street furniture ($B=0.27$, $p<.01$), long sight line ($B=0.12$, $p=.04$), street furniture ($B=0.004$,
373 $p=.02$), active uses ($B=0.94$, $p<.01$), and accent building colors ($B=0.06$, $p=.04$) remain
374 positively related to the number of pedestrians.

375 **Discussion and Conclusions**

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

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

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

390 “Table 4 here”

391 In this study, two out of five urban design qualities were found to be significant for more
392 pedestrians on street: imageability and complexity. Imageability proves important in three out
393 of four studies, including the current one (Table 5). It is described as the quality of a place that
394 makes it distinctive, recognizable, and memorable (Ewing and Handy, 2009). Interestingly,
395 human scale is positively associated with pedestrian volume only in suburban areas. These
396 results may reflect that even in an auto-oriented place, more place-making features and
397 comfortable-scale streetscape would encourage people to choose the route.

398 The non-significance of transparency is contradictory to the other four studies conducted in
399 NYC (Ewing and Clemente, 2013), downtown Salt Lake City (Ameli et al., 2015), downtown
400 Dallas (Hamidi and Moazzeni, 2018), and central street segments in Glasgow, Scotland
401 (Maxwell, 2016) (Table 4). In the equation for urban design qualities (Table 1), transparency
402 mainly depends on the proportion of the first floor with windows. While it can range from 0 to
403 1 theoretically, that feature is not highly variable in this study, with a mean of 0.11, median of
404 0, and standard deviation of 0.20 (Table 2). This might imply that transparency, the degree to
405 which people can see what lies beyond the edge of a street (Ewing and Handy, 2009), is more
406 relevant in highly urban places such as downtowns than lower-density suburbs. On the other
407 hand, in lower density areas with streets like those in this study, improving imageability and
408 complexity might be more conducive to street walkability.

409 Out of 20 streetscape features that were found to have a relationship to urban design qualities
410 (Ewing et al. 2006), this study could identify seven significant streetscape features that are

411 associated with pedestrian volumes. The first three features are the number of historic
412 buildings, the presence of outdoor dining, and the number of buildings with identifiers. The
413 building identifier is defined as clear signs or universal symbols that reveal a building's street-
414 level use – for example, a steeple for a church, tables and chairs for a restaurant, or clear words
415 like “Joe’s Pub” (Ewing and Clemente, 2013). These two variables are important elements of
416 imageability. The presence and arrangement of outdoor dining and identifiers would capture
417 visitors’ attention and create a lasting impression.

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

429 The fifth feature is the number of pieces of street furniture or other street items (e.g., tables,
430 benches, vendors, trash cans, bike racks, street lights, etc.). Providing street furniture and
431 specifically outdoor seating is a common recommendation for activating public spaces, and
432 this study supports this recommendation. The seventh feature is the percentage of active uses,
433 defined as shops, restaurants, public parks, and other uses that generate significant pedestrian
434 traffic. Inactive uses include blank walls, driveways, parking lots, vacant lots, abandoned
435 buildings, and offices with no apparent activity. A lesson from this finding is to monitor the

436 use of street frontage before investing in streetscape projects. For example, a corridor that is
437 losing its commercial identity to inactive uses may not be a priority for streetscape
438 improvements.

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

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

449 Pedestrians are most prevalent in the downtown Salt Lake City area where blocks are long (i.e.,
450 intersection density is low) and most buildings are rectangular. On the other hand, more
451 intersections and more non-rectangular buildings can be found in single-family residential
452 neighborhoods having fewer pedestrians. This difference would yield negative relationships
453 between the intersection density or the non-rectangular-shape buildings and pedestrian counts.
454 Thus, street design might be better described by subtler urban design qualities than a gross
455 measure of intersection density or proportion of four-way intersections. Also, while the other
456 factors such as outdoor dining or building identifiers are related to better imageability and more
457 pedestrians, the number of buildings with non-rectangular shapes would not be an important
458 streetscape feature for pedestrian experience in a smaller region.

459 In the case of the enclosure, in a city with homogenous sprawled landscapes, the higher level
460 of enclosure might actually detract from the pedestrian experience by, for example, blocking

461 sunlight. Table 4 shows that none of the previous studies including the current one found a
462 positive relationship between enclosure and pedestrian counts (Ewing & Clemente, 2013;
463 Ameli et al., 2015; Maxwell, 2016). It may be that, after controlling for such attributes as FAR
464 and population density, enclosure is not an important urban design quality for pedestrians after
465 all.

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

475 Limitations of this study relate to both in validity and in reliability. In terms of the external
476 validity of our findings, cities in Salt Lake County do not represent the variety of cities in the
477 United States, cities in other developed nations, and cities in the developing world.

478 Nevertheless, many cities in developed and developing countries are also dominated by
479 personal cars (Appleyard, 1983; Castillo-Manzano et al., 2014; Liu et al., 2010). In fact, the
480 emerging pattern of results from such studies is complex and challenging to synthesize. A
481 future study could repeat this validation study in multiple cities characterized by more diverse
482 built environments.

483 In terms of internal validity, while our models include comprehensive measures of built
484 environments such as D variables, urban design qualities, and streetscape features, there
485 could be missing variables that are also correlated with pedestrian counts. For example,

486 pedestrian safety, a significant predictor of pedestrian traffic volume, could be measured in
487 more precise ways than with vehicle traffic volume or AADT, used in this study (Boarnet et
488 al., 2011; Landis et al., 2001; Miranda-Moreno et al., 2011; Rodríguez et al., 2009).

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

498 Finally, in terms of significant associations, the model with the most independent variables
499 has 45 of them (see Table 3, column 3). It is certainly possible, at the 0.05 significance level,
500 that two or even three of the variables that appear significant really are not. This type 1 error
501 is always a threat when there are many independent variables in a multi-variate analysis.

502 Having said that, we wanted to depict the effect size and significance level of each predictor
503 in order to help policy makers have more complete understanding about each discussed
504 feature of streets.

505 A threat to the reliability of our results is the limited counts done on each block face. Each
506 block face was observed four times as an observer walked up and down the block face. The
507 days and times of the counts were variable. Field counts during lunch hours or after 4 pm
508 might be higher than those at other times of a day. Our second research recommendation
509 would be to collect the data for a longer period at consistent times of day on each street
510 segment or to use automated pedestrian counters. For example, Ameli et al. (2015) conducted

511 half hour counts in standardized time periods to minimize sampling error. One of the new
512 automated pedestrian counters such as passive infrared counters, micro radar sensors, or
513 portable fisheye cameras will probably need to be employed for studies of this type in the
514 future. The surveyor could place the counter at midblock and then measure urban design
515 qualities while the counts are underway, so as not to lose this time. With the advancement of
516 methodology and reliable and valid empirical evidence, this study and its progeny will
517 provide urban planners and designers with a more compelling guidance for streetscape
518 projects that aim to create walkable places and vibrant street life.

519

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524

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707

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715 qualities in five studies

716

717

718 Table 1. Streetscape Features Contributing to Urban Design Qualities (adapted from Ewing &
 719 Handy, 2009)

Urban design quality	Significant physical features	Coefficients	p-value
Imageability	People (#) ^a		<0.001
		0.024	
	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
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)		0.045
		0.367	
	Public art (#)	0.272	0.066

720 Note: ^a Excluded from the models in this research because the number of people on the street
 721 is our dependent variable.
 722

723 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 (1/4-mile buffer)	FAR	0.4	0.3	0.0	4.4	0.5
	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 (\$1,000)	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
	% 1 st 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

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725 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 (1/4-mile buffer)	FAR	0.553***	0.098	0.225**	0.101	0.225**	0.094
	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 face)	Block FAR	-0.078*	0.045	-0.034	0.044	-0.002
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-					-0.027***	0.008

	rectangular shapes (#)						
	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
	% 1 st 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

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

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Figure 1. Study sites (881 block faces)

Figure 2. Frequency distribution and descriptive statistics of pedestrian counts

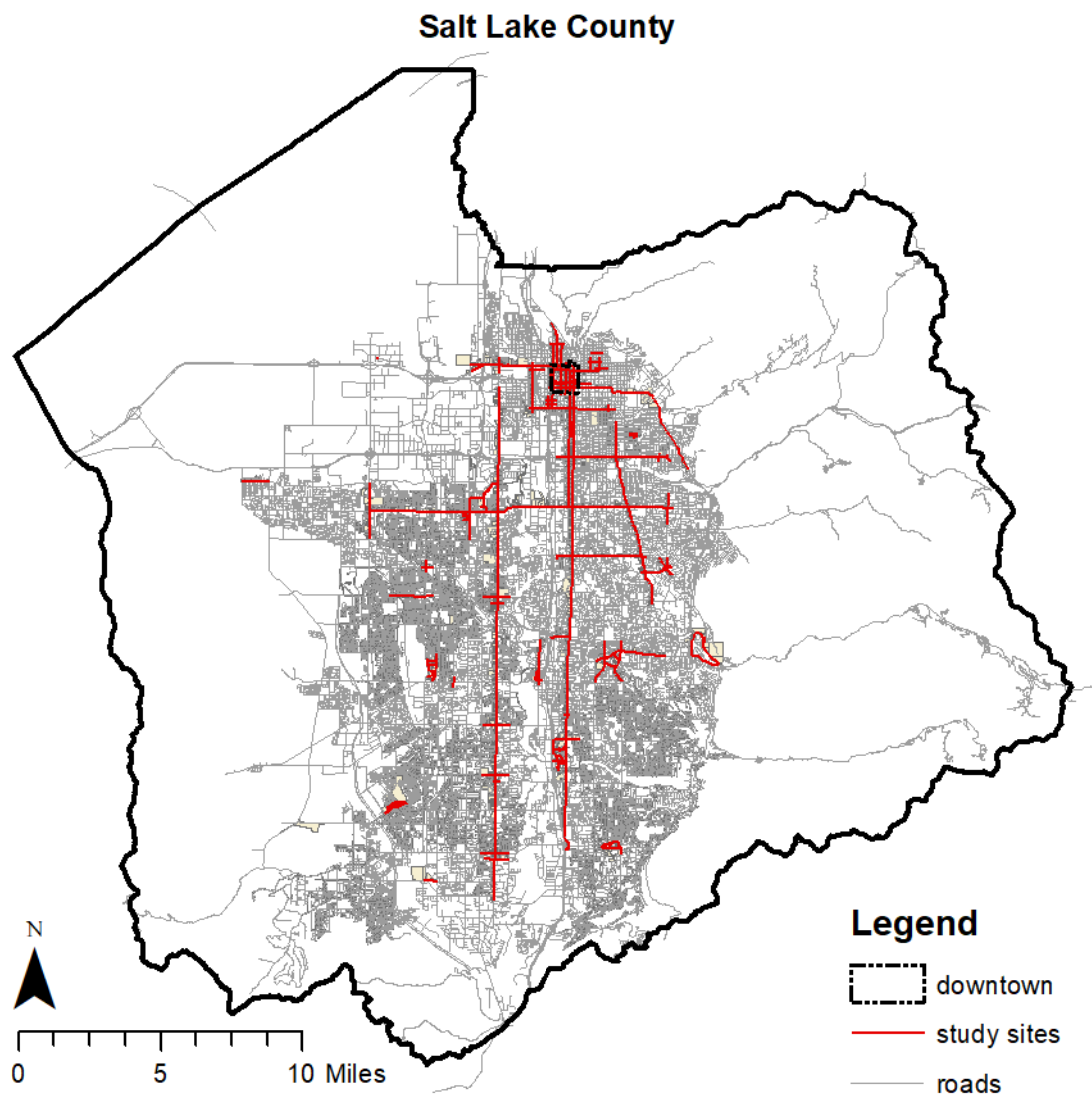


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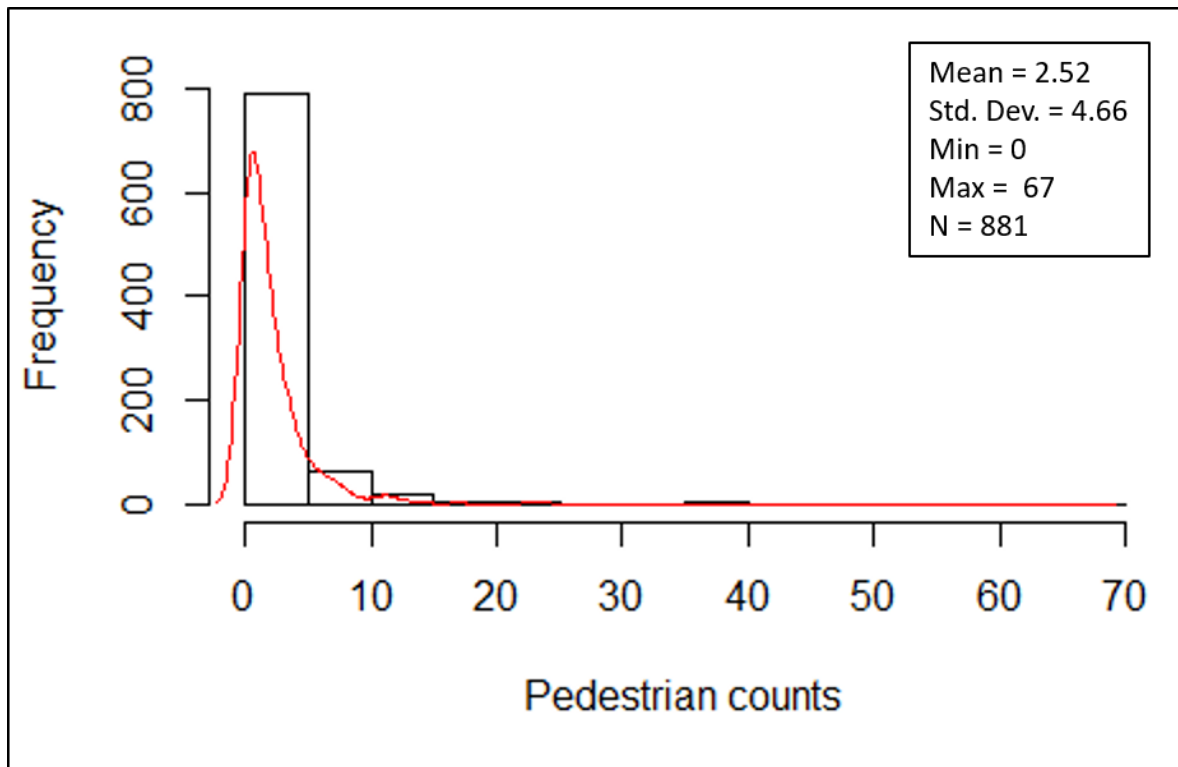


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