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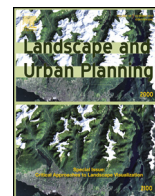
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Research Paper

Effects of skeletal streetscape design on perceived safety

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HIGHLIGHTS

- Building and tree design characteristics affected perceived safety of streetscapes.
- Trees positively affected safety perceptions more than building-related variables.
- Tall, narrow streetscapes were perceived as safer than short, wide streetscapes.
- More buildings per length of streetscape increased perceived safety.
- Urban form and affluence affected perceived safety less than streetscape design.

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ABSTRACT

It is important for planners and urban designers to understand how physical characteristics of urban streetscapes contribute to perceptions of them as safe, comfortable urban spaces. While urban design theory offers numerous suggestions for successful streetscapes there is meager empirical evidence of their effects. We suggest that this is largely due to precision and sample size limitations on audit-based physical design and human perception measurements. This paper overcomes these limitations by identifying a key set of “streetscape skeleton” design variables that can be efficiently measured using a GIS-based method. It then measures these variables on a large and diverse sample of streetscapes, and examines their relationship to crowdsourced perceived safety scores, a useful indicator of environmental comfort. Regression modeling indicates that factors related to streetscape enclosure have a substantial positive effect on perceived safety. These include street tree canopy, the number of buildings along a block, and the cross-sectional proportion—the ratio of building height to width across the street between building façades. Importantly, these streetscape-scale skeleton variables have greater effect than neighborhood-scale urban form and affluence measures that are commonly used to identify desirable urban environments. Planning practitioners can draw on our results to set priorities for urban forestry and design guidelines that shape the spatial proportions of streetscapes and their success as spaces that feel safe and comfortable for human users.

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1. Introduction

Planners and designers recommend myriad strategies for improving the design quality of urban streetscapes. It is easy to get lost in the details. Ewing and Clemente (2013), for example,

identify the importance of more than one hundred variables—windows, pavement condition, building colors, signage—affecting the sensory experience of urban design. The National Association of City Transportation Officials (2013) present an extensive inventory of design strategies—cycle tracks, bus bulbs, bollards, pocket parks—to improve safety and comfort for street users, particularly those outside of automobiles. Design details like these are undeniably important for optimizing the quality of streetscapes. Nonetheless, the skeletons of streetscapes, delineated by the massing of surrounding buildings and trees (Fig. 1), provide spatial proportions that may be elemental to perceptions of them as comfortable urban spaces. This study investigates how skeletal

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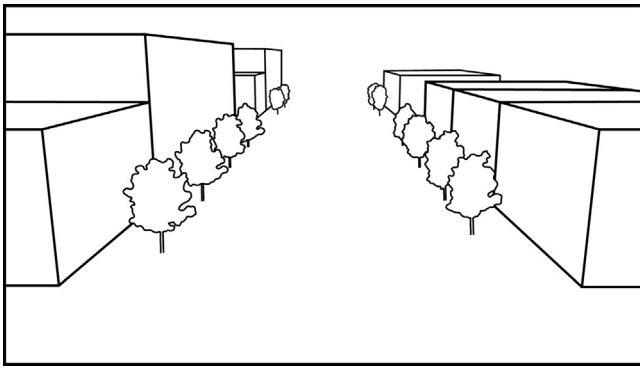


Fig. 1. A streetscape skeleton defined by the outlines and massings of surrounding buildings and trees.

characteristics of buildings and trees along streetscapes may have a baseline effect on perceived safety, a useful indicator of environmental comfort and an important factor of urban livability.

Streetscape skeletons define the spatial extents and influence the visual complexity of streetscape spaces. Buildings are the most visually dominant objects framing urban streetscapes. Aligned façades form walls along either side, providing enclosure that urban design theorists associate with shelter, place identity, and familiarity (Alexander et al., 1977; Cullen, 1971; Lynch, 1960). Repeating patterns or variability in building massing affect the visual complexity of streetscapes and may cue perceptions of intension and order. Trees, which are also visually dominant in many streetscapes, contribute additional enclosure and complexity (Arnold, 1993; Jacobs, 1993). Together, buildings and trees provide a skeleton onto which a skin of design details—architectural styling, sidewalks, travel lanes, streetlights, and other fixtures—can be fitted to produce a complete streetscape. Well-proportioned skeletons may provide enduring bones for many generations of skin-level retrofit.

While the importance of what we term streetscape skeletons is espoused by urban design theorists, the literature offers little direct empirical evidence of their relationship to behavior or psychology. Traditionally, it has been difficult to collect precise and consistent measurements of the built environment and human responses among a sample of streetscapes sufficiently large for making statistical inferences. Novel automated methods for measuring skeleton variables, and recording human perceptions in the same locations, now make it feasible to evaluate these relationships. This study used GIS to measure streetscape skeletons based on building and tree canopy geometry at the spatial resolution of city blocks. Skeleton variables were measured along more than six hundred blocks in New York City where perceived safety measurements were previously collected using crowdsourcing techniques by researchers at the Massachusetts Institute of Technology (MIT) Media Lab (Salesses, Schechtner, & Hidalgo, 2013). Multivariate regression models demonstrated that several skeleton variables were powerful predictors of perceived safety. Streetscapes that were more enclosed by buildings and trees were generally perceived as safer than those that were more open and less vegetated. Skeleton variables were substantially better predictors of perceived safety than household income or Walk Score®, indicating that skeletal design contributes to comfortable urban environments in ways that are distinct from affluence or broader-scale urban form.

2. Background

Seminal urban design theorists draw concise logical arguments about the importance of streetscape enclosure for spatial definition, human comfort, and security, but offer little empirical evidence of

these associations. Enclosure is what gives a streetscape a recognizable interior, allowing someone to be outside *it*, entering *it*, or in the middle of *it* (Cullen, 1971). Such definition is important for sense of place within streets, making them spaces to *be in* rather than vectors to pass *through*. Building façades form enclosing “street walls,” offering shade, protection from wind and rain, and a secure edge from which to observe goings on (Jacobs (1993). Street walls can delineate spaces that feel like outdoor rooms (Alexander et al., 1977). Enclosure also contributes importantly to urban imageability, locational awareness, and orientation, useful for distinguishing streets and neighborhoods from one another (Lynch, 1960). Someone traveling the length of Manhattan, for example, may know where he is—the Financial District, Greenwich Village, Midtown, Uptown, Harlem—simply by the shape and size of the streetscapes surrounding him.

Tree canopy provides additional enclosure by forming a partial roof while subdividing large streetscapes into more compact spaces. Trees may compensate for lack of enclosure where buildings are nonexistent or widely spaced (Arnold, 1993). Paris’s tree-lined Champs-Élysées, parts of which are very wide, demonstrates how well-arranged trees can provide a degree of enclosure all on their own (Jacobs, 1993). Trees provide visual complexity through the organic structure of their branching, colors of their bark and leaves, filtered light and shadows, and their constant, subtle movement (Arnold, 1993). Streetscape microclimates affecting user comfort are also substantially influenced by trees. In an era when buildings are often planned with lifespans of 100 years or less, mature trees can play a similarly enduring role in defining the character of streetscapes.

Social functionality of enclosed streetscapes may also contribute to perceived comfort, though arguments for these relationships are more logical and rhetorical than empirically tested. Alexander et al. (1977) suggest that small, well-defined streetscapes will more readily attract social and economic activity than those that are large and ambiguously shaped. Wide setbacks, originally intended to provide streetscapes with light and air, may also make them feel vast and discourage interaction between the public realm of the street and private land uses to either side (Dover & Massengale, 2013; Montgomery, 2013). Streetscapes intended to foster social vitality must be sufficiently small and enclosed to bring people together. Appleyard, Gerson, and Lintell’s (1981) seminal study of street livability focuses primarily on traffic volume, but the most socially active, livable streets he identifies in San Francisco are also relatively narrow. Jacobs (1961) similarly recognizes the social and safety advantages of narrow streetscapes lined by low-rise buildings in the Greenwich Village neighborhood of New York City, where neighbors and shopkeepers keep “eyes on the street” from their front windows. She critiques streetscapes amidst modern public housing projects as too tall and vast for social accountability. The structure of a community, Jacobs argues, is implicitly directed by its built environment. Authors offer various interpretations of ideal streetscape sizes based on social criteria. Alexander et al. (1977) suggest that buildings be no more than four stories tall to allow interaction between uppermost floors and the street. Blumenfeld (1971) proposes a maximum building-to-building width of 72 ft (22 m) as the distance at which faces remain recognizable. He recommends 48 ft (15 m) as the distance where expressions are detectable and communication is feasible with loud voices. Optimal dimensions, however, have not been tested against social outcomes using a rigorous methodology.

Recent planning and public health literature uses more empirical strategies to evaluate the attractiveness of streetscapes, primarily for walking. Several studies by Ewing identify a framework of urban design qualities important to pedestrians according to expert panels: imageability, enclosure, human scale, transparency, and complexity (Ewing, Clemente, Handy, Brownson, &

Winston, 2005; Ewing & Clemente, 2013; Ewing & Handy, 2009). These qualities are heavily affected by skeletal proportions, which Ewing and his colleagues survey indirectly based on the length of sight lines and sky visibility. They also make more direct estimates of building height, number of buildings and proportion of street wall along either side, inspiring several of the measurements we used in this study.

A handful of studies identify quantitative relationships between skeleton variables and walking behavior or pedestrian comfort. Moniruzzaman and Páez (2012) find that smaller setbacks and taller buildings are consistent with greater pedestrian mode share in Hamilton, Ontario. Nasar (1987) finds that lay pedestrians and design experts in Columbus, Ohio both rate street scenes more highly when they are more enclosed, have more unity of form, and are more vegetated. He recommends conversion of alleyways and other enclosed places to pedestrian use. Pikora, Giles-corti, Bull, Jamrozik, and Donovan (2003) identify street trees and width as important variables of route preference for recreation, but not for transport. Enclosed streetscapes may not be required for a walkable place, but enclosure may encourage walking by improving user comfort.

Neighborhood-scale urban form measures are more commonly studied using quantitative methods. Saelens, Sallis, and Frank (2003) review the consistent relationship between built environment density, street connectivity, and walking behavior identified by transportation, urban design, and planning literature. Ewing and Cervero (2010) similarly review how effects of the 5Ds—density, diversity, design, destination accessibility, and distance to transit—on vehicle use and travel distances are replicated by over 50 studies. While density and connectivity imprecisely represent block-scale streetscapes, they generally translate into taller, narrower, and shorter streetscapes.

The dominance of neighborhood-scale data in built environment research demonstrates the challenges of acquiring reliable streetscape-scale measurements. Audit instruments are the most common strategy for acquiring skeletal data, often with subjective measures that are efficient for human auditors to judge. The Pedestrian Environment Data Scan (PEDS), for example, asks auditors to rate the enclosure of a streetscape as low, medium, or high (Clifton, Livi Smith, & Rodriguez, 2007). Moniruzzaman and Páez (2012), using data collected with the PEDS, make the incongruous conclusion that that smaller setbacks and taller buildings are consistent with greater walkability, while enclosure is not. Such results may be affected by limitations in the specificity and consistency of audited data.

Some researchers question whether it is valuable to focus on the sensory perceptions of streetscapes in lieu of more practical concerns about traffic safety and destination accessibility. These arguments, however, may be largely founded on the relative convenience of quantifying measures of infrastructure and accessibility. Alfonzo (2005) places environmental comfort and “pleasurability” at the bottom of her hierarchy of walking needs, below feasibility, accessibility, and safety. Boarnet, Forsyth, Day, and Oakes (2011) endorse this hierarchy, determining that availability of sidewalks, destinations, and safety from traffic significantly affect walking behavior among neighborhoods in Minneapolis and Saint Paul, Minnesota, while natural and architectural esthetics do not. Nonetheless, the boundaries between these factors are highly ambiguous and arguably codependent on a number of built environment variables. Southworth (2003) argues that, because practical infrastructure is prioritized over esthetic design, environmental satisfaction is often reserved for the elite. However, skeletal factors such as tree canopy and streetscape width may also affect practical concerns such as traffic speed (Ewing & Dumbaugh, 2009).

Another body of literature, rooted in theories of evolutionary psychology, stands in contrast to the proposition that enclosed

streetscapes are comforting, arguing instead that they produce feelings of oppression and vulnerability. *Defensible-space theory* suggests that open spaces are advantageous for detecting and discouraging criminal activity (Newman, 1972). *Prospect-refuge theory* likewise suggests that humans feel safest in places that provide a balance of opportunity for movement and visibility to adjacent spaces (prospect) and protection (refuge) (Appleton, 1975). Streetscapes with highly enclosed, continuous street walls may limit opportunities to see or move to either side and refuge from potential predators.

While *defensible-space* and *prospect-refuge* theory offer compelling frameworks for perceived safety, studies evaluating them have reached variable conclusions. These are likely due to inconsistencies in how physical environments are measured, stimuli are presented, and perceptions are evaluated. Azgarzadeh, Lusk, Koga, and Hirate (2012) find that views of taller buildings are considered more oppressive than those of shorter buildings, and that including trees in the scenes significantly mitigates oppressiveness. Their laboratory-based methodology, however, presents subjects with only head-on views of façades projected on a screen that is tilted above their heads, and potentially leads their responses by using the term “oppressive” in the questioner. Blöbaum and Hunecke (2005) similarly conclude that building façades and alleyways in photographs of public spaces reduce perceived safety by forming feelings of “entrapment” and “concealment.” However, they find that trees contribute to, rather than mitigate, these feelings. Herzog and Chernick (2000) also find that more open spaces, without trees or buildings in the immediate foreground, are considered less dangerous but not necessarily more “tranquil,” suggesting that these constructs are not natural opposites. Other studies, meanwhile, find that physical enclosure is not nearly as predictive of perceived safety as scene lightness and shadow (Herzog & Flynn-Smith, 2001; Stamps, 2005). These studies all suggest the relevance of defensibility, prospect, and refuge to perceived safety, but show that factors contributing to these sensations are extremely complex. Research methods, including terminology, may strongly influence results. Future studies must minimize positive or negative framing and use stimuli that mimic the everyday experiences of street-level users as closely as possible.

With advancements in tools for measuring both the physical and perceived qualities of streetscapes, associations between skeletal design and user perceptions are ripe for further investigation. Streetscape-scale design variables are now measurable with precision, replicability, and efficiency that was previously attainable only for neighborhood-scale urban form measures such as density, grid connectivity, and destination accessibility. Moreover, crowdsourced judgments provide a replicable and large-sample approach for quantifying sensory perceptions (Salesses et al., 2013). Combining these measurements provides an opportunity to validate relationships between skeletal design and perceived safety with unprecedented spatial resolution, sample size, and objectivity.

3. Methods

3.1. Study area

New York City, which offered a nexus of high resolution spatial and perceptual data, was an opportune study area for examining associations between streetscape skeletons and perceived safety. The City boasted more than 750 km² of land area and 45,000 km of public roadways under the jurisdiction of a single municipal government which published high quality building, tree canopy, and street centerline geometry data, allowing us to measure streetscape skeleton variables throughout the entire extent of the city.

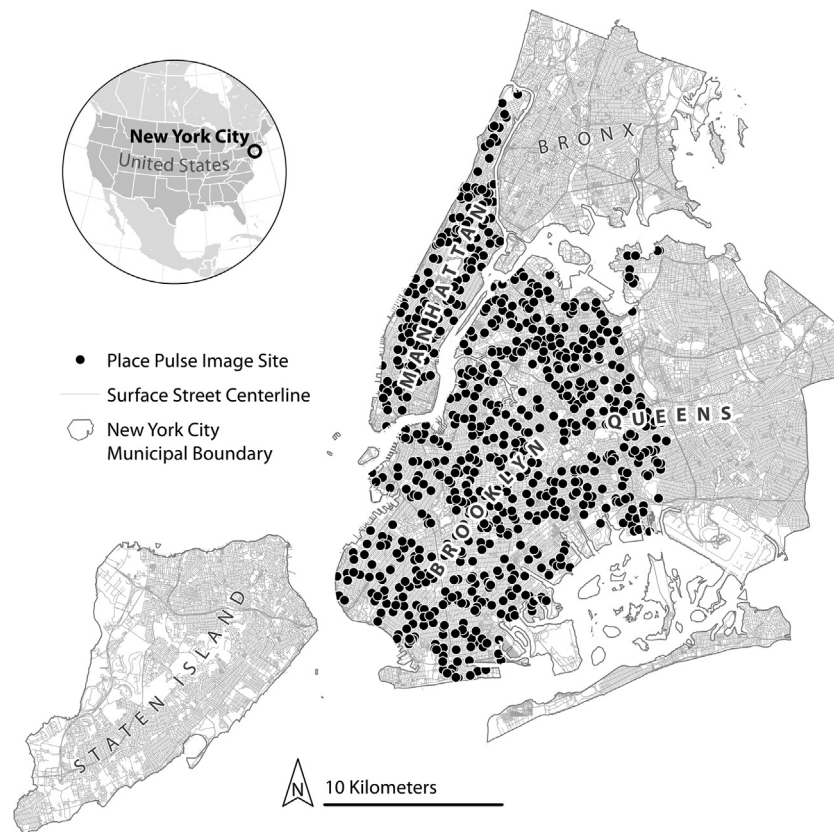


Fig. 2. Place Pulse image sites in Manhattan, Brooklyn, and Queens, New York.

Perceived safety scores of streetscape images, collected by researchers at the MIT Media Lab using an internet-based survey called Place Pulse, were available for more than six hundred sites throughout the city (Fig. 2; Salesses et al., 2013). We investigated how image scores were affected by skeleton variables along the same city blocks.

New York City is particularly conducive to examining the effects of streetscape design because it contains substantial built environment heterogeneity. Development ranges in style and density between residential areas dominated by one and two story detached homes, mixed use low-rise neighborhoods, and downtown high-rises that are dozens of stories tall. Of the city's five boroughs, three are represented in this study. Manhattan is home to the oldest and densest development, with hundreds of high-rise buildings. East of it are Brooklyn and Queens, which have dense downtown areas with high-rises on their western sides and large areas of low-rise residential, commercial, and industrial development to the east. These areas of New York City represent only the most urban portion of the 7000 km² metropolitan area. As such, this study does not account for the full range of suburban environments and their associated design characteristics.

New York City's built environment was heavily influenced by extensive early and mid-20th century development of low-rise mixed-use blocks and high-rises in commercial centers. The city was an early and prolific adopter of the skyscraper, and is now home to more than 600 buildings greater than 100 m tall. Because much of the City was developed before the widespread use of cars, it is dense and vertically oriented. As such, it is not fully representative of more recently developed cities, including those in the southern and western United States, whose urban forms are more horizontal, or smaller cities that lack pressure for such density. Nonetheless, the City's diverse built environments are representative of block-level streetscapes across many urban contexts.

3.2. Data

Streetscape skeleton measurements were derived from publicly available building footprint, tree canopy, and street centerline data processed using a GIS-based method. The GIS evaluated skeletal dimensions of streetscapes along block-length street centerline segments. For each segment, streetscape edges were detected based on alignment of building façades along either side. The edge detection methodology was based on the premise that, from a street level perspective, users recognize an edge where façades align at a predominant setback distance. Mimicking this recognition process, we used an iterative method to draw approximate edges at the setback distances where façades most consistently aligned along either side of each streetscape. These edges defined the horizontal extent of each streetscape, while the heights of buildings along the edges defined the vertical extent.

Seven skeleton variables were measured for each sampled streetscape: *width*, *length*, *height*, *cross-sectional proportion*, *street wall continuity*, *buildings per length*, and *tree canopy coverage*. *Width* was the distance between opposing edges (Fig. 3A), describing the width of the streetscape space that would be experienced by a street-level user. Importantly, this contrasted with more conventional curb-to-curb or right-of-way width measurements. *Length* was the centerline distance between segment ends (Fig. 3B). *Height* was the average height of buildings along the single edge, of the two edges along each segment, with the taller average height (Fig. 3C). *Cross-sectional proportion*, the quotient of height divided by width, described the interaction of these dimensions (Fig. 3D). Narrow streetscapes enclosed by relatively tall buildings had large cross-sectional proportions, while wide streetscapes lined by relatively short buildings had small cross-sectional proportions. *Street wall continuity* was the proportion of an edge that intersected a façade and thus formed a street wall (Fig. 3E). For each segment, street wall

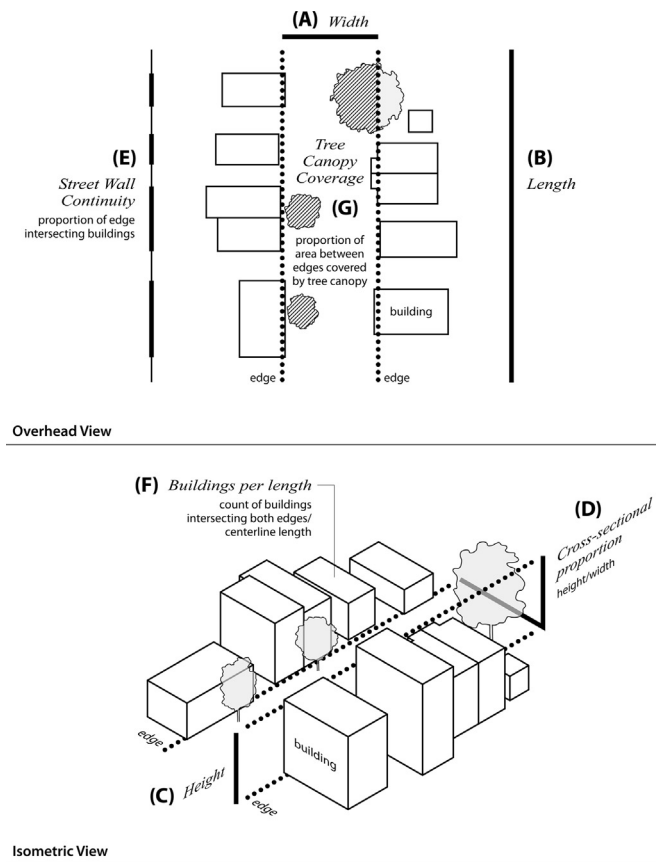


Fig. 3. Skeleton variable illustrations.

continuity was reported only for the more continuous of the two sides. *Buildings per length* were the count of buildings along both sides of a segment per 100 m of centerline (Fig. 3F). *Tree canopy coverage* was the proportion of area between edges that was covered by tree canopy (Fig. 3G).

Spatial data inputs for measuring skeleton variables were publicly available from the NYC Open Data web portal (City of New York, 2013). Building footprint data were derived photogrammetrically from high resolution aerial photography and included a building height attribute. High resolution tree canopy were derived by the University of Vermont Spatial Analysis Lab from aerial photography and aerial light detection and ranging (LiDAR) data using an automated method with manual quality control. The resulting tree canopy map, at 1 m resolution, accurately represented the presence of even small street trees among tall buildings (Locke et al., 2010). Raw street centerline data were manually edited prior to analysis to remove dual centerlines along streets with medians. Centerlines closest to the right-of-way center were maintained. ArcGIS ArcMap 10.2 was used for all GIS data preparation and analysis.

Perceived safety measurements were acquired from researchers at the MIT Media Lab who developed an online interface, *Place Pulse*, for crowdsourcing comparisons between streetscape images (Place Pulse, 2014; Salesses et al., 2013). The interface presented respondents with randomized pairs of images and asked them to indicate a preference according to one of three questions, including “Which place looks safer?” Each image was scored on a fixed scale according to its likelihood of being preferred in a random pairing. Images that were never preferred received a score of 0; those always preferred would theoretically have received a score of 10, though none achieved this status. We rescaled the scores so they had a theoretical range from 0 to 1.

The original Place Pulse dataset included scores for 41 36 images collected at semi-randomly distributed points within the core cities of New York and Boston in the United States and Linz and Salzburg in Austria. A total of 208,738 decisions were collected, each expressing a positive vote for one image and negative vote for another. As such, each score was based on approximately 34 votes. A total of 7872 unique respondents from 91 countries, geolocated by IP address, contributed to the sample. More than 97% of respondents self-reported age and gender, with 76% identifying as male and 21% as female; the median age was 28 years.

Potential bias from the largely young-adult male respondents was a concern. In existing research, older and female observers have generally perceived urban places to be less safe from crime than younger and male observers (LaGrange & Ferraro, 1989). Observers of all ages and genders, however, have been shown to perceive danger from the same types of environmental characteristics (Blöbaum & Hunecke, 2005). As such, we would expect diverse observers to have similar perceptions of relative safety, even if they might have various perceptions of absolute degrees of safety. While it would be ideal to draw on more diverse respondents, Salesses et al. (2013) also report no significant differences in Place Pulse scores based on the age, gender, or geographic location of respondents, suggesting that demographic biases were minimal.

A subset of the original Place Pulse data were used for this study, including perceived safety scores for 1222 streetscape images in the New York City boroughs of Manhattan, Brooklyn, and Queens. The average score was 0.45, the minimum was 0, and the maximum was 0.8. Each image site was geolocated by the latitude and longitude of its camera position. Many images shared approximately the same location but were aimed in different directions. To satisfy the assumption of independence between observations, we aggregated sites within 20 m of each other by averaging their spatial coordinates and perceived safety scores. Sites were then joined spatially to skeleton measurements for centerline segments within a 20-m range. Sites more than 20 m from any segment, or within 20 m of more than one segment, such as at intersections, were omitted from analysis. This yielded a final sample of 635 sites with perceived safety scores and spatially coincident streetscape skeleton variables.

Two variables were also joined to each image site to control for potential effects of affluence and neighborhood-scale urban form. Income statistics were calculated from five-year estimates of median annual household income by block group from the 2012 American Community Survey (U.S. Census Bureau, 2012). Because many image sites were located on streets that formed boundaries between block groups, sites were assigned the average of median household incomes among block groups within 50 m. Walk Scores, which summarized neighborhood-scale urban form characteristics such as pedestrian accessibility of retail, entertainment, natural, and other amenities, as well as the network connectivity of the surrounding street grid, were also collected for each image site. Walk Scores were obtained by manually entering latitude and longitude coordinates for each image site into the search tool at the Walk Score® website (Walk & Score, 2014). While the Walk Score® algorithm was proprietary, scores had been validated by several independent studies as an effective metric for neighborhood-scale urban form (Carr, Dunsiger, & Marcus, 2010; Duncan, Aldstadt, Whalen, Melly, & Gortmaker, 2011; Manaugh & El-Geneidy, 2011).

Descriptive statistics and bivariate correlations between perceived safety scores and predictor variables are presented in Table 1. Nearly all correlations were positive and significant ($p < 0.01$), except the correlation with width, which was weakly negative, indicating that narrower streetscapes were perceived as safer, though the relationship was not statistically significant. Tree canopy coverage had the strongest relationship with perceived safety. Fig. 4 demonstrates the strength and direction of

Table 1
Descriptive statistics and correlations with perceived safety scores.

Variable	Min	Mean	Max	Standard deviation	Correlation with perceived safety score
Perceived safety score ^b	0.05	0.45	0.80	0.13	
Width (m)	16	29	79	11	−0.05
Length (m)	40	178	468	72	0.18 ^a
Height (m)	4	18	289	26	0.15 ^a
Cross-sectional proportion	0.05	0.69	12.03	1.03	0.16 ^a
Street wall continuity	0.02	0.70	1.00	0.16	0.12 ^a
Buildings per 100 m length	0.0	2.1	11.4	2.1	0.26 ^a
Tree canopy coverage	0.00	0.08	0.67	0.10	0.40 ^a
Walk Score ^{®c}	42	86	100	10	0.23 ^a
Median household income	\$10,900	\$61,800	\$250,000	\$32,200	0.31 ^a

^a $p < 0.01$ (two-tailed).

^b Salesses et al. (2013).

^c www.walkscore.com.

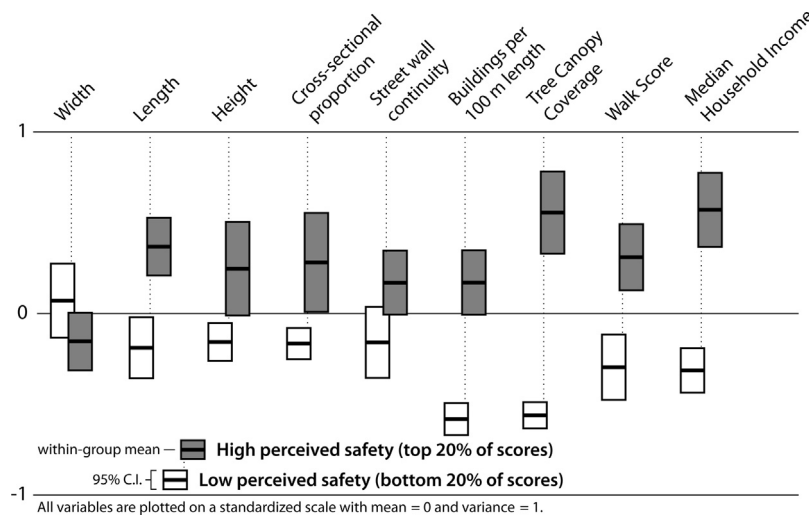


Fig. 4. Skeleton and control variable means of sites with the highest and lowest perceived safety scores.

relationships between each predictor and perceived safety by comparing the means of sites with the highest (gray) and lowest (white) 20% of perceived safety scores. Sites perceived as safest had significantly taller buildings, longer block length, larger cross-sectional proportions, more buildings, greater tree canopy, higher Walk Score[®], and greater income. Those perceived as safest also had marginally greater street wall continuity and were slightly narrower, though these differences were not significant with 95% confidence.

3.3. Statistical modeling

Both ordinary least squares (OLS) and logistic regression models were used to examine the multiple effects of streetscape skeleton measures on perceived safety while controlling for household income and Walk Scores. Results of ordinary least squares were more straightforward to interpret, but the bounded range of perceived safety scores between 0 and 1 violated the assumption of an infinitely continuous response variable. In practice, OLS regression was likely to produce reasonable estimates because the distribution of perceived safety scores was highly normal, with 98% of records falling between 0.2 and 0.8. Nonetheless, we used logistic regression to estimate an alternative model predicting the probability of fixed-range responses between 0 and 1 (Grove et al., 2006; Zhao, Chen, & Schaffner, 2001). Similarity in parameter magnitudes and signs between the two types of models reinforced our confidence in the OLS results.

Linear regression estimates were weighted to account for heteroskedasticity introduced by variability in the number of images contributing to aggregated safety scores. Because each image had approximately the same number of votes contributing to its score, the averages of two, three, or four images were based on larger samples of votes, theoretically resulting in less error than sites with only one image. As such, aggregated scores were weighted proportional to the number of images contributing to them. Coefficients were estimated by minimizing the sums of squared distances between observed and predicted safety scores using the linear regression tool in IBM SPSS Statistics Version 22.

Because safety scores represented the probability of an image being preferred in a random pairing, logistic regression was used to estimate the probability of preference. This was operationalized using a generalized linear model (GLM) with a binomial distribution and a logit link function. The effective response variable was the proportion of preference events to number of trials. However, the GLM tool in the aforementioned SPSS software accepted only integer values for events and trials. Because raw events and trials data were not made available by Salesses et al. (2013), we approximated event counts by multiplying the aggregated safety score at each site, y_i , by the number of images contributing to it, w_i , and the average votes per image, 34. Trials were approximated as the product of images at each site and the average votes per image, 34. Both events and trials were rounded to the nearest integer prior to modeling. Coefficients were estimated by maximizing the likelihood of agreement between observed and predicted event/trial proportions for each image site.

Skeleton variables with distributions skewed to the right were transformed prior to modeling to better approximate normal distributions. Height, cross-sectional proportion, and buildings per length were natural log transformed to correct for highly skewed distributions. Tree canopy coverage, which was comparatively less skewed and included zero values, was square root transformed.

Linear and logistic regression models were each developed using an independent, iterative process. Initially, all predictors were entered into each model; insignificant ($p < 0.05$) coefficients were sequentially removed until all coefficients were significant at the 0.05 level. The sign and significance of the width coefficient, though never large in magnitude, fluctuated substantially based on the combination of predictors included in the model. Due to this inconsistency, width was excluded from both final models. Coefficients for height and street wall continuity were insignificant in both models. The insignificance of height may be explained by its strong correlation with cross-sectional proportion ($r = 0.91$). Including both predictors would have challenged the assumption of predictor independence inherent in both OLS and logistic regression. Multicollinearity within the final models was not considered problematic. The maximum variance inflation factor (VIF) among predictor variables was 1.9, considerably lower than the threshold of 10 that O'Brien (2007) considers problematic in regression modeling.

Due to the spatial nature of perceived safety scores, it was important to consider whether regression coefficients were artificially inflated by spatial autocorrelation. To test this, we used Moran's I to examine spatial autocorrelation among residuals from the OLS model. A Moran's I approaching 1 or -1 would show that residuals were either clustered or dispersed in a regular pattern, indicating that the model was underspecified by not accounting

for underlying spatial relationships. A Moran's I of 0 would indicate randomly distributed residuals, consistent with the assumptions of OLS regression. Using the ArcGIS Spatial Autocorrelation tool, we calculated global Moran's I to be 0.32 ($p = 0.11$) based on Euclidean distance between residuals at each image site. This indicated only minor clustering that was insignificant at the 0.05 level, suggesting that OLS coefficients were reasonably accurate without accounting for spatial effects.

4. Results and discussion

Several streetscape skeleton variables were strongly related to perceived safety. The full OLS model, including controls for Walk Score® and household income, accounted for more than 46% of variability in perceived safety scores (Table 2). When only skeleton variables were modeled—length, cross-sectional proportion, buildings per unit length, and tree canopy coverage—they accounted for 42% of variability in perceived safety. Tree canopy alone accounted for approximately 22% of variability. These effects were similar in the full OLS and logistic models (Tables 2 and 3). Percentage increases in cross-sectional proportion and buildings per length, due to their logarithmic transformation, were estimated to increase perceived safety scores by approximately 0.05 and 0.02 respectively according to the OLS model. The same model estimated that every square increase in tree canopy coverage, due to its square root transformation, increased perceived safety by 0.34. The effects of predictors were best compared by standardizing their means and variances. Across both models, standardized coefficients for tree canopy coverage had the greatest magnitude, followed by buildings per length and cross-sectional proportion. The effects of Walk

Table 2
Final linear regression model.

Predictor variable	Coefficient	Standardized coefficient (bars compare magnitudes)	t-Value
<i>Response variable: perceived safety score^b</i>			
Length	0.0001	0.074	2.475 ^a
Cross-sectional proportion (LN)	0.045	0.258	6.381 ^a
Buildings per 100 m length (LN)	0.024	0.316	9.932 ^a
Tree Canopy Coverage (SQRT)	0.340	0.459	15.024 ^a
Walk Score®	0.001	0.114	3.138 ^a
Median household income (in \$10,000 s)	0.008	0.205	6.592 ^a
Constant	0.219		4.922 ^a
N = 635			
F(6, 628) = 89.9 ^a			
R ² = 0.46			

^a Significant at 99% probability.

^b Salesses et al. (2013).

Table 3
Final logistic regression model.

Predictor variable	Coefficient	Standardized coefficient (bars compare magnitudes)	Wald chi-square
<i>Response variable: perceived safety score^b</i>			
Length	0.001	0.039	14.354 ^a
Cross-sectional proportion (LN)	0.194	0.143	105.934 ^a
Buildings per 100 m length (LN)	0.103	0.178	242.845 ^a
Tree Canopy Coverage (SQRT)	1.413	0.242	530.169 ^a
Walk Score®	0.006	0.063	23.605 ^a
Median household income (in \$10,000 s)	0.033	0.105	96.515 ^a
Constant	-1.149		91.815 ^a
N = 635			
Log likelihood = -2210.419			
McFadden pseudo R ² = 0.22			

^a Significant at 99.9% probability.

^b Salesses et al. (2013).

Score[®] and median household income on perceived safety were relatively minor.

In general, more enclosed streetscapes, with greater cross-sectional proportions and tree canopy creating room-like spaces, were perceived as safer. The substantial contribution of trees to perceived safety is consistent with the negative relationship between street trees and crime identified by Troy, Morgan Grove, and O’Neil-Dunne (2012). Trees may be an efficient strategy for increasing enclosure and improving safety in both subjective and objective terms. Greater numbers of buildings over a given length was also associated with greater perceived safety, potentially because narrower buildings visually partitioned streetscapes into more intimate subspaces, an effect similar to enclosure. Length had the least effect, unsurprising given the difficulty of judging block length from a street-level perspective. Indeed, any effect of length may have been due to correlations, albeit weak, between it and other key predictors. Longer street segments tended to have more buildings per length ($r=0.16$) and greater tree canopy coverage ($r=0.14$). Intersections, which may have been more visible from shorter blocks than longer ones, may have detracted from perceived safety by offering less enclosure and implying greater potential for vehicle interaction.

A notably insignificant skeleton variable was street wall continuity, which theoretically contributes to enclosure. It had no significant effect when added to either model (OLS: $p=0.46$; logistic: $p=0.163$), though it was significantly correlated with perceived safety in a bivariate context ($r=0.12$, $p<0.01$). Streetscapes with more continuous street walls tended to have greater cross-sectional proportions ($r=0.21$), buildings per length ($r=0.35$) and Walk Scores ($r=0.26$), so the effect of street wall continuity may have simply been accounted for by these other predictors. Its effect may have also been limited by respondents’ inability to detect street wall gaps from Place Pulse images that were oriented nearly parallel to the street walls. Only large, foreground gaps—empty lots, parking lots, gas stations—would have been notable from this perspective. Street walls in the sample were largely continuous, with an average of 70% continuity over the length of a block, likely due to high land values and development pressure in New York City.

Neither model included width or height terms, indicating that visual preferences were based purely on spatial proportions, not the absolute scale of streetscapes. For example, tall, wide streetscapes were likely to have the same perceived safety as short, narrow streetscapes with similar cross-sectional proportions (Fig. 5). Jacobs (1993) succinctly articulates the importance of cross-sectional proportion to streetscape perception, noting that “The wider a street gets, the more mass or height it takes to define it, until at some point the width can be so great that real street definition . . . stops, regardless of height” (p. 277). There are also practical limitations on the scale and proportions of streetscapes. Because tall

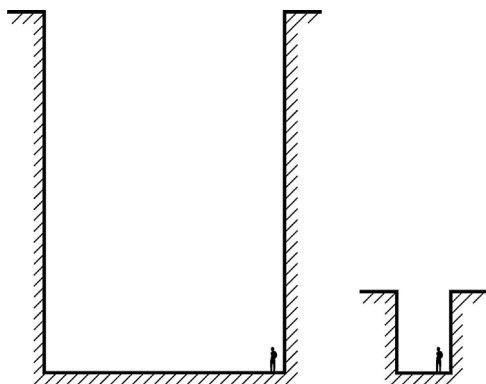


Fig. 5. Contrasting streetscape scales with equivalent cross-sectional proportions.

buildings are only economically feasible in the most central places, the vast majority of streets with low buildings must be relatively narrow to in order to have large cross-sections.

While Jacobs insinuates that comfort in streetscapes diminishes at extreme dimensions, this study revealed only linear relationships, with larger cross-sectional proportions due to taller or narrower streets always predicting greater perceived safety. We experimented with squaring predictors to identify optimum values, but this did not yield better fit in either model. Nonetheless, it is logical to assume that there may be optimal streetscape dimensions and proportions, though these optimums may vary from city to city. While New York City is a opportune setting for testing the extremes of height and cross-sectional proportion, it has few examples of extremely wide streetscapes, like those on the fringe of sprawling cities such as Los Angeles and Atlanta, or extremely narrow streetscapes like those in historic European and Asian cities. Moreover, streetscape images used by the Place Pulse method did not show the full height or width of extremely tall or wide streetscapes. Extending this study across more diverse built environments, and using stimuli that better show full streetscape dimensions, may reveal optimums that vary geographically and culturally. Streetscapes in northeastern U.S. cities may have very different optimums than those in the southwestern U.S., where wide, unenclosed streetscapes might be perceived as safer for those accustomed to that urban style.

Compared with most skeleton variables, Walk Score[®] had minimal effect on perceived safety scores. This suggests that areas with neighborhood-scale urban form that makes them impractical for walking may nonetheless be safe-feeling due to streetscape-scale characteristics. Likewise, areas with high accessibility to amenities may be perceived as unsafe and therefore foster limited use of streetscape spaces despite their practicality. Neighborhood- and streetscape-scale characteristics both likely play important roles in fostering comfortable and inviting urban spaces, but they are distinct qualities that do not necessarily come hand-in-hand.

The relatively weak effect of median household income suggests that skeletal proportions may have a greater effect on perceived safety than design details—building materials, fixtures, architectural styling—that are more directly affected by affluence. It is also possible that subtle but important cues of affluence—brass door knobs or gas street lights, for example—were not detectable in the low resolution images judged by Place Pulse respondents. Whatever the cause, the minor effect of income indicates that streetscape skeletons, and associated safety perceptions, may transcend socioeconomic barriers.

Statistical effects do not imply causation, but because of the temporal precedence of built environment development it is reasonable to suggest that observed variation in perceived safety was a consequence of skeleton variables rather than the inverse. Buildings and trees take decades, if not hundreds of years to develop. They have a durable presence in urban fabric. The perceived safety of a streetscape may certainly affect forthcoming design decisions; an esteemed streetscape may attract more investment, resulting in design improvements through time. However, the Place Pulse survey asked respondents to judge streets at a snapshot in time, from an outside perspective, with no awareness of the development trajectory or contextual setting, and in comparison to images from four cities in two countries. Thus, the Place Pulse scores indicate the effect of visual cues alone, rather than chronological or contextual knowledge.

4.1. Limitations

Our results must be interpreted in the context of several limitations inherent to our data sources and the methods used to derive them. The accuracy and precision of streetscape skeleton

measurements were limited by the building and tree canopy geometry on which they were based. Building footprint data represented only the general outlines of buildings and may not have included, awnings, porches, or other elements extending from façades that might have impacted how respondents interpreted streetscape edges. Moreover, we were unable to account for complex building geometry such as peaked roofs or setbacks at upper levels. All buildings were modeled as vertical extrusions of their footprints with flat roofs. Walls, fences, hedges, lampposts, and other design elements that might have defined the size and shape of real-world streetscapes were unaccounted for due to lack of adequate spatial data. Because tree canopy data were limited to horizontal coverage we could not model the vertical effects of trees, such as partitioning streetscapes into subspaces. Innovative technologies, such as street-level LiDAR scanners, might allow more precise measurement of buildings, trees, walls, fences, and other features, facilitating future research on their effects.

Perceived safety scores from the Place Pulse dataset were subject to a variety of limitations. Of primary concern was the potential for safety judgments to be biased by the largely young–adult male respondents. As discussed earlier, young males may have perceived urban environments to be safer than their older or female counterparts. A more diverse pool of respondents, or the ability to control for demographic characteristics, would have been preferable. However, available Place Pulse scores were aggregated by location, and thus did not include demographic information for individual respondents. Salesses et al. (2013), drawing on their raw data to derive and compare scores based on subsets of respondents, reported no significant differences in safety preferences based on the age, gender, or geographic location. Future research should further explore how cultural and regional differences may impact perceptions of safety and other measures of built environment preference.

Another limitation of Place Pulse scores was their derivation from static images rather than complete sensory experiences. Perceptions of real-world streetscape are likely influenced by sounds, smells, weather conditions, and activity that are challenging, if not impossible to convey through a personal computer interface. In the Place Pulse survey, even visual conditions were imperfectly represented by the small, relatively low-resolution images with specific viewing angles. The upper stories of tall buildings were not visible, so respondents were unable to detect differences in height and cross-sectional proportion among blocks where buildings were more than several stories tall. Also, respondents could only base their judgments on the immediate environment of each photograph rather than the entire block-length streetscape that contributed to skeleton measurements. These limitations might be partially overcome by allowing respondents to pan and tilt within a 360° panorama, move between multiple images along a transect, watch a video, or listen to streetscape sounds. Technology, however, will never fully mimic the sensation of a place, and these developments would substantially increase the time and cognitive load required for each judgment. Researchers must choose how to prioritize the authenticity of field surveys or the efficiency of virtual experiences.

Sensory limitations of the Place Pulse survey may actually have been advantageous for gauging *perceived* safety rather than objective risk. With only small, static images at their disposal, respondents were encouraged to make gut-level decisions based on first impressions, much like they would when deciding whether to walk down an unfamiliar street in real life, rather than overthinking their judgments and grasping for additional information. Moreover, lack of geographic context forced respondents to make judgments based purely on physical characteristics rather than prior knowledge of neighboring areas or activities in those places. Contextual knowledge is undoubtedly important to the way people

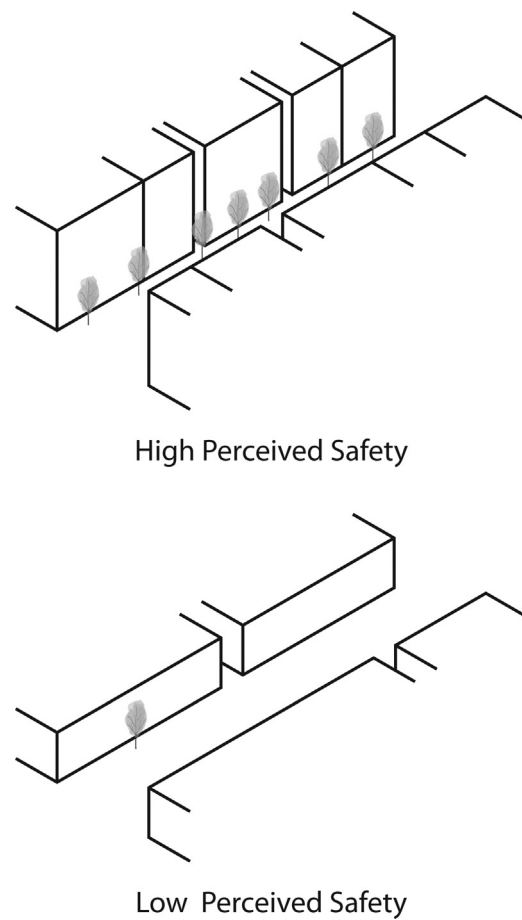


Fig. 6. Examples of streetscapes with high and low perceived safety. Each illustration demonstrates the mean tree canopy coverage, buildings per length, and cross-sectional proportion among sites with the highest and lowest 20% of perceived safety scores. Variation in streetscape height is a function of cross-sectional proportion. Illustrations are not drawn to a particular scale. Both illustrations have the same width and street wall continuity.

interact with the world, but removing these biases in an experimental setting helps us understand the effects of baseline physical conditions.

Walk Scores also presented limitations due to the lack of up-to-date documentation about how they were calculated. The Walk Score® index, as originally released in 2007, was based on accessibility to amenities such as restaurants and grocery stores, and geometric urban form variables such as intersection density. The index did not include crime, esthetic, or traffic variables (Duncan et al., 2011). However, Walk Score® no longer offers publically available documentation of its inputs and proprietary algorithms. As such, the exact combination of factors contributing to the Walk Scores used in this study cannot be confirmed.

5. Conclusion

Our models suggest that the skeletal proportions of streetscapes across New York City accounted for approximately 42% of variability in perceived safety. In general, streetscapes with the greatest enclosure, fostered by substantial tree canopy, many individual buildings, and large cross-sectional proportions, were perceived as safest (Fig. 6). Tree canopy offered the strongest positive effect. Importantly, Walk Score® had far less predictive power than skeleton variables, indicating a clear distinction between the block-scale design of streetscapes and neighborhood-scale urban form. Both

factors are likely important to the vitality of urban places, but are inadequate proxies for one another. Household income also had a relatively minor effect on perceived safety. This suggests that enclosing buildings and trees may have provided a baseline degree of perceived safety, even in less affluent places.

Perceived safety was not strongly affected by several skeleton variables. Enclosure provided by street wall continuity had no significant effect on safety perceptions when other variables were controlled. Streetscape width and height also had no substantial effect. However, since relatively few streetscapes had extreme height, perceived safety benefits of more narrow streetscapes were implied by the benefits of larger cross-sectional proportions.

Our results do *not* suggest that streetscape enclosure should be considered a silver bullet for improving safety perceptions. First, our results do not show that any specific configuration of buildings and trees yields the safest-feeling streetscapes. Rather, they show associations between perceived safety and enclosure achieved in a variety of ways. This leaves substantial opportunity for design that is creative, responds to site constraints, and is sensitive to historical and cultural context. Second, streetscape enclosure is neither fast nor inexpensive to modify. It may, however, be developed incrementally and incentivized by straightforward policy. Enhancing streetscape enclosure provides further rationale for existing tree planting agendas in many cities. Enclosure provided by buildings is also encouraged by market feedbacks. If infill improves both centrality and esthetics it will attract additional infill. Many cities already incentivize such growth through strategies to strengthen downtown areas. Moreover, skeleton variables offer an intelligible language, akin to setback and building envelope regulations, for guiding productive development while allowing stylistic design freedom. Enclosed streetscape skeletons are the product of long-term investments, but may grow naturally over time into one of a city's most enduring assets.

Research on the social implications of built environments is accelerating quickly as the global population urbanizes and simultaneously aspires to higher quality of life. Nonetheless, methods for measuring the intricacies of urban design, human perceptions, and behavioral responses, remain in their infancy. This study demonstrates the application of novel strategies for capturing built environment measurements. GIS data and tools can be used for automated measurement of streetscape design. Perceptions of now-ubiquitous streetscape imagery can be efficiently drawn from thousands of respondents using crowdsourcing technology. Automated approaches for capturing both types of data extend the frontier of research to draw on ever-larger and more diverse samples. Future studies should investigate differences in streetscape design throughout the world and in variously sized cities. It will be particularly valuable to determine whether relationships between enclosure and perceived safety are universal, or have cultural variability and should thus be designed and incentivized differently between cities. Finally, it will be important to investigate how engineering of roadways contributes to the perceived safety of streetscapes around them. This study has concentrated on the vertical elements of streetscapes, but the horizontal layout of sidewalks, bicycle lanes, vehicle lanes, and the traffic running through them strongly effect how streets are perceived and used (Appleyard et al., 1981). Research on the design of streetscapes and roadways must be merged to design whole streets that are comfortable and attractive, while acknowledging that it is inappropriate to strive for an optimal, standardized streetscape. Design variability remains central to human enjoyment of urban places. Researchers should work to provide frameworks that are not overly prescriptive, leaving design flexibility to the discretion of architects, urban designers, and transportation engineers who can make context-sensitive choices.

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References

- Alexander, C., Ishikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., & Angel, S. (1977). *A pattern language: Towns, buildings, construction*. New York: Oxford University Press.
- Alfonzo, M. A. (2005). To walk or not to walk? The hierarchy of walking needs. *Environment and Behavior*, 37(6), 808–836.
- Appleton, J. (1975). *The experience of landscape*. London: John Wiley.
- Appleyard, D., Gerson, M. S., & Lintell, M. (1981). *Livable streets*. Berkeley: University of California Press.
- Arnold, H. F. (1993). *Trees in urban design*. New York: Van Nostrand Reinhold.
- Azgarzadeh, M., Lusk, A., Koga, T., & Hirate, K. (2012). Measuring oppressiveness of streetscapes. *Landscape and Urban Planning*, 107(1), 1–11.
- Blöbaum, A., & Hunecke, M. (2005). Perceived danger in urban public space: The impacts of physical features and personal factors. *Environment and Behavior*, 37(4), 465–486.
- Blumenfeld, H. (1971). In H. Blumenfeld, & P. D. Spreiregen (Eds.), *The modern metropolis*. Cambridge, MA: Massachusetts Institute of Technology.
- Boarnet, M. G., Forsyth, A., Day, K., & Oakes, J. M. (2011). The street level built environment and physical activity and walking: Results of a predictive validity study for the Irvine Minnesota Inventory. *Environment and Behavior*, 43(6), 735–775.
- Carr, L. J., Dunsiger, S. I., & Marcus, B. H. (2010). Walk score as a global estimate of neighborhood walkability. *American Journal of Preventive Medicine*, 39(5), 460–463.
- City of New York. (2013). *NYC OpenData*. Retrieved from <https://nycopendata.socrata.com/>
- Clifton, K. J., Livi Smith, A. D., & Rodriguez, D. (2007). The development and testing of an audit for the pedestrian environment. *Landscape and Urban Planning*, 80(1–2), 95–110.
- Cullen, G. (1971). *The concise townscape*. New York: Van Nostrand Reinhold.
- Dover, V., & Massengale, J. (2013). *Street design: The secret to great cities and towns*. Hoboken, NJ: Wiley.
- Duncan, D. T., Aldstadt, J., Whalen, J., Melly, S. J., & Gortmaker, S. L. (2011). Validation of walk score for estimating neighborhood walkability: an analysis of four US metropolitan areas. *International Journal of Environmental Research and Public Health*, 8(11), 4160–4179.
- Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association*, 76(3), 265–294.
- Ewing, R., & Clemente, O. (2013). *Measuring urban design: Metrics for livable places*. Washington, DC: Island Press.
- Ewing, R., Clemente, O., Handy, S., Brownson, R. C., & Winston, E. (2005). *Identifying and measuring urban design qualities related to walkability*. Robert Wood Johnson Foundation.
- Ewing, R., & Dumbaugh, E. (2009). The built environment and traffic safety: A review of empirical evidence. *Journal of Planning Literature*, 23(4), 347–367.
- Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. *Journal of Urban Design*, 14(1), 65–84.
- Grove, J. M., Troy, A. R., O'Neil-Dunne, J. P. M., Burch, W. R., Cadenasso, M. L., & Pickett, S. T. A. (2006). Characterization of households and its implications for the vegetation of urban ecosystems. *Ecosystems*, 9(4), 578–597.
- Herzog, T. R., & Chernick, K. K. (2000). Tranquility and danger in urban and natural settings. *Journal of Environmental Psychology*, 20(1), 29–39.
- Herzog, T. R., & Flynn-Smith, J. A. (2001). Preference and perceived danger as a functional of the perceived curvature, length, and width of urban alleys. *Environment and Behavior*, 33(5), 653–666.
- Jacobs, A. B. (1993). *Great streets*. Cambridge: The MIT Press.
- Jacobs, J. (1961). *The death and life of great American cities*. New York: Random House.
- LaGrange, R. L., & Ferraro, K. F. (1989). Assessing age and gender differences in perceived risk and fear of crime. *Criminology*, 27(4), 697–720.
- Locke, D. H., Grove, J. M., Lu, J. W. T., Troy, A., Neil-dunne, J. P. M. O., & Beck, B. D. (2010). Prioritizing preferable locations for increasing urban tree canopy in New York City. *Cities and the Environment*, 3(1), 1–18.
- Lynch, K. (1960). *The image of the city*. Cambridge: The MIT Press.
- Managh, K., & El-Geneidy, A. (2011). Validating walkability indices: How do different households respond to the walkability of their neighborhood? *Transportation Research Part D: Transport and Environment*, 16(4), 309–315.
- Moniruzzaman, M., & Páez, A. (2012). A model-based approach to select case sites for walkability audits. *Health & Place*, 18(6), 1323–1334.

- Montgomery, C. (2013). *Happy city: Transforming our lives through urban design*. New York: Farrar, Straus and Giroux.
- Nasar, J. L. (1987). Environmental correlates of evaluative appraisals of central business district scenes. *Landscape and Urban Planning*, 14, 117–130.
- National Association of City Transportation Officials. (2013). *Urban street design guide*. Washington, DC: Island Press.
- Newman, O. (1972). *Defensible space: Crime prevention through urban design*. New York: Macmillan.
- O'Brien, R. M. (2007). A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity*, 41(5), 673–690.
- Pikora, T., Giles-corti, B., Bull, F., Jamrozik, K., & Donovan, R. (2003). Developing a framework for assessment of the environmental determinants of walking and cycling. *Social Science & Medicine*, 56(8), 1693–1703.
- Place Pulse. (2014). *Place Pulse 1.0: The pilot study (2010–2012)*. Macro connections. MIT Media Lab. Retrieved from <http://pulse.media.mit.edu/data/>
- Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental correlates of walking and cycling: Findings from the transportation, urban design, and planning literatures. *Annals of Behavioral Medicine*, 25(2), 80–91.
- Salesses, P., Schechtner, K., & Hidalgo, C. A. (2013). The collaborative image of the city: mapping the inequality of urban perception. *PLOS ONE*, 8(7), e68400.
- Southworth, M. (2003). Measuring the livable city. *Built Environment*, 29(4), 343–354.
- Stamps, A. E. (2005). Enclosure and safety in urbanscapes. *Environment and Behavior*, 37(1), 102–133.
- Troy, A., Morgan Grove, J., & O'Neil-Dunne, J. (2012). The relationship between tree canopy and crime rates across an urban–rural gradient in the greater Baltimore region. *Landscape and Urban Planning*, 106(3), 262–270.
- U.S. Census Bureau. (2012). *American community survey 5-year estimates*. Retrieved from http://www.census.gov/acs/www/data_documentation/summary_file/
- Walk Score. (2014). *Walk Score*. Retrieved from <https://www.walkscore.com/>
- Zhao, L., Chen, Y., & Schaffner, D. W. (2001). Comparison of logistic regression and linear regression in modeling percentage data. *Applied and Environmental Microbiology*, 67(5), 2129–2135.