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Creating and validating GIS measures of urban design for health research

Marnie Purciel^{a,*}, Kathryn M. Neckerman^a, Gina S. Lovasi^b, James W. Quinn^a, Christopher Weiss^a, Michael D.M. Bader^a, Reid Ewing^c, and Andrew Rundle^d

^aInstitute for Social & Economic Research & Policy, 420 West 118th Street, Mail Code 3355, Columbia University, New York, NY 10027, USA

^bRobert Wood Johnson Foundation Health & Society Scholars program at Columbia University, New York, NY, USA

^cCollege of Architecture & Planning, University of Utah, Salt Lake City, UT, USA

^dDepartment of Epidemiology, Mailman School of Public Health, Columbia University, New York, NY, USA

Abstract

Studies relating urban design to health have been impeded by the unfeasibility of conducting field observations across large areas and the lack of validated objective measures of urban design. This study describes measures for five dimensions of urban design – imageability, enclosure, human scale, transparency, and complexity – created using public geographic information systems (GIS) data from the US Census and city and state government. GIS measures were validated for a sample of 588 New York City block faces using a well-documented field observation protocol. Correlations between GIS and observed measures ranged from 0.28 to 0.89. Results show valid urban design measures can be constructed from digital sources.

Keywords

GIS; Urban design; Methods development; Physical activity; Walking

1. Introduction

Research examining the association between the built environment and physical activity has focused on urban form measures such as residential density, land use mix, street connectivity, proximity to physical activity resources, and public transit access (Papas et al., 2007). As a complement to these measures of urban form, more subtle “urban design” characteristics of built space may also influence physical activity and weight. Urban design in the context of this paper refers to urban form at the highest level of resolution – the street segment or block face; it is defined in a variety of ways and assessed through observational and often subjective measures. The term urban design also refers to the discipline that addresses the arrangement of natural and built elements in space. Urban designers are concerned with how individuals perceive and interact with built and landscaped elements; they aim to create lively, comfortable, interesting, and attractive streetscapes.

Practitioners and scholars in urban design and landscape architecture have described the qualities that make a built space comfortable, memorable, interesting, or appealing, and may thereby encourage walking (Ewing, Handy, Brownson, Clemente, & Winston, 2006). For instance, *imageability*, discussed in the classic book *The image of the city* (Lynch, 1960), is the quality of a place that makes it vivid and memorable; imageable places may have distinctive buildings or landscape features as well as a coherent or “legible” organization. *Enclosure* is the extent to which an exterior space is visually bounded by buildings, fences, trees, and other vertical elements, so that it has a room-like quality (Alexander, Ishikawa, & Silverstein, 1977; Cullen, 1961; Jacobs & Appleyard, 1987). A street wall – a continuous row of buildings with minimal setback (distance between the sidewalk and the building line) – contributes to a feeling of enclosure. *Human scale* concerns whether the size and texture of physical elements matches the size and proportion of humans. It is often conceptualized as a matter of building height and street width (Alexander et al., 1977), although windows, building exteriors, and street furniture may also affect the perception of scale. *Transparency* concerns whether a passerby can perceive human activity beyond the sidewalk or building line (Curran, 1983; Jacobs, 1961). Windows or open fences create a sense of transparency, while a solid wall does the opposite. Last, *complexity* refers to visual richness: a complex place stimulates the senses with a variety of colors, architectural styles, buildings, and activities (Kaplan & Kaplan, 1989; Rapoport, 1987, 1990).

Research in environmental psychology finds some evidence of a preference for enclosure (Nasar, 1987) and for complexity (Herzog, 1992; Herzog & Shier, 2000; Isaacs, 2000; Nasar, 1994). Results however, have been mixed (Stamps, 2004), perhaps because researchers have used inconsistent or subjective measures or surveyed different populations. In addition, the response to a scene may be contingent on context: response to enclosure may vary depending on the perception of threat or safety in the environment; response to complexity may depend on the risk of getting lost (Nasar, 1994). Nor is it self-evident that preferences correspond to the likelihood of walking.

The application of urban design principles to the study of built environment effects on physical activity has received recent attention (Ewing, in press; Ewing & Handy, 2009; Ewing et al., 2006). However, urban design constructs are difficult to operationalize across large areas; as a result, we know little about their relationship to health. The closest researchers have come to assessing the effect of traditional urban design on physical activity has been through measures of the attractiveness of neighborhoods (Brennan Ramirez et al., 2006; Handy, Boarnet, Ewing, & Killingsworth, 2002; Pikora, Giles-Corti, Bull, Jamrozik, & Donovan, 2003). Some studies have found that pleasing environments are associated with higher levels of activity or walking (Ball, Bauman, Leslie, & Owen, 2001; Carnegie et al., 2002) and specifically with recreational walking (Ball et al., 2007). While this research is suggestive, it has measured only a few kinds of neighborhood characteristics: green space, such as parks or natural areas (Ellaway, Macintyre, & Bonnefoy, 2005; Giles-Corti & Donovan, 2002; Tilt, Unfried, & Roca, 2007; Troped, Saunders, Pate, Reininger, & Addy, 2003); disamenities such as noise, air pollution, or physical disorder (Boehmer, Hoehner, Deshpande, Brennan Ramirez, & Brownson, 2007; Ellaway et al., 2005; Hoehner, Ramirez, Elliott, Handy, & Brownson, 2005); and attractive architecture or urban design (Ewing, in press; Handy et al., 2002; Lee & Moudon, 2006).

Given the existing strategies of measurement, researchers seeking to relate attractive architecture or urban design to health or health behaviors face both conceptual and practical limitations. Most such studies rely either on respondent surveys (Lee & Moudon, 2006) or on ratings by trained observers (Hoehner et al., 2005; Pikora et al., 2006). At a conceptual level, survey-based studies typically employ descriptors such as “interesting” or “attractive” architecture rather than specific constructs, such as enclosure or complexity, identified by

research in urban design or environmental psychology. At a practical level, survey-based measures must be included in the instrument at the time of data collection – a disadvantage for the many researchers conducting secondary analysis of large scale health surveys – and may present problems of “same-source bias” when measures of environment and behavior are collected from the same respondent (Duncan & Raudenbush, 1999). Observer ratings or field measures are more likely than survey measures to be conceptually derived from the urban design literature, and can be employed in secondary analysis, but the time-intensive nature of in-person data collection makes this approach unfeasible on a large scale.

The goal of the present research is to advance the study of the relationship between urban design and physical activity. We aim to help future researchers avoid the conceptual and practical limitations of survey and observational studies by developing a geographic information system (GIS) method for the direct measurement of urban design features that is conceptually grounded in the urban design literature and can feasibly be scaled up to the city level. We then validate this GIS measurement with observational data from a sample of New York City block faces. To do this we have built on work by Ewing et al. (2006) who developed a detailed and well-documented observation protocol for measuring the five urban design constructs previously mentioned. We implemented their observation protocol for 588 block faces in New York City. Then, with public data from the US Census and state and city governments, we developed GIS methods for measuring the same urban design constructs, using the observational data to validate our GIS measures.

The remainder of this section provides a brief review of how the observation protocol used to measure the five urban design constructs was developed by Ewing et al. (2006) and replicated in our study of New York City. Then, after presenting our methods for replicating their protocol, we explain the GIS methods used to measure the urban design features in a digital environment, and discuss the validation results and implications for future studies.

1.1. Observational measures of urban design

The present study uses observational measures of urban design developed by Ewing et al. (2006). This interdisciplinary team assembled a panel of experts in urban design and planning to review 48 video clips taken on commercial streets in multiple U.S. cities. Experts rated each scene on nine urban design dimensions. Ratings of three urban design qualities – legibility, linkage, and coherence – demonstrated low inter-rater reliability, and these qualities were dropped from the study. For the remaining six urban design qualities, Ewing et al. (2006) identified the physical features of streets that theoretically contribute to the expert ratings, and developed a field manual with detailed measurement protocols for coding these features. After undergoing training based on the manual, student observers coded these physical features for the sample of street scenes. One urban design quality, tidiness, was not included in the final protocol because field measures appeared to be unreliable.

For the five urban design qualities, Ewing et al. (2006) specified the physical features that could reliably be measured and were found to predict expert ratings of the five urban design qualities. The physical features were used to predict expert ratings and scales were created for each of the five urban design qualities by assigning a weight to each feature (positive or negative) equal to its beta coefficient, yielding an equation for calculating a score from physical features for each of the five urban design qualities.

2. Methods

2.1. Observer ratings of urban design

We implemented the Ewing et al. observation protocol in a stratified sample of 588 blocks in all five boroughs that comprise New York City. Using data from the primary land use tax output (PLUTO) database, which is a spatial database of tax parcels created in a geographic information system (GIS) and compiled by the Department of City Planning, we sampled blocks from the population of all blocks in New York City using a multi-stage, stratified sampling scheme. Our first stage was to randomly sample Census tracts based on six strata defined by building density (the ratio of total floor area to lot area, divided at the median) and residential use (the ratio of residential to total floor area, divided into tertiles). Then, from each of the six strata, we randomly sampled 100 blocks. By stratifying our sample in this way we were able to obtain equal numbers of blocks in areas with varying levels of residential use in both high and low density neighborhoods. Of the non-residential uses represented in the data, the majority of these were commercial, although a few were in manufacturing areas. All block faces in a selected area were identified and numbers were randomly assigned to each face and marked on maps that observers took with them into the field. Upon reaching the block, the observer selected block face “1” for observation. If block face “1” was physically inaccessible or did not meet our specifications (a length of 61–244 m and a definable starting and ending point), the observer moved on to block face “2” and so on until he or she reached a block face that met our specifications. Figs. 1–3 illustrate examples from surveyed blocks.

Based on the manual produced by Ewing et al. (2006), we developed a field manual tailored to the New York City context (see http://www.beh.columbia.edu/articles/observational_coding.html). Six field workers were trained using video clips provided by Ewing’s team. The field workers completed ratings of 588 of the 600 sampled blocks during the summer of 2006. (There were 12 blocks for which no block face met our observable criteria.) To assess inter-rater reliability, 13 block faces were scored independently by all observers, and inter-class correlation coefficients were calculated for each urban design quality and each rater. Reliability results show a high degree of consistency among observers (ICCs: imageability = 0.72, enclosure = 0.81, human scale = 0.70, transparency = 0.96, and complexity = 0.79).

2.2. GIS measures of urban design

Because our intent was to develop replicable methods for measuring urban design features with a GIS and to measure these features for all blocks in New York City, we sought to use public data sources and to develop methods that could feasibly be implemented on a large scale. We identified data sources and constructed GIS measures for 14 of the 22 physical features used in the observation protocol (see Table 1). The remaining eight features were unmeasured either because no citywide dataset was identified that catalogued or could proxy these items, as was the case with nonrectangular building shapes, street furniture, small planters, building colors, and public art, or because we did not have adequate methods to measure them, as was the case with the proportion of the sky visible straight ahead and across.

This section summarizes the methods used to create the GIS measures. All GIS measures were constructed using ArcGIS 9.2 and ArcView 3.3. Fig. 4 is a diagram of a block face that includes the primary set of spatial features used to measure block face characteristics; it provides visual definitions of the most commonly used geometries: blocks, tax lots, block face lines, building footprints, and building frontage lines. A block, as defined in this study, comprised all adjacent tax lots not separated from each other by streets; within the block, tax

lot boundaries were dissolved to form one continuous unit. In most cases, these blocks coincided with Census Blocks. Tax lots are the units used by the tax assessor's office to characterize a property by ownership, use, and the bulk or density of the building structures present. The block face line, the length of which served as the denominator in proportion measurements, was made up of the merged edges of the tax lots facing the side of the block being measured. Building footprints are two-dimensional polygon cross-sections of the buildings present on a tax lot. Building frontage lines were made of lines stretched around the building footprint and isolated to the side of the building and block being observed.

2.2.1. Number of parks and gardens—A count of parks and gardens on the block face was estimated using data from the NYC Department of Parks & Recreation, which identifies the locations of city-maintained parks; these data were supplemented with parcel-specific land use measures from PLUTO tax lots and a dataset including the locations of community gardens. No data were available for courtyards and plazas, most of which are privately owned and are not identified in the PLUTO database.

2.2.2. Major landscape features—Key landscape features found in New York City include harbors and other major bodies of water. (Mountains are also included in the major landscape features protocol but are not found in New York City.) To construct the GIS measure, we used a citywide hydrographic dataset—a set of polygons representing NYC's bodies of water—and identified block faces that were within 168 m of a beach, river, or shoreline and had an unobstructed view of the water from several points along the block face. We identified 168 m as a threshold distance to maximize the correlation with observed features.

2.2.3. Proportion historic building frontage—The PLUTO database includes construction year for the primary building on each tax lot. Buildings constructed before 1951 were considered “historic,” and PLUTO tax lot data were matched with building footprints to determine the total frontage of historic buildings along the block. Our measure was the ratio of the sum of these frontage measures to the entire block face line.

2.2.4. Number of buildings with identifiers—Buildings with identifiers include those with signage that clearly indicates building use; in addition, some types of buildings, such as places of worship or stadiums, are often identifiable simply from the shape or appearance of the building. Although we do not have GIS measures that indicate signs, the GIS count of buildings with identifiers included those with retail uses, which are usually marked with signage, as well as specific types of buildings expected to be identifiable; such as gas stations, hotels, or theaters.

2.2.5. Presence of outdoor dining—A list containing the name, street address, and zip code of legally operating sidewalk cafés was obtained from the NYC Department of Consumer Affairs. Addresses were geocoded and block faces with one or more sidewalk cafés present were identified.

2.2.6. Number of sitting, standing, or walking pedestrians—No pedestrian count data were available with adequate coverage of the city, so it was necessary to construct a proxy for pedestrian traffic. We assumed that pedestrians included neighborhood residents, non-residents working in or visiting commercial areas, and public transit riders walking from transit stop to destination. Using measures of population density (US Census, population per 2.6 km²), extent of commercially zoned land (density of commercially zoned tax lots per 2.6 km²), and stop-specific average weekday subway ridership data (stop-specific riders per 2.6 km²), we created raster grids for each of these three datasets using

kernel density methods. Kernel density transforms a series of points, or field values associated with points, to a continuous grid surface, where each grid cell contains a value for either the density of points or the density of a specified field (e.g. population) expected at that cell's location based on the nearby points or the values associated with those points (Gatrell, Bailey, Diggle, & Rowlingson, 1996; Silverman, 1986). Cell values were re-scaled to approximate values comparable to observed pedestrian counts; population density was divided by 10,000, commercial zoning by 100, and subway ridership by 10,000. The transformed raster grids were added together and the cell values of this composite raster were averaged for the areas of the observed block polygons. This value, specific to sampled blocks, represented the estimated pedestrian count.

2.2.7. Noise level estimate—The noise level measure was based on the assumption that urban noise is primarily a function of vehicular traffic (Seto, Holt, Rivard, & Bhatia, 2007). Average daily traffic (ADT) counts were available for the city by feature class code (FCC) road classifications. ADT data were obtained by TeleAtlas from several different government agencies for the years 1985–2002. Using the road network and ADT counts summarized by road network classification, an ADT count was associated with each sampled block face based on the weighted average of street segments within a buffer extending along the block face and 23 m into the intersections on either side. ADT count values were divided into three tertiles corresponding to the recoded observational measure. (Observers coded noise into five levels, but the highest and lowest values were seldom used; we pooled codes 1 and 2 into a combined “low” category, and codes 4 and 5 into a combined “high” category.)

2.2.8. Number of long sight lines—The observation protocol defined a long sight line as the ability to see at least 300 m (about three city blocks) into the distance from any point along the block face. Observers looked in three directions—ahead, to the left, and to the right, yielding scores ranging between 0 and 3 indicating a long sight line in 0, 1, 2, or 3 directions. The primary obstructions to an observer's view were buildings, changes in elevation, and trees. We estimated sight lines based only on building obstructions using building footprints data. Although we had access to a digital elevation model, we could not identify automated methods of incorporating elevation into a sight lines model that would simulate the observational experience. Data containing the exact positions and characteristics of trees (such as tree height or canopy) were not available.

To approximate the observational measures, we constructed a “sidewalk line” offset from the tax lot line (property line) by 3 m in the direction of the street. (This offset was used in order to situate the line on the sidewalk, mirroring the perspective of the observer.) We added one line stretching 1000 ft. beyond the end of the block, as well as perpendicular lines emanating left and right at 15 ft intervals along the sidewalk line. These lines were then intersected with building footprints. If the line ahead was not interrupted by a building footprint, the block face was coded as having a long sight line in this direction. For the side directions, if at least 20% of the left or right lines remained uninterrupted, the block face was coded as having a long sight line in that direction. (For Manhattan, we substituted a threshold of 10%.) The three scores were summed for the final long sight lines measure.

2.2.9. Street wall—As a proxy for the street wall measures, we used the “building to block area ratio,” in other words the ratio between the summed areas of the building footprints and of the corresponding tax lot areas on the block. The reasoning behind this proxy is as follows: where a large proportion of the block is occupied by buildings, we would expect a larger proportion of each block face to be occupied by buildings that front the sidewalk. A more direct measure of the street wall, using distances from the edge of the lot line (or edge of the sidewalk) to the front of the building was considered, but accuracy would have been

limited due to imperfect alignment between the building footprints and tax lots, and such a measure would have been prohibitively time-consuming and computationally intensive to construct.

2.2.10. Proportion of street segment with windows—As a proxy for buildings with windows, we used the ratio of retail building frontage to the block face line. We assumed that if a building contains a retail business, that business is likely to display goods or services in street-level windows; thus the proportion of windows score is likely to be higher when more buildings on the block have a retail use. (Office and residential buildings may also have street-facing windows, but these windows are typically smaller, and visibility is often obstructed with curtains or tinted glass). The GIS measure is the proportion of the total block face line represented by buildings with a retail use.

2.2.11. Average building height—The GIS measure was created by assigning each building frontage line the value for the “Number of Floors” available through PLUTO. The number of floors was then multiplied by 3.7 (assuming an average height of 3.7 m per story) to obtain an approximate total height of the building. The average building height for the block face is the average across buildings on the block face, weighted by the proportion that each building’s frontage represented of the total block face line.

2.2.12. Proportion active building frontage—Active-use buildings are defined as those in which there is frequent pedestrian traffic (more than five people per 20 min) entering and exiting the building. A list of “active” building class codes was defined using the PLUTO database; this list included: parks, stores, restaurants, attached/apartment style residential buildings, hospitals, and schools. The sum of the building frontage lines associated with an active use was divided by the total block face line.

2.2.13. Number of buildings—The number of buildings per tax lot was summarized by block face to calculate the total number of buildings present on both sides of the street.

We were unable to create GIS measures for eight of the observational physical features because of data limitations: number of buildings with non-rectangular shapes, proportion of the sky visible straight ahead or looking across the street, the numbers of small planters or pieces of street furniture, numbers of basic building or accent colors, and the number of pieces of public art.

2.3. Validation of GIS measures

GIS measures were validated by first determining the Spearman’s rank-order correlation between each of the 14 observed and GIS-measured physical features. Second, based on the work of Ewing, Clemente, Handy, Brownson, and Winston (2005), we calculated two sets of final urban design scale scores from observed and GIS-measured physical features for each of the five urban design qualities. Each urban design quality, Y_i^* , is measured for block face i as

$$Y_i^* = \beta_0 + \sum_{r=1}^R \beta_r X_{ri},$$

where β_0 is the conditional mean value of the urban design construct scale; β_r represents the independent weight of physical feature r (see Table 2) on the urban design construct for each of the R features in the scale; and X_{ri} is the value of feature r for block face i . For example, the observed version of the urban design quality score for enclosure is equal to the sum of

the products of the long sight lines feature value and its weight, the *proportion windows* value and its weight, the building height value and its weight, the small planters value and its weight, and the street furniture value and its weight. We used Spearman's rank-order correlation to assess the relationship between the observed and GIS-measured urban design scale scores.

Comparing scales created using GIS-measured features and observed features presented a methodological challenge because eight of the observed features could not be replicated using a GIS. We had several options. The simplest was to use the weights specified in Ewing et al. (2005) and simply to exclude the missing features from the GIS scale scores. Doing so is problematic, however, because the omission of GIS-measured physical features is likely to introduce bias. Omitting features from the GIS scale score equations (but not from the observed score equations) would result in deflated scale scores when omitted features had a positive weight and inflated GIS scale scores when omitted features had a negative weight. Therefore, a comparison of scales using observed and GIS-measured features using this method is not accurate. A second option was to drop the missing features from both the observed and GIS-measured scales, thus making the two final scores more comparable. However, omitting features from the scale found in the original Ewing et al. (2005) study without re-estimating the weights would not efficiently predict the expert urban design quality ratings. This alternative scale would have been conceptually inaccurate. Since neither of these options was satisfactory, we chose a third option. Through a collaborative arrangement with Ewing, we obtained the expert urban design quality and physical feature ratings data used in their study. This allowed us to create revised models and obtain appropriate weights for construction of scale scores that omitted features with no GIS equivalents. These re-estimated weights maintain theoretical and empirical alignment with expert judgments of urban design qualities. Two sets of final urban design quality scores were calculated and used to compare GIS with observational measures. The first set was calculated using the original Ewing et al. (2005) weights with features omitted from the GIS scale score equations (the first option discussed above) and the second set was calculated according to option three discussed above. Table 2 shows the weights estimated in the original Ewing et al. (2005) scales in column one and re-estimated weights from the models that included only those features with GIS equivalents in column two. Beta coefficients changed only slightly between the two sets of models; adjusted *R*-squared values remained fairly stable for imageability, enclosure, and complexity but were attenuated for human scale. The transparency model remained the same because no variables were removed. All analyses were conducted using Stata 9.2.

3. Results

Table 3 shows the mean scores and correlations between observed and GIS measures for all 14 urban design features. All correlations were statistically significant at the 0.001 level, but correlations varied considerably in magnitude. For three measures – the number of buildings with identifiers, the average building height, and the number of buildings – correlation coefficients were higher than 0.70. For one GIS measure, the number of long sight lines, the correlation was only 0.16. For the remaining GIS measures, correlations ranged from 0.40 to 0.70.

Table 4 displays the correlations between observed and GIS scale scores for the five urban design qualities, using the two sets of weights. In the first set, which used the Ewing et al. (2005) weights, correlations were high for two constructs, transparency and complexity, and moderate for two others, imageability and enclosure. The GIS version of human scale, however, has a very weak relationship to the observed score. This low correlation is probably due to the absence of GIS measures of street furniture and planters as well as to the

low correlation between the observed and GIS long sight lines measure. Using the re-estimated weights derived from models that included only the features with GIS equivalents, several correlation values improved considerably. Using the re-estimated weights, three of the five urban design qualities, specifically imageability, transparency, and complexity, had a correlation between observational and GIS scores higher than 0.70; the transparency scale weights did not change because all features included in this scale had GIS equivalents. Correlation coefficients for enclosure and human scale were also higher using re-estimated weights, although the human scale GIS measure still had only a weak correlation with the observed score.

4. Discussion

There is growing interest in how the design of streetscapes may influence walking (McCormack, Masse, Bulsara, Pikora, & Giles-Corti, 2006; Mujahid et al., 2008; Pikora et al., 2003) and subsequent health. However, research on the implications of urban design for health and health behaviors such as walking and physical activity has been hampered by the lack of objective and scaleable measures. Existing studies tend to rely on respondent self-reports, which present problems of same-source bias and cannot be acquired easily for secondary analyses, or on observer audits, which are unfeasible for use with a large and spatially dispersed sample. Objective measures of neighborhood aesthetic features usually emphasize natural elements rather than the design of the built environment.

The analysis reported here is part of an initiative to develop objective and theoretically-grounded indicators of urban design that are feasible for use in research. We used a detailed and well-documented protocol to collect field observation measures for 588 block faces in New York City, and constructed measures of 14 of the observed features using GIS data from public sources. Overall, GIS measures were reasonably valid for most specific features. Correlations between field observation and GIS measures were above 0.60 for five features and between 0.50 and 0.60 for six features. More important, the urban design scales created from the shared items showed a high level of agreement for three constructs (imageability, transparency, and complexity) and a moderate level of agreement for a fourth (enclosure). The low correlation between the observed and GIS-measured scale scores for human scale may indicate a need for alternative measurement strategies for this construct.

Beyond the validation of the specific GIS measures, this paper also contributes to research in public health and environmental psychology by illustrating a methodology for developing objective and scaleable measures of urban design. The constraint we faced – the fact that we could not construct GIS measures of all features in the original Ewing et al. (2005) observation protocol, is one that other investigators are likely to face as well, given the heterogeneity in data sources across locales. Because we were able to re-analyze the original expert and features ratings data, we could produce appropriate weights for calculating urban design quality scores from the GIS features we had available. This empirical exercise underlines the importance of collaboration and data sharing as researchers develop and validate measures of urban design constructs and evaluate their health effects or other dimensions of human response to the environment.

The strengths of this study include its use of a large, random sample of New York City block faces, its replication of a theoretically-grounded and well-documented audit tool, and its use of extensive and detailed GIS data resources. An important limitation was the reliance on expert ratings of urban design qualities to validate measurement, as these may not correspond to the visual preferences of lay observers. The absence of GIS equivalents for some physical design features was also a limitation. One last constraint inherent in this project is its reliance on measures developed for single block segments, thus omitting

aspects of urban design that are more context-dependent or cover a larger spatial area. Lynch's (1960) well-known discussion of imageability, for instance, includes organizational features such as "paths" and "nodes," which are not well measured using results from a single block face (Holahan & Sorenson, 1985).

This research can be extended in multiple ways. Further work pairing observational and GIS measures across geographic locales is required in order to complement our assessment of the validity of GIS measures as proxies for more time-consuming observer ratings. The current study presents a method for combining street features into urban design quality scales based on previous research. Future analytic approaches might include a factor analysis approach to test alternative methods of grouping individual street features into urban design constructs, or into groupings that are relevant for walking or other health and social indicators. Building the body of empirical work relating urban design features to individual-level outcomes can help assess the predictive validity of standard measures. This is particularly important given the limitations of relying on expert ratings. An alternative measurement scheme would involve "ecometric" methods which can reduce the researcher's reliance on a single set of weights as well as provide an assessment of the measurement properties (e.g. scale reliability, explained variance, proportion measurement error) of the various scales (Mujahid, Diez Roux, Morenoff, & Raghunathan, 2007; Raudenbush & Sampson, 1999). Also worth noting, the Ewing et al. scale uses the same physical features in more than one urban design construct, which may mean some features will appear more salient in their ability to predict certain behaviors overall, or it may mean that certain urban design constructs are simply redundant. Alternative methods may reveal a different set of physical features or qualities are related to walking.

In addition, future studies should examine the construction of urban design measures in low-density urban or suburban neighborhoods, and consider specific features that may become more salient in such settings. For instance, visual preference studies show that observers prefer settings with natural elements such as street trees (Ewing, 2005). Although street trees were not significant predictors of the urban design qualities in the expert rating data, and thus were not included in our study, trees might become more important in lower-density environments. Second, because expert judgments do not always mirror those of lay observers, future research should consider the urban design perceptions and preferences of lay raters, and the degree to which urban design measures predict behaviors or mental states. Last, while our work assumed that field observation measures could be treated as a "gold standard" for purposes of developing a GIS scale, the relative advantages of observational and GIS measures merit further study. Although in-person measures may be more sensitive to subjective or subtle streetscape features, GIS measures may provide more precise and reliable measures of features such as building height. Assessing which type of measure is more valid in any specific instance is a complex epistemological question beyond the scope of this paper.

The current research makes a methodological contribution by showing a systematic approach to measuring and validating urban design constructs for use in large scale studies. The research reported here also contributes to the field by introducing GIS urban design measures that could be replicated or adapted to other study sites and added to analyses relating neighborhood environments to walking or physical activity. GIS measures of urban design like those developed here will make it feasible to examine the relationship between urban design and walking at a city scale. These urban design methods and scales have potential applications extending beyond studies of physical activity to those of other health and social indicators, including mental health (Evans, 2003; Guite, Clark, & Ackrill, 2006; Kaplan & Kaplan, 2003), perceptions of neighborhood safety (Stamps, 2005), or social capital (Pendola & Gen, 2008). Opportunities to use measures of this kind are becoming

more widespread as increasing numbers of municipalities collect geospatial data (Moudon & Hubner, 2000). In the longer term, a common standard of GIS data collection would allow construction of comparable urban design measures across cities, facilitating multi-site studies and allowing researchers to take more advantage of extensive national datasets.

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Fig. 1.
Block face scoring high for imageability.

Fig. 2.
Block face scoring high for complexity.

Fig. 3.
Block face scoring low for human scale.

Fig. 4.
Block face diagram illustrating the primary spatial features used to measure block face characteristics with the GIS.

Table 1

Sources of data for physical features measured using the GIS.

	Physical features	Data source/attribute
Imageability		
1 ^a	Number of courtyards, plazas and parks on the block face	New York City (NYC) Department of Parks and Recreation; NYC Department of City Planning (NYCDP) primary land use tax output (PLUTO) database; New York City Coalition Against Hunger – September 2006 community gardens database
2	Number of major landscape features visible from the block face	New York City Department of Information Technology and Telecommunications' (DOITT) hydrographic dataset
3	Proportion of historic building frontage (both sides of street)	NYCDP PLUTO database – “year built” attribute; NYC DOITT building footprints dataset
4	Number of buildings with identifiers (both sides of street)	NYCDP PLUTO database – “building class” and “retail area” attributes; NYC DOITT building footprints dataset
5	Number of buildings with non-rectangular shapes (both sides of street)	No data source available
6	Presence of outdoor dining (observer side of street)	Sidewalk permit data from the NYC Department of Consumer Affairs
7	Number of people (observer side of street)	2000 U.S. Census Bureau – population; NYCDP PLUTO database – “zoning” attributes (commercial zoning); New York State Department of Transportation and NYC Transit Authority – subway stop and ridership data
8	Noise level estimate	Accident Location Information System (ALIS) road network; U.S. Census Bureau's Feature Class Codes (FCC) road classification system – Average Daily Traffic (from multiple government sources) summarized by FCC
Enclosure		
9	Number of long sight lines visible in three directions	NYCDP PLUTO database; NYC DOITT building footprints dataset
10	Proportion of street segment with street wall (observer side of street)	NYCDP PLUTO database; NYC DOITT building footprints dataset
11	Proportion of street segment with street wall (opposite side of street)	Same as above
12	Proportion of the sky visible straight ahead	Variable not measured with the GIS
13	Proportion of the sky visible looking across the street	Variable not measured with the GIS
Human scale		
9	Number of long sight lines visible in three directions	Same as above
14	Proportion of street segment with windows (observer side first floor building façade)	NYCDP PLUTO database – “retail area” attribute; NYC DOITT building footprints dataset
15	Average height of buildings weighted by building frontage (observer side of street)	NYCDP PLUTO database – “number of floors” attribute; NYC DOITT building footprints dataset
16	Number of small planters (observer side of the street)	No data source available
17	Number of pieces of street furniture (observer side of street)	No data source available
Transparency		
14	Proportion of street segment with windows (observer side first floor building façade)	Same as above
10	Proportion of street segment with street wall (observer side of street)	Same as above
18	Proportion of street segment with active uses (observer side of street)	NYCDP PLUTO database – “building class” attribute; NYC DOITT building footprints dataset
Complexity		

	Physical features	Data source/attribute
19	Number of buildings (both sides of street)	NYCDP PLUTO database; NYC DOITT building footprints dataset
20	Number of basic building colors (both sides of street)	No data source available
21	Number of accent building colors (both sides of street)	No data source available
6	Presence of outdoor dining (observer side of street)	Same as above
22	Number of pieces of public art (both sides of street)	No data source available
7	Number of people (observer side of street)	Same as above

^aTable is numbered to show features that are present in more than one urban design scale. Features are numbered in the order in which they appear and numbers repeat.

Table 2

Beta coefficients for physical features predicting experts' urban design ratings in Ewing et al. (2005) and shared features models.

Physical features		Ewing et al. (2005) model used to weight features	Shared features model used to weight features
		Beta	Beta
<i>Imageability</i>			
1 ^a	Number of courtyards, plazas and parks on the block face	0.41	0.41
2	Number of major landscape features visible from the block face	0.72	0.76
3	Proportion of historic building frontage (both sides of street)	0.97	1.10
4	Number of buildings with identifiers (both sides of street)	0.11	0.14
5	Number of buildings with non-rectangular shapes (both sides of street)	0.08	–
6	Presence of outdoor dining (observer side of street)	0.64	0.60
7	Number of people (observer side of street)	0.02	0.03
8	Noise level estimate	–0.18	–0.18
	Constant	2.44	3.06
	Adjusted <i>R</i> -squared	0.46	0.47
<i>Enclosure</i>			
9	Number of long sight lines visible in three directions	–0.31	–0.35
10	Proportion of street segment with street wall (observer side of street)	0.72	0.64
11	Proportion of street segment with street wall (opposite side of street)	0.94	1.54
12	Proportion of the sky visible straight ahead	–1.42	–
13	Proportion of the sky visible looking across the street	–2.19	–
	Constant	2.57	2.19
	Adjusted <i>R</i> -squared	0.49	0.46
<i>Human scale</i>			
9	Number of long sight lines visible in three directions	–0.74	–0.58
14	Proportion of street segment with windows (observer side first floor building façade)	1.10	1.24
15	Average height of buildings weighted by building frontage (observer side of street)	–0.003	–0.003
16	Number of small planters (observer side of the street)	0.05	–
17	Number of pieces of street furniture (observer side of street)	0.04	–
	Constant	2.61	3.30
	Adjusted <i>R</i> -squared	0.41	0.32
<i>Transparency</i>			
14	Proportion of street segment with windows (observer side first floor building façade)	1.22	1.22
10	Proportion of street segment with street wall (observer side of street)	0.67	0.67
18	Proportion of street segment with active uses (observer side of street)	0.53	0.53
	Constant	1.71	1.71
	Adjusted <i>R</i> -squared	0.40	0.40
<i>Complexity</i>			
19	Number of buildings (both sides of street)	0.05	0.08
20	Number of basic building colors (both sides of street)	0.23	–

Physical features		Ewing et al. (2005) model used to weight features	Shared features model used to weight features
		Beta	Beta
21	Number of accent building colors (both sides of street)	0.12	–
6	Presence of outdoor dining (observer side of street)	0.42	0.53
22	Number of pieces of public art (both sides of street)	0.29	–
7	Number of people (observer side of street)	0.03	0.03
	Constant	2.61	2.21
	Adjusted <i>R</i> -squared	0.42	0.41

– Variable not included in model.

^aTable is numbered to show features that are present in more than one urban design scale. Features are numbered in the order in which they appear and numbers repeat.

Table 3

Physical features related to urban design qualities and correlations between observed and GIS measures.

	Physical features	Observed mean	GIS mean	Correlation coefficient ^a
Imageability				
1 ^b	Number of courtyards, plazas and parks on the block face	0.25	0.15	0.59
2	Number of major landscape features visible from the block face	0.02	0.03	0.52
3	Proportion of historic building frontage (both sides of street)	0.22	0.51	0.56
4	Number of buildings with identifiers (both sides of street)	2.46	2.37	0.75
5	Number of buildings with non-rectangular shapes (both sides of street)	9.52	–	–
6	Presence of outdoor dining (observer side of street)	0.01	0.01	0.61
7	Number of people (observer side of street)	5.64	8.74	0.62
8	Noise level estimate	2.05	2.04	0.42
Enclosure				
9	Number of long sight lines visible in three directions	0.40	0.60	0.16
10	Proportion of street segment with street wall (observer side of street)	0.57	0.48	0.58
11	Proportion of street segment with street wall (opposite side of street)	0.55	0.45	0.54
12	Proportion of the sky visible straight ahead	0.12	–	–
13	Proportion of the sky visible looking across the street	0.07	–	–
Human scale				
9	Number of long sight lines visible in three directions	0.40	0.60	0.16
14	Proportion of street segment with windows (observer side first floor building façade)	0.24	0.17	0.44
15	Average height of buildings weighted by building frontage (observer side of street)	39.93	36.19	0.85
16	Number of small planters (observer side of the street)	5.48	–	–
17	Number of pieces of street furniture (observer side of street)	5.55	–	–
Transparency				
14	Proportion of street segment with windows (observer side first floor building façade)	0.24	0.17	0.44
10	Proportion of street segment with street wall (observer side of street)	0.57	0.48	0.58
18	Proportion of street segment with active uses (observer side of street)	0.54	0.40	0.59
Complexity				
19	Number of buildings (both sides of street)	13.27	14.39	0.95
20	Number of basic building colors (both sides of street)	3.32	–	–
21	Number of accent building colors (both sides of street)	4.86	–	–
6	Presence of outdoor dining (observer side of street)	0.01	0.01	0.61
22	Number of pieces of public art (both sides of street)	0.06	–	–
7	Number of people (observer side of street)	5.64	8.74	0.62

– No GIS equivalent measure was created.

^a Spearman's rank-order correlations. All coefficients are significant at the 0.001 level.

^b Table is numbered to show features that are present in more than one urban design scale. Features are numbered in the order in which they appear and numbers repeat.

Table 4

Correlations between observed and GIS urban design scale scores using weights in Ewing et al. (2005) and weights derived from shared features.

	Correlation coefficient using Ewing et al. weights ^a (95% CI)	Correlation coefficient using shared features weights ^a (95% CI)
Imageability	0.45 (0.39–0.52)	0.72 (0.68–0.76)
Enclosure	0.48 (0.41–0.54)	0.53 (0.46–0.58)
Human scale	0.18 (0.10–0.25)	0.28 (0.21–0.36)
Transparency	0.71 (0.67–0.75)	0.71 (0.67–0.75)
Complexity	0.77 (0.74–0.80)	0.89 (0.88–0.91)

^aSpearman's rank-order correlations. All coefficients are significant at the 0.001 level.