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ATTRIBUTES OF FORM IN THE BUILT ENVIRONMENT THAT INFLUENCE PERCEIVED WALKABILITY

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Abstract

A recent focus of design and building regulations, including form-based codes and the Leadership in Energy and Environmental Design for Neighborhood Development rating system, has been on promoting pedestrian activity. This study assessed perceptions of walkability for residential and commercial streetscapes with different design attributes in order to inform form-based regulations and codes that aim to impact walkability. We scored 424 images on four design attributes purported to influence walkability: variation in building height, variation in building plane, presence of ground-floor windows, and presence of a street focal point. We then presented the images to 45 adults, who were asked to rate the images for walkability. The results showed that perceived walkability varied according to the degree to which a particular design attribute was present, with the presence of ground-floor windows and a street focal point most consistently associated with a space's perceived walkability. Understanding if and which design attributes are most related to walkability could allow planners and developers to focus on the most salient built-environment features influencing physical activity, as well as provide empirical scientific evidence for form-based regulations and zoning codes aimed at impacting walkabilit.

INTRODUCTION

The past several decades have witnessed a rapid rise in obesity across the United States, reflecting substantial lifestyle changes in diet and physical activity patterns (Gortmaker, *et al*., 1996; Nader, *et al*., 2008; O'Connor, *et al*., 2006; Ogden, *et al*., 2006; Troiano, *et al*., 2008; Wang and Lobstein, 2006). Physical activity has many known health benefits including weight control; improving heart, lung, and kidney function; decreasing the risk of cancer; and improving bone strength and mental health (U.S. Department of Health and Human Services, 1996). One potential component of a solution to increase physical activity is increased use of the built environment for daily physical activity, which could potentially increase physical activity at a population level (Frumkin, *et al*., 2004; Papas, *et al*., 2007; Sallis and Glanz, 2006). The physical form of the built environment, including how buildings and streets are configured, may have a direct influence on people's physical activity levels and whether they decide to carry out their daily activities on foot or by car. Several new design regulations and guidelines that control the form of the built

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environment, including the Leadership in Energy and Environmental Design for Neighborhood Development (LEED-ND) rating system, form-based codes, and New York City Active Design, seek to create urban environments that foster greater pedestrian activity and reduce vehicle miles traveled.

BACKGROUND

Design regulations that control the physical form of the built environment are meant to create a certain type of "place" and ensure a desired quality of life. These policies can take various forms as regulations, design guidelines, and codes (*e.g.*, LEED-ND, New York City Active Design, form-based codes).

The LEED suite of rating systems, which was developed by the U.S. Green Building Council (USGBC) in collaboration with the Congress for the New Urbanism and the Natural Resources Defense Council, is among the most widely adopted lists of standards and performance criteria regarding environmentally sustainable design (USGBC, 2009). The LEED-ND rating system is a repository of guidelines focusing on neighborhood design, including a section of strategies encouraging the development of walkable streets. The 2009 LEED-ND claims, "The morphology of a sustainable neighborhood — the design of its blocks, streets, and buildings — can serve as the foundation of a walkable environment" (*ibid*.:xvii). The criteria for forming regulations on walkability were based on experts' consensus. The specificity of the guidelines featured in the rating system varies significantly from semi-objective, loosely defined notions to more concrete, measurable attributes.

Many of the LEED-ND criteria can be traced back to theories central to new urbanism, among them claims that new urbanist designs foster more walkable environments that are less dependent on automobile use. To date, most of the empirical research studying the outcomes of new urbanism has focused on environmental impacts, such as demonstrating favorable water and energy use profiles, with little research on people's perceptions of the various design attributes that underlie new urbanist principles, which have largely been incorporated into the LEED-ND criteria (White and Ellis, 2007).

The LEED suite of building metrics and rating systems has become an accepted national benchmark for environmentally sustainable design, and aspects of LEED have been incorporated into legislation, ordinances, policies, and incentives by 14 federal agencies, 34 state governments, and 384 cities and towns (USGBC, 2012). The LEED-ND rating system thereby has the potential to significantly impact the design of the built environment and the resulting urban form of American metropolitan regions. Providing the empirical foundation for informing the LEED-ND system is, thus, a high priority.

The authors of New York City's 2010 *Active Design Guidelines* recommended designing "building exteriors and massing that contribute to a pedestrian-friendly urban environment and that include maximum variety and transparency, multiple entries, stoops, and canopies" (City of New York, 2010:7). While this description offers multiple possibilities for interpretation, it suggests a maximum variety of form, which is not solely dependent on but is clearly related to variation in both setback and height. Based on research (Boarnet, *et al*., 2011) indicating "that the provision of attractive open views from a path encourages increased walking," the guidelines also recommended creating or orienting "paths and sidewalks toward interesting views" (City of New York, 2010:42). What makes a view attractive or interesting is hard to measure in any objective manner. However, having a specific focal point, public building, or landmark to focus the pedestrian's view and present the space as a destination is both objective and significant in informing grid-form related decisions.

Various built-environment attributes related to physical form are posited "to create a safe, inviting, and well-used public realm with visual interest" (USGBC, 2009:xvii). In this study, we defined a built environment's "perceived walkability" as the extent to which the particular environment fosters the desire to walk. To test the perceived walkability of a built environment, researchers must be able to accurately present the built environment's attributes to test subjects and measure the subjects' responses to those attributes (Nasar, 2008). In the past, studies have used real-time audits to test perceived walkability by approaching pedestrians and asking them to rate the space around them (Nasar, *et al*., 1983; Nasar, 1987). More recently, researchers have used interviews and self-administered questionnaires to assess how individuals perceive their environment (Brownson, *et al*., 2009), depicting the built environment either verbally (using descriptions of the built environment) or visually (using still photography or video images of the built environment) (Nasar, 2008; see also Korpela, 2013). Color photography is an effective method of presenting built-environment attributes and has been widely used to assess the walkability of built environments in the past (Kaplan and Kaplan, 1989; Nasar, 1994; Stamps, 1993).

In this study, we focused on measurable attributes of the built form at the urban block and streetscape scale. In addition to meeting the testability criteria delineated by Nasar (2008), the built-environment attributes we selected for testing fulfill several essential design requirements: they are (1) implicitly or explicitly cited in urban-design theory and practice guidelines, (2) objective and measurable, (3) clearly visible and identifiable in streetscape images, and (4) actionable (*i.e*., they could be incorporated into building designs and regulated by codes). We identified four measurable attributes of the built environment that are thought to be associated with walkability and met these criteria: (1) variation in building height, (2) variation in building plane, (3) presence of a street focal point, and (4) presence of windows or transparent glass covering at least one-third of the ground level of buildings (Figure 1) (Alexander, *et al*., 1977; Appleyard, *et al*., 1981; Devlin, 2001; Hillier, 1984; Jacobs, 1961; Lynch, 1960; Rapoport, 1977).

Building massing — the height, plane, and general shape of a building — is the basic arrangement of a building's physical volume. At the urban scale, the aggregation of building masses defines the form of urban blocks and streetscapes and allows for the emergence of different patterns. Form variations within an urban environment are usually expected to reduce apparent mass; provide visual interest; and create a local, pedestrian-friendly character. They are achieved through variations in the facade plane and building heights (skyline treatment) and are encouraged by many neighborhood and city design guidelines (*e.g*., City of Bremerton, 2012; City of Rancho Palos Verdes, 2004; City of Yuba City, 1994; Fairfax County, Virginia, Office of Community Revitalization and Reinvestment, 2012; Silverthorne Town Council, 2008). Form variations and the completeness of the urban fabric are thought to be driving factors underlying people's decisions to gather in urban spaces (Krier, 1993). Research has found visual complexity (the amount and variation of structural attributes in a visual scene) and order (the degree to which an environment is interpreted as unified) — two visual attributes influenced by variations in building height and plane — to be important factors that influence people's perceptions of the built environment (Nasar, 2008). One study assessing perceived street attractiveness for walking found absolute building height to be an important scenic factor, with taller buildings deemed to be less attractive (Borst, *et al*., 2008), but there has been less research concerning the impact of variations in building height. A person's ability to see their destination is thought to increase their likelihood of considering a streetscape walkable (Jacobs, 1961), as is the placement of important structures on axes to break the visual monotony of elongated streets (Lynch and Hack, 1984). Moreover, Nasar, *et al*. (1985) showed that the visibility of distant buildings and destinations impacts perceived distances. Focal points include a broad category of visual markers that serve to illustrate a direction or destination. Buildings with windows are posited to foster a sense of safety (Jacobs, 1961), and ground-floor windows, which indicate a retail presence, have been found to promote pedestrian activity (Saelens and Handy, 2008; Whyte, 1988). The four built-environment attributes tested in this study are grounded in a long history of design and planning theory and relate directly to the overall physical form and programmatic attributes of current neighborhood developments. Each attribute relates to urban-design decisions made by local governments, the design of a proposed neighborhood development, and/or the design professionals undertaking the project early in the urban-design process. Importantly for our study procedure, each attribute can also be adequately represented and is easily discernible in a photograph of a pedestrian's view of a streetscape.

This study sought to assess the impact specific form-related attributes of the built environment have on perceived walkability using cognitive methods. Specifically, it examined perceptions of the effectiveness of four built-environment attributes in fostering pedestrian activity (*i.e*., walkability) by testing participants’ responses to viewing the attributes in urban streetscape images, with the overall aim of evaluating the appropriateness of including such attributes in form-based regulations, design guidelines, and codes.

METHODS

Cognitive testing that assesses an individual's response to viewing photographs of streetscapes is well-suited for ascertaining unconscious perceptions. While past studies assessing built-environment attributes have required participants to explicitly identify the attributes that enhance or facilitate walking (Aidar, 1973; Borst, *et al*., 2008; Frank, *et al*., 2005; Giles-Corti, *et al*., 2006; Herzog, 1992; Jago, *et al*., 2006; Kasmar, 1970; Lazarus, 1984; Webb, *et al*., 1966), this study asked participants generally about a streetscape's walkability without asking them to focus on particular built-environment criteria or specifically identify the attributes that made the streetscape walkable. Specifically, we selected some of the most dominant design criteria described by the design community and included in or related to form-based regulations, codes, and design guidelines that promote pedestrian environments. We then manipulated the criteria one at a time. This approach allowed us to correlate subjective walkability ratings with the presence or absence of each of the built-environment criteria.

To determine the perceived walkability of particular built-environment attributes using methods from cognitive psychology, we displayed color photographs on a computer and asked participants to report the degree to which each image promoted their desire to walk. The study was approved by the Partners HealthCare institutional review board and conducted at the Massachusetts General Hospital Martinos Center for Biomedical Imaging.

Participants

In 2009, we recruited 46 adult (older than 18 years) volunteers from the Harvard University Psychology Study Pool, an online registration system open to Harvard University students and members of the outside community who are interested in participating in psychology research studies. We obtained informed consent from each volunteer prior to participation. One participant was excluded from the analysis due to a lack of variation in his or her responses, having provided the same answer for every item. Thus, we conducted our final analysis using 45 participants. Participants' mean age was 24.4 years (range: 18-51 years), and 47% were male. In terms of race, 53% were white, 11% were black, 27% were Asian, 4% were Hispanic, and 5% were another race.

Built-Environment Attributes

We included four design attributes in our analysis: (1) variation in building height (Height), (2) variation in building plane (Plane), (3) presence of a street focal point (Focal Point), and (4) presence of windows or transparent glass covering at least one-third of the ground level of buildings (Windows). Two of the coauthors, who are design professionals, evaluated color photographs of commercial and residential streetscapes for the presence and degree to which each of the four design attributes was present. For the purposes of comparison, we only included streetscapes that were flat (without a noticeable incline), included a walking surface, and had similar viewing angles. The two coauthors reviewed each photograph separately and then rated the image for the presence of each of the four design attributes on a three-point scale (one = "not at all or very little present," two = "mid-level presence," and three = "definitely present"). We coded the results as each design attribute being present to a low, moderate, or high degree. In cases of disagreement, the two design professionals met to discuss and resolve any inconsistencies. Separate preliminary scoring by the two reviewers resulted in agreement rates of 59% for Height, 73% for Plane, 59% for Focal Point, and 70% for Windows. We included a total of 424 images in the final experimental design.

Procedure

We coded a program consisting of three training trials and 424 test trials using MATLAB (www.mathworks.com/products/matlab/) and the Psychophysics Toolbox (www.psychtoolbox.org). Prior to starting the study, we gave instructions to participants that defined walkability as follows: "a walkable street means that the street makes you want to walk in it rather than drive or take a train." We presented the final images to participants on a laptop computer. In each trial, participants saw a fixation cross presented in the center of the screen for one second, followed by an image of an urban scene presented for one second.

The image was immediately followed by the question, how walkable is this street in your opinion? Participants rated the walkability of each image on a continuous scale from one (not at all walkable) to five (very walkable) by clicking the mouse anywhere along a horizontal line labeled one to five; answers were rounded to the nearest hundredth (*e.g.*, 3.64). After the participant rated an image, the next image was presented. Each participant rated 424 images, presented in random order, and received $10 for his or her participation. Participants failed to respond and provide a walkability score for 309 of the total 19,080 images presented (424 images viewed by 45 raters) (1.6% missing data).

Analysis

We calculated a mean walkability score for each image based on all of the walkability scores reported for that image by all participants. Using univariate analyses, we assessed the mean walkability scores for each image based on the degree of presence (low, moderate, or high) of the given design attribute (Height, Plane, Windows, and Focal Point). We then used one-way analysis of variance to compare the mean walkability scores based on the degree to which each design attribute was present. Next, we used Pearson correlations comparing the walkability scores to identify possible correlations between the design attributes. We also calculated Spearman's rank correlations to test for bivariate relationships between the mean walkability scores and each individual design attribute. The design attributes that were found to be significant ($p < .1$) in the bivariate analysis were retained for multivariate analyses. We then inspected the images whose mean walkability scores were in the highest and lowest 10 percentiles to see if they contained any potential common visual elements that might represent additional predictors or confounders. We identified the presence of cars (Cars), the presence of people (People), and the geographic origin of the image (Geography) as common attributes in the photographs that might influence the outcome variable walkability. We coded these three covariates as binary variables (Cars and People as present/absent, Geography as North America/other) for each image and included them in further multivariable testing.

We conducted our first multivariable linear regression analyses using the mean walkability scores as the dependent variables and the significant design attributes as the independent variables. We then built a parsimonious multivariate linear regression model to include significant design attributes and covariates as independent variables with the mean walkability scores as the dependent variables. Next, we performed linear mixed-effects regression analyses using PROC MIXED in SAS software version 9.2 (www.sas.com) to incorporate all of the participant- and image-level data. Mixed-effects models with crossed random effects examined the associations between the outcome measure (walkability) and the independent variables (significant design attributes), while accounting for the correlation between ratings made by each individual rater and the ratings for any particular image. The mixed-effects models additionally adjusted for the following covariates: Cars; People; Geography; and each participant's age, race, and sex:

Walkability $\text{score}_{ij} = \beta_0 + \beta_1\text{Height} + \beta_2\text{Plane} + \beta_3\text{Windows} + \beta_4\text{Focal Point} + \beta_5\text{People} + \beta_6\text{Cars} + \beta_7\text{Geography} + \beta_8\text{Age} + \beta_9\text{White} + \beta_{10}\text{Black} + \beta_{11}\text{Asian} + \beta_{12}\text{Hispanic} + \beta_{13}\text{Other Race} + \beta_{14}\text{Female} + u_i + u_j + \varepsilon_{ij}$ for the i^{th} image viewed by the j^{th} rater. The terms u_i and u_j

are the random effects for the i^{th} image and j^{th} rater respectively and account for unmeasured traits of the individual images and raters. These terms are assumed to be normally distributed, as is the error term ε_{ij}.

RESULTS

For most of the built-environment attributes, the perceived walkability for a given image varied based on the degree to which a particular attribute was present in the image. Variation in building plane was inversely associated with perceived walkability ($p < .0001$) (*i.e*., built environments with less variation in the building plane were perceived as being more walkable), while the presence of ground-floor windows and a street focal point (both $p < .0001$) were positively associated with walkability. We did not find any significant association for variation in building height ($p = .08$; data not shown). We noted little to no correlation among the four built-environment attributes (R-values ranged from −.01 to −.12; data not shown). In the bivariate analysis, we found statistically significant associations between walkability and the design attributes Plane, Windows, and Focal Point but not Height (Table 1). The additional covariates People, Cars, and Geography were also found to be significant, with the presence of real people in the photographs being positively associated with perceived walkability and the presence of cars being negatively associated with perceived walkability. Streetscapes in North American images were generally perceived as less walkable than streetscapes in non-North American images.

In the multivariate linear regression with mean walkability for each image as the outcome measure, when Plane, Windows, and Focal Point were retained in the model, all three design attributes were found to be significantly associated with walkability ($p < .01$ for all) with an R^2 of .239 ($p < .0001$) for the model (Table 2). When the covariates People, Cars, and Geography were added to the model, the three design attributes (Plane, Windows, and Focal Point) and the covariates People and Cars continued to be significantly associated with walkability ($p < .01$ for all) with an R^2 of .485 ($p < .0001$) for the model.

In the mixed-effects model for walkability that included only the four design attributes (Model 1), Plane ($p = .005$), Windows ($p < .0001$), and Focal Point ($p < .0001$) were significant, while Height was marginally significant ($p = .06$). Model 1 had an Akaike information criterion (AIC) of 35,082 (Table 3). It was important to account for the random effects terms for each image and rater, as evidenced by their p-values of less than .0001. Higher values for both Windows and Focal Point were associated with higher walkability scores, suggesting that a greater presence of ground-floor windows and a more visible focal point are associated with environments that are perceived to be more walkable. When the covariates People and Cars were added to the model (Model 2), only Windows and Focal Point remained significant ($p < .0001$ and $p = .002$ respectively), along with People and Cars (both $p < .0001$). Model 2 had an AIC of 35,002. Interestingly, the design attributes Height and Plane ceased to be significant once People and Cars were accounted for in the images. Adding the covariate Geography and the participant-level variables age, sex, and race did not improve the model's AIC, and none of the variables or the covariate Geography were significantly associated with perceived walkability (Model 3).

DISCUSSION

This study used rigorous scientific methods to empirically test how adults subjectively perceive the walkability of streetscapes by carefully manipulating four attributes of form in the built environment: variations in building height, variations in building plane, the presence of ground-floor windows, and the presence of a focal point within the streetscape. Using two statistical testing methods, we found that two of the four attributes — the presence of ground-floor windows and the presence of a street focal point — were consistently significantly associated with participants' perceptions that an environment was walkable. Moreover, using regression analysis, Plane, Windows, and Focal Point together accounted for nearly 24% of the variance in perceived walkability. The fact that as few as two or three design attributes can explain nearly a quarter of the variance in the perceived walkability of the built environment suggests that it would be possible to identify the key design attributes that influence an individual's desire to walk in an environment rather than drive or take public transit. The mixed-effects model, which included a walkability rating for each image and accounted for the correlation between rater and image, confirmed the strong association between the presence of windows and focal points and perceived walkability, indicating that these two design attributes seem to have the greatest effect on how people perceive the walkability of spaces. After accounting for the presence of people and cars in the images, variations in the height and plane of buildings added only weak effects. Identifying the most salient attributes that influence an individual's desire to walk within a given environment could be useful information for public-policy makers, design professionals, and real estate developers, who ultimately build the environments in which people live.

A study by Borst, *et al*. (2008) assessing the relationship between perceived attractiveness and street attributes found that a model that included specific street attributes explained 32% of the variance in a street's attractiveness. The study included 16 covariates in its final model and assessed attractiveness, not walkability. A model with fewer predictor variables would allow for a more parsimonious understanding of the built environment, which in turn could allow planners and developers to focus on the most salient design features influencing the desire to walk rather than to drive or use transit. Our study explained a comparable amount of variance with only three design attributes, and our target measure was walkability, rather than attractiveness. Attributes other than attractiveness may also influence an individual's decision to walk, including safety, purpose/ destination, and accessibility. The design attributes we chose to test in this study represent form-based attributes that are consistent with current urban-design and architectural theories, best practices, and regulations intended to create environments that promote pedestrian activity (Jacobs, 1961; Lynch, 1960; USGBC, 2009). We sought to test the validity of those theories.

Variation in building height was found to be only moderately associated with walkability. Streetscapes with a moderate amount of variation in building height were perceived to be the most walkable, while small or large variations in height resulted in a less walkable street rating. Variation in building plane was inversely associated with perceived walkability. Environments with little discord in building plane were perceived to be the most walkable, whereas built environments with substantial variations in building plane or with sizable areas missing from the urban fabric were deemed to be less walkable. Large setbacks between buildings may diminish the integrity and usability of an open space (Alexander, *et al*., 1977). Such discord in the building plane may result in a less clear demarcation of pedestrian space and decrease the space's perceived walkability. This study also confirmed that the greater the presence of ground-floor windows in the streetscape, the more walkable the scene was perceived to be. The presence of windows could foster a sense of safety, reassuring pedestrians that onlookers are present in case of hazard or danger (Alexander, *et al*., 1977; Appleyard, *et al*., 1981; Jacobs, 1961). Ground-floor windows also often indicate commercial property, retail space, or mixed land use (combining retail and residential properties in a given space), which have been shown to foster walkable environments (Saelens and Handy, 2008) and may provide a destination or point of interest (Alexander, *et al*., 1977; Jacobs, 1961). Finally, empirical testing found that having a focal point to look at on a street was positively associated with walkability. Having a destination in sight, such as a distant building or monument, might foster the desire to walk or reassure individuals that the distance is walkable (Jacobs, 1961). Similar to windows, being able to conceive of what lies ahead and identify a path by which to reach that destination may provide a sense of security.

In a study by Nasar, *et al*. (1985), perceived distance was shown to be inversely related to visibility, such that participants were more likely to underestimate the distance to a building if the building was visible. While Nasar, *et al*.'s study tested buildings, and our study tested focal points, a plausible common connection would be that a location may be perceived as being within a walkable distance if an individual can visualize and conceptualize a route to get to it.

Knowing that people may favor spaces that reflect human activity (Jacobs, 1961), we adjusted our analyses accordingly to account for the presence of people in the images using regression and mixed-effects analyses. Indeed, we found an estimated effect of .32 for the presence of people in the streetscapes. Assuming all other factors are constant, this translates to an expected increase of .32 points in an image's walkability score if people are present in the image. Given this significant effect, this study validates Jacobs's hypothesis that the presence of people is an important factor in individuals' perceptions of the walkability of different spaces. Similarly, as the presence of cars in an image may subconsciously suggest a space is not walkable, we adjusted our analysis to account for the presence of cars. A survey of U.S. and Japanese students' visual preferences for urban scenes similarly found vehicle prominence to be an important factor in determining one's visual preference for a scene (Nasar, 1984). In our study, we found the presence of cars significantly affected a streetscape's walkability rating, and we therefore controlled for it in our adjusted models. Though we noted while reviewing the images that North American architecture tended to be more prevalent in the images perceived as being the least walkable, when we adjusted the models to account for the geographic origin of the image, we found no association between geography and walkability.

LIMITATIONS

Our study has several limitations. First, our sample included many students from a single institution, which may limit the generalizability of the findings. Second, participants only reported on perceived walkability; we did not collect any data on actual activity patterns. While an individual may indicate that a given streetscape is walkable, it is not known whether that individual would actually walk down the street in real life. However, it is probable that the criteria found to promote walkability in this study are more likely to promote walkability in real life than the criteria we found that did not promote walkability. Similarly, although we found the presence of windows and focal points to be associated with greater perceived walkability, it is not known whether placing more windows or focal points in a given space would actually increase pedestrian activity. Many streetscapes have sidewalks, a minimal attribute that would render walking on them possible but not necessarily desirable. Not all streetscapes have attributes meant to promote perceived walk-ability, and it may not be feasible or even desirable to design environments where every street segment has a configuration meant to shape positive perceptions of walkability. However, identifying the attributes that affect such perceptions is a powerful tool in the hands of design professionals.

A third possible limitation of the study was our use of real streetscapes to elicit responses about perceived walkability. While computer-generated images would allow for exact control of the attributes included in the images, photographs invariably include a certain degree of noise with less ability to control for potential confounders (*e.g*., greenery, sidewalks, streetlights, people, cars, commercial versus residential scenes). We did our best to identify potential confounders by reviewing the images for common attributes, and we controlled for three attributes we felt were consistently present and possible confounders — cars, people, and geography. A major advantage of using photographs with real streetscapes is the brain's ability to distinguish between real objects and digitally altered objects, even when the images are viewed at high speeds of less than one second (Sharan, *et al*., 2008). As the goal of this study was to simulate a real psychological reaction to different form-related attributes in the built environment, we felt that using photographs would provide the most reliable data without creating additional biases. This study did not assess whether the presence of design attributes perceived as promoting walkability primarily influences an individual's specific route choice or his or her overall likelihood of walking rather than driving or taking public transit. An alternative approach to answering some of these questions might be to measure participants' physiological responses to viewing spaces that vary in the presence of form-related attributes, such as measuring participants' heart rates or using functional neuroimaging to detect changes in participants' heart rates or brain function after viewing specific design attributes.

CONCLUSION AND IMPLICATIONS

To the best of our knowledge, this is one of the first empirical studies to rigorously test how people view selected form-related attributes of the built environment with respect to walkability. Many current design and form-based regulations and codes are based on theories and accepted best practices in urban design and architecture that are assumed to foster increased walkability. Using scientific methods to empirically test whether built-environment attributes that are explicitly intended to foster increased walkability are, in fact, significantly associated with an increased propensity for pedestrians to favor walking rather than driving is critically important and could potentially have a major impact on public health. Prior photo-based studies identifying features thought to contribute to or reduce walkability have used methods based on conscious decision making, which are susceptible to various types of bias. By contrast, this study used cognitive testing techniques to better understand how people subconsciously perceive design attributes touted to influence walkability. This novel approach offers an additional method for rigorously studying the complex relationship between the built environment and health. This study selected four built-environment attributes that are posited to affect walkability and, using cognitive testing, found evidence to support the use of some of these criteria while refuting others. Because many form-based codes, design guidelines such as the LEED-ND rating system, and municipal zoning regulations are regularly reviewed to identify areas for improvement (and new versions are periodically released), the findings from this study could potentially be incorporated into future versions of these regulations. Thus, these findings could be widely disseminated to design professionals, real estate developers, and the general public and put into practice in a relatively short period of time. As new neighborhood developments continue to be built and utilized as residences and work-places, increasing the perceived walkability of new neighborhoods could potentially have a significant impact on physical activity and reduce obesity.

Current architectural and planning guidelines are based on a set of criteria purported to increase pedestrian activity. This study rigorously tested the validity of four built-environment attributes theorized to impact pedestrian activity and found two (presence of ground-floor windows and presence of a focal point) — only one of which (windows) can be controlled by a building's architect or developer — to be consistently associated with perceived walkability. The other two attributes (variations in building height and plane), which are also capable of being controlled, had weaker effects. Identifying the design attributes that best promote an individual's desire to walk based on strict scientific methods would allow for the construction of healthier spaces with real public-health benefits.

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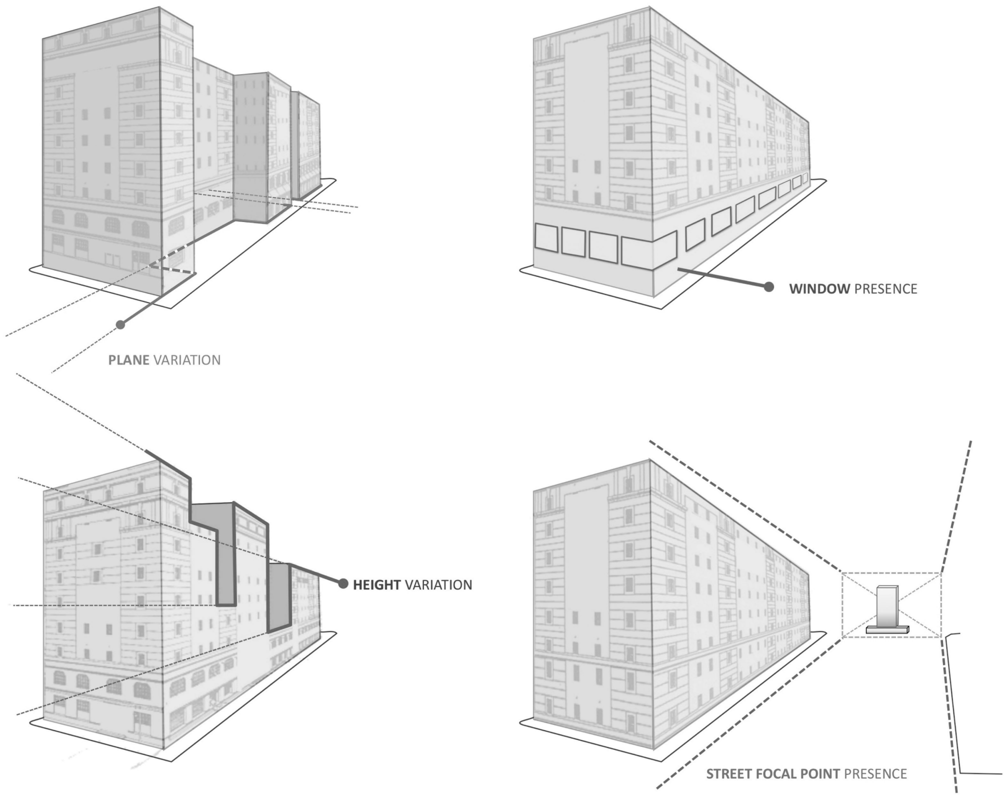

FIGURE 1.
Measurable built-environment attributes that are thought to be associated with walkability.

TABLE 1

Bivariate associations with walkability (Spearman's rank correlations for design attributes and covariates and mean walkability).

Variable	*R*-value	*p*-value
Design attributes		
Height	−.08	.15
Plane	−.21	< *.0001*
Windows	.36	< *.0001*
Focal Point	.23	< *.0001*
Covariates		
People	.53	< *.0001*
Cars	−.40	< *.0001*
Geography	−.28	< *.0001*

Note. Significant associations are indicated in italics.

TABLE 2

Multivariate linear regression of walkability.

	Variable	*β* coefficient	95% confidence interval	*p*-value
Model 1 (R^2 = .239)				< *.0001*
	Design attributes			
	Plane	−.18	−.27 to −.09	*.0001*
	Windows	.22	.17 to .29	< *.0001*
	Focal Point	.23	.14 to .31	< *.0001*
Model 2 (R^2 = .485)				< *.0001*
	Design attributes			
	Plane	−.11	−.18 to −.03	*.005*
	Windows	.17	.11 to .22	< *.0001*
	Focal Point	.12	.05 to .19	*.001*
	Covariates			
	People	.34	.25 to .43	< *.0001*
	Cars	−.39	−.50 to −.31	< *.0001*

Note. Significant associations are indicated in italics.

TABLE 3 Mixed-effects models for walkability.

	Model 1[a]		**Model 2**[b]		**Model 3**[c]	
AIC[c]	**35,082**		**35,002**		**35,008**	
Covariate	**Parameter estimate**	***p*-value**	**Parameter estimate**	***p*-value**	**Parameter estimate**	***p*-value**
Height	−.07	.06	−.05	.10	−.05	.10
Plane	−.13	*.005*	−.06	.13	−.06	.13
Windows	.24	< *.0001*	.19	< *.0001*	.19	< *.0001*
Focal Point	.21	< *.0001*	.12	*.002*	.12	*.002*
People	---	---	.32	< *.0001*	.32	< *.0001*
Cars	---	---	−.32	< *.0001*	−.32	< *.0001*
Geography	---	---	---	---	.01	.83
Age	---	---	---	---	.02	.09
White	---	---	---	---	.43	.31
Black	---	---	---	---	−.33	.50
Asian	---	---	---	---	.19	.66
Hispanic	---	---	---	---	.14	.81
Other Race	---	---	---	---	---	---
Female	---	---	---	---	.15	.32
σ_{image}**	.15	< *.0001*	.10	< *.0001*	.10	< *.0001*
σ_{rater}***	.32	< *.0001*	.32	< *.0001*	.31	< *.0001*

Notes.

[a]model includes Height, Plane, Windows, and Focal Point

[b]model includes Height, Plane, Windows, Focal Point, People, and Cars

[c]model includes Height, Plane, Windows, Focal Point, People, Cars, Geography, Age, Sex, and Race

*a smaller AIC is considered better

**covariance parameter estimate for inter-image variability

***covariance parameter estimate for inter-rater variability. Significant associations are indicated in italics.