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Walkable Streetscapes:
Incorporating Streetscapes into the Pedestrian Travel Paradigm

by

Chester Wollaeger Harvey

A dissertation submitted in partial satisfaction of the

Requirements for the degree of

Doctor of Philosophy

in

City and Regional Planning

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Elizabeth Macdonald, Co-chair

Professor Daniel A. Rodríguez, Co-chair

Professor John Chuang

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Abstract

Walkable Streetscapes: Incorporating Streetscapes into the Pedestrian Travel Paradigm

by

Chester Wollaeger Harvey

Doctor of Philosophy in City and Regional Planning

University of California, Berkeley

Professors Elizabeth Macdonald and Daniel A. Rodríguez, Co-Chairs

Transportation research typically conceptualizes walkability based on access to key destinations and availability of traditional pedestrian infrastructures, such as sidewalks and crosswalks. Urban designers, however, suggest that the designs of streetscapes, the contextual built environments surrounding roadways, play an important role in promoting walking by making it comfortable and enjoyable. Despite the potentially powerful influence of streetscapes, however, there remains a dearth of empirical research unpacking how they are evaluated by pedestrians and impact walking behavior. This dissertation targets this empirical deficit by examining how streetscapes relate to pedestrian preferences. It substantiates how streetscapes are an influential type of pedestrian infrastructure that ought to be more strongly incorporated into walkability planning.

The dissertation consists of four core studies that use an array of methods, including integrative literature analysis, interviews, biosensory measures, and route choice modeling, to examine how streetscapes shape the preferences and behaviors of urban walkers. The first study is an integrative review that draws on multidisciplinary literature to investigate the theoretical foundations of walkability and the role of streetscapes compared with more conventional transportation factors. It finds that research in urban design and environmental psychology offers robust theory about how streetscapes affect walkers through psychological mechanisms, such as visual complexity that allows walkers to explore and understand their surroundings. This contrasts with emphases in transportation planning and engineering on physical constraints, such as path connectivity and proximity of destinations. The study shows that there are strong theoretical rationales for how streetscapes influence pedestrians psychologically, encouraging planners to bridge disciplinary traditions and ensure that streetscapes are accounted for in how walkability is understood, analyzed, and planned.

The latter three studies investigate the validity of theories about streetscape walkability through a variety of empirical methods. The first uses semi-structured walking interviews along a route in Berkeley, California to investigate how demographically diverse walkers without expertise in planning and design observe streetscapes and respond to them when forming preferences about walking environments. While subjects are universally aware of features contributing to streetscapes, such as buildings, trees, storefronts, and other land uses, they are bifurcated about which types of features they favor. One group consistently prefers built frontages, while another tends to prefer more natural, park-like frontages. Both, however, demonstrate preference for features that are more sensorially engaging, consistent with psychology theory suggesting

preference for environments that are explorable and provide information about users' contexts. By contrast, subjects tend to describe less preferable streetscapes as bland or boring. These results confirm that streetscapes are influential for real-world understandings of walkability and suggest that preferred qualities are largely consistent with theoretical expectations, though they may be provided by both built and natural forms.

The next study investigates the efficacy of biosensory measures for evaluating walkers' emotional responses to streetscapes. Mobile biosensors have the potential to collect large volumes of data about walkers' experiences as they navigate real-world contexts, but there are substantial hurdles to meaningfully interpreting biosensory measures collected in uncontrolled field environments such as urban streets. These measures may also be inappropriately interpreted as direct indicators of emotions such as stress, although they tend to be theoretically limited to indicating arousal, one component of stress response. This study evaluates how biosensory and other physiological measures, including electrodermal activity (EDA), heart rate variability (HRV), skin temperature, visual glances, and walking speed, correspond with streetscape conditions along the same Berkeley, California walking route, and with the same subjects as in the previous study. Among these measures, EDA demonstrates the greatest consistency across subjects and its levels are strongly correlated with a variety of streetscape features. Indicators of emotions developed by combining EDA with preference ratings suggest that many high-arousal environments are exciting, counter to assumptions in prior research that EDA-based arousal is a direct proxy for stress. These results demonstrate how biosensory measures have potential to elucidate emotional responses to streetscapes, but they must be interpreted cautiously.

The final study investigates how streetscape preferences are revealed by the routes walkers choose to take. It uses econometric models to compare more than 650 GPS-tracked walking routes from a travel study in San Francisco against algorithmically derived alternatives. Streetscape characteristics are measured throughout the city using an automated approach based on spatial datasets such as building footprints and high-resolution tree canopy areas, then summarized along observed and alternative routes. Models indicate preference for routes that are more continuously lined with buildings and that have smaller setbacks, more storefronts, and more tree canopy, characteristics that may promote perceptual engagement by providing more complex and interactive visual surroundings. Notably, results also suggest preferred ranges of certain streetscape characteristics within the San Francisco context. Streetscape width, measured between opposing buildings across the street, appears to be most favorable within the moderate range of 15 and 25 meters. Likewise, the cross-sectional ratio of streetscape height to width appears most favorable when greater than 1:2 but less than 3:2, consistent with design theories citing distance limitations to sensory perception and preferences for moderately enclosed spaces. Finally, the magnitudes of relationships between streetscape factors and selected routes were comparable to those for additional route distance and uphill grades, suggesting that streetscapes may affect walkers to degrees that are similar to highly physical factors. These findings provide novel evidence of links between streetscape design and travel behavior that are not only measurable, but substantial.

Together, these studies provide a corpus of new evidence that streetscapes influentially shape both perceptions of walkability and the behaviors of real-world walkers. Rather than being ignored by transportation planners, streetscape design ought to be embraced as a form of pedestrian infrastructure that may be incorporated into pedestrian plans as an approach for improving urban walkability.

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Chapter 1 Streetscapes: A Neglected Pedestrian Infrastructure

1.1 The Role of Streetscapes in Walkability

Walkability planning and analyses have traditionally focused on transportation infrastructures and built environment factors that influence the practicality of walking, such as the availability of sidewalks and proximity to destinations (Shields et al., 2021). Recent interest in walking as a sustainable, healthy, and socially engaging activity has spurred development of “complete streets” that address the combined needs of walkers,¹ bicyclists, and other users (Hui et al., 2018). But the transportation field may offer an unreasonably constrained view of what it means for a street to be “complete.” It has tended to emphasize traditional right-of-way infrastructures and neglected a different type of infrastructure: *streetscapes*, the built environmental contexts of streets.

Urban designers, by contrast, have long argued that streetscapes affect whether places feel comfortable and enjoyable to walk in (Alexander et al., 1977; Arnold, 1993; Cullen, 1961; Ewing & Handy, 2009; Jacobs, 1993). Environmental psychologists also suggest how spaces that are more information-rich and legible may be preferred because they afford natural tendencies toward understanding and exploration (Kaplan & Kaplan, 1989; Nasar, 1994, 1998). While researchers have examined how streetscapes may be effectively measured (Ewing & Handy, 2009; Harvey, 2014), how walkers respond to them emotionally (Chrisinger & King, 2018; LaJeunesse et al., 2021), and how they relate to pedestrian volumes (Ewing et al., 2016; Park et al., 2019), evidence validating how streetscapes relate to walkers’ perceptions and preferences remains notably underdeveloped.

This dissertation targets this theoretical and empirical deficiency through four studies that examine (Chapter 2) the psychological mechanisms by which streetscapes may influence walkers, (Chapter 3) how walkers without expertise in planning or design perceive and form preferences about streetscapes, (Chapter 4) how biosensory measures may be used to understand subconscious interpretations of streetscapes, and (Chapter 5) how real-world route choices may reveal streetscape preferences. These studies harness a variety of qualitative and quantitative methods ranging from integrative literature analysis to field interviews, physiological sensing, and econometrics. While each is designed and written to stand independently, they all examine how walkers relate to streetscapes and their results collectively inform how streetscapes may be used to plan more walkable cities.

Findings from these studies converge on a simple but important relationship: streetscapes that provide opportunities for perceptual engagement tend to be most preferable for walkers. In short, these are interesting places to walk. Streetscapes that are less preferable, by contrast, tend to be relatively dull, vacant, or otherwise provide fewer opportunities for walkers to perceive and understand their contexts. This finding is consistent with theory in psychology and landscape aesthetics about the favorability of environments that invite users to seek information (Appleton, 1975; Kaplan & Kaplan, 1989), as well as design theory suggesting preferences for visual complexity, transparency, and human scale spaces in which features that are engaging are readily

¹ Throughout this dissertation, I use the terms *walker* and *pedestrian* to refer broadly to those who travel at walking speeds and in spaces traditionally designated for walkers, including those who use wheelchairs and other assistive devices.

accessible (Alexander et al., 1977; Ewing & Handy, 2009; Gehl, 2011; Jacobs, 1993; Lynch, 1981). While urban designers have long stressed the importance of developing perceptually engaging streetscapes, these studies empirically and theoretically reinforce their importance for urban walkers, indicating how streetscapes may substantially shape where people choose to walk.

1.2 What is a Streetscape?

I use the term *streetscape* to describe the space perceivable from a vantage point along a street. Similar to a *landscape*, which is “a view or prospect ... such as can be taken in at a glance from a point of view” (OED, 2022), streetscapes are bounded by sightlines and often spill across legal boundaries such as property lines or rights-of-way. Their nebulous spatial extents may make planning and designing them both conceptually and logistically inconvenient, a reason they may have received little attention compared with more concretely defined and controlled spaces such as rights-of-way. Nonetheless, streetscapes may provide users with a strong sense of spatial cohesion: “I am outside IT, I am entering IT, I am in the middle of IT” (Cullen, 1961). Despite being difficult to define and measure, streetscapes are intuitively identifiable and influential for how urban spaces are understood and navigated (Harvey & Aultman-Hall, 2016; Lynch, 1960).

Others have used “street”, “street environment”, or “public realm” to describe what I refer to as a streetscape (Ewing & Handy, 2009; Gehl, 2011; Harvey & Rodriguez, 2017; Jacobs, 1993). “Streetscape”, however, reinforces that I am discussing something broader than the roadway. This contrasts with colloquial uses of “street;” a parent warning their child not to “run into the street” is likely referring to the space between curbs, not the spaces to either side. “Public realm” may be used to describe spaces accessible to pedestrians (Dover & Massengale, 2013). This, however, may extend to indoor spaces such as retail and civic spaces that are physically accessible to the public, but may not be visually accessible from the street. “Streetscape” reinforces the importance of elements to the side and above the roadway while also constraining discussion to the outdoors.

Roadways, while theoretically encompassed within streetscapes, are distinct in that they receive outsized attention within the transportation field, tend to be wholly controlled by transportation agencies, and are often designed primarily for automobiles. The remainder of streetscapes, by comparison, are largely ignored within transportation planning, controlled by a complex array of landowners and development regulations, and serve the needs of diverse public and private users. To draw attention up and away from the roadway, toward aspects of streetscapes that receive comparatively less attention, I tend to use “streetscape” to refer to anything *except* the roadway, and “roadway” to refer to features between the curbs. This distinction is admittedly imperfect. Features such as trees, medians, traffic lights, and parklets, may straddle this boundary and be difficult to attribute to one or the other. Nonetheless, I find the juxtaposition between roadways and streetscapes helpful for drawing comparisons between factors that are more and less commonly examined, particularly within the transportation sphere.

“Streetscape,” however, also has another meaning in planning practice. It may refer to landscape design, often within the right-of-way, with elements such as plantings, seating, lighting, and public art (Smart Growth America, 2017). In this context, it does not tend to extend onto private property or relate to buildings. This usage has an intent similar to my own: describing the spaces pedestrians encounter. Its constrained palette of tools and boundaries of influence, however, are informed by practical expediency—what public agencies immediately control—rather than

features and areas that are relevant to walkers. As a researcher, I define “streetscape” more broadly to examine the entirety of street spaces, extending onto privately-owned land and buildings that contribute heavily to the experiences of users.

1.3 Synthesis of Core Studies

The following chapters present four studies that point to the preferability of more perceptually engaging streetscapes. Each examines how walkers respond to streetscapes through different bases of theoretical or empirical evidence to triangulate around an overarching question: what constitutes a walkable streetscape? The first of these studies is primarily theoretical, investigating the mechanisms by which different streetscape characteristics may potentially influence walkers. The latter three are empirical, evaluating how walkers respond to streetscapes in real-world settings. These empirical studies examine streetscape design primarily through the lens of Ewing and Handy’s (2009) five urban design qualities related to walkability—enclosure, complexity, transparency, imageability, and human scale—operationalizing these qualities through measures such as building setbacks and other morphological measures that moderate enclosure, tree canopy that bolsters both enclosure and complexity, and storefronts that promote visual transparency and complexity. A sixth chapter discusses how findings may be applied in planning practice and directions for extending the studies in future research.

The first study, in Chapter 2, is an integrative review that draws on multidisciplinary literature to investigate the theoretical foundations of walkability and how streetscapes may contribute to it through psychological mechanisms. Research associated with walkability is spread across numerous fields, ranging from engineering (TRB, 2010) to planning (Ewing & Handy, 2009; Forsyth, 2015; Lo, 2009; Schneider, 2013), urban design (Alfonzo, 2005; Cullen, 1961; Jacobs, 1993; Lynch, 1981; Macdonald et al., 2018), public health (Pikora et al., 2003; Saelens et al., 2003), geography (Appleton, 1975), and psychology (Kaplan & Kaplan, 1989; Klöckner & Blöbaum, 2010; Nasar, 1998). This study connects these diverse sources of theory and empirics to understand how streetscapes may shape walkability alongside factors more traditionally considered in transportation planning, such as sidewalks and accessible land uses. It unpacks how the mechanisms by which streetscapes influence walkability are largely psychological in contrast with the highly physical influences of traditional transportation infrastructures. The importance of psychological influences is reinforced by research suggesting how qualities such as enclosure, transparency, mystery, prospect, and naturalness may be important drivers of preference for streetscapes (Appleton, 1975; Ewing & Handy, 2009; Kaplan & Kaplan, 1989; Lynch, 1981; Nasar, 1998). While these qualities are multifaceted, they point to the importance of attracting and retaining users’ attention, or enveloping them with enclosing features, such as buildings or trees, that may be more sensorially stimulating than open spaces. Aspects of streetscapes that are directly stimulating, such as transparent windows, or that amplify stimulation by making it more accessible, such as reducing setbacks so that windows are readily visible from the sidewalk, may both promote perceptual engagement. This study reveals both how streetscapes may affect engagement in these ways, and the lack of empirical evidence substantiating these understandings.

The remaining three studies address this empirical deficit. The first of these, in Chapter 3, investigates how lay walkers perceive streetscapes and consider them in deciding which places they would hypothetically prefer to walk. While design theory describing the importance of streetscapes tends to be developed from expert perspectives (Ewing et al., 2006; Ewing &

Handy, 2009), much less is known about how non-experts evaluate streetscape design. Do *lay walkers* concentrate on the same aspects of streetscapes as experts, and are their evaluations consistent with theoretical expectations based on design expertise?

This study uses an unusual method, a mixed methods field experiment, in which subjects participate in a walking interview and with stated preferences for block faces with varying streetscapes along a predetermined route in Berkeley, California. Block faces along the route vary in terms of building setback, active frontages such as storefronts, and tree canopy. Interviews and preferences reveal that demographically diverse subjects are highly aware of streetscape characteristics and that they tend to prefer more sensorially engaging block faces. This is consistent with design literature suggesting the preferability of surface complexity and transparency (Alexander et al., 1977; Ewing & Handy, 2009; Jacobs, 1993). The majority of subjects, however, favor more natural frontages over built ones, reinforcing how features such as trees and park-like spaces may provide similar, if not greater visual engagement than buildings and hardscapes (Kaplan & Kaplan, 1989; Nasar, 1998). Many also disliked spaces with higher pedestrian volumes that require them to navigate physically and socially around others, counter to the assumption that walkers are attracted to other walkers (Dover & Massengale, 2013; Gehl, 2011). These results both reinforce and challenge expert understandings of what makes a walkable streetscape, suggesting that lay walkers tend to prefer perceptual engagement and that a wide range of features may provide this quality.

The interviews from this study provide evidence about the variety of streetscape features that lay walkers perceive, and how they affect preferences, in ways that quantitative methods used in the later studies are unable to do. The later route choice study draws on features that subjects frequently identify in interviews, such as storefronts and street trees, to operationalize qualities such as transparency, complexity, and enclosure. The interviews also provide direct evidence of causality between features and preferences, as well as the reasons for preferences. One subject describes, for example, how “the storefronts are nice ... they look open and used.” This contrasts with the quantitative methods of the later studies that can evaluate relationships between features and preferences, but not why certain features are preferable, nor even if they are primarily responsible for driving preferences. The interviews are crucial, therefore, for confirming that preferences are not just associated with different streetscape features but are formed by them.

Nonetheless, this study is limited by the need for subjects to be conscious of and able to articulate their perceptions and evaluations. Streetscape design factors are conceptually complex, and the interviews demonstrate that lay subjects are not always confident in how they describe or respond to them. While some demonstrate awareness of qualities such as enclosure—“I think I just like the vibe of when ... there are lots of, like, trees hanging over”—many others are only vaguely conscious of what they like or dislike. Interviews, meanwhile, are resource-intensive and can access only a limited sample of subjects and streetscape conditions. The latter two studies address these limitations by accounting for subconscious responses to streetscapes and, in the final one, a much larger sample of subjects and streetscapes.

The study in Chapter 4 examines the potential to use biosensory measures as an indicator of subconscious, emotional responses to streetscapes. A growing body of planning research deploys biosensory measures in field contexts, often with the goal of measuring stress (Chrisinger & King, 2018; Fitch-Polse, 2018; LaJeunesse et al., 2021). Planners’ study designs and interpretations of biosensory data, however, are substantially less refined than those of neurological researchers who have been working with these methods for decades, albeit with

limited expertise in built environment contexts (Roe et al., 2013; Valtchanov & Ellard, 2015). Recent planning studies, for example, have treated autonomic activation as a direct indicator of stress, even though it may conversely indicate excitement if a stimulus is both activating and pleasing (Chrisinger & King, 2018; LaJeunesse et al., 2021). This study investigates how biosensory measures may be appropriately applied in planning research by examining both limitations and opportunities of using them to evaluate walkers' responses to streetscapes. It first reviews what biosensory technologies may be appropriate for studying walking environments and how they have been used previously. Then it uses an exploratory analysis to evaluate how electrodermal activity (EDA), heart rate variability (HRV), eye tracking, skin temperature, and walking speed, relate to real-world streetscape conditions. This exploratory analysis is conducted with the same subjects and predefined walking route as the previous study.

Findings show that the slow-moving *tonic* component EDA signals may be most suitable for capturing how activation fluctuates among walkers as they encounter different streetscapes. When combined with preference ratings, EDA suggests that subjects experience excitement in response to nearby buildings and street trees, calm in response to green areas, boredom in response to parking lots, and stress in response to intersections. These findings are consistent with theoretical expectations about how walkers might perceive these types of features (Ellard, 2020; Jacobs, 1993), and suggest preferential responses to features that may be more engaging and information-rich, such as nearby buildings, trees, and green areas. Notably, responses of excitement and boredom appear to be more common than stress, indicating that high activation responses may often be preferable, while low activation responses may often be unfavorable, counter to prior interpretations of EDA as a direct indicator of stress (Chrisinger & King, 2018; LaJeunesse et al., 2021). These results suggest that while biosensory measures have potential to be useful indicators of walkers' emotions, interpreting these data meaningfully may hinge on other parallel measures of preference, since this cannot yet be confidently determined through biosensory means.

The hypothetical benefit of using biosensors to evaluate streetscapes is that they may capture subconscious responses in ways that can be objective and comparable across diverse subjects. They might also elucidate degree of response, differentiating between features that are barely noticeable and those eliciting substantial reactions. As biosensors are incorporated into consumer devices, such as smart watches, data may be collected at scale, allowing thousands of individuals to contribute data from weeks, months, or years of experiences. In practice, however, comparing biosensory measures between subjects and across times is highly challenging because individuals may respond differently when experiencing the same emotions and responses may be confounded by exertion, movement, and unmeasured environmental factors such as crowds, traffic, weather, or even anomalous events such as passing sirens (Healey, 2015). Appropriately controlling for these may present substantial challenges. Ultimately, evaluating biosensory data requires parsing meaningful signals from a substantial amount of noise. Methods for accomplishing this will undoubtedly improve from those used in this study, but findings from field applications of biosensors will likely always provide only an imprecise indicator of subjects' perceptions.

The last study, presented in Chapter 5, uses a method that is more established in transportation research, route choice modeling, to examine what walkers' selected routes reveal about the streetscapes they prefer (Prato, 2009). This approach has been widely used to study pedestrian

environments, but never with an explicit focus on streetscape design or to evaluate multiple streetscape-related factors simultaneously (Basu et al., 2021).

A primary benefit of route choice modeling is the strong ecological validity provided by evaluating real-world decisions. Whereas walkers' stated preferences in Chapter 3 and biosensory responses in Chapter 4 may be biased by their experimental protocols, the routes demonstrating preferences in this study are unlikely to have been influenced by the study design. Observed route data are provided by the San Francisco County Transportation Authority from a travel survey conducted in the spring of 2019. Survey participants installed an app on their smartphones which automatically tracked their activity and asked them to verify their mode of travel for each trip over a week-long period. Participants likely went about their daily routines with little consideration for their routes being recorded, providing a highly realistic account of their real-world decisions.

By comparing approximately surveyed 550 walking routes to algorithmically derived alternative routes I could investigate what types of streetscapes participants were more likely to walk along, a revealed indicator of their preferences. Measures of streetscape width, height, cross-sectional proportion, tree canopy coverage, and retail frontages, are gathered and summarized along routes based on spatial datasets such as building footprints, tree canopy areas, and detailed land uses. Finally, regression models are used to examine how streetscape measures predict chosen routes.

Consistent with the preceding studies, results suggest preference for streetscapes that are more sensorially engaging due to spatial enclosure and complex or transparent features. Routes that are more consistently bounded by potentially engaging buildings are substantially preferred, as are those with smaller setbacks and more upright cross sections that bring buildings closer to walkers. Tree canopy, which may provide both visual complexity and enclosure, is also preferred, as are storefronts, an indicator of visual transparency and complexity. Moreover, preferences for these streetscape characteristics are similar in magnitude to those for shorter routes, uphill grades, turns, and intersections. This suggests that walkers may be willing to go out of their way or face other physical inconveniences for more appealing streetscapes. While the design of this study precludes definitive causal interpretation of these relationships, the results suggest that preferences for streetscapes may shape pedestrian behavior to a substantial degree. If this is true, streetscapes may provide a valuable lever not only for improving the quality of pedestrian experiences but for modifying whether certain routes are considered walkable.

Despite the benefits of this study for gauging which streetscapes real-world walkers prefer, it faces limitations in both the specificity and generalizability of its results. While route choice models may account for subject- and trip-level characteristics, such as demographics and trip purposes, these data are not available for the present study. It does not, therefore, investigate differences in preferences based on factors such as age, gender, race, or personal history, nor does it distinguish between trips for purposes such as commuting, errands, or recreation. Within this dissertation, the Chapter 3 method is better suited to account for subjects' personal characteristics and control for trip purpose—all subjects in that study are asked to imagine they are commuting. This demonstrates the potential benefits of *both* qualitative methods and more tightly controlled experiments for bolstering the specificity of results.

These studies together provide a novel body of theory and evidence substantiating how streetscapes contribute to both perceptions of walkability and the real-world preferences of walkers. Each of them indicates that walkers stand to benefit from streetscapes that are more

perceptually engaging, either from features that directly provide qualities such as visual complexity or transparency, or by positioning these features closer to walkers through more human-scale dimensions or more enclosed spaces. While the empirical studies in Chapters 3, 4 and 5 are limited to representing subjects and streetscapes from the San Francisco Bay Area, their results are strongly aligned with theoretical understandings of how more engaging streetscapes may provide benefits for walkers in diverse contexts (Ewing & Handy, 2009; Jacobs, 1993). This sets up a natural trajectory for further research probing the generalizability of these preferences by evaluating demographic and geographic differences in walkers' responses. Eventually, widely deployed biosensors may offer a useful method for scaling research on streetscapes to examine much larger and more heterogeneous samples of human subjects and streetscape environments. Until techniques for parsing and interpreting biosensory data are more refined, however, observed routes may offer a viable approach to distinguishing preferences in places where sufficient data are available. The emerging ubiquity of route data from mobile phone records (Yang & Yao, 2022), paired with large-scale datasets representing streetscape-scale features (Microsoft, 2019) or machine interpretation of streetscapes from street-level imagery (Lee et al., 2022; Li et al., 2022), may allow route choice models to be widely scaled, revealing streetscape preferences among diverse populations across the globe.

Chapter 2 Wanting to Walk: A Psychological Lens on Walkability

2.1 Introduction

Promoting walking as a mode of transportation is a popular goal for cities aiming to support sustainability, physical fitness, and community and commercial vitality. Nonetheless, most planning for pedestrians remains narrowly focused on buildout of traditional transportation infrastructures, such as sidewalks and crosswalks, and proximity to destinations, such as grocery stores, that make walking possible on a physical level. These practical considerations—having paths to walk on and places to walk to—are a crucial foundation for walkability. They may not be enough, however, to compel dramatic shifts toward walking as a transportation choice. For these shifts to occur, walking will need to be not only physically possible but psychologically desirable in ways that compete with other modes.

To illustrate the importance of psychology for motivating walking, consider the value proposition of its stiffest competition: automobiles. Automobiles are practical. They are fast, convenient, feel safe to use, and are nearly effortless to operate. But they also offer a slew of psychological benefits that have been carefully nurtured by planners and automakers to make driving feel pleasant, engaging, and secure. Traffic controls, lane markings, and straight, wide roadways minimize driver stress by offering predictable environments with ample margins for response and error. Automobiles themselves, meanwhile, offer relaxing, personalized environments that are heavily insulated from undesirable natural or social surroundings. If it's too hot: turn on the air conditioning. If you're driving through an uncomfortable neighborhood: roll up the windows and lock the doors. If you're bored: turn on the radio. Alongside the physical ability to move from origin to destination, automobiles cater heavily to psychological desires for sense of security, physical comfort, and entertainment. The value of these additional benefits cannot be overlooked.

Yet in planning for pedestrians, these psychological influences are often ignored. Most pedestrian planning emphasizes installation or improvement of physical infrastructure, such as sidewalks and crosswalks, but falls short of considering psychological infrastructure: environmental design that makes walking enjoyable. When this infrastructure is ignored, it is unsurprising that people may choose not to walk, even when it is an entirely practical option.

This chapter draws on theory in planning, design, and psychology to examine how psychological influences of walking environments may be used to advance urban walkability and promote walking behavior. It begins by surveying frameworks for walkability and identifying how psychology is situated alongside physical influences on walkers. It then investigates the mechanisms by which psychology may influence walkers' preferences for different urban streetscapes. Finally, it illustrates these mechanisms through a comparison of real-world streetscapes that may promote or discourage walking through psychological aspects of their designs. By laying out how environmental psychology may influence walkers, the chapter offers a theoretical foundation for empirical investigations of how streetscape designs influence preferences and choices about where and whether to walk.

2.2 What is Walkability?

The term “walkability” appears to be etymologically straightforward: the ability to walk (“Walkable,” 2020). Ability, in its narrowest sense, is the condition of capability. A walkable place, therefore, is one in which someone is capable of walking. A broader definition of ability,

however, is suitability, which connotes not merely the physical possibility of walking, but its psychological favorability in a particular personal, social, and environmental context (“Ability,” 2021). Planning for walking suitability is bound to be more complex than planning for capability, yet it may be considerably more powerful in motivating walking outcomes.

2.2.1 Physical and Psychological Influences

The capability- and suitability-based definitions suggest a spectrum along which factors related to walkability may be positioned. At one end of the spectrum, *physical* factors are those that most directly affect capability due to barriers or discontinuities along paths or limitations of physical ability. Physical factors may be characteristics of either environments or users, though environmental constraints may mediate personal characteristics. For example, a curb ramp could enable a person using a wheelchair to traverse a crosswalk.

At the other end of the spectrum, psychological factors may not physically enable or constrain walking but may nonetheless influence its viability. These factors might include heavy traffic that makes a walking route uncomfortable, or a social norm that makes walking unfashionable. They span environmental and social conditions—do environments feel appropriate for walking in both physical and social terms?—as well as individual-level attitudes and preferences.

Most influences on walking are likely situated along a spectrum between physical and psychological, and may even be positioned differently for different people, adding additional layers of complexity. A sidewalk gap may pose an impassible physical obstacle for one person but have more of a psychological influence on another. Safety, both from traffic and crime, has both physical (e.g., risk of getting hit by a car or mugged) and psychological (e.g., feeling unsafe) aspects that can be difficult for users to differentiate. In practice, however, it may be useful to distinguish between these mechanisms of influence in order to appropriately steer interventions. A street with high rates of vehicle collisions with pedestrians, for example, might be redesigned to elicit caution and slower speeds among drivers, prioritizing physical safety. Another street that has low crash rates but nonetheless makes pedestrians feel vulnerable may be a good candidate for pedestrian realm improvements that prioritize psychological safety. Both types of intervention may ultimately have both physical and psychological impacts, but they lean toward one or the other.

Some walkability theories position physical and psychological influences hierarchically, insinuating that physical ones are more fundamental or foundational (Alfonzo, 2005; Saelens et al., 2003), while others suggest a more equal footing (Klöckner & Blöbaum, 2010; Pikora et al., 2003; Schneider, 2013). An important empirical question is whether such a hierarchy is justified. Are physical influences on walking more influential than psychological ones, or should planners and engineers treat these influences with similar importance? Contemporary practitioners place substantial, perhaps undue emphasis on interventions related to physical capability. Some research, meanwhile, points to the substantial strength of psychological mechanisms. Cho et al. (2009), for example, find that walking behavior may be more strongly influenced by perceptions of safety than physical crash risk. Would refocusing effort toward the psychological experience of walking, despite its substantial socio-ecological complexity, be more useful for encouraging people to walk?

Biases toward addressing physical influences in transportation planning and engineering may be a product of their methodological traditions in quantitative measurement, isolation of cause-and-

effect relationships, and assumption of rational choice. These are notably divergent from the urban design field, which more commonly uses qualitative empirics to examine built environments as wholistic socio-physical systems in which emotion and subjectivity strongly inform how people interact with their surroundings. The fuzziness of psychological influences may, therefore, feel more natural, or even self-evident to urban designers. Convening these disciplinary traditions to develop theories that extend across the physical-psychological spectrum offers potential to improve understanding of walkability by accounting for factors that may have been avoided simply because they were challenging to measure under one methodological paradigm or the other.

2.2.2 Hierarchy of Needs

Maslow's (1943) *Hierarchy of Needs* offers just such a theoretical framework for organizing physical and psychological influences together, though it positions physical needs as more foundational. The original Hierarchy, which Maslow applies to all types of needs, not just those of walkers, suggests that the ability to address higher-order psychological needs, such as self-esteem, is contingent on fulfillment of lower-order practical needs, such as nutrition and bodily safety. Alfonzo (2005) extends this theory specifically to walking (Figure 2.1). Foundational needs, such as the physiological ability, time availability, and aspects of environmental accessibility including proximity destinations and route directness, are highly practical. Safety occupies a middle ground, related to both practical and psychological factors. Comfort and pleasurable occupy the top of the hierarchy, suggesting that they are desired and may motivate walking, but will come into play only once more practical needs are addressed.

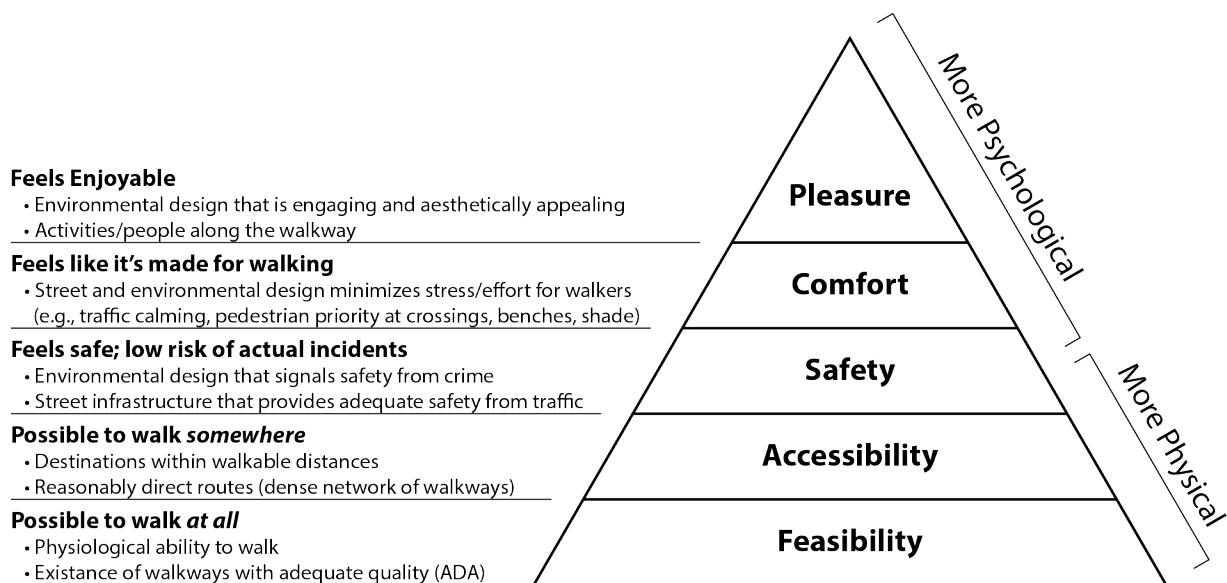


Figure 2.1. Hierarchy of Walking Needs.
(Adapted from Alfonzo, 2005)

The overt hierarchy of Alfonzo's walking needs also suggests a disciplinary hierarchy that is consistent with the contemporary planning and engineering paradigm. The physical ability to walk, along the base of the pyramid, is the foremost need, suggesting that efforts toward walkability must start by developing infrastructures and capabilities that address physical barriers. It is a useful thought exercise, however, to consider whether the pyramid could be turned upside down, its layers shuffled, or marbled together rather than being clearly striated. Would a walker willingly overcome substantial physical obstacles if a place was highly comfortable or pleasurable to visit? How much of a physical obstacle is a baseline requirement rather than a convenient amenity? The answers to these questions likely fluctuate substantially between people, further problematizing the boundaries between Alfonzo's layers. While her Hierarchy suggests that built environment disciplines may be able to hand off neatly-segmented scopes of work to create walkable places—first the planners lay out a well-connect street grid, then engineers build high-quality sidewalks and crosswalks, then urban designers tune streetscapes to make them pleasurable—it is unclear that all these pieces must be addressed in that precise order, or even addressed at all, in order to yield a highly walkable environment.

2.2.3 Walkability Discourses

Lo (2009) identifies similar disciplinary distinctions in how walkability is defined and the factors contributing to it. She identifies five key walkability discourses—*flow capacity*, *multimodal connections*, *sense of place*, *civic engagement*, and *active living*—each of which reinforces factors that tend to lean either pragmatic or psychological. The *flow capacity* discourse emphasizes a transportation engineering analogy to automobility and the need for walking infrastructure that provides adequate space for unconstrained movement. Paradoxically, this framework suggests that many places where there is little foot traffic are actually most walkable because there is plenty of space for additional walkers. There are clear shortcomings to applying this definition on its own, but it exemplifies the extreme possibility of walkability being interpreted in purely pragmatic terms, similar to how quality of service has been traditionally defined for automobiles (TRB, 2010).

The *multimodal connections* discourse focuses on how walking for transportation is a derived demand and thus requires an interaction between infrastructure and potential destinations. Walkability, by this definition, is about how the built environment facilitates physical accessibility for walkers. This discourse is exemplified by accessibility-based explanations of walkability (Ewing & Cervero, 2010).

Lo's discourse on physical capability stands in contrast with her *sense of place* and *civic engagement* discourses, which pose walkability as a function of urban design that encourages walking through aesthetic appeal and by promoting interpersonal connections that foster communality. The sense of place and civic engagement discourses still promote the importance of certain environmental qualities, but their principal influence is more psychological than physical. Moreover, these paradigms recognize that walkers themselves further bolster sense of place and community, creating social feedbacks that may overcome physical challenges to walkability. Under these paradigms, there is also a close connection between walkability and the more nebulous concept of *livability*, which is often used to characterize places where walking is a component of broader urban vibrancy (Ewing & Clemente, 2013).

Finally, Lo identifies an *active living* discourse that takes the commonsense stance of embracing both physical and psychological influences on walking, though with recognizable biases toward

factors that are readily measured quantitatively. She also finds that researchers applying this discourse more commonly examine individual- and group-level factors that may mediate built environment experience. Accounting for these factors reinforces the potential value of approaching walkability not as a characteristic of a place (e.g., “this neighborhood is walkable”) but as a characteristic of a *situation* in the context of a specific actor, place, and social environment (e.g., “this trip is walkable”). If these additional layers of complexity can be measured, they may add specificity to behavioral models and other quantitative understandings of walkability.

2.2.4 Social Ecology

Social ecological models describe behaviors as the products of interrelated personal and environmental factors. They have been applied widely in the field of public health, where they are used to reinforce how health outcomes are rooted in environmental context (Stokols, 1996). Pikora et al. (2003) apply social-ecological models to evaluate walking behavior on the basis of environmental factors that have both physical and psychological mechanisms of influence. (Figure 2.2). Similar to the *Theory of Planned Behavior* (Ajzen, 1991) and *Theory of Interpersonal Behavior* (Triandis, 1977), Pikora et al.’s model also includes both personal and social factors and are moderated by habit and environmental context. This order of influences is inverted relative to Maslow’s Hierarchy, which is grounded in physical constraints. As such, Pikora et al. (2003) suggest how psychological factors might overcome substantial environmental hurdles (e.g., “I like to walk so much that I’m willing to walk next to this freeway”) or advantages (e.g., “I hate walking, so I won’t even walk down this beautiful street”).

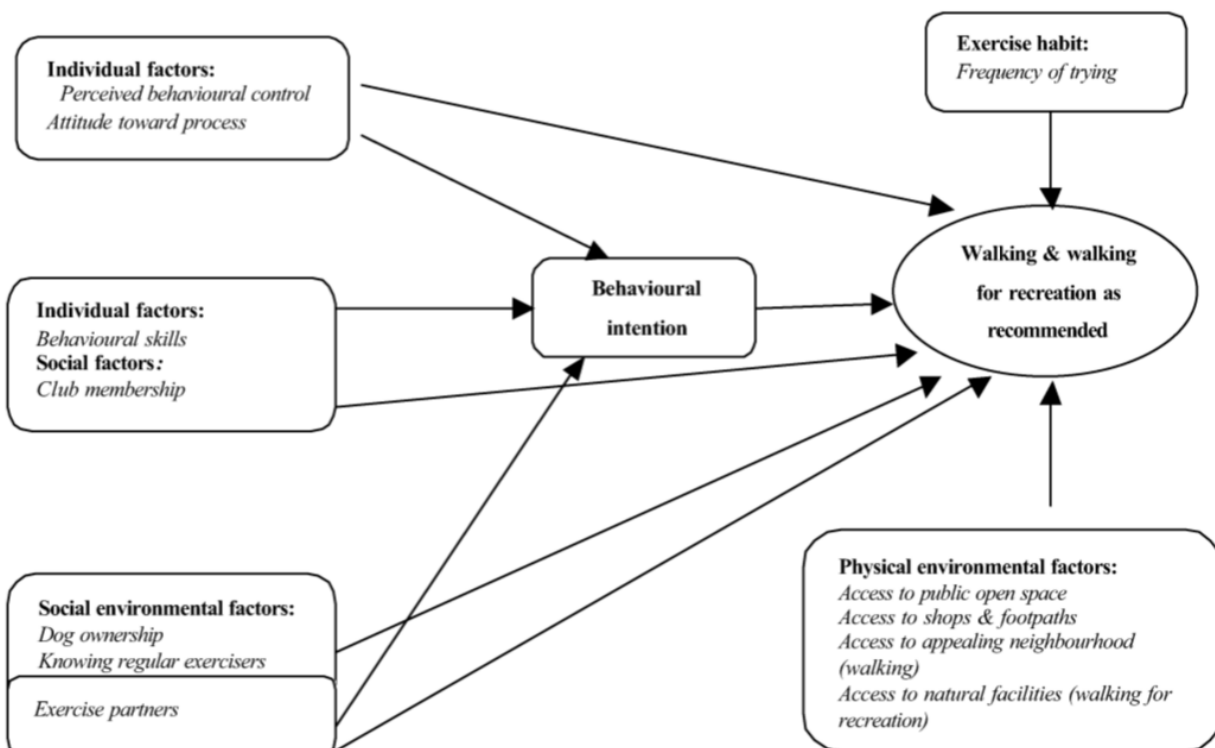


Figure 2.2. Social ecological model of influences on physical activity.
(From Pikora et al., 2003)

In contrast with Pikora et al. (2003), Saelens et al.'s (2003) *ecological model of neighborhood environmental influences on active transport* begins with the assumption that walking behavior is based on physical environmental factors and only moderated by psychological factors (Figure 2.3). It does, however, recognize that environmental factors influence walking via a mix of physical and psychological mechanisms, and that the strengths of these influences are different depending on whether walking is used for transportation or recreation. In particular, physical characteristics such as density and connectivity are thought to be more strongly linked with transportation, while safety and aesthetics are more strongly linked with recreation. This model aptly suggests that walkability may be perceived differently depending on purpose, but it poses important questions about whether transportation and recreation purposes are readily distinguishable. In any transportation mode, enjoyability plays an important role in decision-making (e.g., “I’m going to buy that car because it’s fun and comfortable to drive”), even in the context of routine trips. The line between transportation and recreation may be especially blurry for walking, which, because it is widely considered a relaxing activity (Handy, 1996b), may be frequently pursued in transportation-recreation combinations (e.g., “walking around the lake to buy the paper”) (Forsyth, 2015). Similar to the spectrum between physical and psychological influences on walkability, it may be more appropriate to identify transportation- and recreation-based purposes along a spectrum rather than with discrete categories.

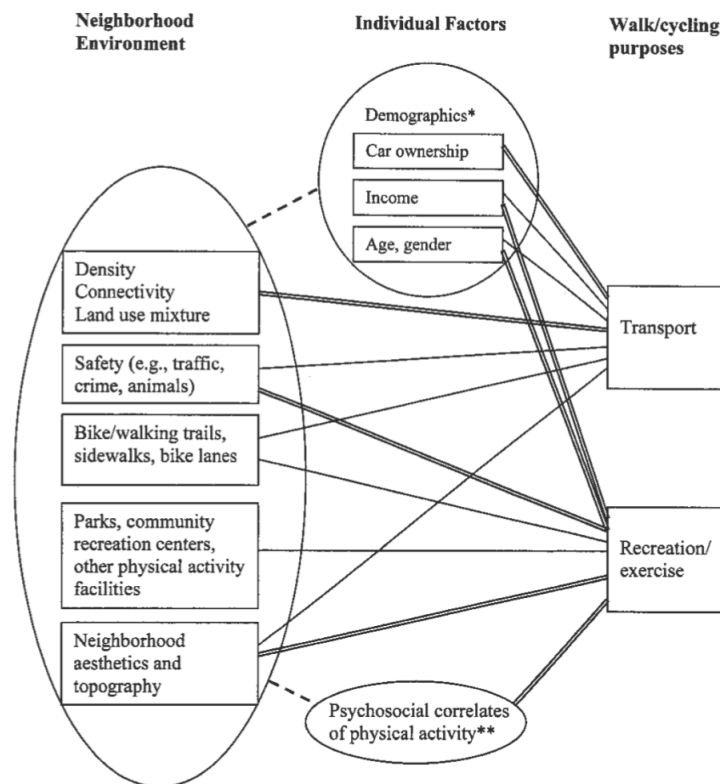


Figure 2.3. Ecological model of neighborhood environmental influences on walking and cycling. Double lines show stronger relationships; dashes show mediating relationships. (From Saelens et al., 2003)

2.2.5 Travel Mode Choice

Frameworks that position walking as an option among alternative travel modes or activities tend to heavily involve psychological influences such as social norms, personal attitudes, and habits. Klöckner and Blöbaum's (2010) *Comprehensive Action Determination Model*, which they apply to mode choice decisions, suggests that decision-making stems from socially constructed norms about what types of behaviors are acceptable, and indeed *necessary* within the context of a given social milieu (Figure 2.4). They argue that needs are not perceived on a strictly pragmatic basis but are rather constructed to conform with social norms (e.g., "I clearly need to drive because everyone else is driving"). These needs generate intentions, which influence actual behavior. Behaviors, in turn, create cyclical feedbacks onto norms, intentions and habits, reinforcing the likelihood of repeated behavior. Physical factors enter the decision-making process either as moderators that facilitate or constrain existing norms, intentions and habits, or as backdoor influences on them, modifying what is desired based on what is possible (or perceived as possible). This framework is focused on short-term decision-making, and thus does not account for the possibility that psychological influences may shape physical constraints over time so that they better align with norms (e.g., building more freeway capacity to accommodate greater demand for driving). The assumption of static or exogenously influenced constraints is a common shortcoming of short-term behavioral models.

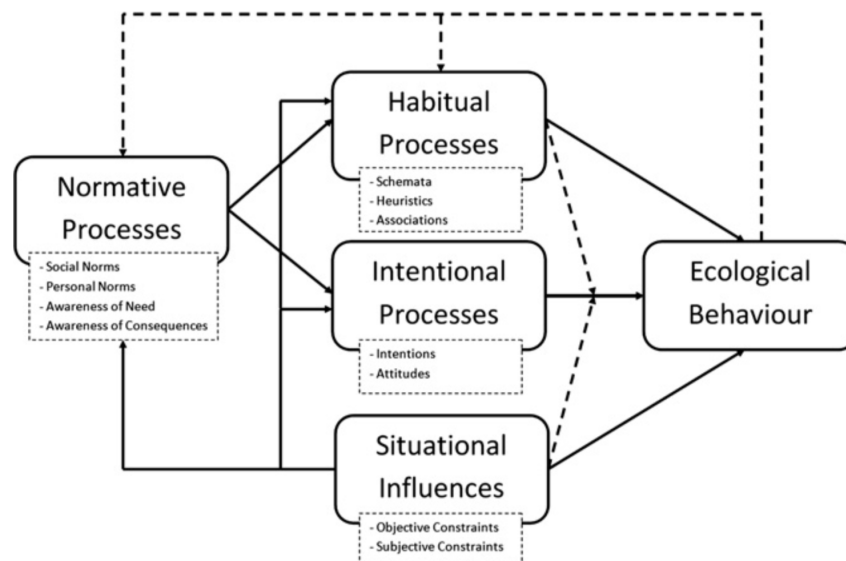


Figure 2.4. Comprehensive Action Determination Model.
(From Klöckner & Blöbaum, 2010)

Schneider's (2013) *Theory of Routine Mode Choice Decisions* closely integrates physical and psychological influences, including cyclical influences on one another (Figure 2.5). Similar to Maslow's (1943) and Alfonzo's (1995) hierarchies, it suggests a series of stages through which decision to use a given mode must pass, including physical availability, safety, and convenience, as well as more psychological influences related to awareness, perceived security, and enjoyment. Similar to Pikora et al. (2003) and Klöckner and Blöbaum's (2010), these influences are moderated by habit, which might reinforce an option that is not otherwise convincing or

derail an unfamiliar yet promising option. Whatever mode is ultimately selected cycles back into the compiled experience, influencing future awareness, sense of security, perceived cost, enjoyment, and habit.

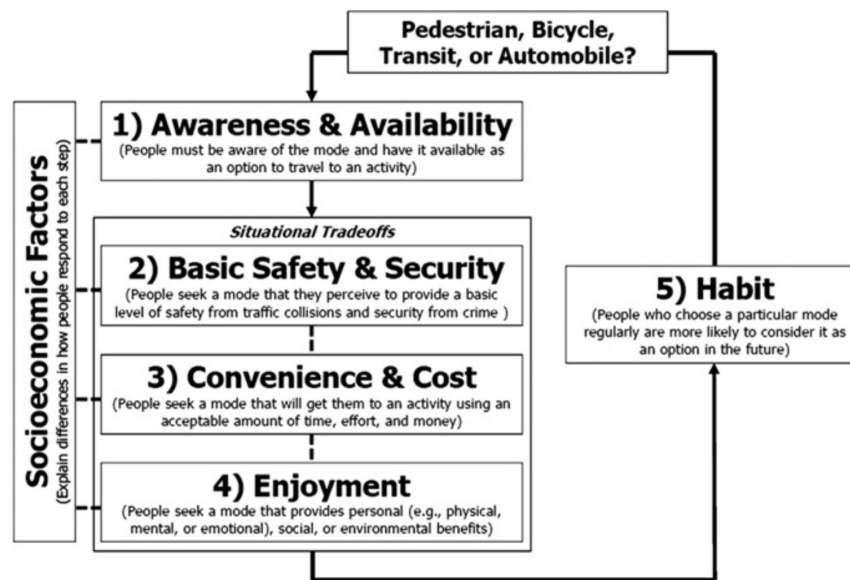


Figure 2.5. Theory of Routine Mode Choice Decisions.
(From Schneider, 2013)

A unique aspect of Schneider’s framework is that it demonstrates the relevance of both physical and psychological influences at nearly every stage of decision-making. Availability, for example, is affected not only by what is physically possible, but also awareness of alternatives. Safety, as previously discussed, can be interpreted as a physical constraint, but is also heavily influenced by perception. Even travel costs, which in most decision frameworks are presented in highly objective and physical terms (e.g., “the store is two blocks from my house, a walkable distance”), include an important psychological element because the effort associated with time and distance may be highly dependent on personal attitudes. Walking a mile may be considered easy by one person and difficult by another, despite equivalent physical capability. Thus, even the most overtly physical factors are, to some degree, psychological, because decision-making always involves filtering sensory input through perceptive and cognitive processes that necessarily shape understanding.

Both the Klöckner and Blöbaum (2010) and Schneider (2013) frameworks identify the importance of habits in directing mode choices. A strand of psychology research further examines how habits affect everyday decision making (Wood et al., 2002), mode decisions (Aarts et al., 1997; Klöckner & Matthies, 2004), and choices about engaging in physical activities such as walking (Wood & Neal, 2016). Habits are theoretically beneficial as decision-making tools because they reduce the need for complex thinking in repeated circumstances. Aarts et al. (1997) note that a person habituated to a single mode might always use it regardless of its appropriateness for a specific trip, resulting in paradoxical behaviors such as driving to a destination across the street. Habits may clearly, therefore, supersede rational decision-making. Research also indicates that habits may form simply from context, regardless of any goal (Wood & Neal, 2009). If everyone drives, for example, it may become habitual without ever considering

its costs and benefits. Likewise, habits around walking behaviors might be entirely divorced from the characteristics of walking environments. This indicates that changes to walking environments alone may be unlikely to dramatically modify walking behavior.

Habituation to walking environments may also shape preferences for them, indicating a circularity between behavior and preference. Wood et al. (2002) find that habitual behaviors are less stressful than non-habitual ones. Someone seeking to minimize stress, then, might simply fall back on habit, further engraining preference for that choice rather than examining other options. Habits may also be set at times of major change, such as relocation to a new neighborhood or learning to commute to a new job, and not revisited even when incremental change increase the viability of an alternative (Gravert & Olsson Collentine, 2021). This suggests a limitation in interpreting real-world behaviors, such as walking routes, as indicators of preference. They may simply be indicators of habit. On the other hand, habitual behavior may simply indicate that downsides are insufficiently strong to motivate a change. Habits may, therefore, serve as a stabilizer in decision making, indicating that choices are *good enough* rather than optimal.

The notable role of habits also reinforces the weakness of conceptualizing choices about walking as rational processes. While rational utility theory has dominated choice research and remains an important mechanism for predicting outcomes (Ben-Akiva & Lerman, 1985), it fails to account for the irrational biases, heuristics, and habits that weigh substantially on real-world decisions (Kahneman et al., 1982). Accounting for additional and individuated influences in a rational choice framework may improve predictions of walking behavior in ways that are useful for planners, but nonetheless inevitably falls short of offering a complete conceptual model for walking behavior.

2.3 Mechanisms of Streetscape Psychology

It is clear how physical mechanisms influence walkability: without a path to walk on or nearby destinations it is physically difficult to carry out activities on foot. By contrast, mechanisms that are more strongly psychological—what makes a place enjoyable for walking—are much less straightforward. This section draws on overlapping theories in urban design and environmental psychology to identify potential mechanisms by which environmental characteristics may fulfill psychological needs for safety, comfort, and pleasure among urban walkers.

In seeking to identify environmental qualities that are pleasurable, we are investigating aesthetics, a concept that remains vague and uncomfortable despite millennia of scholarly investigation (Shimamura & Palmer, 2012). Punter (1994) argues that the field of planning has an uneasy relationship with aesthetics because it is both an unavoidable aspect of how people interpret urban environments and also frustratingly difficult to define and predict: “Every opportunity is taken to circumvent the difficult questions about aesthetic judgement, either by dismissing them, or by applying so-called ‘common sense’ principles or simplified ideas about environmental quality” (p. 38). Planners may be eager to leverage the advantages of aesthetic preferences while obfuscating the complex social and natural science that may underly them.

A key challenge of aesthetics research is that aesthetic conditions are difficult to meaningfully define and measure. Transportation and public health research sometimes accounts for street aesthetics based on variables such as street trees and historic buildings (Ewing et al., 2004; Van Cauwenberg et al., 2012). Audits used to examine walkability include questions about

maintenance, architectural congruity, and overall pleasantness, requiring subjective interpretation by auditors, (Boarnet et al., 2006; Clifton et al., 2007; Macdonald et al., 2018), though it is notable that these audits capture many more variables than they link empirically to walking behavior. Methods to account for aesthetics in walking research tend to be poorly grounded in theory, relying on specific elements that are assumed to be aesthetically positive (e.g., trees) or highly subjective ratings (e.g., pleasantness) rather than general environmental conditions that may be fostered by a variety of designs (e.g., enclosure).

Research in environmental psychology, urban design, and geography offers a pathway for understanding aesthetic environmental preferences in more general terms (Appleton, 1975; Bourassa, 1991; Ewing & Handy, 2009; Kaplan & Kaplan, 1989; Lynch, 1981; Nasar, 1998; Stamps, 2009). The term “aesthetics” is not universally used in this literature, presumably because it hints at superficiality and subjectivity. Indeed, aesthetics are inherently subjective, but this does not diminish their potential influence, nor the ability to identify a degree of commonality in how groups of people, or even people at-large, interpret them. Aesthetics have long been studied scientifically. Kant interpreted aesthetics as the “science of sensory perception” (“Aesthetic,” 2009), and Dewey (1934) wrote extensively about the psychology of aesthetic interpretation, laying the groundwork for evolutionary theories of landscape evaluation that underlie more recent theories of environmental preference.

Subjectivity in environmental aesthetics may be interpreted as a function of the two-stage process of perception and cognition (Nasar, 1998). Perception is the process of gleaning information from sensory inputs. Responses to perceptions of environmental forms, such as “shapes, proportions, spatial relations, complexity, incongruity, ambiguity, surprise, novelty, and order,” may occur subconsciously, preceding any conscious “recognition, comprehension, or cognition” (p. 31). Cognition, as a second stage, involves conscious processing of perceived information. Nasar argues that perceptions have a probabilistic response to environmental stimuli, mediated by individual biology, affective state, and past experiences that may modify subconscious reactions. Cognition and perception may also have probabilistic relationships to one another, mediated by a broader array of personal preferences, symbolic meanings, rationalizations, and other conscious influences. He suggests that “Because of shared biology, culture, and environment, humans will exhibit some agreement in their evaluative response” (p. 30), which is the result of both perception and cognition. Rather than assuming that each person evaluates the world uniquely, as connoted by “subjective,” it may be more realistic to assume that each person’s evaluation follows a probability distribution that widens as it accounts for more varied perceptual and cognitive inputs. The pertinent question for researchers studying walkable environments is how and why this distribution of preference is sensitive to different design conditions that are perceived by users.

2.3.1 Perceptual Qualities

Ewing and colleagues organize design conditions that may affect perceptions of walkability into what they call *perceptual qualities* (Ewing et al., 2013; Ewing & Clemente, 2013; Ewing & Handy, 2009; Handy, 1992). Through a review of urban design literature that draws on Lynch (1981), Gehl (2011), Appleyard et al. (1981), Jacobs (1993; 2013), Schumacher (1986), and others, they identify 51 qualities, some of them highly related (Table 2.1). They subsequently narrow this list to five qualities—*imageability*, *enclosure*, *human scale*, *transparency*, and *complexity*—that they deem most important in the literature, account for many of the other

qualities, are operationalizable based on fairly objective street-level measurements and are most concretely definable according to an expert panel. Ewing et al. conceptualize these qualities as intermediaries along a causal pathway connecting physical features of street environments to holistic interpretations of walkability, and ultimately, to walking behavior (Figure 2.6).

Table 2.1. Perceptual qualities discussed in urban design literature.
(From Ewing & Handy, 2009)

adaptability	distinctiveness	intricacy	richness
ambiguity	diversity	legibility	sensuousness
centrality	dominance	linkage	singularity
clarity	enclosure	meaning	spaciousness
coherence	expectancy	mystery	territoriality
compatibility	focality	naturalness	texture
comfort	formality	novelty	transparency
complementarity	human scale	openness	unity
complexity	identifiability	ornateness	upkeep
continuity	imageability	prospect	variety
contrast	intelligibility	refuge	visibility
deflection	interest	regularity	vividness
depth	intimacy	rhythm	

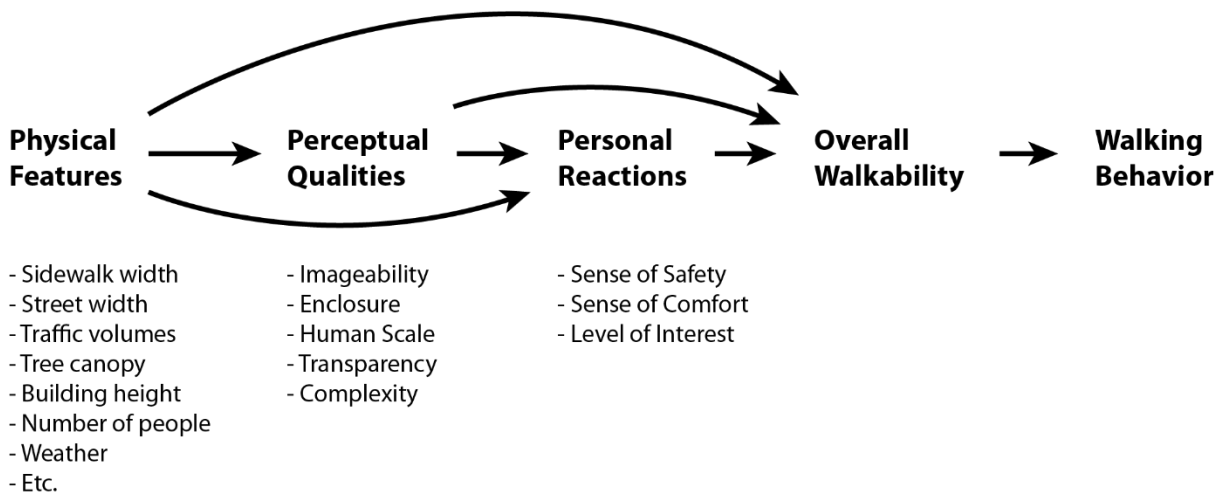


Figure 2.6. Framework linking physical features, through perceptual qualities, to walking outcomes.
(Adapted from Ewing & Handy, 2009)

The literature from which these qualities are identified is largely theoretical, qualitative, and often normative, drawing findings from informal observations of real-world uses rather than experimental research designs. A growing body of research aims to refine approaches for measuring these qualities (Ewing et al., 2006; Harvey, 2014; Harvey et al., 2016) and validate their effects on perceptions of urban spaces, walkability, and walking behavior (Boarnet et al., 2006; Clifton et al., 2007; Ewing et al., 2016; Harvey et al., 2015), but there is substantial potential for improved empirical understanding of how these factors influence walkers.

Even as Ewing and others have refined approaches for measuring perceptual qualities, the reliability and specificity of these measurements remains a substantial challenge for researchers aiming to examine their impacts. Ewing et al. (2006) collected five-point Likert-scale ratings of each quality as perceived in videos of street scenes by a panel of 10 urban design experts. Inter-rater reliability was reported as moderate for the five qualities carried into later studies (Ewing & Clemente, 2013; Ewing & Handy, 2009). Qualities such as tidiness, linkage, and legibility were rated considerably less reliably, reflecting the fuzziness of these concepts. No qualities, however, earned intra-class correlation coefficients (ICC) greater than 0.58, indicating low agreement even among experts. This lack of reliability, the imprecision of Likert ratings, and the expense of manually rating large samples of streetscapes, has spawned investigation of more automated approaches to operationalizing design qualities based on GIS and other data sources. Purciel et al. (2009) found that GIS-based counts and ratio variables were as good at predicting expert ratings of the design qualities as manually-collected measurements of streetscape features. Harvey (2014) also developed GIS-based streetscape measures to operationalize qualities such as enclosure and human scale as ratio variables, and found that they were good predictors of perceived safety (Harvey et al., 2015) and traffic crash risk (Harvey & Aultman-Hall, 2015). Nonetheless, methods for measuring design qualities efficiently, in ways that precisely capture their degree—how *much* enclosure—and reflect the diverse forms contributing to such qualities, remain in their infancy. There is much work to be done to translate nuanced theoretical understandings of these qualities into measurable features, either by human auditors or automated systems.

Imageability describes the extent to which a place is recognizable, understandable, and provides a sense of place. Lynch's (1960) investigation of imageability investigates how physical characteristics of cityscapes are interpreted as simplified elements—*paths, edges, nodes, landmarks, and districts*—to form cognitive maps that facilitate orientation within a city. The building blocks of such citywide images are memorable street-level scenes. He notes how “it is the shape, color, or arrangement [of elements] which facilitates the making of vividly identified, powerfully structured, highly useful mental images of the environment” (p. 9). Streets with greater imageability may be more comfortable for pedestrians because they provide a sense of groundedness and locational awareness (e.g., “I am here”). A street lined with generic buildings and lacking features distinguishable as landmarks, edges, or nodes, might provoke a sense of unease through disorientation (e.g., “am I lost?”). Imageability plays both a physical role in facilitating navigation and orientation, and a psychological role in maintaining a sense of control and awareness.

Imageability is highly relative. What makes an environment imageable is the occurrence of a feature that stands out from its context: a figure on ground. Thus, imageability does not require monumental landmarks. Lynch (1960) famously suggests that a landmark may be “a doorknob or a dome.” What *is* required for imageability is a degree of novelty or irregularity. This may be achieved through buildings that are especially large or complexly shaped (Appleyard, 1969), or through more subtle, but still recognizably unique qualities, such as colors, landscaping, or fixtures. This poses a substantial challenge for new development, which may be most economical through repetitious, cookie-cutter designs. It is unsurprising that many highly imageable urban environments are old enough to have undergone renovations or piecemeal modifications that add substantial internal variability.

Enclosure is the degree to which a streetscape is physically bounded by vertical objects that restrict sight lines, such as buildings and trees (Cullen, 1961). Indeed, the enclosing arrangement of buildings alongside roadways is arguably the most fundamental form-based pattern separating city, where streets are a figure against a ground of buildings, from country, where buildings are the dominant figure (Cullen, 1961; Jacobs & Appleyard, 1987). Cullen (1961, p. 29) further notes that “Enclosure, or the outdoor room, is, perhaps, the most powerful, the most obvious, of all the devices to install a sense of position, of identity with the surroundings ... it embodies the idea of hereness.” In part, this is because enclosure provides definition to outdoor spaces that make them legible as spatial entities: “I am outside IT, I am entering IT, am in the middle of IT” (p. 29). Enclosure provides the spatial foundation for referring to streets as coherent spaces. Jacobs (1993) also notes that pedestrians appear to be attracted to enclosure and the vertical edges that delineate it; this observation is corroborated by Appleton’s (1975) prospect-refuge theory, discussed later in this section, which suggests that some degree of enclosure is essential for providing a sense of protective cover. As Cullen dryly notes, “I am enclosed or I am exposed” (1961, p. 29).

Enclosure is often evaluated in two ways. Both hinge on the popular analogy of a room, whereby the facades of buildings along its edge constitute the walls and the ground represents the floor. The ratio between wall height and cross-street width of the floor can be used to summarize whether a street stands upright (taller than it is wide) or spreads flat (wider than it is tall). Enclosing ratios between 1:1 and 1:3 are described by some urban designers as optimal (Alexander et al., 1977; Ewing & Handy, 2009; Jacobs, 1993). The continuity of a street’s walls also influences enclosure. A highly enclosed street has few or no gaps between buildings, producing continuous street walls that span between intersections. The combination of a reasonably equivalent height-width ratio and continuous street walls create a “corridor street,” which is defined as much by its enclosing structure as by its roadway (Holston, 1989).

Street trees can help fill street wall gaps or provide enclosure where there are few buildings (Arnold, 1993; Boarnet et al., 2006). Mature trees can also add an additional level of enclosure by providing a ceiling-like canopy. Trees in medians or in planting spaces between the roadway and sidewalks can also create arcade-like subdivisions of street spaces. The enclosing effects of street trees are readily identified in field observations, but the diverse shapes and degrees of transparency among tree canopies make it difficult to measure the degree of enclosure they provide in precise and replicable ways. The number of trees, or spacing between trunks, are poor measurements because trees of different species, ages, health, or with different maintenance practices can have vastly different shapes and sizes. Researchers have used two-dimensional canopy area as a rough measurement of tree enclosure (Harvey et al., 2015; Locke et al., 2011), but this ignores the vertical dimensionality of trees, which is crucial to their sense of enclosure. Innovations in measurement of tree shapes and their effects on factors such as sight lines will be important for research examining the effect of trees and for guiding policies on how trees should be planted and maintained.

Within urban design literature, greater enclosure is often regarded as a normative good. Alexander et al. (1977, p. 106), for example, state that “An outdoor space is *positive* when it has a distinct and definite shape, as definite as the shape of a room, and when its shape is as important as the shape of buildings around it” (emphasis added). Jacobs (1993) observes that enclosed streets are safe-feeling and preferred by pedestrians. Nonetheless, the dominant trajectory of 20th century urban development in the U.S. and much of the world has been to

reduce enclosure, espousing the virtues of more spacious suburban forms in contrast with highly enclosed central cities that have been associated with crime, lack of sanitation, and overcrowding (Holston, 1989; Southworth & Ben-Joseph, 2013). The virtues of enclosure championed by urban designers have often been overshadowed by its negative connotations of central city blight. New Urbanism and related design movements are slowly renormalizing enclosure as an advantageous component of walkable urbanism.

Human scale is highly related to enclosure in that it is largely facilitated by bounded spaces. Whereas enclosure describes the shapes of these spaces, scale describes size. “Human” implies that this size is appropriate for human senses or movement. Spaces that are too large, either horizontally or vertically, may feel vast and unknowable. Human scale may be defined in terms of overall dimensions, such as the heights of buildings or the widths of streets. Alexander et al. (1977), for example, suggests a “four story limit” for human scale buildings, explaining that taller buildings restrict the viability of interaction between people on the ground and those in upper stories. This emphasis on building-ground interaction is consistent with Jacobs’ (1961) appreciation for street environments that facilitate “eyes on the street” from both ground-level shops and upper-story offices and apartments. Others are more concerned with how the scale of streets is perceived from ground-level. Tall towers may be incorporated into a human scale fabric if they are set back atop street-facing podiums that are only a few stories tall. For example, Macdonald (2005) demonstrates how high-density residential neighborhoods in Vancouver maintain a human-scale feel with this tower and podium design, often incorporating townhouses and shops with many individual entrances and articulated façades into the street-facing podiums. From street level, a pedestrian might never realize that there are tall towers sitting atop these human-scale streetscapes.

Appropriate horizontal dimensions for human scale spaces may also be based on limits of human perception and interaction. Alexander et al. (1977) note that people are recognizable and can communicate verbally across distances up to 70 feet. In a wide streetscape, it may be difficult for pedestrians to understand and engage with people or built environments on the opposite side, forcing pedestrians to perceive each side as its own ill-defined space rather than simultaneously relating to both sides as a cohesive whole. Jacobs (1993) also notes that pedestrians walking down the length of a street view it at an oblique angle, not straight across, making the two sides of seem even further apart and exacerbating the difficulty of tying them together. As such, even a moderately wide streetscape may pose challenges for pedestrian engagement.

While the overarching size of a street space is an important determinant of human scale, smaller design elements and objects within streetscapes can also substantially influence how users perceive the spatial scale of streetscapes. Trees can partition streetscapes into smaller sub-spaces; rows of trunks running lengthwise between sidewalks and traffic lanes, or in medians, can subdivide a wide streetscape into more human-scale corridors (Arnold, 1993). Tree canopies can also provide vertical bounding, allowing a streetscape lined with tall buildings to maintain a human-scale height. Signs that are designed to be viewed by drivers moving at high speed may be overwhelmingly large and difficult for pedestrians to read, signaling that pedestrians are unwelcome or inappropriate users (Appleyard et al., 1964). By contrast, intricate architectural features that are perceivable only by slow and close observation communicate the appropriateness of pedestrianism, as does street furniture, shop windows, and other features that invite close observation and interaction (Gehl, 2011).

Transparency describes the extent to which the edges of streetscapes are permeable and interpretable, allowing users to understand and relate to contextual land uses. Boundaries that are transparent provide streetscapes with additional depth, draw the interests of users, project a sense of activity and inhabitation, and satisfying curiosities about the lives of others. The quintessential example of transparency is shop windows. Doorways also welcome pedestrians to transcend the edge of a street and experience goings on behind a façade. Windows and doors into private structures, such as houses, may not promote public participation, but they nonetheless increase a sense of transparency by suggesting a connection between public and private realms (Jacobs, 1993). Well-tended yards, stoops, gates, and other intermediary landscaping between buildings and streets may similarly provide welcoming depth and transparency. Large setbacks, however, may have a reverse effect. If buildings are removed too far from the street, this distance, aside from affecting sense of enclosure and scale, can hamper the connection between public and private spaces that transparency affords. It is unsurprising that efforts to improve privacy almost inevitably reduce transparency.

Blank street walls and tinted windows are impediments to transparency, and key drivers of poor transparency in contemporary cities (Whyte, 1988). They also demonstrate the difficulty of balancing multiple perceptual qualities within the same street environment. Continuous street walls with little to no setback are important for providing enclosure, but they need to have real windows, doors or other articulation in order to stimulate a sense of transparency. Benefits of transparency and enclosure are somewhat dependent on one another, and enclosure may even be counterproductive if street facing walls are impenetrable.

Complexity is highly related to transparency, human scale, and imageability, in that it makes street environments more interesting and relatable to human users. Without visual complexity, streets would run together monotonously and be difficult to differentiate from one another. Gehl (2011) substantiates the importance of complexity by noting that it reduces perceptions of distance; interesting routes will simply feel shorter than those that are boring.

However, enjoyable complexity, like other perceptual qualities, is unlikely to be achieved simply through maximization. Complexity must be balanced against visual coherence and regularity, which help make spaces predictable and intelligible. An incredibly complex street, perhaps crowded with signs, may simply be interpreted as chaotic (Jacobs, 1993). More moderate levels of signage, however, adds dynamic energy to street spaces, introducing colors, shapes, and illumination that are notably missing from the non-commercial streets. At a broader scale, variability in form, including signage, between streets with residential, commercial, and other dominant land uses provides valuable complexity along routes. While mixed uses are valuable for pedestrians in a practical sense, they also provide interesting aesthetic variability.

Though complexity tends to be manifest in variability of finely grained features, it may be encouraged by broader patterns. Mixed land uses and small lot sizes may promote diverse architectures of different ages, styles, and states of repair (Gehl, 2011; Jacobs, 1961).

Neighborhoods that have been developed or renovated piecemeal rather than en masse are likely to provide more visually complex streets (Alexander et al., 1977). The organic forms, continuous movement, and filtered light of street trees provide substantial visual complexity (Arnold, 1993; Jacobs, 1993). Streetscapes that are sufficiently old to have mature trees have a significant advantage in providing rich yet subtle complexity that appears to be highly valued by pedestrians (Jacobs, 1993).

2.3.2 “Good City” Performance Dimensions

Lynch (1981) proposes five performance dimensions for evaluating “good” city form: *sense*, *fit*, *vitality*, *access*, and *control*. Of these, the sense and fit dimensions speak particularly strongly to the psychological and physical needs of urban walkers and align closely with other theoretical and empirical research about what contributes to preferable walking environments. Lynch also discusses how the same urban forms may perform differently for different individuals or groups. A highly performing city is unlikely to be one-size-fits-all, but rather a reflection of individually or socially informed needs. This is consistent with the social ecological understanding that walkability is informed by both physical- and socio-environmental factors.

The sense dimension is where Lynch most strongly focuses on the psychological needs of walkers. He describes how cities offering a high degree of sense are perceivable and understandable through empirical observation, particularly through sight, but also other senses. High sensory performance culminates in a strong sense of place. This is consistent with research in environmental psychology that is discussed more thoroughly below, which indicates how sensory engagement and understandability are preferable environmental qualities (Appleton, 1996; Kaplan and Kaplan, 1989). Lynch’s framing around sense of place, however, emphasizes the potential importance of deep, meaningful understanding: not only what can be sensed on the surface, but layers of social and environmental history that are perceived and understood through repeated exposure from different perspectives. It may be difficult to account for how deep understanding affects walkers’ perceptions and behaviors because it is likely self-reinforcing, similar to habit. Nonetheless, such deep understanding clearly plays a crucial role in how cities are evaluated, especially by those who have accrued substantial experience in a given place.

Lynch also discusses how specific design qualities support understanding. The concept of *transparency*, which Lynch describes as important for piquing interest in places, giving them life, and demonstrating their individuality, features heavily in his discussion of sense. Lynch defines transparency not in physical terms but rather the ability of an environment to allow users to understand about what is going on around them: the ability to “directly perceive the operation of the various technical functions, activities, and social and natural processes that are occurring within the settlement” (Lynch, 1981, pp. 138–139). Specific physical features, such as windows and doors, may often provide transparency by facilitating sightlines or movement between the public and private realms. But transparency may also be offered by activities that take place within the public realm, where they can be seen and understood by passersby. Construction workers in the street, for example, may enhance transparency, as might outdoor dining or a street festival. Environments that allow everyday activities to be publicly viewable may be attractive for urban residents, including walkers, because they enhance sense through transparency. Lynch’s emphasis on sensory transparency is consistent with Kaplan and Kaplan’s (1989) evidence that people prefer environments which offer opportunities for exploration and understanding (Section 2.3.3), and with Appleton’s (1996) theory of preference for places that afford views through which to understand environmental context.

The flow of sensory information over time or across space may be important for maintaining users’ engagement and not overwhelming them with information from a single vantage point. Lynch uses the term *unfoldingness* to describe how an urban space might be sensed progressively as someone walks or otherwise moves through it. His appreciation for unfoldingness is consistent with findings by Kaplan and Kaplan (1989) of preference for environments that offer mystery, where additional information is revealed as someone moves down a path or turns a corner. Given

this preference for collecting unfolding information, it may be most useful to distribute sensory improvements throughout walking environments rather than concentrating them in particular locations.

Lynch's *fit* dimension demonstrates how many aspects of urban form have both physical and psychological influences on walkers and other city users. To fit well, a city must facilitate, in both physical and psychological terms, the activities its residents desire to undertake. For example, a well-worn path may provide appropriate physical conditions for travel by foot, but also make it psychologically clear that it is a place appropriate for walking. An open surface, such as a parking lot or field, might provide similar physical capacity, but without so succinctly communicating its appropriateness. Indeed, basic aspects of street form, such as enclosure and edges, may also invite movement by providing obvious linear pathways. If these spaces are human scale, it may further communicate that a place is intended for walking as opposed to other uses, such as driving.

The idea that physical forms communicate their fitness for certain activities is similar to Gibson's (1966) theory of affordance, which posits that forms communicate elemental functional capacities to the people who perceive them. A surface that is the right height and shape for sitting, Gibson argues, can be clearly interpreted as a seat. Likewise, a linear horizontal surface, like a path, affords walking. Lynch similarly contends that fit ought to be communicated directly by city form rather than requiring supplementary cues. A person aiming to walk should be able to tell where it is appropriate to do so without, for example, a sign that says, "walking path here."

Fitness for walking may also be affected by disturbances from adjacent activities. Vehicular traffic, for example, poses a sensory challenge to walkers, even in places where there are no obvious safety risks. A path alongside a busy roadway may be unpleasant for walking due to traffic noise, dust, fumes, and other byproducts of vehicular mobility. Appleyard et al. (1981) demonstrate how high vehicle traffic volumes discourage pedestrianism and associated social ties with neighbors. Streetscape designs that incorporate trees, parking, or other buffers between sidewalks and traffic lanes may help shield pedestrians from traffic disturbances (Bosselmann et al., 1999; Jacobs, 1993). The role of physical separation for improving sense of fit among pedestrians is similar to the paradigm of separation espoused in bicycle planning, where the *Level of Traffic Stress* (LTS) is understood to decrease when facilities that offer greater separation from traffic, such as buffered bike lanes, are installed (Mekuria, Furth, & Nixon, 2012). For both pedestrians and bicyclists, however, the most comfortable, best-fitting facilities are likely those where traffic volumes are already low as opposed to being mediated by a design intervention (Mekuria et al., 2017).

A notable caveat to Lynch's discussion of fit is that it focuses on actual behavior, or, at most, behavior consciously desired. Unconscious needs are slippery, unless there is evidence of a link to health or another commonly-agreed-upon benefit. Even conscious desire may be a poor predictor of future satisfaction because it may rely on prior experience (Lynch, 1981, pp. 154-155). A walker, or any other city user, may not know that something fits, or doesn't, if they have never experienced it before. In short, they likely don't know what they don't know.

The difficulty of reliably accounting for residents' desires, or trusting whether they even know their own desires, poses challenges for modifying a status quo based on traditional sources of empirical evidence, such as revealed or stated preferences. More sophisticated understandings of psychological satisfaction, stress, or overall happiness may eventually be useful for revealing

appropriate environmental fit in ways that are disconnected from actual behavior. While theory and empirics in environmental psychology, discussed in the following sections, address some aspects of what Lynch describes as sense and fit, examination of how these dimensions may be operationalized and their impacts on users remains substantially underdeveloped.

2.3.3 Information-Processing Theory

Cognitive psychologists Rachel and Stephen Kaplan offer a substantial body of theoretical and empirical work investigating environmental preferences. Their research is largely focused on natural environments, but their findings and associated theory offer valuable extensions into urban settings. Collection and processing of information, which they frame as an essential commodity for human survival, is central to their explanations for environmental preference. The Kaplans (1989) describe attraction to information according to two basic needs: understanding and exploration (Table 2.2). They posit that these general informational needs apply to all humans, although the ways that information is understood and explored may vary based on personal and cultural context.

Table 2.2. The preference matrix.
(from Kaplan & Kaplan, 1989, p. 53)

	Understanding	Exploration (seeking understanding)
Immediate	Coherence (Order)	Complexity (Quantity of distinct elements)
Inferred/Predicted	Legibility (Structural understanding)	Mystery (Potential to understand by moving)

The first informational need, understanding, is the most elemental. It describes the process by which environmental phenomena are sensed, perceived and interpreted in order to improve knowledge about definition, association, and causation. The second need, exploration, supports the desire for continually improved and accumulated understanding. A place that can be readily understood, but offers few possibilities for exploration, may be interpreted as dull, simplistic, or may even leave the observer feeling unconvinced that there is not more “behind the scenes.” The Kaplans argue that knowing what goes on behind the scenes is, for most people, an appealing proposition. They suggest that this impulse is the result of a natural preference for opportunities to expand understanding. Interestingly, people may not need to *have* understanding in order to value it. Clear opportunities to accumulate information are also preferential.

Further, the Kaplans identify two *degrees of inference* through which information can be gathered and synthesized. The first is information that is immediately available without much further synthesis or context. This type of information hints at what Nasar (1998) might consider pure perception, without requiring any, or at least much, cognitive processing. Immediate information gathering may include identification of known objects: e.g., that is a tree, that is a building. The Kaplans suggest that the environmental property of *coherence*, which allows objects to be clearly and quickly differentiated from one another, is preferential for supporting immediate understanding. Environmental *complexity*, meanwhile is preferential for supporting

immediate exploration. A more complex view will provide fodder for exploring a broader array of relationships between sensed features. The need for both understanding and exploration help explain simultaneous preferences for both coherence and complexity. Indeed, an environment may be most appealing if it manages to be both ordered and complex (Table 2.3).

Table 2.3. Relationship between coherence and complexity.
(from Kaplan & Kaplan, 1989, p. 54)

	Low Complexity	High Complexity
Low Coherence	Not much there	Visually messy
High Coherence	Clear and simple (boring)	Rich and organized

The Kaplans argue that preferences for two other basic environmental qualities, *legibility* and *mystery*, depend on a greater degree of cognitive inference. Legibility, which they define similarly to Lynch as the extent to which an environment is readable based on common physical patterns and transparent design, facilitates understanding of unknown or more complex features. Mystery, which is conceptually similar to Lynch's *unfoldingness*, is appealing because it provides the opportunity for deep exploration of elements that are not immediately obvious. Scenes that offer mystery, including elements of semi-transparency, such as open doors or pathways leading out of sight, may provide an attractive lure for exploratory movement. It is easy to imagine how walking might be crucial for investigating an environment that offers mystery.

The Kaplans identify many of the same preferential environmental qualities as earlier urban design theorists, including Lynch. Their primary contribution, however, is providing a richer theoretical framework for explaining *why* these qualities might be attractive based on the informational resources they afford. Further, they harness visual preference surveys using a variety of stimuli, including static images, video, and real-world exposure, to systematically test these theories, providing robust evidence of consistent preferences for environmental coherence, complexity, legibility, and mystery (Kaplan & Kaplan, 1989). Their work continues to provide one of the best examples of closely-coupled theory development and empirical validation in the field of environmental psychology.

2.3.4 Habitat Theory (Prospect-Refuge)

Appleton (1975) proposes another widely cited theory explaining how certain qualities of landscapes are aesthetically preferential. Like the Kaplans, Appleton focuses primarily on natural and rural landscapes. Despite his background as a human geographer, his theory is constructed through an art historical lens, based on landscape paintings, but his ideas have often been extended to urban contexts. His overarching framework, *habitat theory*, asserts that habitat preferences among humans, like those of other animals, are likely shaped by our biological need for certain behaviors, such as eating and drinking, finding shelter, and mating, while avoiding threats such as predation. In a pre-modern context, fulfilling these needs hinged on perceiving

and interpreting one's physical environment. Therefore, he argues, innate preferences for certain environments are likely to have evolved to best facilitate such needs.

The more widely known *prospect-refuge theory* references two environmental characteristics that Appleton suggests are most elementally associated with the needs of seeking resources and avoiding threats. Environments that afford prospect are those with vantage points from which a sizable territory can be surveyed. Those with refuge offer shelter from the view of others. The ideal landscape, according to this theory, provides both prospect and refuge simultaneously, allowing someone to “see without being seen.” In a natural setting, prospect might be provided by an open plain, while refuge is provided by a tree or a forest edge. In an urban context, a street edge might provide a comfortable vantage point from which to survey in either direction, while the street wall provides a continuous source of refuge from behind (Figure 2.7). Prospect-refuge theory thus offers an explanation for the attractiveness of environmental enclosure, and in particular, the edges of enclosed spaces. It also helps substantiate the appeal of transparency, which offers prospect beyond the immediate edges of streets.

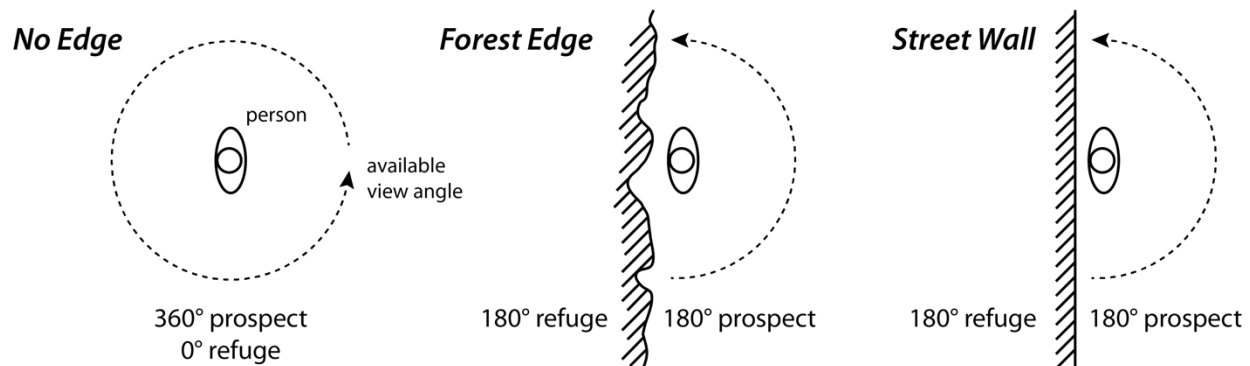


Figure 2.7. An edge provides a mixture of both prospect and refuge.

At its core, prospect-refuge theory is an information-based theory, similar to the Kaplans'. Unlike theirs, however, it considers not only the benefit of accruing more information for one's self, but that of limiting the information of potential opponents. It supposes that humans require information and must balance that need against the threat of exposure, or at least controlling whether observation is reciprocal. By this logic, an unfavorable environment might be one where an observer can see you, but not vice-versa. This contrasts with Jacobs' (1961) notion that “eyes on the street” from upper-story windows provide a more comfortable and controlled environment. It also conflicts with the tradition of promenading, the ritual of bourgeoisie urbanists walking along grand streets and garden paths in order to *see and be seen* (Jacobs et al., 2002). Perhaps social benefits derived from these forms of visibility are simply greater than the benefits of biological inclinations toward refuge.

A twist in Appleton's theory is that observers may favor not only “direct” prospect from their current vantage point, but also “indirect” prospects, such as scenes with vantage points that symbolize the potential for additional views. These might include a curving pathway that facilitates exploration of novel territory, much like Lynch's unfoldingness, or the Kaplans' mystery. Secondary vantage points are visible features, such as towers, hilltops, or high windows which might facilitate greater prospect. Appleton argues that these are pleasurable as symbols of

prospect, even if they are not immediately attainable. It is nonetheless difficult to understand how such features might not symbolize vulnerability to the prospect of others. Presumably, more immediate sources of refuge would be required to provide cover from potential onlookers at these vantage points, reinforcing the necessity of continually balancing prospect and refuge conditions.

Bourassa (1991) builds on habitat theory by arguing that evolutionary biology may provide an important foundation for landscape preferences, but that individual-level preferences cannot be completely understood in such generalized terms. He advocates a nested system of influences, beginning with what he calls *biological laws*, which are presumably applicable to all people. Appleton's and the Kaplans' theories are central to this biological foundation. At the next level are *cultural rules*, which are transmitted socially rather than biologically, and may modify or supersede the influence of biological laws. If, for example, a cultural norm placed substantial value on wide open spaces, this might moderate biological preferences for a degree of enclosing refuge. Finally, Bourassa notes that *personal strategies*, which are exclusive to individuals or very localized groups, such as families, may diverge from both biological and cultural influences. An apt analogy for the relationship between biological laws, cultural rules, and personal strategies is combined waveforms, where a dominant, underlying signal is progressively distorted by additional layers that together form a complex combination (Figure 2.8). Underlying biological and cultural signals may conceivably be distinguished from personal-level noise, allowing researchers to identify common tendencies. Nonetheless, endeavoring to untangle empirical evidence of intertwined biological, cultural, and personal influences presents a substantial research design challenge.

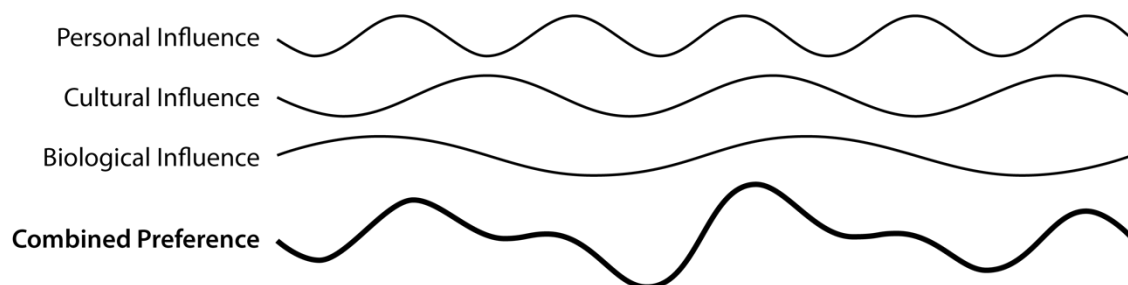


Figure 2.8. The combined effects of personal, cultural and biological influences may be analogized by waveforms. Each of the three top waves depicts a different influence, with the personal influence being the most intricate and the biological influence providing a more basic, underlying current. The waves combine to form the perspective held by an individual, which is most readily observable by a researcher.

The mechanism through which biological laws develop is conceptually straightforward—landscape preferences that facilitate survival and reproduction are likely passed down to future generations. By what mechanism, then, do cultural rules and personal strategies develop? Bourassa posits that cultural and personal landscape preferences emerge, at least in part, to substantiate cultural and personal identity. While novelty can be attractive, people are often attracted by settings and situations that are, at least in some ways, familiar. Even the most unusual or exotic architectural spaces tend to have familiar qualities—floors, walls, windows—that seed connections with existing understandings of what constitutes a building, street, or other type of space. This sense of familiarity may be derived from a combination of personal (e.g., “I

recognize that”) and cultural (e.g. “that looks like where I come from”) experience. Preferences for historic architectural styles, which lead to historic preservation, for example, are expressions of identity with a particular culture and its stylistic artifacts.

Personal strategies for landscape preference provide opportunities for self-identity, primarily through the mechanism of creativity. This may take the form of creative landscape alteration, such as built environment design, whereby individual or collaboratively developed concepts are implemented as an intervention to a culturally or biologically informed status quo. (In practice, it may be difficult to distinguish between biologically and culturally informed norms, as both are resilient over long periods and may become highly intertwined.) Conversely, personal strategies may simply involve creative approaches to perception and cognition of existing landscapes. In either case, personal strategies are the cutting edge of gradual change in cultural rules and biological laws, which may develop from proliferation of a creative concept, and eventually, biological adaptation, if the concept has implications for survival and reproduction.

2.3.5 Likability

Nasar (1998) theorizes about what characteristics of urban environments are preferable, or “likeable,” using a more inductive empirical approach. He suggests that “Likeability refers to the probability that an environment will evoke a strong and favorable evaluative response among the groups or the public experiencing it” (p. 3). Nasar is essentially concerned with public opinion, positing that places which are deemed most likable on average may provide useful guidance for designing similarly likable environments. While he recognizes personal and cultural variability in preferences, he also observes considerable consistency in ratings for certain types of landscapes. Thus, he surmises, it is possible to design cities in ways that many people agree are enjoyable, particularly within a given cultural-geographic context.

Through interviews with several hundred residents and visitors in the cities of Chattanooga and Knoxville, Tennessee, Nasar (1998) identifies five environmental qualities that were consistently identified as likable: *naturalness*, *upkeep*, *openness*, *historical significance*, and *order*. In many ways, these qualities are consistent with those identified by urban design and environmental psychology theorists, while others, especially openness, pose a notable contrast. These results may demonstrate how actual users of urban environments can have interpretations of what constitutes an enjoyable cityscape different from design theorists or professionals. Rapoport (1977) describes such differences using the anthropological terms *emic* and *etic*, the former relating to the perspective of a cultural insider, the latter describing the perspective of an outsider, such as a researcher or professional (Moudon, 1992). Compared with Ewing and Handy’s (2009) qualities, which were identified and substantiated based on a literature review and a panel of urban design experts, Nasar’s interviews with on-the-ground users represents a substantially more emic perspective on what matters in urban design. Conversely, it might be argued that lay users may lack conceptual or linguistic sophistication to adequately identify or convey environmental influences and are therefore an untrustworthy source for understanding their own experiences. To the extent that emic and etic perspectives conflict, understanding what drives their differences is an important area for additional investigation.

Naturalness and historical significance share many similarities with the qualities Lynch, Ewing and Handy, and the Kaplans’ describe as complexity, imageability, and transparency. These qualities all provide visual interest by increasing the depth, both physically and culturally, of environmental scenes. They also describe a desire for *quantity* of environmental features, either

in a general sense, or particularly natural or historical features, which themselves tend to offer fairly high levels of visual and cultural complexity. Each of these authors agree that too many features may, theoretically, be unfavorably overwhelming, but since few real-world environments have such extreme complexity, it is difficult to empirically identify such a level. As such, Nasar's studies suggest a monotonically positive relationship between landscape complexity and favorability.

Upkeep and order are also well-aligned with other researchers' discussions of coherence and legibility. These qualities describe *structure* rather than quantity. More structure appears to be preferable up to a point, though extreme structure, especially if complexity is lacking, may be monotonous. By identifying qualities that represent both quantity (naturalness, historical significance) and structure (upkeep, order), Nasar presents a framework that is quite similar to the Kaplans' interrelation of complexity and coherence (Table 2.3).

Upkeep, which describes maintenance rather than overall form, emphasizes the multi-scalar nature of environmental characteristics that may drive user comfort. Perceptions of upkeep are likely driven by finely grained, surficial characteristics rather than broader forms, making them difficult to measure concretely and also difficult for urban designers to modify. A space may be designed and constructed with extreme attention to comfort for human users, but if the space is not maintained, these initial considerations may be moot. Likewise, extreme attention to upkeep may help an otherwise poorly designed space be moderately comfortable. The importance of ongoing, finely grained maintenance reminds us that well-considered urban design is not, on its own, a silver bullet for facilitating enjoyable pedestrian spaces. A maintenance worker may be equally, or even more crucial for this effort than an urban designer.

The most notable discrepancy between Nasar's research and conventional urban design theory relates to the desirability of openness rather than enclosure. In particular, Nasar finds that his subjects are attracted to vistas, open space, and scenery, and dislike spaces that feel restricted, crowded, and congested, such as narrow roads. There are a few possible explanations for this discrepancy. Firstly, Nasar's finding in Chattanooga and Knoxville may be the result of what Bourassa calls a *cultural rule*, embedded in the social norms of this particular region. It is understandable that places with more traditionally open environments, or where enclosed environments potentially represent poverty or backwardness, might promote favorability for openness. Openness may be an important communicator of status and privilege since it requires a degree of wealth to own land without developing it. Suburban areas with large lawns and large streets demonstrate that residents can afford such extravagances. Replicating Nasar's research across more diverse geographies would offer insights into underlying social influences and their geographic structures.

Alternatively, discrepancies about the favorability of enclosure may be due to differences in emic and etic understandings of how users relate to enclosure. It is possible that users, potentially for cultural reasons, think that they prefer openness, while in practice, they are drawn to enclosing, human-scale spaces. An open park, for example, may be conceptually attractive, potentially because it contrasts with a more intensely developed context. People might nonetheless prefer to sit along the edge of the park or under a tree, not in its wide-open spaces. Discrepancies between conceptual norms and actual behavioral outcomes may be inadequately captured through interviews.

Finally, Nasar's interpretation of preferences for openness may not actually contradict preferences for enclosure, but instead describe these same preferences using different terms. Nasar discusses how subjects prefer spaces with well-defined edges, such that the openness of the space is clearly articulated, vistas are framed, and open spaces visually guide users between them. This is consistent with how Ewing and Handy (2009) define enclosure, and how the Kaplans describe mystery. They may be describing the same fundamental phenomenon, though some define it in terms of positive space (the enclosing edge) while others focus on negative space (the open middle). All would likely agree that too much or too little openness or enclosure is detrimental—a middle ground is preferable. What constitutes an appropriate middle ground, however, remains ambiguous and may nonetheless vary based on cultural norms.

2.4 Streetscape Psychology in Practice

The frameworks of environmental qualities described in the previous section provide a toolkit for analyzing how urban streetscapes may be designed in ways that are psychologically conducive to walking (Table 2.4). This section demonstrates how these frameworks may be used to analyze streetscape examples and identify concrete design modifications that could encourage walking.

Table 2.4. Frameworks of psychology-oriented environmental design qualities conducive to walking.

Perceptual Qualities (Ewing et al.)
Imageability
Enclosure
Human Scale
Transparency
Complexity
Performance Dimensions (Lynch)
Sense
Sense of Place
Identity
Structure
Legibility
Transparency/Immediacy
Unfoldingness
Fit
Information-Processing Theory (Kaplan and Kaplan)
Understanding
Coherence
Legibility
Exploration
Complexity
Mystery
Habitat Theory (Appleton)
Prospect
Refuge
Likability (Nasar)
Naturalness
Upkeep
Openness
Historical significance
Order

The example streetscapes are along four adjacent blocks of Broadway, an arterial street north of downtown Boulder, Colorado (Figure 2.9). All of them fulfill the physical needs at the base of Alfonzo’s (2005) hierarchy of walking needs. They all have well-maintained, ADA-accessible sidewalks and crosswalk facilities, are accessible to a variety of land uses (Broadway runs through a residential neighborhood and has commercial uses along it) and have low incidences of traffic crashes and crime. They all front the same four-lane street with approximately the same traffic volumes, speeds, and no street parking, so the psychological “cost” of the adjacent roadway is held constant between them.



(a) Most walkable residential



(b) Most walkable commercial



(c) Moderately walkable residential



(d) Moderately walkable commercial



(e) Least walkable residential



(f) Least walkable commercial

Figure 2.9. Streetscape examples with varying degrees of psychological walkability along four adjacent blocks of Broadway, an arterial street in Boulder, CO.

What differs between the examples is how their streetscape designs, including green strips, sidewalk zones, setbacks, and buildings, either address or ignore the psychological needs—sense of safety, comfort, and pleasure—toward the top of Alfonzo’s hierarchy. Pedestrians are capable of traversing all these streetscapes, but some are more suitable for walking than others.

To illustrate how psychological walkability may vary across land uses, the examples include streetscapes with both residential and commercial buildings. Though they demonstrate only a narrow range of building types, the same frameworks of psychology-oriented environmental design qualities may be applied to buildings ranging from single family houses to high-rise towers. The primary influences on psychological walkability are related to setback, articulation, access to buildings, and landscaping along the sidewalk zone, all of which are applicable to development across a wide range of densities and uses.

Among the residential examples, Figure 2.9(a) is most walkable because it balances all three of Alfonzo’s (2005) psychological needs: safety, comfort, and pleasure. Sense of safety is promoted by enclosing buildings and trees (Ewing & Handy, 2009), which provide refuge by limiting the territory across which a walker may feel compelled to track and appraise potential threats (Appleton, 1975). The low fence to the right of the sidewalk and plantings in front yards enhance enclosure while still offering visual access to the buildings, an important source of prospect (Appleton, 1975), transparency (Ewing & Handy, 2009; Lynch, 1981), and visual information (Kaplan & Kaplan, 1989). Imagine if the fence were above head height and opaque. This might marginally increase protective refuge, but at the cost of greatly reduced prospect, potentially diminishing the sense of safety that relies on both. Further, this would likely reduce pleasurability by limiting visual complexity and transparency. While Alfonzo positions safety as a more fundamental need than pleasure, the most psychologically walkable streetscapes are likely to strike a balance across needs, especially regarding safety. A place that feels entirely risk free may also be exceedingly boring.

In addition to providing a sense of refuge, the buildings and trees along Figure 2.9(a) are visually rich. The scene is complex, with layered yards, stoops, planting areas, and façades, but also coherently divided into separate rowhouses with distinct boundaries: what Kaplan and Kaplan (1989) would call “rich and organized.” Further, we can imagine that new variations on the scene will unfold as we traverse the sidewalk and view each house, yard, or tree from a different angle, what Kaplan and Kaplan (1989) call mystery, and Lynch (1981) calls unfoldingness. While we can’t see directly into the houses, street-facing doors and windows offer a conceptual connection, a degree of legibility and transparency (Ewing & Handy, 2009; Lynch, 1981), to the residential life behind them. We can imagine conversing with someone on a stoop or even standing there ourselves, an example of Appleton’s (1975) indirect prospect.

The most walkable of the commercial examples, Figure 2.9(b), offers some of these same benefits but lacks others. Notably, it has less enclosure due to the lack of a green strip and trees between the sidewalk and roadway, so pedestrians may feel more exposed to passing traffic. The buildings are architecturally nondescript, so they are not highly imageable or engaging based purely on their exteriors. Their zero setbacks and large street-facing windows, however, offer a large degree of transparency (Ewing & Handy, 2009) and mystery (Kaplan & Kaplan, 1989). A walker approaching this block may be eager to glance through each window, essentially hopscotching between unfolding views into the buildings’ interiors. They are unlikely to be disappointed. The foreground building contains a restaurant, and the front windows offer a view onto tables and an often-lively bar. The next building has a computer repair shop on the ground

floor, with large windows displaying vintage computers. Both have doors opening onto the sidewalk, offering further opportunities for exploration. This unfoldingness, as Lynch would describe it, turns an otherwise drab streetscape into an engaging path, even with only modest exterior design.

The streetscapes in Figure 2.9(c) and Figure 2.9(d) are both recent construction for which efforts have clearly been made to create high quality walking environments but have nonetheless missed the mark in important ways, largely due to lack of transparency along their ground-level façades. Walkers along Figure 2.9(c) traverse a nearly continuous wall with little surface texture and only a single entrance set back in an alcove. This street-level design is uninteresting and unwelcoming. It is, essentially, a fortress against potential imposition from passersby. Whereas the stoops and yards in Figure 2.9(a) are visible from the street, providing a liminal zone where walkers and residents might have friendly, or at least cursory interactions, the fortress-like building in Figure 2.9(c) suggests that residents have no interest in engaging with the outside world aside from looking down on it from the distance of a balcony. This signals that the street is unsafe, reinforces a social hierarchy where people at street level are inferior, and gives pedestrians little to engage with sensorily while they pass. The trees may help compensate by providing visual complexity and enclosure as they mature, but this will never be a building that welcomes pedestrians, despite the ample space and infrastructure allocated to them.

Figure 2.9(d) demonstrates a common strategy for offering what appears to be a pedestrian-oriented façade, perhaps to satisfy a design review process, while offering little psychological value for actual pedestrians. The difference hinges on two major factors: false windows and setback. Architects know that fenestration is a powerful design tool for organizing and adding visual complexity to façades. Indeed, this wall would be even less engaging if it were continuous brick. The windows in this case, however, are permanently blacked out. For a variety of reasons—need for wall space, security, ease of maintenance, hiding unsightly spaces, control over light levels—windows are undesirable for many commercial and industrial uses. The easiest solution to accommodate both exterior and interior needs is false windows. Presumably, a future use that is more public facing could reopen the windows. In the meantime, though, they feel like a deceptive design, luring momentary interest until it's obvious that there is nothing to see. Whereas real windows and doors entice more engagement the closer one walks, fake windows and doors are uninteresting, or even resented, as soon as the deception is evident.

Compared with the buildings in Figure 2.9(b), those in Figure 2.9(d) are also too far from the sidewalk to strongly engage with pedestrians. The awnings provide no meaningful sense of refuge for sidewalk users. If the windows were real, it would still be difficult to see what was inside across fifteen feet of planters, railing, and a raised walkway adjacent to the building. A pedestrian could detour onto that walkway to get a better look (and cover from the awning), but that removal signals that the building is intended to be isolated from, rather than connect to, the sidewalk and its users. The hedge in the setback is the most street-facing element of the design. It adds depth and complexity in ways that hint at the planted yards in Figure 2.9(a), but it is mostly continuous, making it feel more like a barrier between the public sidewalk and private building rather than a place for exchange between them.

The least walkable examples, in Figure 2.9(e) and Figure 2.9(f), suffer from lack of both refuge and visual complexity. The foreground apartment building in Figure 2.9(e) is set back the same distance from the roadway and is approximately the same height as the commercial building in Figure 2.9(d), but pedestrians are placed further from the building because the sidewalk is

directly adjacent to the roadway, and the flat lawn accentuates the feeling of openness. The brick wall facing the street is eminently dull and communicates that residents have no desire to interact with passersby. A pedestrian's attention is likely drawn to the refuge- and mystery-providing tree along the next lot, and they will try to get there as quickly as possible.

Figure 2.9(f) is somewhat more hospitable, owing largely to the trees that offer a minimal but valuable buffer between the sidewalk and traffic. In the absence of any street-facing buildings, these trees provide the only sense of enclosing definition to the pedestrian space, and their branches, leaves, and movement add complexity to an otherwise homogenously paved space. When they are more mature, their canopies may even provide a great deal of refuge, transforming this sidewalk into a green tunnel. For now, though, the space feels vast and distant from the storefronts across the parking lot that are most likely to attract the attention of pedestrians. If these storefronts were instead lined up along the sidewalk, like in Figure 2.9(b), this might instead be the most walkable example, with ample prospect and refuge, visual complexity and transparency, and mystery-inducing windows, doors, and corners, lined up all the way down the block. Instead, such a first-rate pedestrian environment is secluded behind a parking lot, catering to shoppers who became pedestrians only after disembarking their vehicles. People walking from the neighborhood, meanwhile, must traverse the desolate parking lot to reach the pedestrian oasis behind it.

These examples demonstrate how streetscapes can be examined for psychological aspects of walkability—whether they feel safe, comfortable, and pleasurable for walking—and how streetscape design may be leveraged as a tool for improving walkability. Regulations and guidelines that govern urban development already mandate physical walking infrastructure. Cities are completing sidewalk networks, installing curb ramps and upgrading signals, and reforming zoning to encourage mixed uses that put commercial destinations within walking distance of residential neighborhoods. Now it is time to attend to psychological infrastructure for walking: streetscape designs that make walking not just possible, but desirable. As these examples demonstrate, improving this infrastructure will be contingent on the architecture, landscaping, and site layouts within individual lots, a more difficult proposition than modifying rights-of-way controlled by a single agency. Nonetheless, there is strong precedent for controlling basic factors related to streetscape psychology with zoning—setbacks, parking lot sizes and locations, ground floor uses—and great potential to encourage more subtle design factors, such as transparent street-facing windows and street trees, with form-based codes. Once psychological influences on walkability are recognized and taken seriously, there is great potential to address them in new construction and redevelopment.

2.5 Conclusions

Planners looking to improve walkability through the built environment have tended to focus on the physical needs of pedestrians, such as pathways, proximate destinations, and safety from traffic, which make cities *capable* of supporting walking. This is a necessary but low bar. Research on walkability and walking behavior points to additional factors related to psychological needs that help an environment feel *suitable* for walking based on perceived safety, sense of appropriateness, and pleasure. If an urban environment fails to address psychological needs, it may fail to encourage walking despite being highly walkable in physical terms. In a transportation landscape where walking competes with other modes that offer ample

psychological benefits—e.g., a cozy and stimulating automobile—walking will have difficulty gaining ground as a viable mode without consideration for psychological infrastructure.

Environmental psychology is strongly embedded into theoretical frameworks for walkability and the decision-making about walking. Psychological factors form the capstone of Alfonzo's (2005) hierarchy of walking needs, indicating that there is substantial additional value—even pleasure—to be derived from walking if these factors can be addressed. This value is reflected by Lo's (2009) walking discourses, including sense of place, civic engagement, and active living, which highlight how much more may be gained from walking than arriving at a destination. If it is comfortable and pleasurable, walking may contribute to personal identity and socio-environmental awareness. Pikora et al. (2003) and Saelens et al.'s (2003) social-ecological models position psychology-related environmental factors comfortably alongside more physical ones, suggesting that psychological and physical factors have similar roles in influencing walking outcomes. Schneider's (2013) mode choice framework similarly integrates strongly psychological environmental factors alongside more physical ones at most stages of decision-making, indicating the difficulty of incentivizing decisions to walk if psychological factors are ignored.

Theoretical frameworks for the mechanisms by which environmental design influences walker psychology suggest the importance of balance between stimulation and protection. Streetscape qualities identified in urban design literature through a series of studies by Ewing and colleagues point to enclosure as an important protective quality, while imageability, complexity, transparency, and human scale promote walkers' sensory interactions with their immediate environments (Ewing et al., 2013; Ewing & Clemente, 2013; Ewing & Handy, 2009). Lynch's (1981) sense and fit performance dimensions similarly identify the importance of spaces that minimize stress and which users can identify, understand, and explore. Kaplan and Kaplan's (1989) information-processing theory digs deeper into users' desires to consume well-structured information about their environments and to seek places that may offer additional understanding. This reinforces how successful walking environments cannot simply be practical and sterile but must be sensorially engaging. Appleton's (1975) habitat theory likewise posits that favorable environments offer a balance of information-providing prospect and protective refuge. For ancient humans, this may have made forest edges, with prospect into open spaces and refuge from the forest, an ideal habitat. In today's urban context, this edge pattern is emulated in buildings and trees lining a street. Interestingly, Nasar's (1998) empirical studies point to favorability for open views rather than tightly-constricted spaces. This finding may not, however, be as contradictory as it immediately seems, since the other frameworks stress the importance of information gathering and balance between prospect and refuge. Imbalance in either direction may yield a less psychologically favorable environment for walking or other outdoor activities.

These frameworks for psychological aspects of walkability offer a toolkit for practitioners looking to analyze and improve walking environments, and a theoretical launching point for further research to test and measure the effects of specific design interventions on walking outcomes. The upcoming chapters explore how streetscape design and its effects on walker preferences and behaviors can be measured using a variety of methods to substantiate the role of environmental psychology as a lever for promoting urban walking.

Chapter 3 How Do Lay Walkers See Streetscapes?

3.1 Introduction

Walkable urban environments are comprised of an amalgam of factors for which planning and design experts have developed complex theoretical and measurement frameworks. These include factors traditionally evaluated by transportation planners, such as sidewalk infrastructure, destination accessibility, and traffic stress, alongside those more commonly addressed by urban designers, such as the enclosure, transparency, and imageability of urban streetscapes, the built environmental contexts of streets. Applying these frameworks to study and plan for walkable urban places depends on the non-expert public perceiving and responding to them in choices about where or whether to walk. Experts and non-experts may have incongruent interpretations of what constitutes walkable urbanism, especially to the extent that certain aspects are more well-understood or commonly discussed in the public eye (Bösehans & Walker, 2022). Factors traditionally associated with transportation, such as pedestrian infrastructures like sidewalks and crosswalks and destination accessibility, popularized by Walk Score (Hall & Ram, 2018; Walk Score, 2011) have fairly straightforward, physical influences on the ability to walk. Their connections with walking behavior are also strongly supported by empirical evidence (Ewing & Cervero, 2010, 2017; Kitamura et al., 1997; Rodríguez & Joo, 2004). Streetscape design, while acknowledged by experts as important for supporting walkability (Ewing & Handy, 2009), is more conceptually ambiguous and may be difficult for non-experts to interpret, even if they may react to it subconsciously. While there is growing research examining relationships between streetscapes and pedestrian behavior (Ewing et al., 2016; Park et al., 2019; Purciel et al., 2009; Tian & Ewing, 2017), there remains a dearth of understanding about how non-expert walkers interpret streetscapes and what aspects of them are perceived as favorable or unfavorable. Knowing how, or even whether, non-experts see and appraise streetscapes is crucial for understanding how they can be used to advance walkability.

This study probes the role of streetscapes in how walkers without expertise in planning and design, whom I call *lay walkers*, perceive and form preferences about streetscapes.¹ It uses an unconventional methodological approach: a mixed-methods field experiment in which subjects who self-identified as non-experts in planning or design but were otherwise demographically and experientially diverse, walked individually along a defined route while I collected both quantitative and qualitative data about their preferences and perceptions. The method was designed to yield diverse data about subjects' preferences and the factors affecting them, offering control against confounding influences on walkability, such as proximity of destinations, while also acknowledging the importance of real-world context and leaving room to collect subjects' nuanced impressions of the study site. It bridged the methodological traditions of transportation scholars, who have tended to focus on quantitative evidence and internal validity, and urban design scholars, who have conversely focused on qualitative evidence and ecological validity, to offer a platform for more integrated understanding of the role of streetscapes between these two highly related but often divergent fields.

¹ While all chapters in this dissertation examine non-expert walkers, this chapter places a particular importance on the distinction between expert and lay voices. The term *lay walker*, used in this chapter but not others, is intended to reinforce how subjects represented lay perspectives while discussing differences between expert and lay interpretations of streetscapes.

Using this method, I investigate the role of streetscapes in lay walkers' perceptions and preferences for different walking environments, and the consistency of their preferences with theory espousing the benefits for walkability of streetscape enclosure, engaging frontages, and street trees. Results show that subjects were acutely aware of features contributing to streetscapes, including buildings and large trees, and heavily relied on their interpretations of streetscapes to form walking environment preferences. Trees and greenery were strongly preferred, serving as a primary driver of preference for many subjects. While subjects clearly favored engaging building frontages over those that were dull or non-transparent, they tended to be even more attracted to the visual complexity and imageability of more natural, treed areas, reinforcing how trees and greenery may be useful for activating otherwise bland built spaces. Building enclosure, meanwhile, was not strongly observed or favored. Indeed, many described favoring openness, a quality that overlapped heavily with treed and natural areas. It is possible that the benefits of enclosure, a quality that is challenging to conceptualize, went unnoticed alongside concurrent factors that were more recognizable, such as storefront windows. However, many subjects described broad favor for more spacious environments, including wider streets, sidewalks, and building setbacks. Many also favored spaces with fewer other people. These findings challenge expert understandings of walkable streetscapes as dense spaces with high levels of activity. While subjects clearly favored having interesting things to look at, they tended to prefer spacious calm more than dense vibrancy. These results do not suggest that lay walkers homogenously share such preferences—indeed, subjects exhibited substantial preferential variability—but it does indicate that some lay walkers, perhaps even a large proportion, may prefer streetscapes that fall outside the normative mold of walkable design.

3.2 Background

3.2.1 Importance of Examining Lay Perspectives

A primary goal of urban planning is to serve the needs of the lay public, and there is substantial attention in both research and practice toward public participation in planning processes (Arnstein, 2019; Innes & Booher, 2004). Substantially less attention, however, has been paid to differences in how the lay public and planning experts understand what contributes to well-planned built environments (Bösehans & Walker, 2022; Xenias & Whitmarsh, 2013). Studies on architectural design indicate that lay audiences tend to prefer more aesthetically conservative styles than do experts, suggesting normative differences due to experience with unconventional forms or conceptually sophisticated concepts (Groat, 1994; Stamps & Nasar, 1997). These results indicate that experts and lay audiences may not consider the same design characteristics as preferable, or they may perceive complex concepts differently. Ewing and Handy (2009), found that whether an auditor of streetscape features was an urban designer was a significant indicator of expert ratings of human scale. This indicated that expert interpretations, even of ostensibly objective features associated with this quality, were significantly different than those of non-experts. A recent study by Bösehans and Walker (2022) similarly found that lay understandings of sustainable urbanism only partially overlapped with expert frameworks, showing how a nebulous concept such as sustainability may take on meanings for lay audiences that experts do not expect. This is important because lack of understanding among experts about what the lay public values may diminish public commitment to planning projects or their perceived benefits once built. Differences between lay and expert understandings of sustainability provide an apt precedent for the similarly complex concept of walkability.

Investigating how lay walkers conceptualize walkability, especially to the extent that they are influenced by streetscapes, will help planners and designers understand the validity of their expert understandings and support walkability in ways that will be most valuable for the walking public.

3.2.2 Approaches to Studying Walkability in Transportation and Urban Design

Both urban design and transportation scholars have dedicated substantial attention to investigating how built environments affect walkability. Nonetheless, these fields tend to evaluate walkability in notably different ways, posing challenges for understanding how transportation systems and their contextual built environments work together to form walkable places. Urban design, born out of architecture, has tended to use qualitative analyses to examine how diverse aspects of urban environments meet the needs and desires of their inhabitants across a broad spectrum of dimensions, often with strong attention to how users perceive and understand urban spaces (Lynch, 1960, 1981; Moudon, 1992). Transportation research, born out of engineering, tends to use quantitative methods to evaluate discrete measures of system performance, such as mode share or destination accessibility. While urban designers often evaluate the city as a whole, including both streets and their streetscape contexts, transportation planners tend to focus on infrastructure and operations within their direct scope of influence, namely rights-of-way and roadways within them. Walkability planning understandably requires the involvement of both these fields, harnessing understanding of both streets and streetscapes to promote walking as a transportation behavior. Nonetheless, their substantial methodological differences have posed challenges for conducting research in ways that are interpreted as meaningful and robust by urban designers and transportation planners alike, convening these fields around shared interests rather than dividing them methodologically.

A major impetus for the emergence of the urban design field in the mid 20th century was critique of automobile-oriented urban modernism (e.g., Jacobs, 1961) and interest in improving human experiences, largely for pedestrians, in the urban “public realm.” Urban design scholarship often examines how users understand, relate to, and are affected by their built environments in emotive ways (Moudon, 1992). Cullen, for example, describes how “traffic routes sweep along impersonally but the tenacious and light-hearted pedestrian network creates the human town” (1961, p. 54). Efforts to operationalize such descriptions have identified interwoven and loosely defined perceptual qualities (Ewing & Handy, 2009). Each of these may be related to how travelers are affected emotionally by their surroundings but are difficult to define and measure. Determining which yardstick is appropriate for evaluating urban design poses similar challenges. Do such places facilitate more walking, or simply more enjoyment among those who already walk? To what extent do non-travel activities, such as social interaction, sitting, or street dining, influence walking behavior? Many urban designers argue that the performance of street environments must be judged holistically, based on diverse and interactive parameters and a variety of behavioral and perceptual outcomes (Forsyth, 2015).

Environment-behavior research in urban design has tended to prioritize ecological validity—applicability to real-world circumstances—and, therefore, emphasizes fieldwork to observe how people interact with their environments in naturalistic ways, often embracing the complexity of these relationships rather than attempting to control for them. Observation of naturalistic behavior in public spaces has been seminal in environment-behavior studies, with research designs ranging from systematic (Gehl, 2011; Lynch, 1960; Whyte, 2001) and quasi-

experimental (Appleyard et al., 1981) to phenomenological (Jacobs, 1961). More recently, walking interviews (Battista & Manaugh, 2017; Dean et al., 2020; Evans & Jones, 2011) and participant photography with methods such as photovoice (Hergenrather et al., 2009; Meenar & Mandarano, 2021) have emerged as approaches for gathering first-hand accounts of environmental perceptions from on-the-ground perspectives. Some urban design researchers have adopted more closely controlled, quantitative research designs to investigate user perceptions of walking environments (Johansson et al., 2016; Stamps, 2009), and urban designers have a strong tradition of examining proximity of everyday destinations, what transportation scholars would call accessibility (Alexander et al., 1977; Lynch, 1981; Moreno et al., 2021). Nonetheless, there remains a tension between accounting for general responses to features or qualities that may be found in many environments versus individual and contextualized responses to specific and wholistic places.

Transportation research, by contrast, has tended to focus on internal validity to isolate specific influences on behavioral outcomes. Relationships between travel and the built environment have traditionally been evaluated with cross-sectional research designs that rely on large samples of environmental and behavioral data that allow confounding factors to be controlled statistically (Broach, 2016; Broach & Dill, 2015; Ewing & Cervero, 2010; S. Handy, 1996a). This approach works well for evaluating variables such as destination accessibility and street network design, which can be summarized meaningfully within neighborhood-scale spatial units and compared against large samples of surveyed travel data (e.g., Khattak & Rodriguez, 2005). Streetscape design, however, can be highly variable from block to block, so neighborhood-scale aggregations of built environment and behavior measures are insufficiently precise for detecting their effects. Some researchers have used experimental approaches with photographic or virtual stimuli to examine stated preferences to specific infrastructural or environmental interventions (Nakamura, 2021; Sanders, 2014). Nonetheless, preferences alone, whether real or stated, provide little evidence about which features walkers find salient, and how their perceptions contribute to preferences and behaviors. Qualitative approaches that ask subjects to explain their observations and preferences are better suited for examining not just whether they are influenced by streetscapes, but how.

Mixed methods research offers opportunities for convergence and complementarities between the methodological strengths and priorities of the urban design and transportation fields. By triangulating between context-rich narratives and stated preferences in response to naturalistic but semi-controlled stimuli, researchers have simultaneously probed the breadth of environmental influences on walking and how these factors relate to specific perceptual and preferential outcomes (Isaacs, 2000; Leslie et al., 2005). Experimental controls, such as having all subjects respond to the same walking route, can be used to examine particular aspects of walkability, such as streetscape design, while avoiding confounding influences such as destination accessibility. Such a mixed methods approach can examine which aspects of streetscapes have meaningful influences on walkers' preferences while also revealing variability and contextual nuance in how factors are interpreted. These methods may also identify factors that are overlooked by prevailing theory.

3.2.3 Theory on Streetscape Preferences

Urban design research describes numerous streetscape characteristics that may contribute to the experiences of walkers. In their review of this literature, Ewing and Handy (2009) identify 51

perceptual qualities, such as *ambiguity*, *meaning*, *regularity*, and *vividness*. It is understandable how walkers might like or dislike these qualities in the abstract, but less clear if they would interpret them similarly to experts, or even recognize them at all, in real-world circumstances. Even designers asked to develop more formal definitions for these qualities could not agree on how to operationalize many of them (Ewing & Clemente, 2013). Ewing and colleagues ultimately identify five key qualities that were similarly identifiable among experts: *enclosure*, *human scale*, *transparency*, *complexity*, and *imageability* (Ewing & Clemente, 2013; Ewing & Handy, 2009). Design theory largely suggests that these qualities have positive implications for walking. Whether and how non-expert walkers react to them, however, has not been thoroughly evaluated. Given the difficulty of developing consensus on definitions and meanings among experts, it would be unsurprising if non-experts had even more varied responses.

3.2.3.1 Enclosure

Enclosure describes the extent to which the physical boundaries of a streetscape are contained and defined by vertical objects to give the impression of an outdoor room (Cullen, 1961). Buildings and trees are substantial drivers of enclosure due to their prevalence and large size, but free-standing walls, fences, hedges, and other features that form visual boundaries can also contribute. In the most abstract sense, enclosure can be conceptualized as restriction of sight lines, or the degree to which sky is visible above and around a space. Thus, it depends both on the sizes of objects and their arrangement. A taller building will create more enclosure than a shorter one in the same place but bringing the shorter building and the observer closer together might have the same enclosing effect. Thus, factors such as building heights and setbacks have concurrent influences. Likewise, gaps between buildings can erode enclosure, expanding sight lines to the horizon and sky. The quintessentially enclosed streetscape is lined by buildings that are taller than the width between them across the street and closely spaced along both sides, forming a well-delineated corridor (Jacobs, 1993). Trees, by and large, accentuate enclosure, sometimes bounding a streetscape in lieu of buildings, or further subdividing a streetscape that is lined by buildings (Arnold, 1993). Overhanging limbs add the feeling of a ceiling, further restricting sight lines and increasing enclosure. Awnings or other overhanging structures have a similar effect (Jacobs, 1993).

Designers suggest that enclosure is beneficial to walkers because it helps make streetscapes more intelligible and recognizable as discrete spaces. Cullen (1961) notes that enclosure provides a sense of “hereness” that reifies the city, distinguishing it morphologically from open countryside and providing a sense of shelter and security. “I am enclosed or I am exposed,” he observes (1961, p. 29). This protective aspect of enclosure is reinforced by Appleton’s (1975) prospect-refuge theory, which postulates that humans are instinctively drawn to liminal spaces—edges—from which we can observe potential threats and opportunities while simultaneously feeling sheltered. Continuous buildings or trees along the edges of streetscapes may provide just such an advantageous position for viewing goings-on while simultaneously gleaning shelter. Consistent with this theory, seminal design literature tends to describe enclosure as a normative good, though with little empirical support. Alexander et al. (1977, p. 106) describe how an outdoor space is “positive ... when it has a distinct and definite shape ... [that] is as important as the shape of buildings around it.” Jacobs (1993) suggests that enclosed streets are safe-feeling. The underlying assumption is that users prefer spaces that are readily observable and unambiguous.

3.2.3.2 Engaging Frontages

The other key qualities identified by Ewing and Handy (2009)—human scale, transparency, and complexity, and imageability—converge around the importance of features that are sensorially stimulating, recognizable, and interesting. I use the term “engaging” as an umbrella for these qualities. Human scale describes features that are appropriately sized or otherwise designed to enable human interaction, such as distances that are small enough to recognize faces or design details, or presence of street-facing windows. Transparency similarly describes the ability for walkers to identify, interact with, and understand land uses, classically facilitated by doors and windows that permit them to enter adjacent spaces either physically or sensorially. Even a smell wafting from a restaurant, however, could enhance transparency by allowing passersby to connect with goings-on around them. Likewise, complexity describes the depth and interest of sensory experience. A space that lacks complexity might be considered bland or boring. Finally, imageability is the degree to which features are unique and recognizable, accentuating environmental understanding and emotional connection. These qualities are promoted by many of the same physical elements—windows, doors, architectural details, street furniture, art, plantings, and trees—and they all describe greater potential for visual or other sensory engagement.

More engaging streetscapes are theoretically desirable for walkers because they provide richer understanding of environmental surroundings and greater potential for human interaction. As Jacobs (1993) puts it, *great streets* have “qualities that engage the eyes” and keep them moving (p.281). Research in environmental psychology provides strong evidence of preferences for environments that are rich in information, especially when it is well-organized, reinforcing the importance of design qualities such as coherence and legibility (Kaplan & Kaplan, 1989; Nasar, 1998). This research also demonstrates the favorability of seeking of information, what Kaplan & Kaplan (1989) call *unfoldingness*. Appleyard (2010) finds that access corridors that are “visually rich” and close enough to the street to be perceivable by passing pedestrians encourage walking to public transit. This reinforces how streetscapes that are transparent, providing literal or figurative windows into nearby goings-on, may be attractive for walkers.

Similarly, other people may be an important source of dynamic interest for walkers (Appleyard et al., 1981; Gehl, 2011; Whyte, 2001). Isaacs (2000) finds that walkers tend to prefer streets where other people are more present and active. Agrawal et al. (2008) similarly find that other people are a substantial driver of preference for walking routes. While using density of human activity as an indicator of walkability runs the risk of circular logic—a place where people walk is walkable—it is important to recognize the potential for a positive feedback cycle whereby pedestrians attract additional pedestrians.

Engaging frontages are not limited to particular land uses—even the most boring use might conceivably be engaging with the right design—but land uses that tend to be intentionally designed in ways that are sensorially engaging and facilitate coming and going of human users may be valuable proxies. Storefronts and restaurants, for example, tend to have highly transparent façades to display products and project a sense of welcome. They also tend to have substantial foot traffic, as might civic buildings such as libraries and arenas. While there may be exceptions—storefronts that are bland and opaque, for example—such land uses may serve as a useful indicator of engagement in lieu of more direct physical environment measures.

3.2.3.3 Trees & Greenery

Trees and vegetation are theoretically important for senses of enclosure, complexity, and other qualities associated with engaging streetscapes. They provide shelter and spatial definition, the more general basis for enclosure, and their structure and movement provide interesting visual complexity. Particularly recognizable trees may add imageability, and well-tended trees and greenery may be a welcoming signal of human activity and intension: a place that is natural, but cared for (Arnold, 1993). Trees add visually engaging complexity through their branch structure, bark, and leaves, which are additionally complex in their constant movement and seasonal change (Jacobs, 1993). Moreover, urban trees and greenery can be psychologically restorative, reducing stress improving mental health (Wolf et al., 2020). Shade from trees, or lack thereof, may also regulate the light and temperature of streetscapes, affecting both their psychological and physical comfort, though which of these conditions is favorable may differ between walkers and depending on the contextual climate and weather (Jacobs, 1993; Arnold, 1993).

There is strong theoretical consensus around the preferability of trees for walkers. Arnold (1993) describes how the organic forms of trees add favorable life and dimensionality to otherwise hard and rectilinear street environments. Kaplan and Kaplan (1989) identify how trees are powerful sources of preferred environmental qualities such as complexity and mystery. Harvey et al. (2015) finds that street trees have a strong positive correlation with visual assessments of safety. While trees may pose challenges for streetscape maintenance and have been critiqued in auto-oriented transportation planning as obstacles to visibility and crash hazards (Dumbaugh, 2006), they are by-and-large considered an asset to pedestrian spaces.

Because trees and greenery are such a dominant category of streetscape features and appear to be ontologically distinct from hardscapes, even if they may provide some of the same abstract qualities, I situate trees and greenery as a distinct dimension along which to evaluate streetscapes.

3.3 Methods

This study used a mixed-methods, quasi-experimental field protocol to examine how non-expert subjects identified and interpreted environmental factors related to streetscapes, with a particular emphasis on probing the favorability of enclosure, engaging frontages, and greenery, including trees, plantings, and park-like spaces. In individually scheduled sessions, subjects walked with me along the same six-block urban street corridor while comparing and rating block faces: the opposing sides of each block between intersections. The experimental treatments were streetscapes that varied between block faces, allowing subjects to experience and compare diverse streetscape conditions as they traversed the walking route, herein called the *study corridor*. As such, the study resembled a common format for laboratory experiments in which subjects respond to a series of photographs (Stamps, 2009). In this study, however, real places were substituted for photographs to bolster ecological validity.

This study was approved by the University of California, Berkeley's Committee for the Protection of Human Subjects (Protocol ID 2019-08-12447).

3.3.1 Study Corridor

3.3.1.1 Selection Process

The study relied on a corridor along which streetscapes conditions varied substantially between nearby block faces. Likewise, it was important for other conditions that might confound preferences for walking environments, such as sidewalk quality, traffic volume, and slope, to be fairly constant along the corridor. Finally, the site needed to be accessible for both subjects and researchers and be reasonably safe from traffic and crime to ensure the wellbeing of participants.

To identify such a corridor, I surveyed streets within a quarter mile of rapid transit stations in the downtowns of Berkeley and Oakland, California using a combination of aerial photographs, street-level photography, and site visits. Along each block-face, I qualitatively classified three streetscape dimensions—building enclosure, tree canopy, and engagement—into high, medium, and low levels. These dimensions were used to identify a corridor with a reasonable degree of streetscape heterogeneity across block faces.

Enclosure was operationalized based on a combination of setback, building height, and spacing. Block faces with continuous buildings immediately along the sidewalk, prototypical of densely developed urban settings, were classified as high enclosure. Those with a mixture of sidewalk-adjacent buildings and larger setbacks or gaps were considered to have medium enclosure. Those with consistently large setbacks or expansive gaps between buildings were considered low enclosure.

Tree canopy was evaluated based on the size and number of trees both within the right-of-way (i.e., “street trees”) and to the side of the street. Block faces with large trees that were highly enclosing and visually dominant were considered to have high tree canopy. Those with moderately sized trees that were less visually dominant were classified as medium tree canopy. Those with small, few, or no trees were considered to have low tree canopy.

Finally, engaging frontages were operationalized based on façade elements that promoted visual transparency or physical permeability, such as windows and doors, along with other elements that promoted visual complexity and engagement, such as signs, plantings, sidewalk seating, and landscaping. Block faces with many windows, doors, design details, or in lieu of buildings, well-maintained and intentional landscaping, were considered highly engaging. Those with more moderate or inconsistently interactive features were considered moderately engaging. Those with little opportunity for transparency or engagement, epitomized by blank walls or poorly maintained landscaping, were considered low engagement. Human activity was not used as an indicator because the study was primarily focused on how walkers interpreted physical streetscapes and because sites were not always evaluated at times of peak activity. Nonetheless, highly engaging frontages were often associated with more human activity.

An ideal corridor would have consisted of 27 block faces (3^3) representing each combination of high, moderate, and low classes across the three dimensions: enclosure, tree canopy, and engagement. It would also have offered substantial contrast between opposing block faces—opposite sides of the street along the same block—to enable comparisons between contrasting conditions from a single vantage point, reducing reliance on memory between blocks.

Unsurprisingly, no readily accessible corridor offered these ideal conditions. Moreover, a 14-block corridor, the minimum length to include 27 block faces, would have been too long to feasibly conduct one-on-one walking interviews and may have posed an unreasonable challenge

for subjects with mobility limitations. Through trial sessions, I determined that six blocks, with 12 block faces, offered an appropriate compromise between streetscape heterogeneity and viability of conducting field sessions within a 90-minute timeframe, which accommodated diverse subjects' schedules and physical capabilities.

3.3.1.2 Selected Corridor

Among several candidate sites, a section of Fulton and Oxford Streets, directly adjacent to the UC Berkeley campus and one block from the Downtown Berkeley BART station, was deemed most advantageous (Figure 3.1). Sites that were less accessible did not offer sufficient additional streetscape variability to justify the logistical and subject recruitment obstacles they posed.

The selected corridor was organized along six contiguous blocks running approximately south to north from a predominantly residential neighborhood toward the western entrance of the UC Berkeley main campus at the Crescent Lawn. The west side of the route, closer to downtown Berkeley, had predominantly retail and restaurant ground-floor frontages with small setbacks that yielded high enclosure and relatively more engaging frontages due to storefront windows, sidewalk seating for cafés, and relatively high pedestrian traffic (Figure 3.2). Tree canopy on the western block faces was comparatively low. The eastern side, by contrast, had predominantly institutional uses with lower enclosure from buildings due to larger setbacks, less engaging frontages due to poorly maintained open spaces and a prominently blank wall, and substantial tree canopy along the edge of campus.

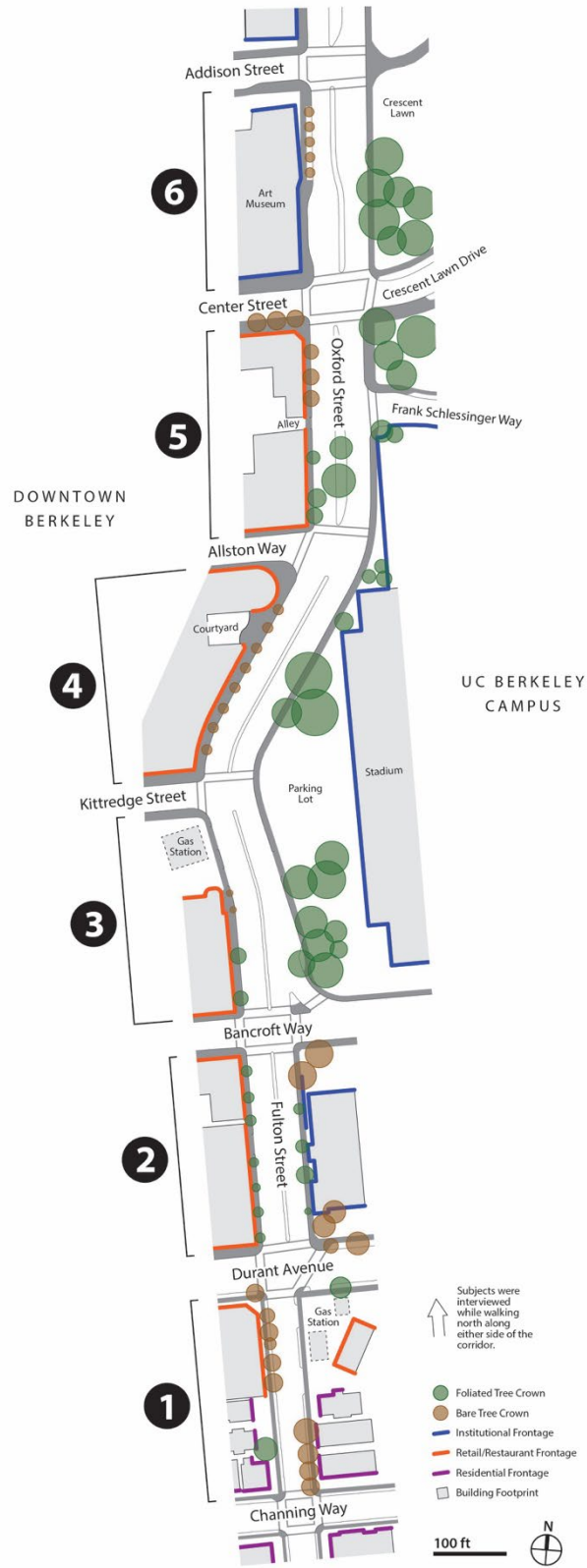


Figure 3.1. Six-block study corridor between downtown Berkeley and the UC Berkeley campus

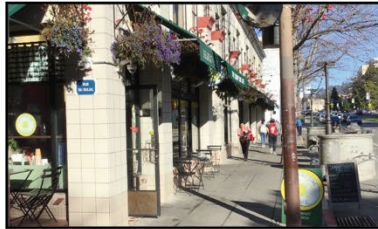
- 6W** (Looking North)
 • Art Museum



- 6E** (Looking North)
 • Lawn
 • Trees
 • Bus stop



- 5W** (Looking North)
 • Storefronts



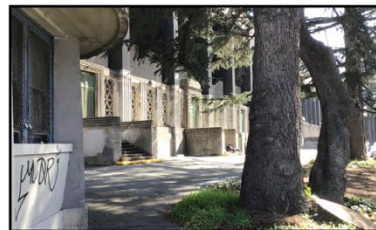
- 5E** (Looking North)
 • Trees
 • Intersection



- 4W** (Looking South)
 • Storefronts



- 4E** (Looking South)
 • Stadium
 • Trees
 • Ticket Booth



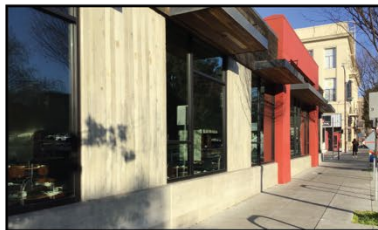
- 3W** (Looking North)
 • Gas Station



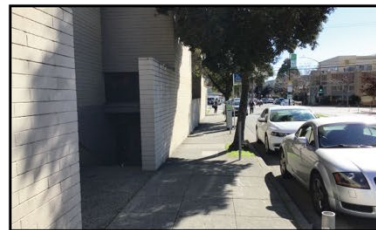
- 3E** (Looking North)
 • Parking Lot



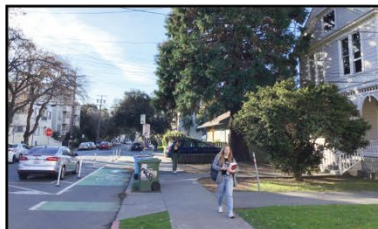
- 2W** (Looking North)
 • Restaurant
 Windows



- 2E** (Looking South)
 • Blank Wall



- 1W** (Looking South)
 • Houses
 • Bike Lane



- 1E** (Looking North)
 • Gas Station



Figure 3.2. Photographs looking along each block face from central positions. Major features are noted. The photographs were taken by various subjects while they participated in the study.

While the corridor provided a valuable degree of streetscape variability, it was limited along certain dimensions, particularly tree canopy. All block faces had trees, either in curbside tree

wells or in park-like spaces outside the right-of-way. Block faces classified as having low tree canopy had fewer, smaller trees (approximately 3- to 6-inch trunk diameter and 5- to 15-foot crown diameter), while those with high tree canopy had mature conifers, including redwoods, some of which were more than 100 feet tall. Having some block-faces with no trees at all may have been useful for eliciting more robust observations about the role that trees played in preferences. Moreover, there were no block faces with low tree canopy and large setbacks, a common condition around strip mall-style retail with street-facing parking lots, so subjects did not have a robust opportunity to differentiate between preferences about tree canopy and enclosure from buildings. These limitations demonstrate the difficulty of identifying real-world sites that offer variability across multiple dimensions.

Another limitation of the selected corridor was that it provided a fairly narrow, middle-ground example of walking environment quality along dimensions other than the main streetscape treatments. This was advantageous for isolating the effects of streetscapes but limited ecological validity. The corridor presented little danger in terms of either crime or traffic safety, tended to be well-maintained, and had reasonably high-quality sidewalks and crosswalks along its length. Given the well-documented importance of factors such as crime, homelessness, and environmental cleanliness on perceptions of walkability, and the gendered nature of these concerns (Golan et al., 2019), this was important for ensuring that a broad variety of subjects felt comfortable participating and that preferences would not be overwhelmingly steered by these factors. Nonetheless, the corridor was unlikely to be considered a walking utopia. Some sidewalks, buildings, and open spaces were in clear need of maintenance, there was moderately-heavy vehicle traffic along the corridor and at many cross-streets, and it tended to be occupied by a diverse social milieu ranging from well-resourced students to people experiencing homelessness. Nearly any subject was likely to find something they could critique along all block faces, no matter their underlying preferences. While this middle-ground quality—neither horrible nor excellent—limited the breadth of observations that subjects were likely to make, it was also useful as an approximate constant across all block faces and for ensuring that a wide variety of subjects felt comfortable traversing the entire corridor.

Even after careful consideration for how the corridor provided variability or constancy across a wide range of factors, it was unusual or unideal in several regards. Foremost, a substantial portion of the east side of the corridor was fronted by the university. Because of this, comparisons between opposite sides of the street may have been informed by the university's cultural symbolism—potentially, favoritism or resentment toward the institution—rather than physical qualities of the streetscape. The university frontages also made the east side unusually green and park-like. While this provided an opportunity to examine preference for green features, it was atypical of urban streets, perhaps better representing a suburban setting. Roadway characteristics that were not consistent along the entire corridor were also unideal confounders of preference. While five of the six blocks had similar, two-way traffic patterns with between three and four lanes, the first block had only a single, one-way lane and considerably less traffic. Parking and bike lanes fluctuated along the corridor, resulting in a lack of control over separation between the sidewalk and traffic. Ultimately, the particularities of the selected corridor shaped subject responses in ways that were infeasible to entirely control.

3.3.2 Subject Recruitment

A two-stage process was used to recruit a diverse sample of subjects from the lay walker population (Figure 3.3). The final sample was not intended to be statistically representative of the general population, nor was it designed to enable strong statistical comparisons between groups. Rather, it was intended to reveal breadth in how walking environments were perceived by lay walkers with diverse positionalities. Undergraduates were not recruited in order to maximize representation across ages and life experiences.

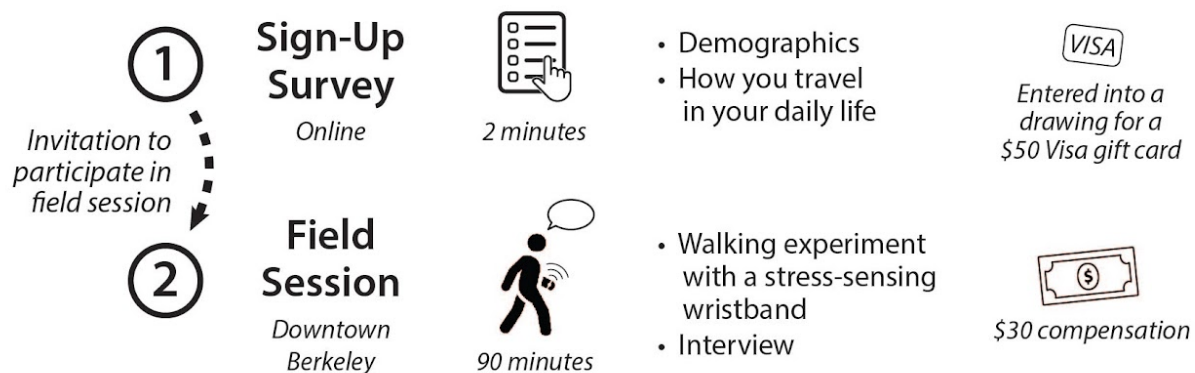


Figure 3.3. Summary of the Two-Stage Recruitment Process.

The first stage of recruitment used a web-based sign-up survey to identify interested subjects and collect demographic and life experience data that were used to determine who received an invitation for a field session. Links to the sign-up survey were broadcast by email through two networks: (1) a pool of graduate student, staff, and community-members who were interested in participating in research, maintained by the UC Berkeley Experimental Social Science Laboratory (XLab), and (2) members of the UC Berkeley Osher Lifelong Learning Institute (OLLI), which offers courses and lectures for people aged 50 and above. More than 10,000 people across these two networks received the signup survey email. Participation was incentivized by entering respondents into a drawing for a \$50 Visa gift card. The survey asked respondents to affirm that they were at least 18 years old, did not have professional or substantial personal experience with planning or design, and lived within the nine-county San Francisco Bay Area. One hundred seventy-three (173) eligible survey responses were received within three weeks of distribution, forming the pool for the second phase of recruitment.

Respondents were categorized by self-identified demographics and experiential factors related to walking and automobile use, collected by the sign-up survey (Table 3.1). Up to three respondents were randomly selected from each category, yielding 80 respondents who were invited to schedule a field session.

Table 3.1. Subject counts by demographic and experiential categories self-identified in the sign-up survey.

	Sign-Up Survey	Invited for Field Session	Completed Field Session
Gender			
Female	131	43	15
Male	38	33	13
Non-binary or other	1	1	1
Prefer not to self-identify	3	3	0
Age			
18-29	61	31	13
30-39	35	17	4
40-49	14	8	4
50-59	13	9	3
60-69	13	6	2
70-79	32	5	2
80-89	5	4	1
90+	0	0	0
Race/Ethnicity*			
American Indian or Alaska Native	1	1	0
Asian	43	21	6
Black or African American	13	11	2
Hispanic or Latino	19	17	9
Native Hawaiian or Pacific Islander	1	1	0
White	104	29	14
Other	5	3	1
Education			
No Schooling Completed	0	0	0
Nursery school to 8th grade	0	0	0
Some high school, no diploma	0	0	0
High school graduate, diploma or equivalent (GED)	1	1	1
Some college credit, no degree	15	7	3
Trade/technical/vocational training	2	2	0
Associate degree	3	3	0
Bachelor's degree	67	30	9
Master's degree	66	29	13
Doctorate degree	19	8	3
Do you typically use a private automobile to access daily activities such as work, school, or shopping?			
Yes (use an automobile daily)	103	38	20
No (don't use an automobile daily)	70	42	9
Where you live, is it possible for you to access daily activities such as work, school, or shopping without a private automobile?			
All daily activities accessible without an automobile	83	39	16
Some daily activities accessible without an automobile	82	36	11
No daily activities accessible without an automobile	8	5	2
How often do you walk either for transportation or recreation?			
Walk almost daily	128	53	24
Walk every few days	31	18	4
Walk about once a week	7	4	1
Walk less than once a week	2	2	0
Almost never walk	5	3	0

	Sign-Up Survey	Invited for Field Session	Completed Field Session
Which best describes your access to an automobile?			
I have my own automobile.	84	38	11
I share an automobile with other(s) in my household.	27	12	1
I do not have regular access to an automobile, but other(s) in my household do.	27	17	10
No one in my household has regular access to an automobile.	35	13	7
* Race/Ethnicity counts exceed totals because subjects could identify multiple races and ethnicities.			

Twenty-nine out of 40 scheduled subjects completed a field session prior to COVID-19 shelter in place orders in March 2020, which halted data collection. By July 2020, it was clear that research would not be able to continue in the foreseeable future, so I proceeded to analyze data from the 29 subjects who participated prior to the pandemic.

Among the 29 final subjects, just over half identified as female and one as nonbinary. Subjects skewed young; 13 were between 18 and 29 years old, though all decadal age brackets between 30 and 89 years old were represented. Nearly half of subjects (14) identified as white, including three who identified as both white and another race or ethnicity. Compared with the rates at which prospective subjects were invited based on stratification, Hispanic or Latino subjects were overrepresented in the final sample while Asian and Black or African American subjects were underrepresented. Subjects tended to be highly educated, which was unsurprising due to the University-based pools in which the study was advertised; 16 held a graduate degree and only four had no college degree. Most subjects had access to automobiles and used them regularly, but 24 reported walking almost daily and 16 reported living in a place where all daily activities could be achieved by walking. Eleven were UC Berkeley staff, nine were graduate students, five were recruited through the OLLI program, two were former students, and two were community members who had no relationship with the university. All subjects were at least minimally familiar with the study corridor, especially its northern end, which was near the western entrance to the UC Berkeley campus. Just over half of the subjects described having little to no familiarity with the southern end of the study corridor.

Data on physical ability were not collected nor used to stratify invitees. Recruitment materials welcomed and offered logistical support for prospective subjects with disabilities and those who used assistive devices. One prospective subject who used a wheelchair expressed interest in participating but was unable to do so due to COVID-19 shelter in place orders. All subjects in the final sample walked without visually identifiable assistive devices.

3.3.3 Field Protocol

Subjects participated a two-stage field protocol that involved a solo walk from north to south along the study corridor followed by a semi-structured walking interview back along the opposite side from south to north. The solo walk was designed to acquaint subjects with the entire corridor prior to the interview and give them first-hand experience with the side of the street opposite the one on which the interview was conducted. It also provided an opportunity to collect biosensory data for a second, related study (Chapter 4). The sides of the street used for the solo walk and interview were selected randomly for each subject. Sixteen were interviewed along the east side, while thirteen were interviewed along the west side.

I met subjects at individually scheduled times at the entrance to the Berkeley Art Museum and Pacific Film Archive (BAMFA) on Center Street, a convenient landmark alongside the corridor. At the beginning of the protocol, subjects were asked to review and sign a consent form and were oriented to the study's purpose, procedure, and the route along which they would be walking. Subjects fitted themselves with a lavalier microphone tethered to a small digital voice recorder that provided a record of their interview for transcription.

For the solo walk, subjects were instructed to walk straight along the study corridor until they reached Channing Street, imagining that they worked somewhere near the north end of the corridor, lived near the south end, and were commuting home. For safety, they were asked to stop and wait for walk signals at signalized intersections, even if they might typically jaywalk. I reconvened with subjects at the opposite end of the corridor, where we crossed the street and began the walking interview.

The interview consisted of three components designed to elicit a broad array of observations in response to both the study corridor and subjects' broader experiences and perspectives on walkability. Two of the components were repeated alternately along each block of the study corridor. The third consisted of follow-up questions at the end (Figure 3.4). For the first component, the subject and I stopped at observation sites near the center of each block where I asked which side of that particular block the subject would prefer to walk on, and what they found appealing or unappealing about each side. As we progressed along the corridor, the subject also compiled an ordered ranking of block faces, from 1, least preferable for walking, to 12, most preferable, using photographs of features they found distinguishing or memorable, captured on an iPad, to facilitate comparisons. Ranks were built by dragging and dropping the photographs in an ordered list using the Keynote slide presentation app—each photograph was a slide that could be rearranged within the presentation. Most subjects found this process very intuitive.

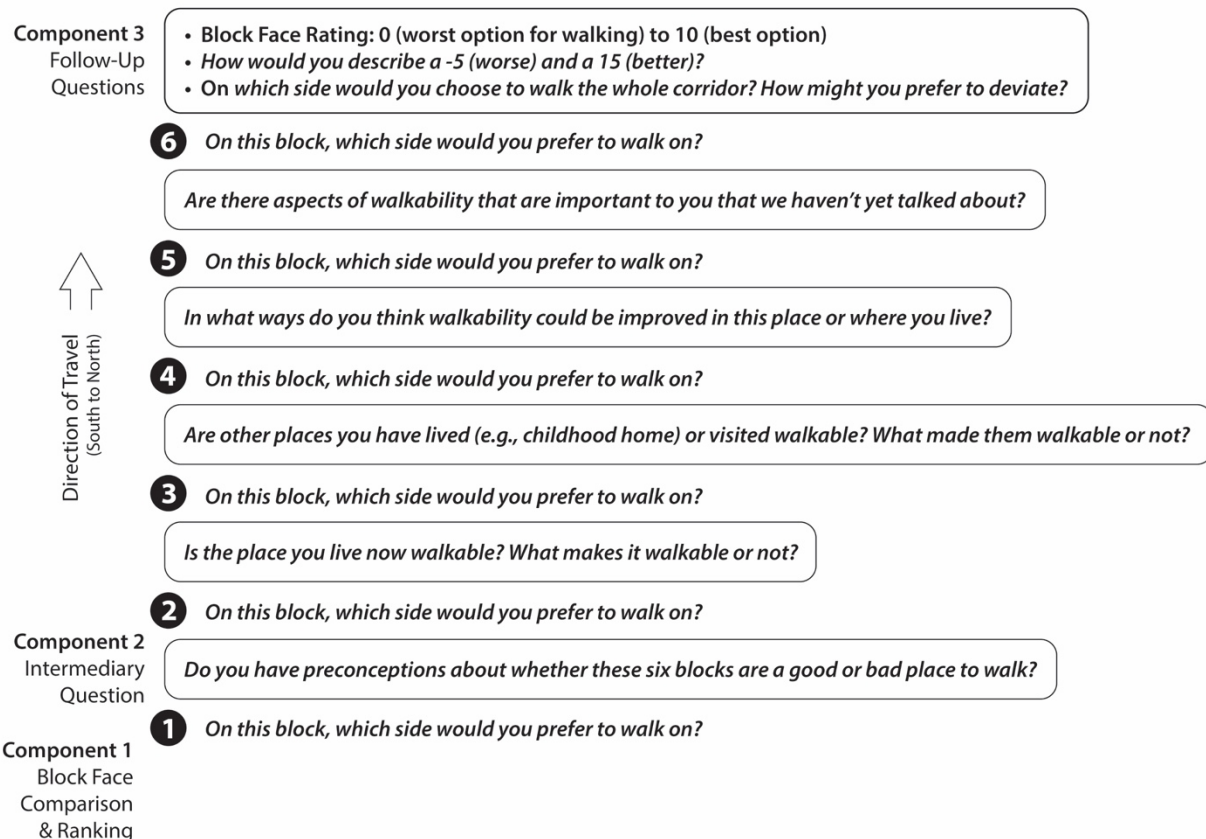


Figure 3.4. Organization of interview components along study corridor blocks ordered south to north.

The second component consisted of a series of questions, asked while walking between observation points, probing the broader experiential contexts of subject's preferences around walkability and considerations that might not be adequately prompted by the study corridor. Questions addressed subjects' preconceptions about the study corridor due to past experiences or understandings, how they interpreted walkability in places they currently and formerly lived, how they thought cities could improve walkability, and whether there were aspects of walkability that other parts of the study did not give them adequate opportunity to discuss.

The third component was a series of follow-up tasks and questions posed after reaching the end of the corridor. The primary task was to collect a second quantitative measure of subjects' preferences for each block face: ratings on a scale from 0 to 10. These ratings were designed as a cross-validation for the rankings—in theory, they would yield similar results—and as a way for subjects to express major differences in the magnitude of their preferences for different block faces. While ranking was insensitive to *how much* better one block face was than another, the rating provided an opportunity to, for example, note that one block face was much better than another, or that several block faces were about the same. While ratings had the potential to be more precise than rankings, subjects could only meaningfully rate block faces after they understood the extents of the scale. Therefore, it was necessary to collect rankings while subjects moved along the corridor and gathered initial impressions, then ratings once they could compare those impressions across the entire corridor at once.

To collect the ratings, I superimposed graphic scales over each photograph on the iPad. I then set their least favorite block face, at the bottom of their ranking, as “0” on the scale, and their most favorite, at the top of their ranking, as “10.” These examples defined the extent of the scale. The subject then rated the remaining photographs by dragging a slider between 0 and 10 (Figure 3.5).



Figure 3.5. Screenshot from the iPad that was used to record subjects’ rankings and ratings of each block face. The column of photographs on the left, which could be vertically scrolled to include all twelve block faces, was used to denote ranking. As subjects walked along the corridor, they took photographs of each block face and positioned them in the lefthand column in the appropriate order: more preferred block faces toward the top and less preferred ones toward the bottom. Following the walk, scales were superimposed over each photograph and subjects rated the block faces by dragging the red triangle along the scale.

Next, I probed the subject’s conceptions of extreme conditions for walking by asking them to imagine and describe places that were even better and worse than what they had experienced along the corridor. Referencing the 0 to 10 scale we had just defined, I asked them, “how would you describe a ‘15,’ a place that’s far better than anything you’ve seen here,” and “how would you describe a ‘-5,’ a place that’s much worse than you’ve see here.”

Finally, I asked several questions about the corridor as a whole, including which side the subject would choose if they were to walk the entire length on one side, whether they would walk to work if this was their actual commute route, and whether they might deviate from it for a better alternative.

Each field session was scheduled for 90 minutes. Many subjects completed the protocol within 60 minutes, while some volunteered to continue the interview past 90 minutes. All were compensated \$30 for their participation.

3.3.4 Analysis

The field protocol produced both quantitative data from rankings and ratings, along with a substantial volume of qualitative data on subject observations from the interviews. Descriptive statistics were used to compare subjects' likelihoods to prefer block faces over their opposites, as well as consistency of rankings and ratings between subjects.

Thematic content analysis was used to identify the breadth and similarity of factors that subjects discussed while evaluating block faces along the corridor and considering walkability in other aspects of their lives. Content analysis was facilitated by coding of both the topics of subjects' observations and the contexts in which they were discussed, such as locations along the study corridor. To facilitate coding, I manually transcribed audio recordings of the interviews. Thematic codes were then defined and refined ad-hoc while I assigned them to interview passages ranging in length from individual words to multiple lines. Codes were designed to represent unique concepts or contextual markers, so multiple overlapping codes were assigned to passages involving multiple concepts or contexts. Codes were maintained if they were conceptually distinct from other codes, even if they were only used once. Codes that were conceptually similar were grouped into more general codes through an iterative process. The final code structure consisted of nearly four dozen primary codes, some with secondary codes representing key subfactors.

Valences indicating like or dislike for observed factors were attached to codes when they were clearly articulated by subjects. If a subject observed a feature but did not specifically describe liking or disliking it, the factor was coded thematically but without a valence. To identify consistencies in preferences that were conceptually similar but expressed in inverse ways, such as disliking auto traffic or liking *lack of* auto traffic, I grouped codes that described a given factor with those that described lack of that factor, then flipped valences associated with the latter so they were consistent with the former. This transformation allowed conceptually similar codes to be counted together.

Codes were primarily used to examine the number of subjects who discussed different streetscape and other environmental factors, demonstrating the consistency with which factors were recognized. To ensure that more loquacious subjects were not overrepresented, I counted the number of subjects who discussed each code at any point in their interview rather than individual code instances; the maximum count was 29. Code counts were further broken down by valence to examine variability in preferences for different factors. Subjects could express both like and dislike for the same factors in different parts of their interviews, so the maximum counts for both positive and negative valences were also 29. Because subjects could also discuss factors without articulating a valence, factors could have fewer valenced counts than the total counts.

Interviews were transcribed and coded with MAXQDA software. Code data were then analyzed with custom Python scripts in Jupyter notebooks with the Pandas and Numpy analytics libraries.

I also used close reading of the interview transcripts to examine how subjects formed preferences and to recognize what factors contributed most strongly to them. Analyses of shared preferences

generated by close reading were ultimately used to identify groups of subjects with similar types of preferences and dominant observations.

3.4 Results & Discussion

Results from the field sessions suggested that lay walkers were, by and large, aware of streetscapes when forming preference about walking environments, but these preferences were not always consistent with theoretical expectations that more enclosed and sensorially engaging streetscapes would be preferred. Many subjects preferred block faces that were relatively less enclosed and that had less engaging frontages, suggesting that lay walkers may be drawn to such spaces even without being aware of what factors are driving their preferences. Several subjects also overtly described preferences for more or less enclosed or engaging streetscapes, demonstrating a degree of conscious awareness of these qualities. Nearly all discussed seeing and evaluating aspects of streetscapes—the spaces to either side of the roadway—even if they did not identify more conceptually complex qualities such as enclosure. These findings point to the importance of streetscapes for informing lay understandings of preferable walking environments, even if they are not always consistent with prevailing theory about what makes a walkable streetscape.

My analysis makes use of the diverse data from the field sessions by examining subjects' walking environment preferences through three lenses. The first investigates how favorability for different walking environments is revealed by preferences at the level of entire block faces, potentially without subjects being consciously aware of what motivated their preferences. The second examines conscious preference for specific factors that subjects discussed as either preferable or unpreferable. Finally, the third probes what factors influenced preferences most strongly. Together, these analyses triangulate around how lay walkers perceive and form preferences around streetscapes and other aspects of urban walking environments.

3.4.1 Which Block Faces Did Subjects Prefer?

Preferences for block faces were largely consistent with expectations that subjects would favor more engaging streetscapes but challenged expectations of favorability for enclosure from buildings. Subjects tended to prefer block faces with highly engaging building façades, such as the storefronts along the west side of block 5, over duller frontages, such the blank wall along the eastern side of block 3 (Figure 3.6). These findings were consistent with Jacobs' (1993) straightforward proposition that the most inviting streets give their users something to look at. Subjects did not, however, appear to be interested in looking only at buildings. Many considered block faces lined by large trees and park-like spaces, such as the east sides of blocks 3 through 6, more preferable than those with even the most engaging building frontages. This reinforces how the complexity, transparency, and dynamism of trees and green spaces may be just as sensorially engaging, if not more so, than building frontages (Arnold, 1993).

West Side

Block

East Side

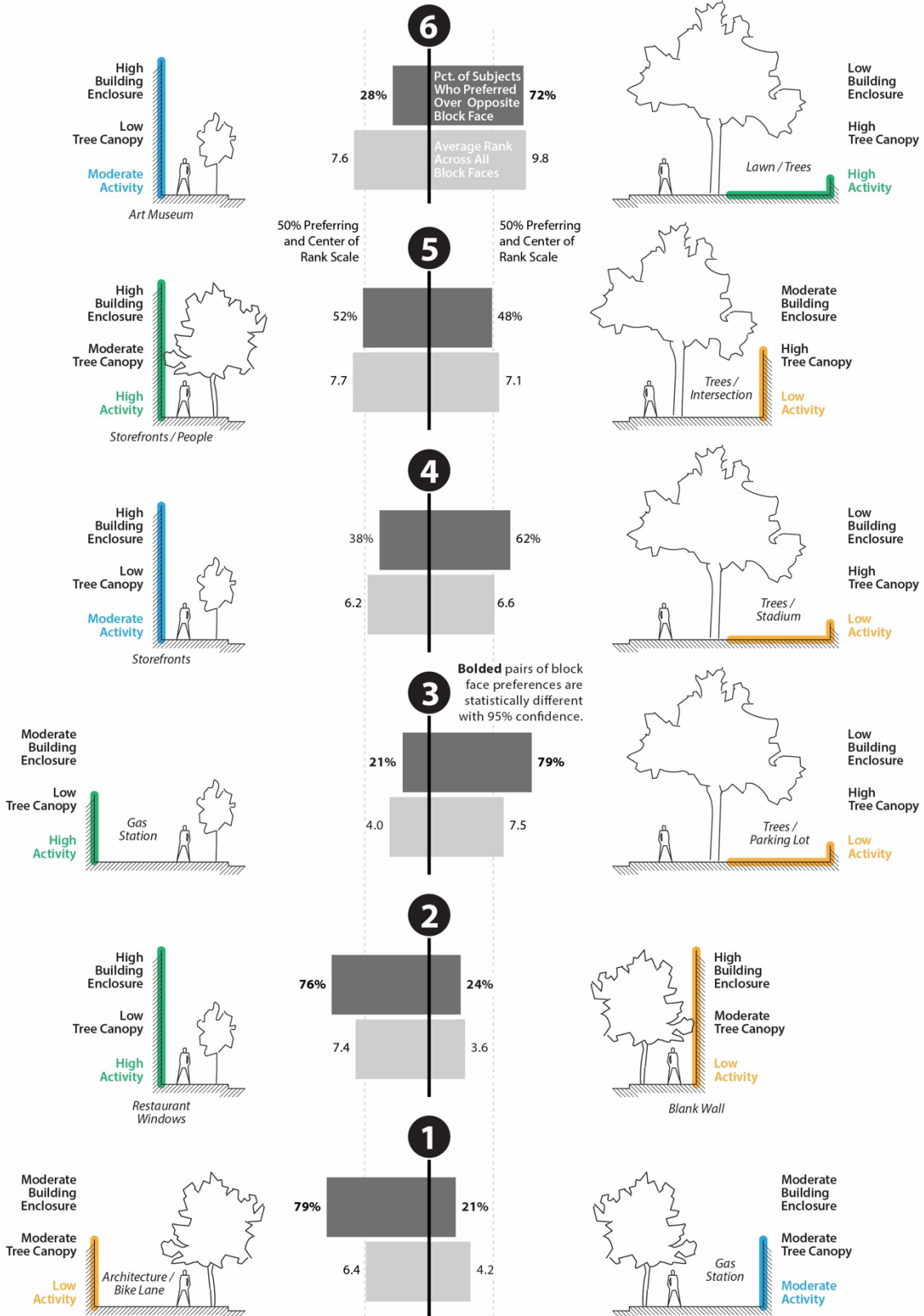


Figure 3.6. (Previous page) Preferences and streetscape characteristics along block faces.

Bars in the central column show two preference measures: (dark bars) the percent of subjects who preferred each block face compared with the opposing face of the same block ($n=29$ across the two sides of each block), and (light bars) the average rank on an ordinal scale from 1 (least preferred) to 12 (most preferred; $n=29$ for each block face).

Bars diverge from the central axis to show preferences for the west and east faces of each block. Cross-sections indicate low, moderate and high levels of building enclosure, tree canopy, and engagement as identified by the author. Dominant features identified by subjects are noted in italics. Cross-sections are iconographic. They do not represent specific conditions (e.g. building height or setback) along each block face and are not drawn to scale.

Figure 3.6 summarizes block faces rankings in two ways that demonstrate consistent trends. The darker bars show the percentage of subjects who ranked each block face higher than the opposite face on the same block ($n=29$ across the two sides of each block). Differences in these percentages were significant with 95% confidence for four of the blocks, indicated by bolded percentages. The lighter bars show a block-face's average rank across all subjects ($n=29$ for each block face) on a scale from 1, least preferred, to 12, most preferred. Bars representing either side of each block diverge from the central axis to juxtapose preferences for opposing sides. These two ways of summarizing block face rankings—percentage of subjects who preferred a block face over its opposite, and average rank—were moderately correlated ($r = 0.68$). To validate the block-face rankings ($n=348$; 12 block faces evaluated by 29 subjects), I examined their association with subjects' ratings for the same block faces; they were highly correlated ($r = 0.99$). Because rankings were gathered from a more in situ rather than retrospective perspective, I used rankings as the primary quantitative measure of preference throughout the remainder of my analysis.

While expectations that subjects would prefer more engaging block faces were upheld, similar expectations about building enclosure were not. Block faces along the eastern sides of blocks 3 through 6 were strongly preferred even though buildings tended to be substantially set back. This suggests either that subjects found building enclosure unimportant, or that engaging qualities of these green features did not require the framing of enclosing buildings to be highly enjoyable. On the other hand, these block faces *did* provide a degree of enclosure, albeit from large trees rather than buildings. Subjects' preferences for these block faces may still have been motivated, at least in part, by enclosure, even if buildings were the dominant sources of enclosure. This would be consistent with Arnold (1993) and Jacobs' (1993) observations that trees may partition and enclose streetscapes just as powerfully as buildings, if not more so because their overhanging branches may provide a sense of overhead enclosure: a roof on the outdoor room.

Two block faces with gas stations, which lacked enclosure from *both* buildings and trees, were largely unpreferred by subjects. This was consistent with theoretical expectations that these unenclosed spaces might be considered dull and impersonal because interesting features would be too far from the sidewalk to engage with easily. The gas station along the east side of block 1, for example, had a convenience store with many street-facing windows (Figure 3.2), but this was set back nearly 50 feet from the sidewalk, so the windows were too far for passersby to see into. This example highlights the close interrelationship between qualities such as enclosure, human scale, and transparency. Transparent building façades may be moot if setbacks, which influence both the scale and enclosure of streetscapes, are too large.

The gas stations also, however, highlight the difficulty of distinguishing the influence of physical environments from activities within those environments, such as vehicle traffic, that may strongly impact favorability for walking. As discussed in the next section, many subjects

identified safety hazards from turning vehicles as a reason they disfavored the block faces with gas stations, while very overtly recognized lack of enclosure in these spaces. It is possible that this simply reflected unawareness among lay subjects of the concept of enclosure, even as it subconsciously influenced their perceptions. It seems more likely, though, that traffic and other undesirable qualities of gas stations, such as odors and dirtiness, were dominant concerns, substantially confounding interpretation of causality between lack of enclosure and lower preference.

There were strong preferences for block faces with high levels of tree canopy, as demonstrated by eastern sides of blocks 3 through 6. While tree canopy and other green features likely contributed to senses of enclosure and engagement, consistently high preferences for these particularly green block faces suggests that naturalness may be an important way of understanding their favorability, above and beyond their other qualities. It was particularly notable that almost half of subjects preferred the eastern side of block 5 over its western counterpart. The eastern side was more heavily treed but required crossing a mid-block intersection and was fronted along a large portion by a concrete wall. The western side, by contrast, featured the largest concentration of pedestrian-oriented storefronts along the corridor and had planters, sitting areas, and regularly spaced street trees. It was, theoretically, the posterchild of walkable urbanism along the corridor. And yet many subjects were drawn instead to the heavily treed east side, similar to the popularity of treed block faces before and after it along the corridor. This result suggests that trees may be favorable for lay walkers to a degree that is comparable to even the most engaging buildings, reinforcing Arnold's (1993) premise that even urban settings can be strongly shaped by trees and other green features.

Subjects' preferences for block faces were strikingly consistent, suggesting that even among lay walkers from diverse backgrounds there are strong commonalities in what constitutes a favorable place to walk. On most blocks, about three quarters of subjects preferred one block face over the opposing face, and confidence intervals around average rankings were small enough to statistically distinguish the three least-preferred block faces from the six most-preferred ones (Figure 3.7). Clearly, subjects' preferences were not randomly distributed, but rather informed by some degree of shared values. These findings empirically justify design theories suggesting that streetscape preferences are, to some extent, generalizable rather than being wholly individual, a foundational assumption for development of walkable urbanism that addresses the needs of a broad population. However, there was also a high degree of overlap in ratings within the middle of the scale, suggesting that, while lay walkers may agree on what constitute exceptionally good and bad places to walk, there is considerably less agreement about more mediocre environments that may predominate along real-world pedestrian networks. Whether or not walkers find such mediocre environments acceptable may hinge on subtle or highly personalized factors that are harder to predict than the consistently favorable large trees and storefronts, or unfavorable blank walls.

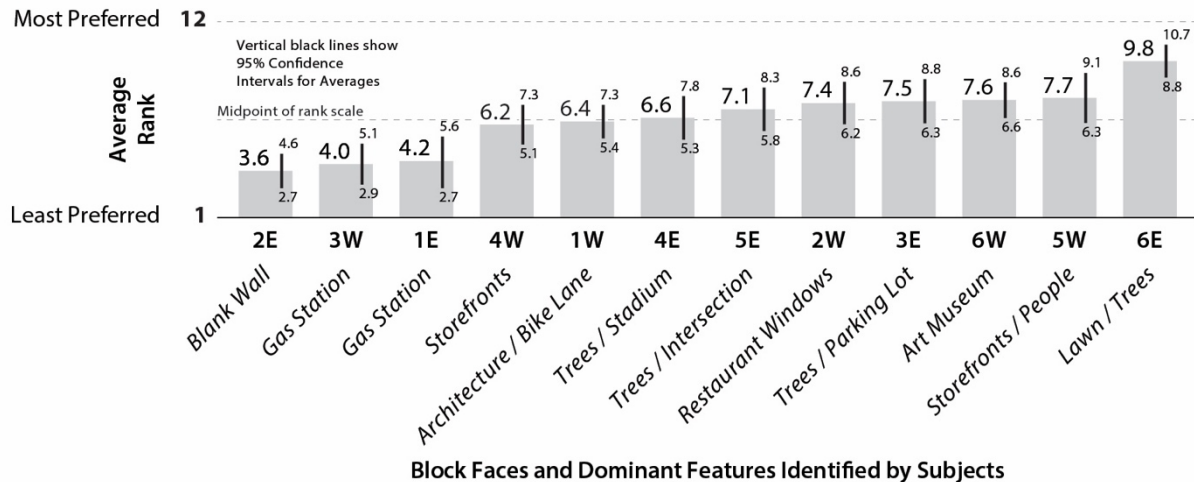


Figure 3.7. Average rank of block faces.

Blocks are sorted from lowest (least preferred) to highest (most preferred), with 95% confidence intervals for averages ($n = 29$). Italicized labels denote dominant features that were identified by subjects.

Nonetheless, nearly a quarter of subjects preferred the block face with the lowest average rank, the eastern side of block 2, which featured a blank wall, compared with the more quintessentially engaging western side of that block. No block face was preferred over its opposite by fewer than 21% of subjects. This reinforces how lay preferences are far from universal. Even environments considered off-putting by most walkers may be preferable for a minority. This underscores the importance of understanding not only dominant trends in preferences but, as Bourassa (1991) underscores, the structure of preferences within groups that have internal norms and among individuals who reflect their own experiences.

3.4.2 Which Factors Did Subjects Discuss and Prefer?

Individual factors that subjects discussed while evaluating each block face helped reveal what they were perceiving, how these things contributed positively or negatively to their impressions of walkability, and how streetscape design played a role in these impressions. Subjects universally identified factors related to streetscapes, such as buildings and trees, but also broadly discussed factors related to roadway and pathway design, traffic, and social milieu, consistent with social-ecological models of walkability that position streetscapes alongside other physical and psychosocial factors (Pikora et al., 2003; Saelens et al., 2003). Some subjects were heavily focused on traffic safety and roadway infrastructure, even expressing surprise that I was interested in observations about factors outside the roadway. One noted, “I have to say, when you said you were in transportation, I thought it'd be a lot of, just, all about traffic more than anything else. [laugh]” (Subject 19). This shows how even a lay audience may interpret walkability as having quite a narrow scope that is centered around traditional transportation infrastructure and activity. Others, by contrast, were keenly aware of streetscape aesthetics, expressing interest in minute details—“That brick work is just—it's fantastic” (Subject 17)—or thinking abstractly about how spaces affected them: “I guess it's maybe something about the feeling of walking in, like, a discrete space that you can kind of ... um ... I don't know, it feels comfortable. You can kind of monitor all of it” (Subject 2). Still others were plainly aware of their surroundings and able to judge what felt more or less comfortable in vague terms but were

minimally descriptive: “I’m just thinking about safety and whether an area is interesting to walk through” (Subject 14). These examples illustrate the difficulty of simply asking lay walkers about their interpretations of walkability because they may lack the conceptual frameworks of lexicon to describe their impressions, a limitation that has led researchers such as Ewing et al. (2006) to instead rely on expert judgements. Consistent with Nasar (1998), however, many lay subjects were clearly able identify and evaluate complex built environment qualities, even if they lacked technical vocabulary to express their perceptions. This reinforces the feasibility of studying walkability through lay perspectives rather than relying on expert evaluations.

As a basic indicator of similarity between subjects’ perceptions of the corridor, I counted the number of subjects who discussed similar factors within their interviews. The left-hand column of Figure 3.8 shows the counts of subjects who discussed listed factors and major sub-factors at any point along the corridor. The right-hand column shows counts of subjects who specifically disliked or liked each factor. Bars representing dislikes and likes face to the left and right, respectively.

All 29 subjects discussed buildings/architecture and other people, and all but one discussed five other top-level factors: auto traffic, gas stations, greenery, storefronts, and safety. Commonly discussed factors were not necessarily more important for shaping subjects’ preferences, but nonetheless indicate points of convergence in how subjects perceived the study corridor. It was unsurprising that most subjects identified large and attention-grabbing features such as buildings, trees, storefronts, and auto traffic. Both personal and traffic safety were also common concerns. Factors that were discussed by fewer subjects tended to be more technical or abstract (e.g., enclosure, authenticity), dependent on rare occurrences (e.g., wind, wildlife), or related to a subject’s particular needs (e.g., disability access, bathrooms). These less commonly discussed factors demonstrate the breadth of observations, but also reveal gaps in awareness. Artistic features such as murals, for example, were discussed by only five subjects, suggesting that more than 80% of subjects either did not notice them or considered them uninfluential for their experiences as walkers. The distribution of factor counts, with some identified by all subjects and others by only a few, indicates that there were sizable commonalities in what subjects perceived, though also substantial particularities.

	Discussed	Disliked	Liked
Buildings & Architecture	29		
Specific Building	26	14	23
General Building	23	11	20
Engaging Frontage	23	4	21
Architectural Design	17	6	16
Modern	8		7
Historic & Old	7	1	6
Human Scale	4		3
People	29		
General	29	22	24
Homelessness	17	17	
Students	2	1	2
Auto Traffic	28	27	3
Gas Station	28	25	3
Greenery	28		
General	28	2	26
Trees	27	1	26
Green Space	23		23
Retail	28		
General	28	10	27
Specific Establishment	17	4	11
Safety	28		
General	16		16
Personal	18		12
Traffic	17		16
Tidiness	25	1	24
Intersections	25	21	8
Bike Infrastructure	24	7	12
Engagement	23		21
University	23	2	15
Parking	22		
Lot	18	16	1
On-Street	11	3	7
General	1		1
Sun (vs. Shade)	22	19	6
Path Width	21	2	20
Access to Destinations	20		11
Enclosure	20	15	8
Setback	3		2
Residential	19	1	17
Directness & Efficiency	18	2	10
Stress	18	14	1
Beauty	17		16
Liveliness	17	9	8
Sidewalk Availability (Hypothetical)	16	1	13
Transit	16	5	1
Familiarity	15	1	12
Construction	14	11	1
Lighting (Hypothetical)	14	2	12
Sounds	14	11	11
Different Time of Day (Hypothetical)	14	9	5
Sidewalk Surface Quality	13	1	13
Smells	11	6	5
View of the Other Side	10		5
Usual Routes	10		
Hilliness (Hypothetical)	9	6	
Street Width	6	3	2
Art	5		3
Temperature	5	3	2
Police	4	1	2
Urbanity	4	1	2
Water Body (Hypothetical)	4		4
Disability Access	3		1
Dogs	3		2
Bathrooms	2		2
Wildlife	2		2
Wind	2	1	1
Sky	2		2
Wealth	1		

Figure 3.8. (Previous page) Counts of subjects who disliked (left-facing bars) or liked (right-facing) each factor. Secondary factors are indented below their primary factors. Factors marked “Hypothetical” were not directly observed along study corridor during a field session, but were discussed by subjects in reference to other places or times.

In addition to key streetscape-related factors such as buildings, trees, and major land uses, many subjects discussed more abstract aspects of streetscape design, such as enclosure and engagement—I used “engagement” as an umbrella code for discussion of attention-grabbing qualities such as transparency, complexity, interest, and explorability. Indeed, subjects discussed streetscape-related factors more consistently than several factors traditionally associated with pedestrian transportation, such as traffic safety and sidewalk quality and width. Streetscapes were not conclusively more important than traditional transportation factors, but they were substantially meaningful for how subjects viewed and assessed their walking environments. This reinforces perspectives from seminal urban design literature that streetscapes play a crucial role alongside more conventional transportation infrastructure in creating walkable urban environments (Appleyard et al., 1981; Cullen, 1961; Jacobs, 1993; Lynch, 1981).

3.4.2.1 Trees, Greenery, and Naturalness

Trees and other greenery were among the most consistently preferred features and the dominant factor driving many subjects’ preferences between block faces. All but one subject discussed greenery, and the vast majority described it favorably. The block face that subjects ranked highest on average, the east side of block 6, was especially green, featuring a redwood grove and a grassy lawn at the west entrance of the university. Subjects consistently remarked on its greenness, describing, for example, how “this side is nice because of all the greenery. The trees, again. The ivy, the lawn. That’s all really pleasant. So, I definitely prefer walking on this side” (Subject 18). The dominance of trees and other greenery in subjects’ discussions reinforced the outsized role they may play in shaping the spaces and textures of streetscapes (Arnold, 1993) and their potential to efficiently improve urban spaces in lieu of more resource-intensive architectural or hardscape alternatives (Dümpelmann, 2019).

While greenery was a dominant factor along eastern block faces fronted by large trees, it was also among the most-discussed factors on all but two western block faces, indicating its nearly universal appeal, even in places with relatively less of it. The single instance of a subject expressing disfavor for trees was due to their obstruction of the sidewalk. This same subject, however, later noted, “actually, I think I like the same thing that I find an impediment. [laugh] ... The trees. The hanging plants [on the west side of block 5]” (Subject 6). Two subjects described how they disliked messy or overgrown plantings. In the vast majority of cases, however, trees and other greenery were viewed favorably, a more consistent trend than for any other widely-discussed factor.

Even small amounts of greenery seemed to be meaningful, and it in some cases it seemed to overshadow detractive factors. One subject who favored the trees along the east sides of blocks 3 and 4 described how “I don’t like the parking lot that much. But ... it doesn’t bother me hugely” (Subject 2). She was comparatively more attuned to the trees. Another noted about an otherwise unfavorable frontage, “I think it’s a little bit more appealing because of ... the flowers” (Subject 23). Others described the value of flowers on a different block face: “I really like all these plants here ... that, sort of, like, float over you as you walk” (Subject 18), “the flowers on top. You know, like, it kind of makes it a cool place to be” (Subject 3), and “the building is nice to begin

with, and then the, um, flowerpots are great” (Subject 16). Plantings stood out as attractive details in streetscapes, either making up for deficiencies or accentuating already-appealing spaces.

No block face lacked trees entirely, though some had recently planted deciduous trees with no leaves in February and March, when the study was conducted. Subjects noticed the relative lack of foliage along the west side of block 6. One straightforwardly noted, “I dislike the lack of trees on that side” (Subject 19). Another described how “there’s no trees on it. So ... that doesn’t appeal to me. It just feels very white and, like, very harsh” (Subject 19). This contrast was especially noticeable given the green lawn and redwood grove across the street, where another subject described how “the trees and grassy area is nice. So it’s, kind of, done up a little bit in that regard. So it’s not just, you know, a stretch of concrete sidewalk and nothing else” (Subject 15).

A number of subjects described greenery as central to their conceptions of ideal walking environments. One subject said he would prefer to walk in “green lavish landscapes” (Subject 4). Another described an imaginary “place with no buildings, no people except for people on the sidewalk, and lots of trees, flowers and kept vegetation. ... Maybe even some greenery along the sidewalk instead of just beyond the sidewalk. In fact, having—having a barrier of greenery between the sidewalk and the roadway is—would be a huge plus for me” (Subject 11). Several subjects noted how they preferred to walk in residential neighborhoods because they were green; one described how residential areas are “quiet and there’s trees and people have gardens” (Subject 19). Someone who had visited Amsterdam described how “you have the trees all along the canals in some places. And then a lot of people have, like, hollyhocks growing by their doors which is—it’s just very friendly looking” (Subject 19). Another remembered how in his hometown, “all the houses had, like, nice yards ... pretty trees and bushes” (Subject 7). Conversely, when asked to describe a place worse for walking than anywhere along the study corridor, one subject offered, “Oh, if it was, maybe, six lanes of traffic, and no trees” (Subject 25). Trees and greenery were not only core to subjects’ observations along the study corridor, but their mental images of good walking environments in general.

The study corridor did not include any access to water bodies, but four subjects volunteered that they liked to walk along water, either as part of their regular walking routines or in memories of traveling or living in other places. One, recounting a place they had visited on Maui, described how his ideal walking environment would have “ocean waves on one side and a walking path above it” (Subject 26). The same subject drove nearly daily to walk for exercise around Lake Merritt in downtown Oakland, specifically seeking out this park-like, shorefront environment. Another subject similarly described the enjoyment of walking along Lake Geneva, in Switzerland. Another, contemplating an ideal walking environment, suggested “maybe along the coast or something ... water would be nice. Maybe, more birds” (Subject 18). These responses, unconstrained by the practicality of access to waterfronts, nonetheless imagined them positively in ways that were similar to green spaces. Both represented naturalness that stood in contrast to urban hardscapes.

While subjects did not tend to reflect about *why* they preferred trees and other natural features, their preferences were consistent with psychology theory about how such features may be engaging and restorative for human users. Green features were clearly eye-catching, offering complex structures and movement, along with unfolding explorability: layers of features at a broad range of scales, from whole trees to branches, leaves, flowers, grassy areas, and shadows.

Kaplan and Kaplan's (1989) Information Theory postulates that this combination of complexity and explorability is highly attractive for human users because it provides ongoing opportunities for understanding. This is consistent with Lynch's (1981) theory about preference for unfoldingness, and is foundational for the concept of transparency, offering perceptual similarities to looking through a multilayered entrance or storefront window (Ewing & Handy, 2009). The Kaplans also suggest that the natural features may be psychologically restorative, relieving stress by redirecting attention away from everyday concerns and toward foci that are involuntarily fascinating (Kaplan & Basu, 2015; Kaplan, 1995). The attention-grabbing and restorative qualities of natural features may underlie widespread preferences for them identified by design theorists (Arnold, 1993; Jacobs, 1993) and among subjects in this study.

3.4.2.2 Buildings & Architecture

Every subject discussed buildings and architecture, consistent with expectations that buildings would strongly influence how they perceived qualities such as enclosure and sensory engagement within streetscapes. Like trees and natural features, most subjects did not offer conceptually sophisticated interpretations of why or how they liked or disliked buildings and architectural features. Nonetheless, they universally observed and formed opinions about buildings, reinforcing seminal theory about how buildings frame perceptions and understandings of urban spaces (Alexander et al., 1977; Appleyard et al., 1964; Cullen, 1961; Gehl, 2011; Lynch, 1960).

When buildings were present, they tended to be focal points for subjects' evaluations of block faces: "the architecture is pretty here," (Subject 4) or "buildings on that side are just kind of 'blech'" (Subject 19). Conversely, places that lacked buildings offered recognizable contrasts: "I don't like the [laugh] gas station. It's kind of like walking by a big empty lot" (Subject 5), or "[on that side] there aren't buildings. Whereas here you have a lot of commercial buildings" (Subject 11). More subjects expressed preference for presence of buildings than for lack of them, but others described liking block faces with fewer buildings or where they were farther from the sidewalk: "it's more open, I think. That's a really good feeling" (Subject 21). In either case, subjects demonstrated awareness of how buildings shape urban spaces, consistent with Gehl's (2011) understanding of the public realm as spaces "between buildings," and Cullen's (1961) observation that streets lined by buildings are a defining quality of urbanity.

More than two thirds of subjects discussed specific buildings, indicating that they bolstered imageability, a theoretically valuable quality for walkability (Ewing & Handy, 2009), even if they were viewed unfavorably. Nearly eighty percent of subjects brought up the Art Museum, one of the newest and most architecturally distinct buildings along the corridor, in terms that ranged from straightforward approval—"I like the museum" (Subject 21)—to architectural critique: "the Art Deco side is not really—they need a little more deco. And a little more art" (Subject 20). Even those who disapproved of the building appeared to find it interesting, indicating that walkers may find value in a building that is visually engaging, consistent with theory around complexity (Ewing & Handy, 2009), even if they ultimately dislike it stylistically. More than half of subjects specifically discussed architectural design, including materials and decorative details, consistent with research demonstrating that even non-experts have substantial awareness and appreciation for architectural design (Stamps & Nasar, 1997).

3.4.2.3 Engaging Frontages

Subjects were highly observant of whether buildings had street-facing windows and doors at ground level, coded as *engaging frontages*. This is consistent with theory espousing the benefits of transparency that breaks down the barrier between public and private realms, allowing passersby to engage with and understand goings on within buildings to either side (Ewing & Handy, 2009; Lynch, 1981). Favor for such permeability outweighed disfavor by a wide margin, with subjects describing how “it just makes me feel very happy to walk past them, to look in the windows” (Subject 28), remarking on the “beautiful window display” (Subject 5), or describing how “there’s good windows to look in. I might stop in here and grab a something” (Subject 17). Windows enriched walking experiences by effectively expanding the sensory space of the walking environment. Quite simply, they gave subjects more to look at.

Impressively, more than two thirds of subjects also discussed conceptual qualities related to engagement, using terms such as “transparent,” “complex,” “interesting,” and “explore.” More than half of subjects remarked on how features were either “interesting” or “uninteresting,” suggesting that this served as an important, albeit vague, litmus test for preferability. One subject, for example, described how “the juxtaposition between the plantings and the building, you know, adds a little interest to your walk.” In response to a different block, another noted, “it’s not the most interesting block to walk, you know. ... But not every block is going to be interesting” (Subject 25). Subjects’ use of more abstract concepts to describe sensory engagement suggests that it is highly salient, even for a lay audience, and that expert attention around these qualities is well-aligned with lay perspectives.

Subjects were also highly aware of architectural complexity, or lack thereof, which I also coded as discussion of engaging frontages. Many subjects, for example, were drawn to the ornate art deco façade of the stadium along the east sides of blocks 3 and 4, despite its shuttered doors and disrepair. Meanwhile, less ornate buildings, such as along the west side of block 4, were heavily critiqued when they lacked transparency; subjects observed that they felt vacant. This suggests that positive perceptions of engaging architecture may be useful for counteracting negative impressions of opacity, vacancy, and even dishevelment. As indicated by the variety of streetscape design qualities that are closely related to sensory engagement—transparency, complexity, and imageability among them (Ewing et al., 2016)—it is possible that preferable engagement may be achieved through several avenues, not necessarily requiring all these qualities to be satisfied along every streetscape.

Subjects did, however, indicate consistent disfavor for a block face fronted by a long blank wall, which was comparatively unengaging on nearly all terms. One described how, on the opposite side, there was “literally more to see. ... whereas here it’s just, like, a brick wall” (Subject 28). Another noted, “I can easily say I would prefer to walk on that side of the street because this side is just a bunch of blank walls” (Subject 19). In essence, subjects found the wall to be boring, an emotion that Ellard (2015) identifies as particularly influential for negative assessments of urban environments, and the antithesis of what Kaplan and Kaplan (1989) describe as favorable richness of information. One subject grasped to find interest in the wall, noting that it had “a different texture than most of the other stuff that’s around” (Subject 28). By and large, however, the wall demonstrated a notable dearth of engagement, providing subjects with a useful point of comparison for how they valued engaging features along other blocks.

3.4.2.4 Enclosure

More than two thirds of subjects discussed qualities of enclosure or openness. Contrary to design theory (Ewing & Handy, 2009), however, most of them expressed preference for more open, *less* enclosed spaces. Subjects described how they preferred “ample space” (Subject 8), “really like how much space there is on the side” (Subject 18), or how a block face felt a “bit more narrow and closed. ... I prefer to be someplace that's wider” (Subject 22). These findings call design theories espousing the preferability of more enclosed urban spaces into question (Ewing & Handy, 2009). They also indicate that lay walkers are conceptually aware of enclosure and can be sensitive to subtle differences in it. One subject, walking alongside the western side of block 6, contrasted it with the previous block face with many storefronts: “[block 6] feels way more open ... it's nice and spacious. It's empty. It's got no people or shops. It's pretty good” (Subject 29). Both block faces were highly enclosed by sidewalk-adjacent buildings, but the latter block nonetheless felt more spacious due to smaller trees and lack of awnings, street furniture, and other people. Another subject similarly described discomfort with confining spaces: “that side of the street ... it's not that it's claustrophobic. ... there's room, but it's just, you've got that wall, you've got the trees, you got the bikes. ... you're kind of pinned in” (Subject 8). While enclosure tends to be operationalized based on the morphology of large, immobile features, such as buildings and trees (Ewing & Handy, 2009), these observations reinforce how it may be influenced by a combination of large and more finely-grained features.

Several subjects also discussed enclosure in terms of sidewalk congestion, reminiscent of traffic engineering frameworks for evaluating walkability based on the number of pedestrians per square area (Lo, 2009; TRB, 2010). One noted that “I would prefer this side because there's less—to me it feels more open. So it's easy for me to just walk really fast” (Subject 22). One subject even considered how open space would allow them to bypass a distinctly Berkeleyan type of crowd: “if something was going down here, like, you know, people were protesting or whatever, I have a lot of room to ... cruise around” (Subject 8). These responses demonstrate close conceptual links between feelings of enclosure and density, either of physical built environments or of people within them.

Unsurprisingly, few subjects demonstrated awareness for how building heights, setbacks, or gaps between them might influence enclosure, indicating how these more abstract factors may be unlikely to figure consciously into lay walkers' perceptions of walking spaces. One noted, “I guess those apartment buildings are nice, how they're set back. That makes it feel a little more spacious” (Subject 25). Another described how “it's nice to be walking next to a building that's a little set back and there's, kind of, some green space in between” (Subject 2). No subject specifically discussed preference for smaller setbacks, though some implied this with strong preferences for windows and storefronts directly along the sidewalk. It is possible that discourses around urban openness, which Fishman (2011) describes as a symptom of architectural modernism and campaigns against urban density, continue to position larger setbacks as a normative good among lay walkers, in contrast with expert support for more densely enclosed spaces espoused by movements such as New Urbanism (Garde, 2020).

Subjects also referenced enclosure in the vertical dimension. One described how a block face was “still kind of open. It's nice. It's not, like, towering buildings.” (Subject 21), while another said that an ideal walking environment would “maybe not [have] large buildings looming over. I don't like that. Just open space” (Subject 21). Consistent with definitions of enclosure based on sky visibility (Yin, 2017; Yin & Wang, 2016), two subjects described how built features

impacted their view of the sky. One described how “building height—I think there's something nice—this side feels lower, maybe it's the perspective we have on it, but it feels more open to the sky and things above, whereas, I feel like this side has consistently felt a little bit more closed. And I think that's partially the shade and, like, our angle” (Subject 2). Others specifically described how awnings created unpreferable enclosure: “I don't like all the overhangs. I mean, I get why they're there and stuff. But it doesn't make for as pleasant of a walking experience. It doesn't feel like you have the sky over your head as much” (Subject 18), and “[this] just has this oppressive feel to it. Maybe it's all those overhangs and stuff ... [it] feels claustrophobic” (Subject 7). By and large, subjects who discussed vertical enclosure tended to be critical of it.

Nonetheless, a minority of subjects described preferences for enclosed spaces, describing them as sheltering and well-defined, consistent with interpretations that Ewing and Handy (2009) find common among design theorists. One subject noted, “as opposed to this open space, there's taller buildings on the left and ... it makes me feel hugged and not exposed.” (Subject 5). Another said, “I guess it's maybe something about the feeling of walking in a discrete space that you can kind of ... I don't know, it feels comfortable. You can kind of monitor all of it. Whereas, with a bigger space you're a little more out in the open. I don't know” (Subject 2). One subject also alluded to trees creating an enclosing feeling: “I think I just like the vibe of when ... there are lots of, like, trees hanging over” (Subject 12), consistent with Arnold's (1993) observation that trees can provide a roof-like sensation over a street. About two thirds of subjects also expressed preference for shade, which trees and overhangs might be likely to produce. Discordance between dominant preferences for shade and more open spaces indicate potential gaps in logical consistency between preferences. Likely, many subjects enjoyed aspects of both, evocative of Appleton's (1975) balance between prospect and refuge.

Other subjects described how openness within auto-oriented spaces detracted from their walking experiences. One described a corridor in her neighborhood where “having a whole row of car dealerships is really unattractive ... I don't like the stretches of nothingness. If they could fill it in ... even if it's just a park.” (Subject 22). This subject demonstrated a sophisticated understanding of how the character of open spaces—a car dealership versus a park—affected her preferences for them, and how a vacant-feeling space might be “filled” with a more engaging use. Most subjects who disliked openness, however, did not make this conceptual leap to describe them as deficits of enclosure or engagement. The difficulty of conceptualizing the potential benefits of filling such gaps may help explain many subjects' tendencies to prefer openness over enclosure. Perhaps it was simply easier for lay subjects to imagine how things might be removed from a landscape, a change toward openness, rather than added, a change toward enclosure.

3.4.2.5 Storefronts

Observations about storefronts, including restaurants and cafes, overlapped heavily with those about engaging frontages. Storefronts were discussed by all but one subject, predominantly favorably, consistent with expectations that they would offer a high degree of visual transparency and complexity. Street-facing doors, windows, and sometimes sidewalk seating, provided opportunities for the exploration and understanding that are core to Kaplan and Kaplan's (1989) theories about preference for information. A notable example was windows into a restaurant that were immediately adjacent to the sidewalk along the western side of the block 2. More than half of subjects commented on these windows, describing how they liked “looking at what people are

eating in that restaurant” (Subject 20), or “just like to see what’s going on in [the restaurant] ... seeing what’s up.” One subject noticed how the restaurant staff were “in there having their dinner now” (Subject 20). Likewise, many were attracted by the sociability and liveliness of storefronts along the west side of block 5. One subject described this block face as “very friendly” (Subject 19). Another noted that “the storefronts are nice ... they look open and used” (Subject 12). Overall, subjects tended to describe storefronts as welcoming, visually interesting, and opportunities to engage with others.

Nonetheless, about a third of subjects described *disliking* storefronts at least once, demonstrating that the same streetscapes may be interpreted quite differently by those with varying priorities. Notably, however, dislike for storefronts was often related to congestion of adjacent sidewalks rather than design characteristics of the storefronts themselves. One subject noted how “lots of times people just walk right out, so you’re constantly having to dodge people” (Subject 7). Another, referring to the same retail-heavy block that many others preferred, described how “there’s a lot going on on that side. Like, a lot of businesses. ... It’s, like, too much—too much in the way. And, you know, I don’t want to bother people’s meals or whatever” (Subject 21). Another noted how that they “like the idea of sidewalk cafes and seating like that, but ... it’s too close here” (Subject 7). It was difficult to untangle practical considerations, such as wanting to walk quickly and avoid obstacles, from social considerations, such as discomfort with proximity to strangers. Notably, men tended to disfavor busy block faces more than women. Women, by contrast, tended to feel safer in areas with more foot traffic such as along storefronts. One woman noted that she would feel safer walking on the side “with a store right there and some restaurants. So, if something were to happen, I know someone will notice” (Subject 27). Preferences for more highly trafficked areas among female subjects reflected other research that points to gendered interpretations of safe and comfortable walking environments (Clifton & Livi, 2005; Golan et al., 2019).

While engaging storefronts tended to be viewed favorably, many subjects described how vacant storefronts with limited transparency due to dark or covered windows made them feel uneasy. This underscored how even lay observers were highly sensitive to the distinction between actively-used storefronts and frontages that had similar surface-level characteristics but were actually vacant or being used for less public-facing purposes than their street-level façades communicated. A storefront in a historic building on the west side of block 1 was currently vacant, with the windows frosted sloppily from the inside. Three subjects noted that it looked “abandoned” (Subject 27, Subject 18, Subject 15). A row of commercial spaces in a recently constructed building along the west side of block 2 had dark reflective windows that were difficult to see through, suggesting that they were intentionally screened from public view. One subject noted that “it’s kind of strange that all those offices are closed. ... All those storefronts look, kind of, empty” (Subject 19). Likewise, storefronts with austere and poorly maintained window displays along the west side of block 3 were perceived as “not very welcoming” (Subject 2). Subjects were attracted to storefronts into which they could see easily and interpreted opaque windows as unwelcoming or insincere. This reinforces how design codes that require ground-floor windows to promote walkability may be ineffective unless they further stipulate that windows must be transparent or uncovered, allowing for the transparency that storefront windows quintessentially provide (Hamidi & Moazzeni, 2019).

3.4.2.6 Gas Stations

Gas stations were, unsurprisingly, interpreted quite differently from other types of retail frontages. Nearly all subjects discussed both gas stations along the corridor, and the vast majority described them as primary reasons they disliked those block faces, consistent with Golan et al.'s (2019) interpretation of them as “walking-inhibiting businesses.” Many subjects’ critiques were straightforward and nonspecific: “I don't like the gas station” (Subject 5), “I prefer not to walk in front of a gas station” (Subject 26), or “walking by the gas station I would necessarily try to avoid” (Subject 12). Some, however, described more specifically how auto traffic and design characteristics of the gas stations contributed to their disfavor. Potentially hazardous auto traffic was the most common critique, consistent with other research pointing to the substantial influence of traffic on perceptions of walkability and livability (Appleyard et al., 1981; Golan et al., 2019; Loukaitou-Sideris, 2006). Many subjects described how cars would be turning in and out, for example: “there's people turning in and maybe leaving as you're walking along the sidewalk here” (Subject 28), or “there's this carwash thing and you have to be paying attention to traffic coming in and out” (Subject 19). Another described how “gas stations can be iffy. There's a ton of cars coming in and out of there at all times and you just have to make sure that they're not gonna pull out without seeing you” (Subject 18). While many subjects were also concerned about the safety of auto traffic within the roadway and at intersections, gas stations were the primary opportunity for mid-block conflicts with turning cars, and subjects were strongly aware of this potential hazard.

Only a small number of subjects described more specific aversions to gas stations, primarily related to being dirty and chaotic. One noted that the gas station on the block 3 had “a lot of noise. It looks very industrial. ... it just seems kind of grungy” (Subject 21). While urban design theory suggests that pedestrians might feel uncomfortably exposed due to lack of enclosure around gas stations, no subject specifically described such a feeling, though this may have been implicit in observations about exposure to traffic. Indeed, conversely, a subject who was particularly concerned about observing her surroundings to ensure personal safety described preferring a gas station because “it feels more spacious. Like, there's more space” (Subject 27). This demonstrates how preferences for highly enclosed streetscapes may stand in conflict with preferences for visibility (Appleton, 1975), and how preferences for security-enhancing visibility may be gendered (Golan et al., 2019).

3.4.2.7 Buffers from Traffic

Unsurprisingly, the vast majority of subjects noted displeasure with auto traffic, many due to concerns about safety or disruptive noise, consistent with both theoretical and empirical research on how traffic affects pedestrian preferences, stress levels, and behaviors (Appleyard et al., 1981; Basu et al., 2021; Chrisinger & King, 2018). Eight subjects specifically discussed the benefits of buffers that provided “distance between cars and the sidewalk” (Subject 26), reinforcing the potential benefits of street cross-sections that separate pedestrians from traffic (Rodriguez-Valencia et al., 2022). Namely, bike lanes along the west side of block 1 and a bikeshare station on the east side of block 2, were described as advantageous buffers. One subject described how “there's a bike path on that side. So, [there are] less cars directly [along the sidewalk]” (Subject 21). Another similarly noted, “there's a bike lane there so you're, kind of, divided, or you're away from the cars when you're walking” (Subject 14). Similarly, several subjects described liking the bikeshare station because it made them feel “protected from the road with all the bikes” (Subject

18). Parallel parking also provided a recognizable buffer. One subject described how, “even though as a driver I mentioned it was annoying that the cars are parked there, I feel like, as a pedestrian, it, like, adds another buffer between me and the street, and the cars.” (Subject 28) Another noted the “distance from traffic” (Subject 6) that parking provided. Discussion of buffers from traffic demonstrated awareness among lay subjects about how streetscapes might be organized to remediate unfavorable impacts of the roadway, similar to the Level of Traffic Stress system in bicycle planning, which suggests that more separated facilities are less stressful and therefore appealing for a wider array of cyclists (Mekuria et al., 2017).

3.4.2.8 Looking Across the Street

While the field protocol asked subjects to interpret and compare opposing block faces independently, about a third of subjects described qualities of one side as attributes of the other, challenging the efficacy of using the two sides as distinguishable experimental treatments. For example, one subject noted while standing on the east side of block 6, opposite the Art Museum, “I like this side is because you've got this lovely view of the museum” (Subject 23). Another aptly noted that their side preference might depend on the scale of the feature they were interested in viewing: “if it's small enough, I would rather walk on that side, but if it's huge, I would rather walk on the opposite so that I can see the whole landscape” (Subject 4). Similarly, another described how “those buildings are pretty cool, but had I been walking on that side I would have to raise my neck pretty high to look at the whole architecture. But over here it's pretty fine, so, I would stay on this side.” (Subject 4). Others used walking on one side while looking at the other to experience, in a sense, the best of both. One subject who preferred openness but was interested in architecture noted, “the architecture is pretty here. So ... it would be better visible on [the other side], plus the added advantage of open space on this side would, you know, leverage walking on this side more than the one over there” (Subject 4). Another similarly preferred the openness of the east side, but enjoyed looking at the west side, describing how one block offered “nicer across-the-street viewing relative to the last block” (Subject 15). A subject who disliked foot traffic along the retail frontages on the western side of block 5, noted how they “would probably prefer to walk on [the east] side, but I would definitely be looking at [the western site]” (Subject 12). The ability to look across the street allowed subjects who disliked certain conditions, such as crowds, to nonetheless appreciate associated factors, such as engaging architecture, albeit at a distance.

Subjects' difficulty in evaluating different sides of the street as distinct spaces revealed a deficiency in my study design, which asked them to acknowledge somewhat arbitrary boundaries between sides, as well as between blocks along the corridor. Experimentally, I considered it advantageous that subjects could perceive these spaces simultaneously because it allowed them to draw direct comparisons without relying on memory. In retrospect, however, this conceptual framing of distinct yet simultaneously viewed spaces somewhat violated my own definition of a streetscape—a built environment that is perceived from the perspective of a street—which does not insinuate boundaries or a particular viewing direction. Features on the same side may dominate walkers' views, but in most cases, they will also be able to see the other side and even along the street to neighboring blocks. Thus, the streetscape is perceived and interpreted as a wholistic space, a 360-degree view, and may not be readily partitioned either perceptually or conceptually.

Subjects' difficulties partitioning between sides were consistent with how streetscapes are often represented and evaluated in urban design practice and research. Cross section diagrams that illustrate the width of a streetscape in relation to the heights of surrounding buildings are core to designers' understandings of the public realm (Figure 3.9). These tend to depict both sides of a streetscape because the distance between opposing buildings is crucial for understanding the scale and enclosure of the bounded space. Design researchers have typically studied streetscapes as two-sided spaces. Jacobs' (1993) drawings and evaluations of streetscapes tend to encompass entire cross-sections rather than being constrained to one side or the other, except in cases where median trees visually partition the space into multiple corridors. Appleyard et al. (1981) examine conditions across both sides of residential streets. Both studies approach streetscapes with the assumption that they are cohesive physical spaces.

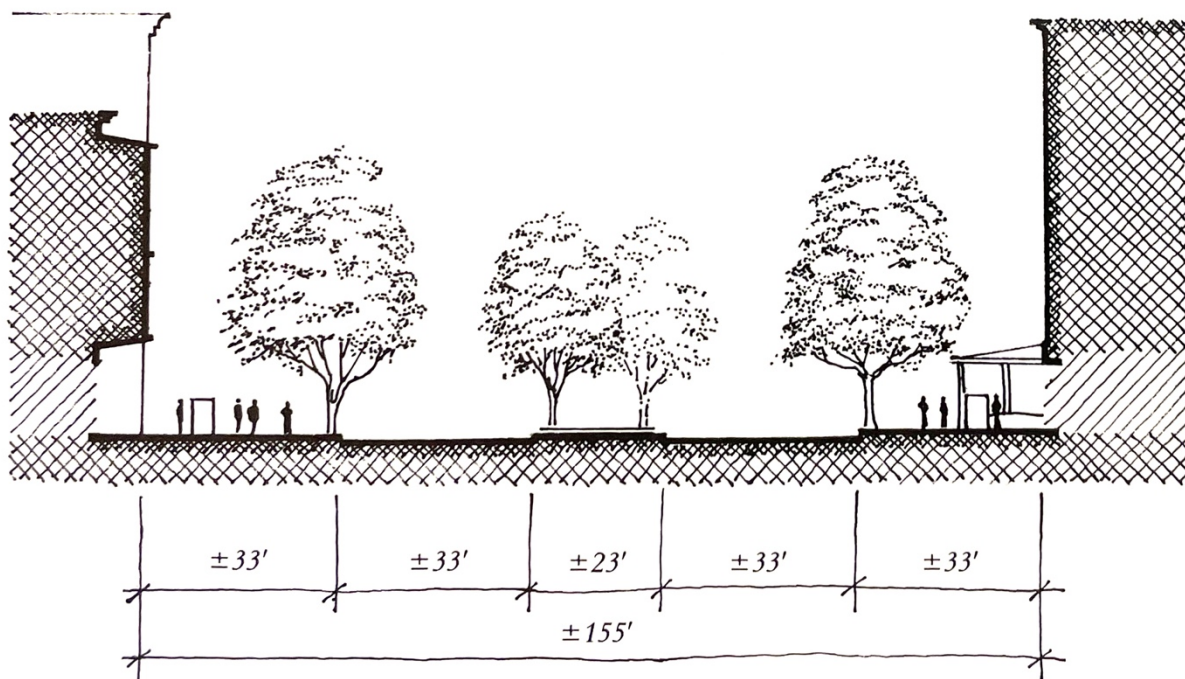


Figure 3.9. Typical streetscape cross section showing width between opposing buildings (Jacobs, 1993, p. 159)

Nonetheless, both studies also reveal ways that this cohesion may be degraded, suggesting how sides of streetscapes may sometimes be conceptualized separately or singularly. Jacobs (1993, p. 194) discusses how streetscapes may be “one-sided” when bounded on the *other* side by an open space, similar to blocks 3 and 4 along the study corridor. While both sides of such streetscapes will likely contribute to users' perceptions of these spaces, one-sidedness challenges traditional understandings of how streetscape boundaries are defined. Can a one-sided streetscape feel enclosed? What is its width? Cross-sectional ratio as a measure of enclosure effectively relies on double-sided streetscapes. One-sided streetscapes compel alternative approaches to understanding vertical enclosure and the horizontal extents of streetscape spaces. Perhaps a boundary along just one side may nonetheless offer the sensation of a defined space, though skewed toward a single side. If this is the case, could either side of a two-sided street be

conceived of as separate spaces? Appleyard et al.'s (1981) findings of lower social cohesion between residents on either side of streets with heavy traffic also suggests how activity patterns, not just physical design, may affect perceptions of separation between sides. Perhaps a one-sided street may be created not only by bias in visual prominence, but lack of social connectivity due to an obstacle such as traffic. While streetscapes may tend to be viewed as cohesive wholes in ways that were methodologically problematic for this study, there are opportunities to further unpack how both lay walkers and design experts understand streetscape boundaries.

3.4.3 Which Factors Were Primary Drivers of Block Face Preferences?

Through close reading of the interviews, I identified two major dimensions of preference that appeared to have an outsized influence on subjects' comparisons between block faces: environments that were more natural versus built, and social engagement versus solitary remove. Subjects expressed varying extreme positions along these dimensions, but nearly all returned to these factors repeatedly and leaned in one direction or the other along both dimensions in ways that consistently informed their preferences. Both dimensions were closely associated with streetscape design, though the natural versus built dimension was more overtly physical, while the social versus solitary dimension reflected both design elements that promoted social engagement, such as transparent storefronts, and human activity that tended to be coincident with these spaces. As such, both dimensions describe streetscape characteristics that could be consciously designed.

For many subjects, these dimensions appeared to serve as heuristics, allowing them to rapidly and confidently determine which block face was preferable over another, even when they appreciated or critiqued aspects of both. One subject, for example, was immediately drawn to "smells coming from the restaurants and the action" along the west side of block 5, even though he noted that the "trees and foliage are also appealing" on the other side of the street (Subject 26). Despite finding the more natural side favorable, he nonetheless preferred the more built and socially engaging alternative. These results suggest how it may be less productive to conceptualize lay walkers' decisions about preferable environments as rational comparisons of costs and benefits, and more useful to identify heuristics, as a behavioral economic approach would suggest (Tversky & Kahneman, 1986).

Many urban design theorists suggest that social engagement is an important goal for successful streetscapes and that pedestrian traffic may be a useful metric of environmental preference (Appleyard et al., 1981; Gehl, 2011; Lynch, 1981; Whyte, 2001). Counter to this assumption, however, nearly 70% of subjects tended to prefer block faces that were more solitary (Figure 3.10). Moreover, about 60% of subjects tended to be drawn to natural features, such as large trees and green spaces, rather than buildings and hardscapes. One subject, who was particularly oriented toward natural features, pointed out trees and plantings along every block, even noticing "the little olive trees" along the east side of block 2, while paying little attention to the large blank wall that was a dominant feature for many subjects. When he finally noticed the wall he noted, "it's not, like, a filthy looking wall. It's fine. You know" (Subject 18). For subjects who were oriented toward natural features, buildings seemed to fade into the background while the trees and other greenery were forefront in their views. This preference for natural features is consistent with environmental psychology research demonstrating their restorative and engaging qualities compared with purely built spaces (Kaplan, 1995).

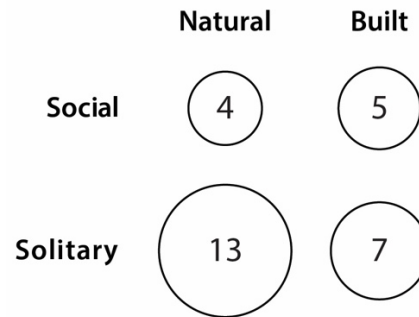


Figure 3.10. Cross-tabulated counts of subjects who tended to prefer natural versus built and social versus solitary walking environments. Circle areas are scaled to represent counts.

Nonetheless, about 40% of subjects tended to prefer buildings and built features, many of whom were drawn to architectural styles or otherwise engaging frontages. One subject described how they “like looking at the architecture and seeing how people have remodeled and how they keep up and stuff. This is more urban, you know?,” and “I like looking at the museum. The architecture is really neat” (Subject 26). These subjects found the greener eastern side of the corridor substantially less compelling: “I mean, I do—well, right at the corner you’ve got the UC sign and the trees and stuff” (Subject 26). Other subjects who favored built spaces were especially drawn to storefronts: One, for example, noted that “I just really like checking out shops and different things that are going on,” while describing the treed area on the opposite side as “a pretty boring area to walk by” (Subject 14). For these subjects, buildings were the main attraction.

Interestingly, what subjects liked *about* both built and natural spaces were conceptually quite similar: both liked the ways they were sensorially complex and engaging, adhering to Kaplan and Kaplan’s (1989) Information-Processing Theory. This suggests that both types of spaces may confer similar types of benefits for those who prefer them. In essence, nearly all subjects were seeking sensory engagement from their physical environments in one form or another.

Conversely, only a minority of subjects were seeking social engagement. Counter to theory suggesting that walkers are attracted to other walkers (Gehl, 2011), nearly 70% of subjects expressed tendencies to avoid others. Many were displeased with foot traffic that either impeded movement or invaded personal space. One described preferring “just not have too many people to bump into.” Another, who grew up in India, noted that “Back in India, I would have half the size to walk on and twice the number of people walking on it” (Subject 4). He was quick to prefer whichever block side had fewer people. Others simply preferred the calmness of walking by themselves, away from commotion. One described walking along a greenway near his house: “It’s solitary. It’s kind of a bit of a reflective route. It gets me away from traffic. That’s what I like” (Subject 11). Still others were cautious about other people, especially those they viewed as homeless, for reasons of personal safety: “you have to be aware of who is around you, like, for example, that person yelling” (Subject 3). Many subjects described a delicate balance between having enough other people around to feel safe but preferring fewer people who might be bothersome or imposing. Along the study corridor, where there was at least some foot traffic on nearly every block face, subjects tended to be more concerned by too many people than too few. This suggests that theories about how other walkers may contribute positively to walkability may

need to acknowledge non-linearities, such as both physical and psychological needs for personal space, and non-generalities, such as individual preferences for personal space, in these relationships.

About 30% of subjects, however, clearly preferred opportunities for sociability and being “right in the middle of it,” (Subject 21) seeking block faces with more people along them. One described how “I really like this bar that's near Center Street. So, I like to go there to see if there are any bartenders who I know who are there” (Subject 14). Sociability was central to her walking experience. Others noted how more people made them feel safer: “I find myself walking pretty much any hour of the day, starting from maybe 6am to as late as two or three in the night, and I feel pretty safe about it. It has partly to do with the fact that there's a lot of undergrads in the area and there's, like, frats around that place. So part of it makes it a little uncomfortable at night because it's noisy. But that's exactly why I prefer being there. Just because there's more people (Subject 29). On one hand, this subject disliked noisy crowds, but they also felt safer with many people out and about and tended to prefer places with more activity. Another described how people were part of what made a place enjoyable, describing an ideal walking space as “more people enjoying their environment. I like looking at people” (Subject 23). These perspectives are more consistent with popular theory that positions walking as an opportunity to build social cohesion and put “eyes on the street” (Jacobs, 1961; Mouratidis & Poortinga, 2020)

Cross-tabulating the dimensions, nearly 45% of subjects preferred environments that were both natural and solitary, a combination that is unsurprising given that natural places are often less populated. One subject described how their ideal walking environment would be low-traffic and park-like, with little potential for disruption: “a whole continuous stretch. So it's, like, a huge park, and I'm walking on the side of the park with no streets to cross for, like, four or five blocks in a row” (Subject 29). Of course, this idealized vision begs the question: where would this subject be walking from or to, or would their walking be purely recreational? Reconciling desires to be *away from it all* with the practicality of walkable destinations is a formidable design challenge that designers and planners, particularly in the modernist tradition, have wrestled with for decades, often resulting in environments where walking is likely impractical on a day-to-day basis, even if it might be pleasant on occasion (Holston, 1989).

A small proportion of subjects, about 14%, were inclined toward natural settings but also preferred to be around other people, a combination that is congruent with urban parks or heavily vegetated streetscapes. Several in this group did not express overt displeasure with densely built spaces, such as the west side of block 5—indeed, they described favoring them for their sociability—but paid most attention to greenery rather than built features. Their preferences might be addressed simply by incorporating more trees, plantings, and parks into urban settings with already high levels of human activity.

Another group of subjects were drawn to engaging built spaces but disliked crowds, a somewhat paradoxical combination. Nonetheless, it draws some similarity to Appleton's (1975) prospect-refuge theory, which suggests the preferability of watching goings-on from a protected position. Urban design has tended to idealize built spaces with high levels of human activity (Gehl, 2011), but this group suggests that some lay walkers may benefit from relatively low-traffic environments, so long as they are still architecturally engaging.

Subjects who preferred both greater social interaction and built spaces may be most easily accommodated by normative principles in urban design that promote well-trafficked built spaces.

However, only about 20% of subjects consistently preferred this combination of characteristics. If designers assume that such environments are preferable, they may be unsuccessful at attracting the potentially large number of walkers who do not share this ideal. While this study's small and non-representative sample does not reliably indicate the specific proportions of walkers who may share these preferences across the general population, it does suggest that many lay walkers may not fit the mold of preferring built and sociable spaces that has become a dominant norm in walkable urbanism (Dover & Massengale, 2013).

3.5 Conclusions

This study evaluated how streetscapes contribute to lay walkers' perceptions of walkability, demonstrating that subjects without expertise in planning and design were deeply aware of streetscape-related features while evaluating real-world urban walking environments. Nearly all subjects discussed features such as building, trees, storefronts, and gas stations, as criteria for forming preferences between block faces, indicating that they were consciously aware of streetscape contexts alongside transportation factors such as sidewalks and auto traffic. These results suggest that modifying streetscapes may be a viable mechanism for improving walkability, encouraging planners to harness streetscape design alongside more conventional transportation infrastructures as tools for promoting walkable urbanism.

While results reinforced the importance of streetscapes for lay walkers, they also demonstrated substantial variability in the conditions they preferred. Notably, subjects challenged conventional understanding about the preferability of more enclosed streetscapes lined by continuous buildings (Ewing & Handy, 2009). Instead, many preferred more open and natural environments. Preferences for openness may have been an artifact of the particular sample of subjects, many of whom demonstrated preference for natural features, and the block faces they were asked to evaluate, along which openness and naturalness tended to be highly correlated. Nonetheless, these results challenge the assumption that enclosure, especially from buildings, is preferable for urban walkers, and demonstrate how more open and natural spaces may be valued by many. Finding ways to merge or mix natural openness with built density may offer the best of both options.

Engaging building frontages tended to be viewed preferably, though they were not as influential as expected. Nearly all subjects identified interesting and transparent frontages as positive factors and disliked dull and boring façades that featured blank walls or covered windows. Many subjects reacted negatively to facades that felt abandoned, vacant, or disingenuous, including windows and doors that felt ornamental or intentionally closed off rather than offering meaningful access to interior spaces (Figure 3.11). This suggests how surface-level design elements aimed at making streetscapes more visually engaging may do little to improve appeal. In short, they aren't fooling anyone. Such frontages need conspicuous uses to be convincingly appealing.



Figure 3.11. Disingenuous windows and doors with no storefront behind them along the western side of block 2. Subjects tended to react negatively to such frontages, which signaled vacancy, despite apparent attention by building designers to offer a more complex, engaging streetscape. (Image source: Google Street View)

Nearly all subjects found trees and other greenery to be highly preferable, and the majority tended to prefer natural features over built ones. Similar to transparent storefronts, subjects found trees and green spaces to be visually rich and engaging, qualities that even overshadowed less desirable built contexts. Large trees along the eastern side of the study corridor were sensorially captivating for many subjects and a primary reason they often preferred these block faces despite other less appealing features: a large parking lot, poorly maintained landscaping, and a deeply set back building with no active windows or doors. Preference for the trees appeared to overpower these substantial drawbacks. Subjects similarly described how street trees and plantings helped soften otherwise dull block faces alongside buildings. These findings suggest how trees and greenery may offer a relatively efficient approach for improving walkability in places with architectural shortcomings. They also show how preferences for whole streetscapes may be buoyed by a relatively small number of favorable features. An engaging tree might effectively distract from an otherwise dull block face. Similarly, a tidy storefront or particularly engaging façade might mitigate issues with maintenance elsewhere on the block. Unwelcoming streetscapes might be improved with relatively few modifications that provide focal points that draw walkers' attention—what Kaplan and Kaplan (1989) describe as attractive *mystery*—rather than requiring design overhauls along their entire lengths.

Subjects' difficulties attributing streetscape characteristics to specific block faces—many described the ability to look at what was on one side as a positive attribute of the other—revealed a weakness of the study design, which relied on discrete comparisons between opposite sides and adjacent blocks. It also, however, demonstrated the importance of conceptualizing streetscapes as wholistic spaces, even if their characteristics may vary between sides or across their lengths. Indeed, many subjects appeared to value this internal variability because it provided them with choice. One subject who liked to look at storefronts, but disliked wading through crowds, favored viewing the stores from the opposite side of the street. Those who preferred more natural streetscapes prioritized walking along the more park-like side, while those who preferred buildings could traverse the other. These results suggest that rather than aiming

for symmetrical streetscapes with similarly favorable conditions on both sides, planners might encourage asymmetry that provides walkers with choices about the types of spaces they prefer to walk along.

The quasi-experimental study design aimed to balance competing emphases on control and ecological validity in the transportation and urban design fields. It successfully achieved aspects of both, but nonetheless demonstrated the challenges of such a methodological compromise. Conducting the study in the field rather than with photographic or virtual stimuli substantially increased the realism of the study environments, allowing subjects to draw on their full breadth of sensations and imagine themselves making real-world choices. Comparisons between opposing block-sides were intended to allow subjects to perceive both simultaneously, a real-world equivalent to viewing side-by-side photographs in a lab. Experiencing both sides together, however, revealed their connectedness, making it difficult for subjects to interpret them independently. Interestingly, subjects had little difficulty deciding which side they preferred to walk on; these decisions felt natural. But their reasons for preferring a block face often involved characteristics of the opposite side, adjacent blocks, or even the broader urban context, such as the location of the university or downtown. This simultaneously demonstrated the importance of studying environmental preferences in rich, real-world contexts, and the impossibility of conclusively identifying discrete effects without laboratory control.

Many other factors were not ideally controlled, both due to practical constraints and to ensure that the study involved sufficient variability to be ecologically representative. While I could, for example, have limited subjects to a very specific demographic to minimize potentially confounding demographic effects, I instead chose to construct a demographically diverse sample that might represent a wide range of perspectives. My results, therefore, better accounted for breadth of potential observations than the degree of consistency between them. The field site changed subtly between participants in ways that were inherent to a real-world urban space. Weather, sun angle, traffic, crowds, trash, construction, and other factors differed between every subject. Arguably, these factors were somewhat controlled by randomness in when subjects chose to schedule sessions, but they were nonetheless unmeasured influences. My semi-structured interviews varied slightly between subjects, but they allowed me to dig deeply into how and why subjects perceived things as they did. After considering myriad ways I might add control to strengthen between-subjects comparability, I diverged from experimental principles to ensure that I engaged a diverse pool of subjects, that they were responding to real-world conditions, and that I more fully captured the breadth of their individual responses.

A similar mixed-methods field experiment might be extended or modified to prioritize either internal or ecological validity. Identifying a study site that offered more substantial contrasts in streetscape design between block faces would offer greater opportunity for clear differentiation of preferences. In the present study, lack of strong contrasts in enclosure, for example, may have made it difficult for subjects to identify and react to these differences. A corridor with much more varied degrees of enclosure, including both highly enclosed streetscapes such as alongside tall buildings, and highly open streetscapes such as along strip mall parking lots (Figure 3.12), would accentuate these differences so that subjects might be more likely to respond to them. However, such contrasting streetscapes are unlikely to be within walking distance of one another limiting the practical potential to compare them within the span of a single walking interview. Driving or otherwise transporting between different environments, in addition to requiring more subject and researcher time, might degrade subjects' memories of each environment, making it

difficult to compare between them. Moreover, because highly contrasting streetscapes are not often found close to one another, comparing such places directly might degrade ecological validity. Using a corridor with only moderate differences in streetscapes along it may be most representative of the variability pedestrians regularly encounter.



Figure 3.12. Examples of high (left) and low (right) enclosure streetscapes.
(Image source: Google Street View)

An even more ecological approach would be to evaluate walkers along their real-life routes. This would be akin to many photovoice studies, which ask subjects to photograph and discuss features they encounter in daily life (Hergenrather et al., 2009). The major downside of this approach is that subjects would logically be biased toward streetscapes they prefer, providing limited opportunity to respond to those they dislike. Interpretations of frequently encountered streetscapes may also have been strongly biased by familiarity. This was a meaningful factor even in the present study, as subjects described favor for recognizable landmarks, but it would likely have shaped observations from everyday routes even more strongly. Using a consistent corridor with an intentional degree of variability required subjects to examine streetscapes they may have found preferable, likely diversifying the stimuli they encountered. It also enhanced comparability between subjects because all experienced approximately the same streetscapes, albeit under varying weather, traffic, and other dynamic conditions. Many also had similar degrees of familiarity with the corridor, helping to control for these influences. These considerations highlight the difficulty of balancing priorities for ecological and internal validity.

A notable deficiency of the present study was underrepresentation of subjects who were not already frequent walkers. More than 80% of subjects said they walked almost daily for transportation or recreation, and many described being avid walkers who were motivated to participate because they wanted to help advance walkability. Ironically, however, the perspectives of those who walk infrequently or not at all would likely be more valuable for planners to hear. To the extent that streetscapes can help promote walking, either as an alternative to other modes, or simply as an opportunity to be more active, they need to attract

those who aren't already walking. Recruiting from this population is likely challenging but is an important consideration for future research that aims to account for underrepresented perspectives.

A key aspect of the study design that might be approached differently in future work was conceptualizing opposing block faces as separate observational units. On one hand, subjects tended to intuitively understand the question of which side they would prefer to walk on. The sides were conceptually discrete options. They were not, however, perceptually discrete, as demonstrated by the common tendency to enjoy looking across the streets. This was consistent with theoretical understanding of streetscapes as wholistic spaces (Jacobs, 1993), but it substantially muddled examination of relationships between preferences and streetscape features. Future work might adopt a more wholistic spatial unit that includes both sides of the street on a given block. This still, however, presents challenges regarding spillover between blocks. Turned corners or other means to block sightlines might reinforce independence. This would also, however, compromise the ability to compare multiple options simultaneously. Ultimately, there is likely no ideal solution for partitioning adjacent streetscapes into distinct units of analysis. Their boundaries are inherently fuzzy, so comparisons between sides of the street or adjacent blocks will never truly be independent.

The difficulty of distinguishing between block faces also hints, however, at a potential solution to divergent streetscape preferences. Instead of designing streetscapes symmetrically, with the same characteristics on both sides, contrasting sides could be designed to appeal to divergent preferences. In the present study, the east side of the corridor often attracted subjects who preferred more natural and solitary environments while the west accommodated those preferring more built and social environments. Both these dominant needs were met, making the street appealing for a broad range of walkers, or even changes in preferences due to different trip purposes, times of day, or even just for variety. Moreover, looking across the street provided opportunities to glean value from both sides of a street simultaneously, suggesting that walkers may mix and match the benefits from both sides at once. Streets with differing sides may give walkers a valuable degree of flexibility to choose which factors they prefer to experience, either close up or at a distance.

Ultimately, this study demonstrated not only variability in lay walkers' preferences, but also their flexibility. Despite numerous critiques of the study corridor, all subjects noted that they would happily walk along it if it were a convenient route in their everyday routine; its various imperfections were not, they thought, enough to discourage using it. Nonetheless, building streetscapes where walking is not only possible, but truly enjoyable, will be important for advancing it as a favorable activity that people choose to pursue.

Chapter 4 Using Biosensors to Study Walkers' Emotional Responses to Streetscapes

4.1 Introduction

Emotions such as happiness and stress are increasingly embraced as a lens for evaluating user experiences in urban environments, reinforcing how cities ought to be not merely serviceable for living but rather inspire enjoyment and comfort in everyday life (Ellard, 2015; Montgomery, 2013; Resch et al., 2020). Because emotions can be associated with physiological markers, a number of studies have aimed to validate and improve understanding of how urban environments elicit emotions with physiological measurements from biosensors (Berger & Dörrzapf, 2018; Caviedes & Figliozzi, 2018; Chrisinger & King, 2018; Emo, 2014; Engelniederhammer et al., 2019; Fitch-Polse, 2018; Fotios et al., 2015; Hollander et al., 2018; Hollander & Foster, 2016; LaJeunesse et al., 2021; Mantuano et al., 2017; Noland et al., 2017; Osborne & Jones, 2017; Roe et al., 2013; Valtchanov & Ellard, 2015; Zink et al., 2016). Researchers are hopeful that biosensory measures may elucidate how users respond to features in ways that may be subconscious or that are difficult to articulate. Subjects in Chapter 3, for example, often had difficulty describing exactly how they felt about certain aspects of streetscapes. Perhaps biosensors could provide a window into lay walkers' emotions in ways that are more reliable than they can identify themselves. They might also enable data to be collected from thousands of sensor-wearing participants as they move through their everyday lives, increasing both the scale and ecological validity of measurements compared with interview or survey methods.

Unsurprisingly, however, this vision for biosensing is tempered by technical and theoretical challenges to deploying them in field settings and meaningfully interpreting the data they produce. Sensor technologies have traditionally been designed for use in laboratory settings and can be disrupted or confounded by the movement, exertion, and diverse stimuli that are inherent to navigating real-world urban environments. Physiological measures also tend to be incomplete indicators of emotion, relating in many cases to autonomic activation—degree of stimulation—without necessarily indicating if that stimulation is positive or negative in valence. They may be incapable, for example, of distinguishing between stress and excitement (Healey, 2015), both of which involve activation, but with opposite valences, and clearly different implications for user experience. Ambiguity about appropriate interpretations of biosensory measurements has led researchers to assume they provide direct proxies for valenced emotions such as stress (Chrisinger & King, 2018; LaJeunesse et al., 2021), even if they may only reasonably indicate activation.

This chapter draws on built environment and sensing literatures, along with a field study examining biosensory responses among walkers, to investigate the capabilities of biosensors for evaluating emotional responses to urban streetscapes. The first part of the chapter examines the neurological foundations of physiological responses to emotions, how biosensors capture these physiological markers, how they can be reasonably interpreted, and how they have been previously deployed in built environmental contexts. In short, it offers a menu of biosensory options for urban environment research. The second part evaluates the efficacy of biosensory measures of electrodermal activity (EDA), cardiac activity, skin temperature, eye movements, and walking speed, for capturing walkers' responses to varying streetscape conditions along a six-block, real-world urban route. It examines whether biosensory signals were consistent between subjects, an indication of response generalizability, and how signals corresponded with streetscape and other environmental conditions along the route. Through both these parts, the

chapter examines which biosensory measures show both practical and theoretical promise for investigating how walkers respond to their environmental contexts.

Findings show that biosensors have substantial potential for application in research on walking and related environments, but encourage tempered expectations around the types of emotions biosensors may realistically and confidently detect. EDA, and particularly its underlying *tonic* component, demonstrated the greatest potential to reflect responses to walking environments. Compared with other biosensory measures, EDA tonic was most consistent across subjects and most clearly reflected changes in built environmental conditions at the block and sub-block levels. It was significantly correlated with features including buildings, businesses, green areas, street trees, parking lots, intersections, and one-way streets. When paired with valenced ratings, it suggested that these features elicited a range of emotions, including excitement in response to street trees, stress in responses to intersections, calm in response to green areas, and boredom in response to a parking lot. Emotional responses were not, however, always so consistent with expectations: windows looking into a restaurant appeared to elicit excitement among some subjects, and boredom among others. This suggests the potential for EDA to be a valuable approach for measuring walkers' emotional responses but demonstrates that it must still be interpreted cautiously and must be paired with measurements of valence to meaningfully interpret emotions.

Advancements in biosensory detection of valence, if this is even possible, may be crucial for making biosensors more useful for built environment research, as planners and designers may ultimately be most interested in understanding whether features are favorable or unfavorable. While there is limited empirical evidence of biosensory responses corresponding with valence, there remains no strong theoretical justification for these links. In this chapter's field study, heart rate variability (HRV) was correlated with EDA tonic in opposing directions depending on subjects' reported preferences, suggesting that EDA and HRV may be interacted to predict valence. To-date, however, there is no theoretical understanding of a neurological mechanism to support this relationship. Indeed, HRV is theoretically expected to indicate activation (Healey, 2015). The empirical and theoretical incongruity of this finding, and those from other studies that identify correlations between biosensory measures and valence, indicate a need for more basic research about how valence is expressed physiologically before it can confidently be measured in more applied contexts.

Biosensors are likely to play an increasing role in understanding human responses to walking environments and other urban spaces, but they remain an immature technology, particularly regarding how signals are processed to handle noise from naturalistic settings and enable comparison between individuals, and how they are interpreted to provide meaningful insights about emotions. As biosensors are increasingly integrated into consumer devices, such as smart watches, there is likely to be a glut of data that is attractive to urban researchers. It will be incumbent upon these researchers to become increasingly familiar with what these data do and don't tell them due to limitations in their spatiotemporal resolutions, sensitivity to environmental stimuli, and theoretical understandings of links between emotion and biosensory response. Biosensors are unlikely to be a silver bullet for understanding the emotions of city dwellers, but they will nonetheless offer a useful way to noninvasively measure how people react to the built contexts of their everyday lives.

4.2 Capabilities & Limitations of Biosensing

Biosensing has a narrow technical origin that has expanded into a broad scope of application. Nafus (2016) describes how electrical and biomedical engineers traditionally defined biosensors based on *how they work*: a class of technology that “combines a biological element ... with a physiochemical detector ... and converts some aspect of it into an electrical signal” (p. xiv). Some of the sensors I examine in this chapter, such as those measuring electrodermal activity (EDA), fit this narrow definition. As applications and approaches for biosensing have grown, however, biosensors are increasingly defined by *what they measure*. Nafus broadly positions biosensors as “technologies that indicate something about the body or the physical environment” (p. xiii). In essence, biosensing is the practice of “reading people” through instrumentation (Pentland & Heibeck, 2008).

A salient critique of this broadened definition is that it has nebulous boundaries. Is tracking location and auditory exchange (e.g., Pentland & Heibeck, 2008) a form of biosensing? Are travel surveys, or even public observations of urban spaces, such as Whyte’s (1988) video studies of walking and seating patterns in New York City Plazas, examples of biosensing? Human eyes and ears are themselves sophisticated sensors; does nearly any observation of a human subject fall under the biosensing umbrella? While it is philosophically intriguing to probe these definitional boundaries, the greatest value in biosensing—what distinguishes it as a useful methodological domain—is likely to be derived from more conservative examples. In literature examining human-environment interactions, biosensors tend to use electronic and computing technologies to detect physiological properties of human subjects (Müller & Fritz, 2015; Osborne & Jones, 2017). Increasingly, biosensors are small and mobile, so they are often discussed under the umbrella of “wearables” (Ploetz & Healey, 2018). Examining human emotion, or affect, is an increasingly common application for biosensors; they are closely associated with the field of *affective computing* (Healey, 2015). This chapter discusses biosensing chiefly within the scope of wearable and computational instruments for measuring physiological indicators of emotion.

Biosensing promises an approach for capturing objective data on human emotions that are more detailed and convincing than self-reports (Picard, 2015). Unfortunately, neither biosensing technologies nor scientific understandings of emotion are sufficiently well-developed to provide such unequivocal evidence. Biosensing, like other adolescent technologies, may present a certain degree of “false hope” that it will offer easy answers to difficult questions (Nafus, 2016, p. xxiii). Near-term biosensing research is likely to be as much methodological (e.g., investigating the *capacity* of biosensors to accurately and reliably capture emotional responses in various contexts) as it is topical (e.g., investigating how built environments influence emotion). Harnessing biosensing where it is practical and useful, and to advance it methodologically, must be balanced with more traditional subjective approaches for evaluating human-environment interactions. Even advanced biosensing research tends to triangulate sensor data with more qualitative evaluations of emotional response (e.g., Müller & Fritz, 2015), indicating the lack of conclusiveness currently offered by biosensing data.

4.2.1 Emotion & Physiology

Biosensors account for emotion by leveraging relationships between systems of emotion and physiological reactions in organs such as the skin, eyes, heart, other muscles, and brain. Relationships between emotion and physiology have been observed for centuries, but the precise

states of these relationships are still greatly debated. Ancient Chinese and Greek philosophers believed that emotion was manifest within different bodily organs and fluids, and that maintaining proper balance between them was vital for maintaining physical health. The 19th century American philosopher William James posited that emotions were the direct result of physiological states. Smiling, for example, would induce happiness. Charles Darwin also observed consistent relationships between emotion and physiology (Healey, 2015).

Whether physiology causes emotions, or the other way around, has itself been a matter for debate. Psychologist Stanley Schachter theorized that the two systems were inherently intertwined: emotion could cause physiological changes, and vice versa. The early neurologist Walter Cannon, however, noted that physiological changes were insufficiently nuanced to be the root of a much more complex field of potential emotions. He thought that emotion, therefore, must be a cognitive process (Healey, 2015).

The autonomic nervous system (ANS), the part of the central nervous system (CNS) that acts unconsciously and controls basic physiological processes, such as heartbeat and respiration, is core to contemporary neuroscientific understanding of the relationship between emotion and physiology. Emotion, which acts unconsciously but is clearly influenced by conscious perception and social experience, likely represents a critical link between the ANS and higher-order cognition. The ANS itself contains two systems that control physiology, each of which consists of spinal endings and nerves connecting to organs. The sympathetic nervous system (SNS) is responsible for controlling alertness and energy, mobilizing *fight or flight* reactions. The parasympathetic nervous system (PSNS), by contrast, sends signals related to restoration and relaxation. A resting-level balance between the SNS and PSNS is described as the autonomic tone. This modern neurological understanding of physiological control suggests that physiological states are structured along a continuum between stress and relaxation (Mai & Paxinos, 2011).

A widely adopted contemporary model of emotion is similarly structured around a continuum between relaxation and stress, often described as *activation*, but adds a second dimension accounting for *valence*, the spectrum between positive and negative emotions. The circumplex model of affect (Figure 4.1) suggests that the numerous emotional states recognized by traditional psychology literature as *basic* categorical emotions (e.g., Ekman, 1992) can instead be represented by linear combinations of the activation and valence dimensions (Posner et al., 2005). Whereas categorical models of emotion suggest that each emotion is controlled by a discrete neural system, dimensional models suggest that diverse emotions may be associated with a limited number of neural systems. The circumplex activation dimension, for example, has a notable correspondence to the relationship between the SNS and PSNS, which control stress and relaxation on a physiological level.

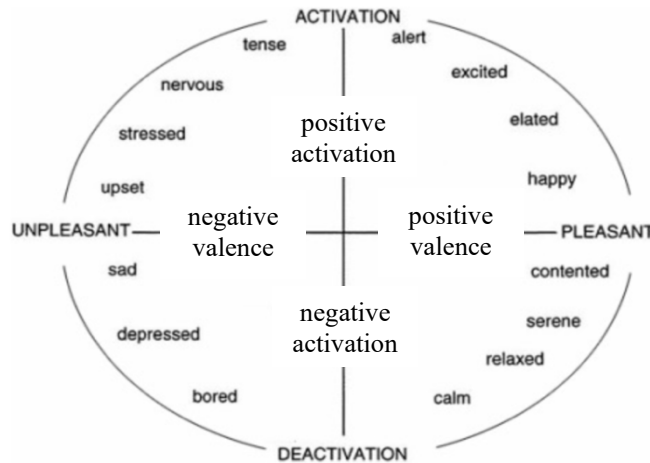


Figure 4.1. The circumplex model of affect
(Adapted from Posner et al., 2005)

The circumplex model reinforces how there may be many-to-one relationships between emotions and physiology. Physiological stress, to the extent that it is associated with emotional activation, for example, may be associated with many degrees of valence. Limited biosensing research suggests that valence may also be linked with physiology, though neural explanations for this linkage are unclear (Müller & Fritz, 2015).

Emotional theorists also continue to develop new models to better represent the range of emotional states and their links to neurology and physiology. While numerous studies empirically corroborate the two-dimensional nature of emotion, some have classified these dimensions differently: as positive and negative affect, tensions and energy, or approach and withdrawal (Posner et al., 2005). Others have postulated that three or more dimensions, are necessary to account for the range of emotional states. Lövheim (2012) suggests a three-dimensional model that relates levels of three neurotransmitting substances—dopamine, noradrenaline and serotonin—to eight basic emotions (Figure 4.2).

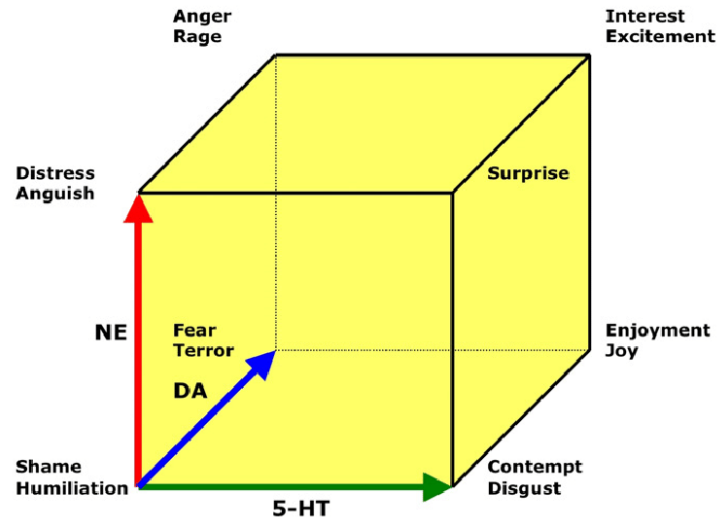


Figure 4.2. The Lövheim cube of emotion (From Lövheim, 2012)

Models of basic emotional categories also continue to emerge. Cowen and Keltner identify 27 distinct categories of semantic emotional responses to video stimuli. How these emotions map to physiology, however, remains undeveloped. Science about what constitutes emotion, what drives physiology, and how the two are related, are distinct areas of research. All of them are foundational for using biosensors to examine emotion, and none are sufficiently mature to concretely predict emotion based on physiological indicators. Biosensing data must be interpreted with these scientific limitations in mind.

4.2.2 Biosensing Technologies

A range of biosensing measures and associated tools are widely used in human-computer interaction (HCI) and affective computing studies (Calvo & D'Mello, 2010). I briefly describe several of the most widely used technologies, especially those that have been used for field research in the context of built environments.

4.2.2.1 Electrodermal Activity (EDA)

Electrodermal activity (EDA), also known as galvanic skin response (GSR), measures how electrical conductance of the skin changes in response to varying amounts of activation in sweat glands (Healey, 2015). Skin is normally an electrical insulator. Conductance increases with greater levels of sweat, even at a level that is not noticeable by touch or sight. Sweat production is a function of SNS activation and skin conductance has been found to be linearly associated with emotional activation (Lang, 1995). EDA has also been used to distinguish between emotions of anger and fear (Ax, 1953), conflict and non-conflict (Kahneman, 1973), and as a measure of stress (Healey, 2015). Because of its close relationship to the SNS, EDA is presumed to be primarily an indicator of emotional activation, as described by the circumplex model. Some researchers, however, have nonetheless found it to be useful as a predictor of affect (Healey et al., 2010).

Sweat glands on the palms of hands and soles of the feet appear to be most responsive to emotional stimuli. As a result, laboratory apparatuses for measuring EDA tend to be positioned

on the hands, often connecting an electrode to separate fingertips in order to measure the conductivity between them. Electrode gel can improve signal quality. In field studies, where such apparatuses are impractical, electrodes tend to be mounted on the wrist, arm, or leg. Wristbands such as the Empatica E4 allow EDA to be recorded wirelessly and non-invasively throughout normal activity patterns (Osborne & Jones, 2017). However, movement of electrodes, due to bumping or vibration during daily activity, can create spurious artifacts in data streams. Researchers cannot assume that field instruments will produce the same quality of data as their laboratory relatives.

EDA sensors provide a continuous data stream that is often interpreted as consisting of two components. The *phasic* component is made up of peaked features that represent responses to short-term events, what psychologists call *orienting responses* (Figure 4.3). The *tonic* component represents an underlying state of conductance in response to longer-term trends in activation. Tonic trends may be useful for understanding overall emotional state, while phasic peaks may help identify how environmental stimuli cumulatively shape the tonic trend.

Processing EDA signals in ways that are interpretable and comparable between subjects poses a substantial challenge. Signal processing algorithms have been developed for separating phasic and tonic components, yielding a phasic curve that depicts *skin conductance responses* (SCRs) which are normalized around a zero baseline, and a tonic curve that depicts a slowly evolving *skin conducting level* (SCL) (Braithwaite et al., 2015). Phasic SCRs can be further distinguished into *event-related SCRs* (ER-SCRs), which correspond with known stimuli (e.g., the audio startles Figure 4.3) and *non-specific SCRs* (NS-SCRs), which occur in absence of known stimuli (e.g., peaks 1 and 6 in Figure 4.3). Measures commonly extracted from these processed signals include the mean, variance, slope, minimum, and maximum of SCL; amplitude of ER-SCRs (vertical dashed arrows in Figure 4.3); rise time of ER-SCRs (time between local minimum and maximum associated with each ER-SCR); latency of ER-SCRs (temporal difference between a stimulus and an ER-SCR's local maximum); half-recovery time of ER-SCRs (time between an ER-SCR's local maximum and descending half its amplitude); and frequency of NS-SCRs (Braithwaite et al., 2015; Healey, 2015).

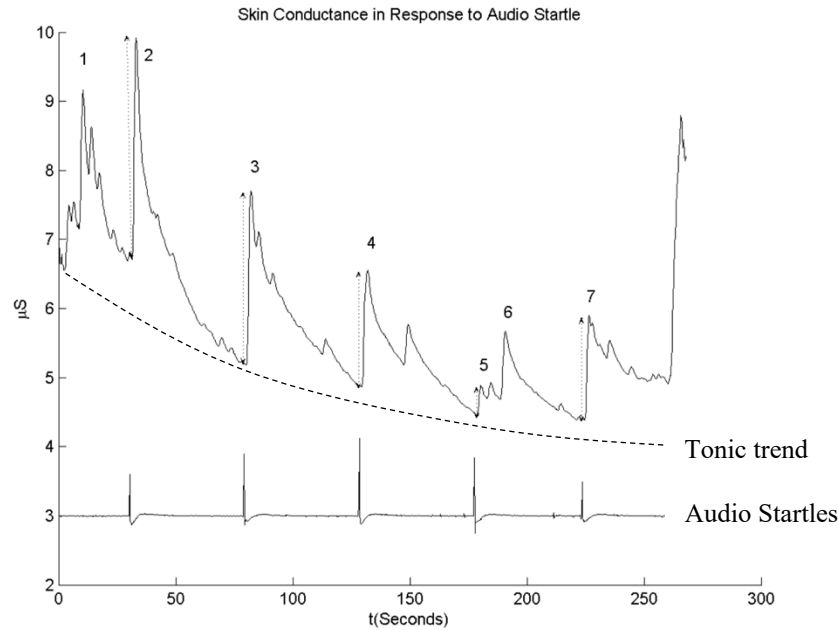


Figure 4.3. EDA (top curve) in response to audio startles (bottom curve). Phasic peaks are numbered; tonic trend is approximated by the dashed line. (Adapted from Healey, 2015)

Because sweating varies between subjects, and even within subjects based on climatic conditions and exertion, tonic SCL cannot be interpreted as a raw value but must be compared to a resting state or other benchmark. Study designs incorporating EDA generally include a period of baseline data collection, where the subject wears the EDA sensor at a resting state without any stimuli (Chrisinger & King, 2018). If EDA is being evaluated over long periods of time, segmentation of the data stream into appropriate windows, or *epochs*, and identifying baseline conditions within each epoch, can be a challenging but important aspect of the study design (Healey et al., 2010).

4.2.2.2 Cardiac Activity

Cardiac activity is closely linked with the ANS and has been found to indicate the emotions of fear and anger (Levenson, 1992), panic (Hofmann & Barlow, 1996), and appreciation (Healey, 2015; McCraty et al., 1995). Heart rate (HR), or pulse, is the most common measure of cardiac activity, but vasoconstriction, whereby blood vessels constrict and increase blood pressure, is another potentially useful property. According to Kahneman (1973), vasoconstriction is a defensive reaction that increases in response to pain, hunger, fear, and rage, and decreases in conditions of relaxation. Frijia (1986) also suggests that vasoconstriction may relate to affect. Stress is thought to be associated with lower HRV, whereby overall heart rate may be high, but the interval between means is consistent, while calm is thought to be associated with greater HRV—less consistency in inter-beat-intervals over time (Healey, 2015; Kim et al., 2018).

A number of technologies can be used to measure heart rate, ranging from consumer- to medical-grade. A much smaller suite of technologies can capture vasoconstriction. Electrocardiography (ECG) is the most accurate, but a relatively invasive option. Medical-grade equipment requires gelled electrodes that are mounted on skin that is shaved and cleaned (Healey, 2015). Consumer-

grade devices, such as chest strap heart rate monitors, rely on sweat in lieu of gel, so they work best on active subjects. These can also be uncomfortable and are invasive to install.

An increasingly popular alternative to ECG is *photoplethysmography* (PPG), which measures blood volume pulse using an optical sensor. These sensors are increasingly incorporated into smart watches (e.g., Apple Watch) and fitness trackers (e.g., Fitbit), which measure pulse on the back of the wrist. PPG has the benefit of being able to detect vasoconstriction, but these measurements are sensitive to movement, which can alter localized blood flows (Healey, 2015). Approaches for non-contact photoplethysmography, using cameras that detect subtle changes in skin color that correspond with pulse, make it possible that heart rate may someday be measurable noninvasively. This technology is currently limited to close-range photography that directly faces subjects, such as webcams (Poh et al., 2010). Aside from technical hurdles, such remote biosensing raises serious concerns about privacy.

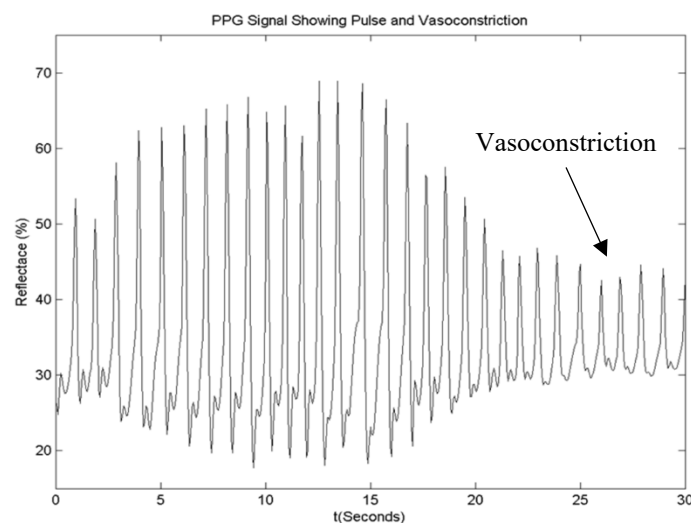


Figure 4.4. Photoplethysmography signal showing pulse and vasoconstriction.
(Adapted from Healey, 2015)

Heart rate, like EDA, is highly variable between and within individuals, so it is generally interpreted relative to a trial-specific baseline or normalized within epochs. HRV is the most common cardiac metric. Rate is calculated by measuring the time difference between pulse peaks (referred to as *R-R difference*), and can be summarized in terms of epochal mean, variance, range, the percent of R-R differences that exceed 50 milliseconds in length (pNN50), and the root mean square of R-R differences (RMSSD) (Healey, 2015). HRV measured over longer epochs tends to be considered more reliable, as it reflects larger samples of heart beats and can better accommodate poor or missing data. Epochs of 5 minutes are considered “short term” within the HRV literature, and epochs of 24 hours are common length for “long term” studies (Kim et al., 2018). A study by Salahuddin et al. (2007) found that “ultra-short term” epochs, between 10 and 50 seconds, collected with mobile sensors were sensitive to mental stress. This suggests the potential to use HRV to evaluate responses to block-scale streetscapes, so long as R-R data are reasonably complete within these short spatiotemporal units.

4.2.2.3 Skin Temperature

Skin temperature is affected by blood flow, which is mediated by vasoconstriction, localized muscle tension, and arterial blood pressure, all of which are affected by the ANS. Thus, changes in skin temperature can be used as an indicator of ANS activity (Kim & Kaplan, 2004). Lower skin temperatures are expected to correspond with increased activation (Haag, Goronzy, Schaich, & Williams, 2004). Skin temperature can be detected noninvasively with an infrared thermometer, infrared imaging, or thermopile attached to a body-mounted sensor.

4.2.2.4 Electroencephalography (EEG)

Electroencephalography (EEG) measures the amount and location of brain activity using a series of scalp-mounted electrodes. *Full EEG* employs hundreds of electrodes (typically 128 or 256) to map brain activity with high spatiotemporal precision. Commercial EEG equipment, acceptable for non-specialized laboratory and field research, may have only a few electrode channels (Berger & Dörrzapf, 2018; Stikic et al., 2014; Zink et al., 2016).

Large EEG arrays in laboratory setting have the potential to distinguish positive and negative valences (Davidson, 2004), levels of activation, and orienting responses (Leventhal, 1990). Smaller arrays that are more portable and more easily installed have traditionally been considered unreliable for examining emotional responses (Healey, 2015). Healey (2015) notes that recent studies examining how asymmetries in prefrontal cortex (PFC) activity relate to emotional states may allow EEG to be more efficiently leveraged for measuring emotion. For now, however, this application remains fairly undeveloped.

4.2.2.5 Eye Tracking

Eye tracking allows for monitoring and interpreting the physiology of the eyes, which are heavily integrated into environmental perception and cognition. To the extent that *interest* is a positive emotion, as Lövheim's cube model suggests, eye tracking may be used to identify instances and objects of particular interest. Shimojo et al. (2003) also demonstrate that gaze bias, the propensity to fix one's gaze on one thing more than another, can indicate preference. Since many other biosensory signals (e.g., EDA and cardiac activity) are more clearly related to emotional activation than to valence, eye tracking may provide a useful indicator of valence in research aiming to account for both circumplex dimensions.

Several types of eye tracking devices may be used in both laboratory and field settings with varying degrees of precision. *Electrooculography* uses electrodes placed on either side of the eye to track the small difference in electrical charge between the cornea and retina, which tend to be relatively positive and negative, respectively. As the eye moves, the motion of this electrical field can be passively detected and recorded. Another type of sensor, the *scleral coil*, is embedded into a contact lens and measures the angle of gaze relative to an externally generated magnetic field. This technique is considered the "gold standard" for precision, with resolution up to 0.01°, but it is highly invasive and only practical in laboratory settings (Navalpakkam & Churchill, 2014). Video-based pupil monitoring, by contrast, is non-invasive. For laboratory stimuli where subjects are facing a consistent direction, such as a computer monitor, a pupil tracking camera can be stationed remotely, such as being attached to the monitor. For field settings, or where subjects must have a full range of motion, eye-facing cameras are built into the frames of glasses or other head-mounted apparatuses, while a front-facing camera captures the subject's point-of-view, allowing gaze locations to be overlaid on simultaneously recorded video

for analysis (Morimoto & Mimica, 2005). Research-grade eye tracking glasses are now sufficiently small and unobtrusive to be worn in public spaces without drawing too much attention, though they are notably different than regular glasses; they might be confused with Google Glass or other augmented reality headgear. A major limitation of eye tracking technology is that it continues to be expensive—at least \$10,000 for research-grade glasses or other camera-based systems.

Eye trackers produce data about where subjects look, called a *fixation*, the length of each fixation, and the trajectory between fixations, called a *saccade*. Common eye tracking analyses examine the proportion of fixation time allocated to different objects or types of objects, the relative positions of primary fixation points (e.g., top, center, or edges of a stimulus), and the trajectories of saccades (Navalpakkam & Churchill, 2014). Fixation trends are often represented with density maps, which can be coded or otherwise analyzed for patterns (Figure 4.5). The variability of fixations can also be summarized based on the number of times, for example, saccades cross the centerline of a stimulus (Emo, 2014), or have a certain arc length.



Figure 4.5. Examples of fixation density mapping from eye tracking with still image stimuli.
(From Noland, Weiner, Gao, Cook, & Nelessen, 2017)

4.2.3 Biosensing in Built Environments

Biosensing has been employed in a number of studies investigating user responses to streetscapes and related built environments. The researchers undertaking these studies come from varied backgrounds. They range from psychology, neuroscience, and affective computing experts who have identified built environments as a salient application for biosensing technology, to those with subject-matter expertise in environmental design, geography, and transportation, for whom biosensing offers novel measurement capabilities. As such, the sophistication of technical background, research design, data analysis, and interpretation of biosensory data varies dramatically across this literature.

Some of these studies are sophisticated technically but not in application to built environment research and planning (e.g., Valtchanov & Ellard, 2015; Zink et al., 2016). Other researchers offer sophisticated understandings of how biosensing might be used for built environment research, but less sophistication in technical implementation (e.g., Osborne & Jones, 2017). Still others appear to be throwing biosensing technology at the complex questions of human-environment relationships for the sake of novelty, without well-developed technical or domain

knowledge (e.g., Berger & Dörrzapf, 2018). This variability highlights the importance of approaching biosensing as an interdisciplinary endeavor that requires substantial technical and theoretical grounding in neurology, psychology, and biosensing technology, as well as in the domain to which it is applied, such as environmental design or transportation planning.

This section demonstrates the breadth of research designs used to harness biosensing technologies in the context of walking and related environments, including several exemplary studies, and a few that demonstrate the potential for ill-informed study design and poor interpretation of biosensory data. It examines both laboratory studies that use multimedia stimuli and field studies that evaluate real-world stimuli with mobile sensors on moving subjects. Because biosensors have been more heavily used with bicyclists than pedestrians to-date, and there are substantial parallels between studying these two types of users—both involve movement through space, physical exertion, and direct sensory exposure to contextual environments—I also review bicycling studies that may usefully inform pedestrian applications.

4.2.3.1 Laboratory Studies

Laboratories offer the benefit of highly controlled settings in which subjects can be presented with finely tuned stimuli in a precise or random order for a set amount of time, diverse stimuli can be efficiently transitioned, and confounding influences on biosensory signals, such as physical exertion, can be largely eliminated. Laboratories also allow use of larger, potentially more sophisticated biosensing instruments that cannot be transported into the field.

A number of studies have used laboratory-based eye tracking to evaluate preferences among static environmental scenes. Compared with mobile eye trackers, laboratory trackers can be less expensive, more precise, require little setup for each subject, and fixation points can be efficiently matched to known stimuli rather than laboriously coded based on point-of-view video. Emo (2014) used a desktop eye tracker to examine how visual fixations reveal attention toward objects and focal points related to urban wayfinding. Subjects ($n=15$) were presented with images on a computer screen that showed street corners with two directions of possible travel. They were asked “Which way would you go?”, an *undirected* spatial question, and “Which way would you go to find a taxi?”, a *directed* spatial question. Emo found that real-world spatial characteristics of potential paths, such as their degrees of connectivity to other streets—described by *Space Syntax* theory as more “connected” (Hillier & Hanson, 1984)—were highly correlated with both directed and undirected decisions, and that fixation time and ordering of fixations were biased toward chosen directions. Moreover, structural aspects of the images, such as the longest sight lines, were correlated with fixation points. These results show how understandings about the structure of urban environments are highly informed by views from intersections, and that visual examination of these views are biased toward preferred environments.

Emo’s study demonstrates both a sophisticated understanding of urban design theory and of experimental design with biosensors. She randomized stimuli, included copies of images that were flipped on their vertical axis to limit right-left bias, displayed a disambiguating grey screen with a neutral fixation point between the stimuli, and compared eye movements associated with her spatial tasks to a non-spatial recall task (“Have you seen this image before?”) to control for more universal aspects of eye movement in analyzing the stimuli. As a result, she convincingly harnessed eye tracking without distracting from her wayfinding-related research goal.

Another study, by Noland et al. (2017) used eye tracking to examine the types of objects on which users focused most heavily while rating street scenes. Subjects ($n=20$) were presented with a series of images on a computer screen and asked to rate their preference for the image on a scale; a screen-mounted eye tracker located and timed their fixations. Fixation times within predefined areas of each image that corresponded to certain types of objects (e.g., signs, cars, storefronts), were summed. Fixations corresponding to New Urbanist design, such as people, pedestrian features, and greenery, were associated with positive image ratings, while fixations on cars and parking areas were associated with negative ratings. This study demonstrates how basic coding of image content can be paired with fixation data to examine what objects are being fixated on, but that applying meaning to these data may require supplementary information about preferences.

Hollander et al. (2018) similarly explored how eye tracking might be used to identify what urban design feature contributed to appraisals of preference and relaxation. They used stimuli from two urban neighborhoods, Boston's North End and West End, which represented traditional, human-scale urban design and more modern, car oriented urban design, respectively. The North End is reported to demonstrate *cognitive architecture* (CA) principles, including clear edges, face-like shapes, repeating patterns, sense of narrative/history, and biophilia, as described by Sussman and Hollander (2015). Subjects ($n=18$) were given seven seconds to view randomized images from each neighborhood before responding to questions about their likelihood of spending time in each place and their level of relaxation after viewing the image. Fixations were coded by object type.

Fixations in the North End images lasted longer than in those from the West End, and were focused primarily on façades, signage, and street edges, corresponding to several of the CA principles. Large open spaces in the West End images attracted few fixations—subjects appeared to be straining for details. This demonstrates how it may be possible to interpret the significance of fixation locations, but it cautions against “reading into” fixations as evidence for a preferred framework. Follow-up interviews, like those used by several of the field studies discussed below, might be useful for identifying how or whether subjects interpreted the elements on which they fixated.

Valtchanov and Ellard's (2015) paper examining cognitive load related to urban and natural scenes demonstrates a technically and theoretically advanced approach to eye tracking study design. Ellard is a neuroscientist who has recently directed his research toward what he calls “psychogeography” (Ellard, 2015). Unlike most other eye tracking papers, Valtchanov and Ellard's use blink rate, which is understood to be positively correlated to cognitive load, as their primary metric. They also use a combination of raw images and variants with their legibility adjusted in order to accentuate broad patterns of light and dark while removing edge details (low spatial frequency), or accentuate detail while removing broad patterns of contrast (mid-high spatial frequency). Subjects ($n=55$) viewed the randomized images on a screen for 15 seconds and were then asked to rate how pleasant they found the image and how well they could identify the objects in the image.

Interestingly, Valtchanov and Ellard found that pleasure, measured by the questionnaire, and cognitive load, measured by blink rate, appeared to be influenced by different aspects of the imagery. Nature scenes were judged as more pleasant than urban scenes, but this difference was obviated by removing edge details. Cognitive load was also higher for urban scenes, but not when broad contrast was removed. As such, they concluded that different spatial frequencies

drove preference and cognitive load. These results are difficult to translate into immediate design practice, but demonstrate the capacity for environmental valence and activation to be decoupled, yielding effects within all four quadrants of the circumplex model.

In a laboratory study using EEG, Roe et al. (2013) also examined differences in responses to urban and natural scenes. They use a 12-channel commercial-grade Emotiv EPOC EEG and proprietary software, the Emotiv Affectiv Suite, that automatically analyzes the signals into five *emotional parameters*: short-duration excitement, long-duration excitement, frustration, engagement, and meditation. Subjects ($n=20$) are first presented with each scene for 20 seconds on a large, flat-screen television while EEG signals are captured. Then scenes are displayed again while the subjects rate their overall attraction, willingness to visit, and whether the scenes make them feel happy-sad (valence) or calm-excited (activation). Emotional parameter measurements for each scene, calculated by the software based on the EEG signals, are further reduced using factor analysis to identify two key dimensions associated with activation (excitement and meditation) and interest (engagement and frustration). The activation factor was more correlated with urban scenes, while interest was more correlated with natural scenes. Natural scenes were consistently rated more positively on the questioners.

Similar to several of the eye tracking studies, this study also demonstrates the importance of parallel questionnaires for corroborating or contextualizing biosensed data. It also, however, demonstrates the difficulty of harnessing biosensed data, especially complex signals from EEG, without expertise in neuroscience—Roe and her colleagues are environmental scientist and architects. The emotional parameters provided by the Affectiv Suite, while conceptually attractive and conveniently labeled, were an analytical black box. What, exactly, these parameters indicate, is unknown to the reader, and also presumably the researcher. This issue might be avoided by processing signals with custom built, open-source, or at least highly documented software that offers a high degree of transparency about how outputs are being generated. Eventually, software that simplifies signal processing based on industry-standard methods may broaden the accessibility of biosensing methods to less technically sophisticated researchers. Currently, however, such simplifying software raises questions about the reliability and meaningfulness of its outputs.

4.2.3.2 Walking Studies

A number of studies outfit walking subjects with mobile biosensors to capture their experiences in more realistic settings than could be practically reproduced in a controlled laboratory. Osborne and Jones (2017) take an inventive approach to a comparative laboratory and field walking study to evaluate affective responses using the same array of biosensors in both settings. In the field study, subjects ($n=30$) were recruited in Birmingham, UK and asked to take an unaccompanied walk around their neighborhood while wearing an Empatica E4 wristband to track EDA, blood volume pulse, and skin temperature. They also wore a GPS and a chest-mounted GoPro camera approximating their fields of view. Following the walk, subjects participated in a qualitative interview where they watched the GoPro video and discussed their emotional responses to the spaces they passed through. The laboratory study was similar except that subjects ($n=25$) were instructed to take a 20-minute exploratory “walk” through the virtual world of the *Assassin’s Creed: Syndicate* computer game, which simulated 19th century London. They wore the same biosensors, and their screen view was recorded by a video camera. The laboratory setting was

less realistic than the field, but it reduced potential signal errors related to motion, or confounding influences of exertion on EDA, pulse, and skin temperature.

Osborne and Jones (2017) qualitatively examined the three types of data—EDA signals, interviews, and video—for corresponding evidence of activation, valence, and the environmental conditions that might have triggered them. They find some similarities, but also major differences. Patterns in EDA data, for example, were inconsistent between subjects. Some subjects exhibited very little fluctuation despite substantial environmental differences, while others exhibited broad (i.e., tonic) fluctuations, and still others exhibited spikey (i.e., phasic) fluctuations. This indicated substantial variability in sweat gland physiology between individuals. Among those with EDA peaks, they rarely corresponded neatly with subjects' recollections of emotion or video evidence of a major trigger. As expected, the field data were substantially noisier than those from the laboratory.

Osborne and Jones conclude that while biosensing might ideally be considered a window into somatic and emotional responses, it needs to be treated with caution until there are more established methods for interpreting its meaning. They also caution that there is danger in using new technology purely for its novelty; there should always be a clear purpose for its application. Otherwise, less sophisticated and proven techniques, such as interviewing, may be more useful.

Chrisinger and King (2018) also used EDA combined with photographic evidence and qualitative assessments to examine how built environments along walking routes affected stress. Their subjects ($n=14$) were also fitted with the Empatica E4 wristband but were guided along a pre-defined walking route in a central San Francisco neighborhood. While they walked, subjects were asked to use a customized smartphone app to take photographs of scenes or objects and rate positive or negative valences—like or dislike—for these features. EDA data were normalized against baseline measurements taken prior to the walk, and geolocated based on timestamped correspondence to a GPS trace. Photographs were also geolocated. Patterns in the EDA signals and valenced ratings of coincident photographs were then analyzed spatially.

They found that EDA was generally lower alongside major streets, offices and vacant buildings, which they interpreted as more stressful, and higher along smaller streets and mixed and residential land uses, which they interpreted as less stressful. While they demonstrated differences in EDA between environments that might be colloquially understood as more and less preferable for walking, their results counterintuitively suggested that stress and activation were inversely related. The circumplex model, by contrast, positions stress as a high-activation state. The inconsistency of Chrisinger and King's (2018) results with theoretical understandings of relationships between EDA, activation, and stress demonstrate both the lack of conclusiveness about these relationships and the potential to inappropriately interpret EDA as a direct indicator of a particular emotion.

Chrisinger and King (2018) further found that EDA tended to be higher around photographs that were rated positively than those rated negatively. On the surface, this suggested that EDA might be a useful predictor of valence. However, it might also have simply indicated that subjects' positive emotions within the particular context of their study were skewed toward high-activation states, such as excitement, and their negative emotions were skewed toward low activation states, such as boredom. Perhaps environments with low EDA were not stressful, but instead boring? The ability to cross-reference EDA with measures of valence may allow for a much more precise understanding of emotional context. While Chrisinger and King (2018) appeared eager to use

EDA to indicate stress versus calm, they may have instead been dominantly capturing excitement versus boredom.

LaJeunesse et al. (2021) similarly aimed to evaluate EDA as a proxy for stress among urban walkers, though they examined more naturalistic trajectories tracked by GPS during their subjects' everyday activities. They collected data from 21 walking trips in Chapel Hill, North Carolina that were made by 15 university students and staffmembers—some subjects made more than one trip—fitted with Empatica E4 wristbands and GPS trackers. Both EDA and heart rate (HR) measurements were collected and aggregated within 5-second intervals. The locations of these intervals were then mapped and used to summarize built environment characteristics along them. Mixed-effects regression models were used to predict mean and maximum EDA values within each interval as a function of subject demographics, road type, presence of sidewalk, traffic volumes, and adjacent land uses. Rather than normalizing EDA values prior to modeling, random intercepts were fit for each of the trips. Models predicting mean and maximum HR were structured similarly.

Modeling results demonstrated higher EDA levels along roadways with higher traffic volumes, and lower EDA along off-street paths, consistent with expectations of stress caused by vehicular traffic. EDA was also higher in commercial, industrial, and mixed land uses compared with residential, campus, and park settings. Likewise, HR tended to be higher in mixed land use contexts and in relatively higher-traffic environments. These results were consistent with expectations that environments with higher levels of land use and traffic activity would stimulate higher autonomic responses, reflected both by EDA and HR in similar ways. It was notable that LaJeunesse et al. (2021) used fairly straightforward approaches to summarize biosensory measures, evaluating means and maximums of raw EDA and HR, and nonetheless demonstrated sensitivity to environmental contexts and associations that were consistent with expectations, even with only a moderately large sample. This suggests that planning researchers may be able to draw value from raw EDA measures even without separating phasic and tonic components, or from HR even without calculating HRV. These processing steps are common in neurological research investigating subtle responses; they also allow for more direct interpretation based on theories of autonomic response (Healey, 2015). In planning applications aiming to detect major differences in response between highly contrasting environments, however, this complex signal processing may add unnecessary complication.

Hollander and Foster (2016) applied EEG in a pilot walking study of the same cognitive architecture (CA) principles examined by Hollander et al. (2018). They used a consumer-grade device, the NeuroSky EEG, which algorithmically generates two parameters related to attention and meditation, similar to the algorithmically identified parameters used by Roe et al. (2013). In Hollander and Foster's (2016) study, college student subjects ($n=5$) walk along a route transecting between Boston's North End and West End, the same neighborhoods used by Hollander et al. (2018). However, because the EEG signals, even in their preprocessed, two-parameter state, were too noisy to examine as a continuous measure throughout the walk, subjects were asked to stop at 16 points along the transect to collect a stationary measurement that approximated the sudden revelation of photographic stimulus, though with greater peripheral and other sensory context.

At each stop, subjects were primed by looking at a white piece of paper with a black "x" to focus their attention for 10 seconds. EEG measurements during this prime were taken as a baseline. The prime was then removed from view. The change in each EEG parameter was recorded on a

three-point scale: increase, neutral, or decrease. They found that attention and mediation parameters were both higher in the North End than the West End, which supports the premise that CA factors have a positive influence on urban experience. The nebulousness of the EEG parameters, the coarseness of their measurement, and their very small sample size, however, substantially limit confidence in their results.

An eye tracking study by Fotios et al. (2015) examined “critical visual tasks” of pedestrians in order to guide lighting design for residential roads. Subjects ($n=40$) were outfitted with an eye tracker mounted to a helmet and tethered to a laptop in a backpack worn by the subject. Each subject walked a route circumnavigating the University of Sheffield campus, once during the day, and once at night, in a randomized order and direction. The occurrence of a “critical visual task” was identified by slow reaction time to a concurrent task: pressing a button in response to an auditory beep. Subjects were instructed to complete this task throughout the walk. Point-of-view videos with overlaid fixation points were analyzed to categorize the objects on which subjects fixated at “critical” times, according to the delayed response. Among these, other people and path-related objects were the most frequent categories of fixation. These results reinforce how people, not environmental design, may be a crucial component of pedestrian attention and affect.

4.2.3.3 Bicycling Studies

A substantial body of literature on biosensing with transportation users focuses on bicyclists. Because bicyclists, like walkers, are relatively exposed to their environments, experience them at fairly low speeds, experience personal movement and exertion while being outfitted with sensors, and require small and lightweight sensing equipment that can be carried fairly innocuously, they offer a useful model for studying walkers.

A 2018 study in Portland, Oregon used EDA from fingertip electrodes, GPS location, and point-of-view video to examine which traffic and bikeway design features influenced bicyclist stress (Caviedes & Figliozi, 2018). Subjects ($n=5$) with varying levels of cycling experience each rode a predetermined route twice: once during peak traffic and once off-peak. EDA data were also collected for five minutes before and after each ride to establish a baseline level. After the ride, subjects identified locations where they remembered feeling stressed on a map of the route. EDA data were used to produce a response measure based on the location and intensity of SCRs. The authors interpreted this response measure as an indicator of stress.

In general, Caviedes and Figliozi (2018) found substantial positive associations between the locations of subjectively reported stress and SCR-based response. A random effects linear model was used to estimate SCR-based response based on spatially concurrent street environment and traffic condition data. While peak hour had a significant positive association with response, indicating that traffic was stressful, intersections did not have a significant effect, despite broad understanding of intersections as stressful for bicyclists. Also surprisingly, they found that riding along a bike lane yielded higher SCR-based response, indicating more stress, than riding in traffic along a shared roadway. Riding along a multiuse path, meanwhile, yielded lower response, indicating lower stress, as might be expected. The authors suggested that parked cars and higher traffic along streets with bike lanes might, counterintuitively, make them more stressful. These discrepancies from theoretical assumptions suggest either that the EDA data were not accounting for stress in the way the authors intended, or that more detailed controls for

variables such as traffic volume are necessary to appropriately gauge the relative stress of bicycle infrastructures.

A paper by Berger and Dörrzapf (2018) also used EDA to track bicyclist stress in one experimental study, and eye tracking to examine bicyclist attention in another, posing the question, “Can new sensor technologies capture objective, valid, and reliable data to determine what makes cycling stressful?” (p. 527). This vague research agenda, and the paper’s problematic research design, make it a prime example of how biosensing may be harnessed with inadequate understanding of its interpretation or its technical limitations. The first study examined how cyclist stress might be induced by headwind. Subjects ($n=11$) were fitted with an EDA sensor while riding routes with varying amounts of headwind. EDA signals were mapped, and the authors interpreted the mapped signals as direct evidence of stress, noting that areas with greater headwind exhibit higher EDA. They appeared to ignore, however, that EDA is highly sensitive to sweat induced by exertion, which more likely explains such a sharp correlation with headwind.

In their second study, Berger and Dörrzapf (2018) used eye tracking glasses to examine whether cyclists were distracted by construction sites along two study routes. Automated analysis of the fixation points using the tracker manufacturer’s proprietary software revealed “moderate focus on construction sites.” While this paper is, arguably, a case study in poor research design and even poorer interpretation, it underscores how biosensing, especially when researchers, reviewers, and editors do not fully understand it, may provide an attractive but false sense of precision and objectivity. Berger and Dörrzapf note that “the analysis software for the gaze data provided by TobiiGlasses [*sic*] should guarantee the objectivity of data interpretation” (p. 531). Did they suspect that it would guarantee the meaningfulness of the data, too?

Mantuano et al. (2017) execute a substantially more robust study using mobile eye tracking to investigate what types of objects demand bicyclist’s attention, similar to the Fotios et al. (2015) study of pedestrians. They defined a fixed cycling route with varying path attributes and environmental contexts in the city of Bologna, Italy, and outfitted subjects ($n=13$) with eye tracking glasses. Like other studies, fixation objects were coded by examining frame-by-frame video with overlaid fixations. Using fixation frequency as an indicator of bicyclist attention, they found that path discontinuities (e.g., intersections) and obstacles (e.g., pedestrians) demanded the greatest degree of attention. These results are not surprising, but they do indicate that biosensing can yield conclusions with fairly direct practical application, such as the heavy importance of intersection design for bicycle network planning.

Fitch-Polse (2018) examined the effectiveness of HRV as an indicator of traffic stress among cyclists, using a sophisticated research design to control for aspects of HRV associated with physical exertion rather than psychology. Subjects ($n=20$), all of whom are female UC Davis undergraduates who bicycle regularly for transportation, participated in (1) a pre-experiment survey on general health, attitudes about bicycling comfort and safety, travel behavior, and socio-demographics; (2) a computerized stress-inducing task, during which there is no physical exertion; (3) a off-street path bicycle ride, where there is no stress from traffic; (4) an on-road bicycle ride, where there *is* stress from traffic; (5) surveys immediately following each ride, and (6) an open-ended interview about the rides. During the computerized task and bicycle rides, participants were fitted with an ECG. GPS and point-of-view cameras were carried on bicycle rides to track location and environmental context. Author-programmed signal processing techniques based on HRV research were used to subtract baseline HRV measurements from on-

road measurements, indicating the portion of HRV associated with traffic. Fitch-Polse found measurable differences in traffic-induced stress between small local roads and larger, collector and arterial roads, but not between the latter two categories. Like other studies using biosensing in field contexts, he also noted substantial between-subject heterogeneity in responses to the same environments, even after controlling for baseline HRV, making it difficult to draw definitive conclusions about environment-physiology relationships.

Despite the complexity of EEG analyses, Zink et al. (2016) used a mobile EEG with 24 channels on bicyclists to disentangle influences on brain activity from real-world environmental stimuli and physical activity. This study demonstrated a sophisticated research design informed by an advanced understanding of EEG technology and neuropsychology, though its conclusions are not directly relevant to environmental design practice. It does, however, suggest that mobile EEG might be used to conduct a robust study with research questions more specifically tailored to built environment topics.

Zink and colleagues use a three-condition study design to examine brain activity while subjects ($n=15$) are sitting on a stationary bicycle while outside facing a natural setting (“still”); pedaling on the same stationary bicycle (“pedal”); and riding a bicycle on an adjacent route (“move”). During all conditions, subjects were required to attend to an auditory *oddball* task: counting instances of a tone played at random intervals through a headphone. This task created a comparable, baseline cognitive load throughout all conditions. The researchers found that, compared with the “pedal” condition, subjects in the “move” condition had a substantial increase in cognitive load, demonstrating that the process of navigation and moving sensory experience had a substantial effect on brain activity above and beyond the physical exertion of riding a bicycle.

4.2.4 Potential for Advancing Application

Existing research indicates substantial promise for using biosensors to understand emotional responses to built environments, but also the early state of research in this area. Studies vary widely in the sophistication of their experimental designs, analytical methods, and interpretation of their results. Researchers from the fields of neuroscience and psychology apply biosensors and interpret their data with careful attention to what they do and do not explain. Built environment research demonstrates exciting potential for applying biosensors but tends to interpret the meanings of biosensory signals more crudely, such as assuming that EDA is a direct measure of stress. Advancing the use of biosensors in built environment research will require more critical analysis of which biosensory measures are sensitive to particular environmental stimuli, and what, precisely, these measures indicate about subjects’ responses. This will require additional empirical evidence both of how biosensory measures reflect environmental features, and theoretical understanding of how the biosensory responses relate to emotions.

The next section contributes to these goals by using a field study to examine how several biosensory measures, collected side-by-side with the same subjects and stimuli, reflect responses to different walking environments. The results elucidate which measures may be most useful for built environment researchers going forward, and what types of conclusions may reasonably be drawn from these data.

4.3 Field Study Methods

The field study was designed to examine consistency in responses between subjects and associations with environmental features for six biosensory measures collected along a real-world walking route. An Empatica E4 wristband was used to collect EDA tonic and SCRs, HRV, and skin temperature measurements. In lieu of a head mounted sensor for tracking eye movements, data about side-to-side glances were collected manually by observing subjects' head movements as they walked. Walking speed was similarly collected by timing when subjects passed predetermined markers along their route. While these latter measures do not conform with popular conceptions of biosensory data collected with an electronic instrument, they nonetheless constitute measurements of human physiology that may reveal subconscious responses and, as such, were considered biosensory measures for the purposes of this study. Parallel data were also collected about environmental preferences as an indicator of emotional valence. These biosensory and preference data were collected from 27 participants who walked along a predefined urban route with variable built environmental characteristics. Consistency in biosensory measures between subjects was evaluated graphically and with descriptive statistics. Associations between biosensory measures and with environmental characteristics were evaluated with mixed-effects linear models.

Data for this study were collected alongside those for the previous chapter, where the subject recruitment process and characteristics, study site, and the field protocol used for data collection are described in greater detail.

This study was approved by the University of California, Berkeley's Committee for the Protection of Human Subjects (Protocol ID 2019-08-12447).

4.3.1 Subjects

Subjects were recruited through two organizations at the University of California, Berkeley (UCB): The Experimental Social Science Laboratory (XLab) and the Osher Lifelong Learning Institute (OLLI). The XLab maintains a pool of UCB students, faculty, staff, alumni, and community members unaffiliated with the university, who are interested in participating in research and receive regular email advertisements for opportunities. OLLI is a membership organization that offers classes and lectures to adults aged 50 and above and allowed me to recruit subjects through an email newsletter to their members. All prospective subjects from both sources took a short online signup survey that collected information about demographics and everyday walking behavior. These data were used to select final subjects who represented a broad range of demographics and who had a variety of travel behavior profiles. This sample was not intended to be representative of the general population, but rather capture a broad spectrum of demographics and everyday experiences. The recruitment pool specifically excluded undergraduates to promote diversity in age and life experience.

Selected subjects were invited to sign up for individual field sessions scheduled in February and March of 2020. Twenty-seven sessions with complete biosensory data were completed prior to pandemic lockdowns in March 2020. Two sessions yielded incomplete data due to sensor malfunction, and 21 additional sessions were not completed due to pandemic-related restrictions on human subjects research.

Demographic and travel behavior characteristics of the 27-subject final sample are presented in Table 4.1. Self-identified genders were skewed slightly female. Ages were skewed young, with

44% of subjects under the age of 30. Subjects identifying as white, either solely or in combination with another race or ethnicity, made up 44% of the sample. Unsurprisingly, given the university-based recruitment pools, the sample was highly educated, with nearly 60% holding a Master's or Doctoral degree. The vast majority of subjects both walked and drove regularly and lived in places where walking was practical for accessing at least some daily activities, indicating that they were habituated to an urban walking environment such as the study site.

Table 4.1. Self-identified subject demographics and travel behavior characteristics

	Number of Subjects
Gender	
Female	14
Male	12
Non-binary or other	1
Age	
18-29	12
30-39	4
40-49	3
50-59	3
60-69	2
70-79	2
80-89	1
Race/Ethnicity*	
Asian	6
Black or African American	2
Hispanic or Latino	7
White	12
Other	1
Education	
High school graduate, diploma or equivalent (GED)	1
Some college credit, no degree	3
Bachelor's degree	7
Master's degree	13
Doctorate degree	3
Do you typically use a private automobile to access daily activities such as work, school, or shopping?	
Yes (use an automobile daily)	18
No (don't use an automobile daily)	9
Where you live, is it possible for you to access daily activities such as work, school, or shopping without a private automobile?	
All daily activities accessible without an automobile	14
Some daily activities accessible without an automobile	11
No daily activities accessible without an automobile	2
How often do you walk either for transportation or recreation?	
Walk almost daily	22
Walk every few days	4
Walk about once a week	1
Walk less than once a week	0
Almost never walk	0
Which best describes your access to an automobile?	
I have my own automobile.	11
I share an automobile with other(s) in my household.	1
I do not have regular access to an automobile, but other(s) in my household do.	10
No one in my household has regular access to an automobile.	5
* Race/Ethnicity counts exceed totals because subjects could identify multiple races and ethnicities.	

4.3.2 Study Corridor

Field sessions were conducted along a six-block section of urban street, approximately 0.3 miles long, adjacent to the UC Berkeley campus and downtown Berkeley (Figure 4.6). The corridor was selected to offer a variety of streetscape stimuli to which study subjects might respond emotionally in different ways, including more and less actively utilized storefronts and other business frontages, gas stations, blank walls, parklike areas, street trees, and a parking lot. While streetscapes may be conceptually understood as encompassing the roadway, I reserve “streetscape” to draw attention to features outside the roadway that are less commonly evaluated in transportation research. The corridor also offered variability in roadway features, including intersection crossings, street parking, bike lanes, and a change in traffic pattern from two-way to one-way.

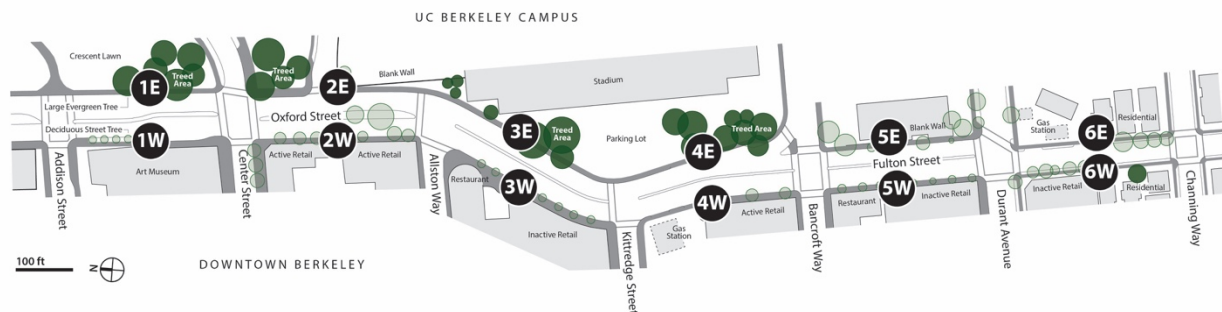


Figure 4.6. The six-block study corridor.
Labels indicate block numbers along east (E) or west (W) sides of the street.

The corridor was organized into two sides of the street—east and west—and blocks numbering 1 through 6 from north to south, the direction that subjects walked while collecting biosensory data. (Note: this block numbering is opposite that used for the interview-based study in the previous chapter.) Block faces—one side of the street on a given block—were used as units of analysis for subjects’ environmental preferences and for coarse aggregation of biosensory and environmental measures. Block faces were additionally broken into 5-meter segments for more finely grained analyses.

All subjects walked along the same corridor, beginning with block 1 and ending with block 6, though the side of the street was randomized between subjects. As such, effects from order of exposure and distance along the walk, such as increased exertion, were held approximately constant between subjects. Order and distance might have alternatively been controlled by randomizing the direction in which subjects walked, staggering the start and end locations so each subject encountered subsections of the corridor, or using a circular route along which subjects could start at randomized points. A circular route with appropriate streetscape variability, however, could not be identified in a location that was convenient for subjects to access. Randomizing direction along the straight corridor, meanwhile, posed challenges for access without priming some subjects by walking along the corridor itself, and still would have biased end blocks compared with those in the middle. Holding walking direction constant exposed all subjects to approximately the same biases, minimized exposure to the corridor directly before the experiment, and minimized interruptions to data collection that might have resulted from starting a stopping at different points. Identifying a circular route might be a

valuable refinement for future research, though this may still pose practical challenges, such as guiding subjects to the different starting positions without priming their responses.

4.3.3 Data Collection

Data were collected through a field protocol that I conducted with each subject individually. The protocol consisted of two main parts: (1) a *sensor walk* from north to south along the corridor to collect the primary biosensory, glance, and walking speed data, and (2) a *walking interview* from south to north along the opposite side of the corridor. Ratings for each block face were collected during a structured component of the walking interview. Thirteen subjects conducted the sensor walk on the east side, while 16 conducted it on the west.

The Empatica E4 wristband included sensors for electrodermal activity (EDA) at a sampling frequency of 4 Hz, blood volume pulse (BVP) at 64 Hz, and skin temperature at 4 Hz, along with a three-axis accelerometer that detected movement at 32 Hz. The E4 is a medical-grade instrument that was originally designed for research and clinical applications in neuroscience, such as treating epilepsy, but is opportune for research in naturalistic settings due to its portability and discrete form—it is similar in size and shape to a large sports watch.

Subjects were fitted with the E4 while standing on the sidewalk where I met them near the north end of the study corridor. Most subjects accessed this location from directions perpendicular to the corridor (campus or downtown Berkeley), minimizing their exposure to it prior to the experiment. The E4 collected baseline data as subjects stood stationary for several minutes, during which I further explained study procedures and addressed questions. Collecting baseline data while stationary was important for minimizing motion artifacts and exertion effects that might impact sensor signals while walking. Baseline data were later compared to those from the sensor walk to identify data quality issues and normalize EDA signals. Accelerometry data were used to identify baseline periods with minimal movement.

During the sensor walk, subjects walked independently from north to south along the study corridor on their assigned side. Subjects were asked to imagine that they were commuting home from a workplace somewhere near the north end of the corridor to a home location somewhere near the south end. For safety, they were asked to comply with walk signals at intersections. Otherwise, they were encouraged to walk however they might normally. I followed approximately 10–20 meters behind the subject and did not interact with them until they reached the south end of the corridor.

While following subjects, I observed and tallied their side-to-side glances to provide a rough measure of eye fixations in lieu of a more conventional electronic eye tracking device. This measure, while extremely coarse, was collected to examine the hypothesis that eye fixations might be associated with preference: perhaps a more preferable frontage would motivate subjects to look at it more frequently. Glances were defined as a clearly visible turn of the head to the left or right. In the case of a prolonged turn of the head, I continued to mark glances approximately once per second until the subject turned back to center or the opposite direction. I originally planned to outfit a subsample of subjects with a mobile eye tracking device from Pupil Labs, allowing me to validate the glance data against more robust fixation data. These eye tracking data, however, were never collected owing to pandemic-related fieldwork cancelations. While unvalidated, the glance data nonetheless served as a potential indicator of where and whether subjects engaged with features alongside the walking route.

I also observed subjects' walking speeds by timing when they reached consistent markers at the beginnings and ends of each block. Markers were located on either side of intersections in order to exclude time spent waiting for walk signals or crossing intersections. Block-level speeds were then calculated by dividing block lengths—the distances between markers—by subjects' walking times for each block. Pilot testing indicated that this approach for observing subjects' locations and speeds was considerably more precise and reliable than tracking with a GPS device.

Timestamps for glances and block markers were collected with an iPad app configured to log times when I pressed on-screen buttons assigned to specific events (e.g., “right glance,” “left glance”, “block 2 start,” or “block 2 end”). This allowed me to record timestamps with minimal latency and without drawing substantial attention from passersby.

Subjective ratings for each block face were collected as part of a semi-structured walking interview as I accompanied subjects back along the opposite side of the study corridor. Stopping near the center of each block, subjects were asked to take a photograph of a memorable characteristic—good or bad—of each block face on an iPad and then use the photographs to rank the block faces from most to least preferred for walking. The photographs helped subjects remember block faces they had evaluated earlier, since not all block faces could be viewed simultaneously in real life. This procedure constituted a compromise between real-world stimuli, which offer subjects an unparalleled depth of understanding about complex environments, and photographic stimuli that enabled side-by-side comparisons but were sensorially constrained. Subjects in this study were able to make a degree of side-by-side comparison between block faces that directly faced one another and those visible up or down the street, but the photographs were useful for reminding subjects what they liked or disliked about block faces that were out of view.

At the end of the interview process, after subjects had ranked all twelve block faces along the corridor, they were asked to rate each block face on a Likert scale between zero and ten, with zero represented by the block face along which they would least prefer to walk, while ten was represented by the one they most preferred. As opposed to the initial ranking, the rating gave subjects an opportunity to indicate whether block faces were equally favorable or if there were substantial separations in degree of favorability that were not adequately represented by the ranking. Again, their personalized photographs helped subjects remember each block face while rating.

Streetscape features were tabulated within 5-meter-long segments along each side of the study corridor. These were coded as binary indicators of whether a given feature existed alongside each segment, as determined by aerial photography, street-level photography, and field observations. Features included sidewalk-adjacent buildings, street-facing transparent windows, storefronts, lawn, street trees, park-like areas, gas stations, blank walls, bike lanes, on-street parking, and bus stops.

4.3.4 Data Processing

Data collected during the sensor walks were processed to locate them along the study corridor, clean abnormalities, separate EDA tonic and phasic components, and identify SCRs.

Timestamped E4 and glance data were located along the study corridor based on observations of when subjects crossed markers at the start and end of each block. Time differences between start and end markers defined the temporal extents of each block or each subject. Block-level linear

references for each data point were then interpolated by assuming that subjects walked at a constant speed within each block.

EDA data from each subject were processed to normalize signals that varied substantially in range between subjects, separate tonic and phasic components, identify SCRs, and adjust for linear trends reflecting the exertion of walking along the study corridor. Normalization was conducted by subtracting the minimum and dividing by the range to improve comparability between subjects, then subtracting the mean and dividing by the standard deviation to yield centered and consistently scaled signals (Chrisinger & King, 2018; Healey & Picard, 2005). Tonic and phasic components were then separated, and SCRs were identified from normalized EDA signals using the NeuroKit2 Python package, an open source toolkit for biosensory data processing developed by researchers in neuropsychology (Makowski et al., 2021). SCR's were identified using four different methods—the default NeuroKit method that examines the distance between local maxima, along with methods by Gamboa (2008), Kim et al. (2004), and van Halem et al. (2020)—to enable comparison.

The E4 automatically calculated R-R intervals when BVP signal was sufficiently clear, as determined by a proprietary algorithm. I also independently calculated R-R intervals from raw BVP signals using the HeartPy Python package (van Gent et al., 2019). Following Fitch-Polse (2018), I used standard deviations of R-R intervals as a measure of HRV. These were calculated for each block face, following the recommendation by Laborde et al. (2017) to use discrete epochs rather than rolling windows to promote interpretability of HRV statistics. HRV was calculated from both the E4-derived and HeartPy-derived R-R intervals to compare between them.

4.3.5 Analysis

The quality and characteristics of biosensory measures were evaluated through timeseries visualizations and descriptive statistics. Relationships between EDA tonic, other biosensory measures, subjective preferences, and environmental factors were then evaluated using mixed-effects regression models that controlled for non-independence of biosensory measures within subjects. Figure 4.7 shows the directed acyclic graph (DAG) used to conceptualize causal pathways between environmental features, the primary treatments of interest, and EDA tonic. The relationship of foremost interest was between environmental factors and EDA tonic, across the top of the diagram. Backdoor pathways through non-EDA biosensory measures were controlled by including these measures as covariates in the models. Pathways through preference were controlled by estimating separate models with subsamples stratified into high (rating > median) and low (rating < median) preferences. This positioned preference as a mediator between environmental factors and EDA tonic. Environmental factors such as time of day, weather, and air temperature were not accounted for and may have influenced both biosensory measures and preferences, though similar studies have also treated these factors as sources of random error and they were likely controlled, at least in part, by within-subjects normalization of biosensory measures. All field sessions were conducted during daylight hours with fair weather and temperatures between approximately 50 and 70 degrees Fahrenheit. Unmeasured personal and social factors may have also confounded environment-EDA relationships but were not controlled, limiting causal interpretation. Moreover, EDA tonic may have reciprocally affected non-EDA biosensory measures and preferences, but the models assumed only unidirectional relationships.

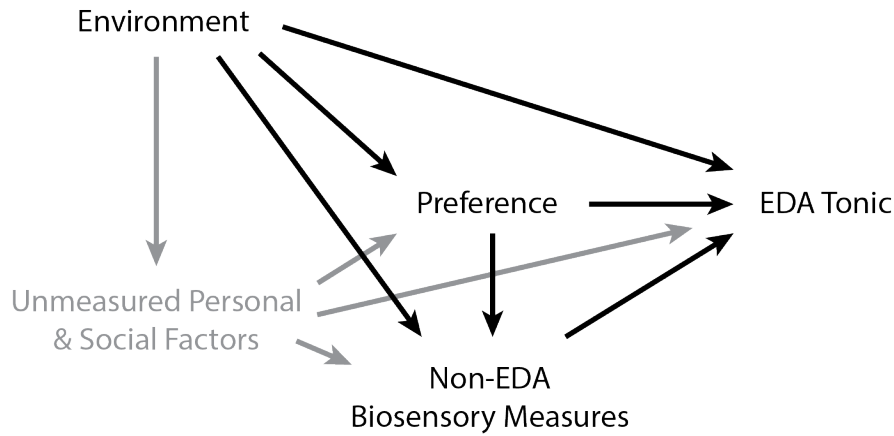


Figure 4.7. Directed acyclic graph (DAG) of causal paths between environmental features, preference, other biosensory features, and EDA.

4.4 Field Study Results & Discussion

The majority of biosensory signals collected in the field study demonstrated limited potential to indicate walkers' responses to streetscapes due to high variability between subjects and low variability in central tendencies across subjects. In short, biosensory signals appeared to be substantially muddled by differences in how subjects responded to similar environments, and responses tended to be difficult to distinguish from the background noise of confounding influences on these signals and potential errors in their measurement. The notable exception was EDA tonic, which, once normalized, was relatively consistent across subjects and exhibited clear variability in central tendencies both within and between block faces. Models predicting EDA tonic based on streetscape and roadway features demonstrated that tonic levels were highly associated with environmental contexts, largely in ways that were consistent with theoretical expectations about sensorial engagement stimulating biosensory activation (Healey, 2015). The high spatiotemporal resolution of EDA measurements, which were collected every quarter-second and therefore provided an essentially continuous data stream, allowed for such finely grained comparisons with environmental features. Relatedly, the low latency of EDA responses made them straightforward to associate with potential stimuli. By contrast, measures that required summarization across larger spatiotemporal epics, such as SCRs, HRV, glances, and walking speed, or that lagged behind stimuli, such as HRV and skin temperature, were naturally limited in their abilities to reflect more finely grained features. These benefits of EDA, and its tonic component in particular, may explain its high rates of adoption for mobile biosensing studies compared with other measures (Berger & Dörrzapf, 2018; Caviedes & Figliozzi, 2018; Chrisinger & King, 2018; LaJeunesse et al., 2021; Osborne & Jones, 2017). The only other known study to provide a side-by-side comparison of EDA and another biosensory measure, HR, focused primarily on EDA as its indicator of emotional response (LaJeunesse et al., 2021). Results from the present study, therefore, corroborate EDA's track record as a preferred biosensory measure for mobile applications while providing a novel head-to-head comparison between it and a wide range of alternative measures.

Results also corroborate neuroscientific understandings about how EDA is not a direct measure of stress, as assumed by prior studies about walking environments (Chrisinger & King, 2018; LaJeunesse et al., 2021), but rather an indicator of activation, which may be combined with information about perceived valence to indicate stress and other emotions (Healey, 2015; Lang, 1995). Models predicting EDA exhibited better fit and substantially different parameter estimates when conditioned by valence, suggesting that EDA responses ought to be interpreted differently depending on whether subjects view environments favorably or unfavorably. Indeed, in many cases subjects appeared to view unfavorable environments as boring rather than stressful and activating environments as exciting rather than stressful. Using EDA as a direct proxy for stress, as described by LaJeunesse et al. (2021), may substantially oversimplify interpretations of emotional responses by assuming, for example, that environments subjects view as exciting are instead stressful. My results caution against this assumption.

The following sections summarize results from each of the parallel data streams collected during the field sessions, as well as models predicting EDA tonic as a function of walking environment characteristics and preferences.

4.4.1 Preferences

Subjects demonstrated a substantial degree of agreement in their block face preferences, suggesting that they responded to walking environments in conscious and non-random ways that largely aligned with prevailing theories of environmental favorability (Ewing & Handy, 2009; Kaplan & Kaplan, 1989; Nasar, 1998). The most preferable block faces were fronted by sensorially engaging green spaces (1E, 2E, 3E, and 4E) or interactive facades, such as storefronts (2W) or restaurant windows (5W), while the least preferred were fronted by a dull or vacant-feeling spaces, such as a blank wall (5E) or gas station (4W and 6E; Figure 4.8). It was notable that green spaces tended to be similarly, if not more, preferable than engaging building façades, challenging the contemporary norm of walkable urbanism that includes enclosing buildings and interactive façades (Dover & Massengale, 2013; Ewing & Clemente, 2013; Forsyth, 2015; Forsyth & Crewe, 2009). From a psychological perspective, however, the complexity and transparent depth of green spaces may have promoted sensorial engagement in ways that were similar to pedestrian-facing architecture (Kaplan & Kaplan, 1989; Nasar, 1998), making it unsurprising that they elicited similarly favorable responses. These results demonstrate both strong central tendencies in preference, as well as a degree of variability that suggests a notable subset of subjects may have had contrasting emotional responses to the same environmental stimuli.

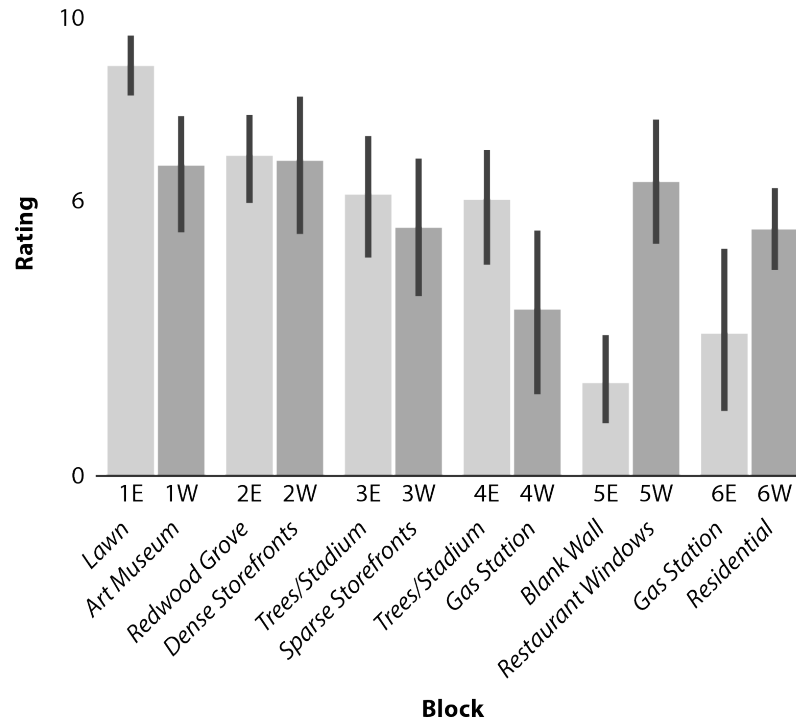


Figure 4.8. Mean rating by block face.
 Grey tones differentiate between east (lighter) and west (darker) sides.
 Bars show 95% confidence intervals on the means. The median rating was 6.
 Descriptions for each block face denote primary streetscape features for reference.

4.4.2 EDA Tonic

Among the biosensory signals collected, EDA tonic most clearly and consistently reflected environmental stimuli along the study corridor. Once normalized for each subject, it also exhibited strong central tendencies across subjects, as demonstrated by the light blue bands showing one standard deviation from the dark blue mean curve in Figure 4.9. Nonetheless, a minority of subjects exhibited large swings in tonic levels, evident in the grey hairlines in Figure 4.9 that show subject-level measurements. These swings were consistent with findings from both laboratory and real-world EDA studies demonstrating sometimes-dramatic within-subject variability in EDA response, largely owing to sweat gland physiology (Healey, 2015). Despite the noise introduced by these deviations, several trends emerged from the between-subjects mean of tonic measurements.

Notably, EDA tonic tended to increase with overall distance along the corridor, suggesting a potential influence of walking duration or exertion. This was consistent with findings by Berger and Dörrzapf (2018), Chrisinger and King (2018), and Caviedes and Figliozzi (2018) as well as theoretical understanding about the sensitivity of EDA to exertion-based perspiration (Healey, 2015). The only apparent exception to this trend was along block face 1E, though this mean was heavily influenced by two subjects whose tonic curves descended quickly from high starting levels; if these subjects were excluded, the mean increased along this block face as well. Variance between subjects also fluctuated predictably, with the greatest variances toward either end and tighter distributions toward the middle of the corridor. Subjects appeared to settle into

more consistent activation levels after beginning the walk with variable baselines. This suggests that researchers using EDA with ambulatory subjects may want to design experiments so that subjects begin walking a block or more ahead of where they expect to collect data, allowing subjects to settle into a more consistent response. It is less clear why variability might have increased again toward the end of the corridor, especially on the eastern side. Potentially, this variability was due more to the specific characteristics of this block face rather than its position along the corridor.

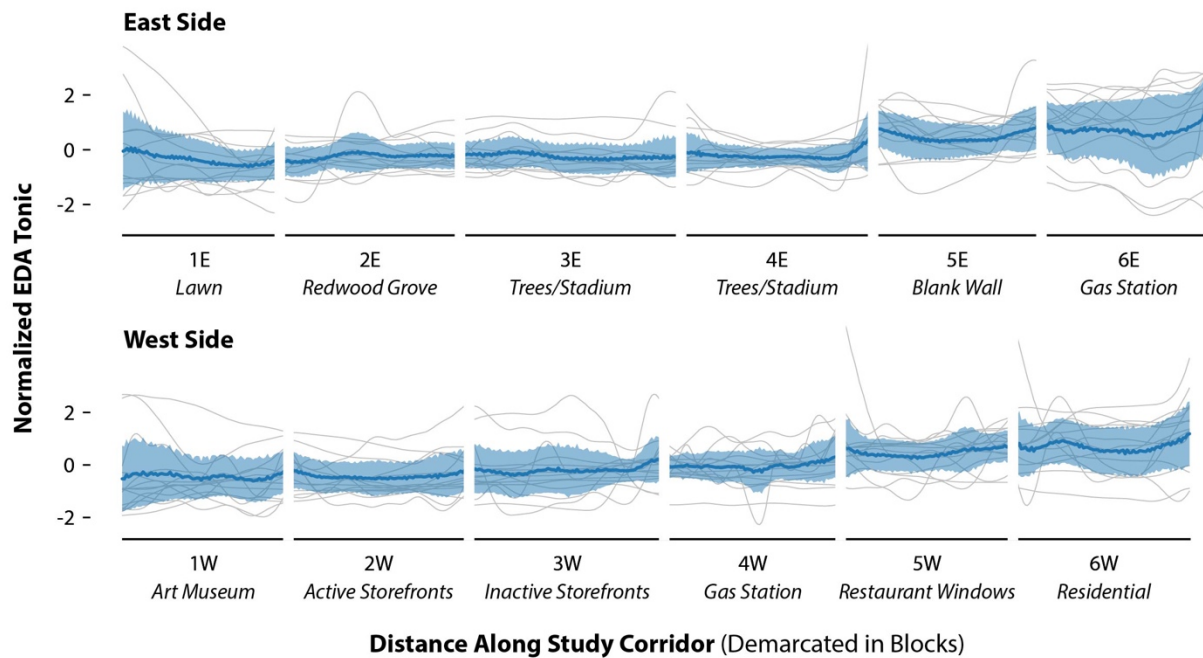


Figure 4.9. Normalized EDA tonic levels by side and block along the study corridor.

Dark blue curves show the mean across all subjects on that side, calculated within one-meter cells. Lighter blue bands show one standard deviation on either side of the mean. Grey hairlines show tonic curves for individual subjects. Horizontal axes show linear distances along each side of the study corridor. Intersection crossings are excluded. Note that the east side is slightly longer than the west due to fewer intersection crossings. The linear extents of each block face are marked and labeled.

Even mean trends in EDA tonic reflected specific environmental features. They were recognizably higher immediately before and after intersection crossings, which separated most block faces, but were essentially flat between 2E, 3E, and 4E, which were continuously connected without crossings. High tonic levels around crossings were consistent with the expectation that these spaces might be stressful or otherwise activating. Indeed, the longest and most complex intersection, between 4E and 5E, which required crossing a slip lane to a pedestrian island, then another two traffic lanes and a two-way cycle track, corresponded with a particularly large tonic spike. Chrisinger and King (2018) identified similarly found elevated EDA levels around intersections.

The symmetry with which localized tonic peaks were centered around intersections also demonstrated the low latency of EDA measurements. EDA climbed even as subjects were approaching intersections, then descended as they moved away, with no perceptible lag. Such low latency may make EDA especially well-suited for studying fluctuations in walkers’

responses as they move across a corridor, allowing for discrimination between responses to environmental features at sub-block spatial scales.

Tonic signals also suggested that certain environments elicited relatively little activation. Steady and low tonic levels across block faces 2E, 3E, and 4E reflected the uniformity of their streetscapes, with large trees, a parking lot, and the long façade of the stadium set back from the street. Block face 6E, meanwhile, had a highly varied streetscape—a gas station on one end, followed by three-story residential buildings and plantings with varying degrees of visual interest and upkeep (Figure 4.10)—and correspondingly more variable tonic levels. Some subjects were highly activated by this space, potentially due to visual interest, while others exhibited lower activation, potentially due to relaxing greenery on the southern end of the street or its relatively lower traffic volume. It was unsurprising that a more variable environment might yield more varied responses.

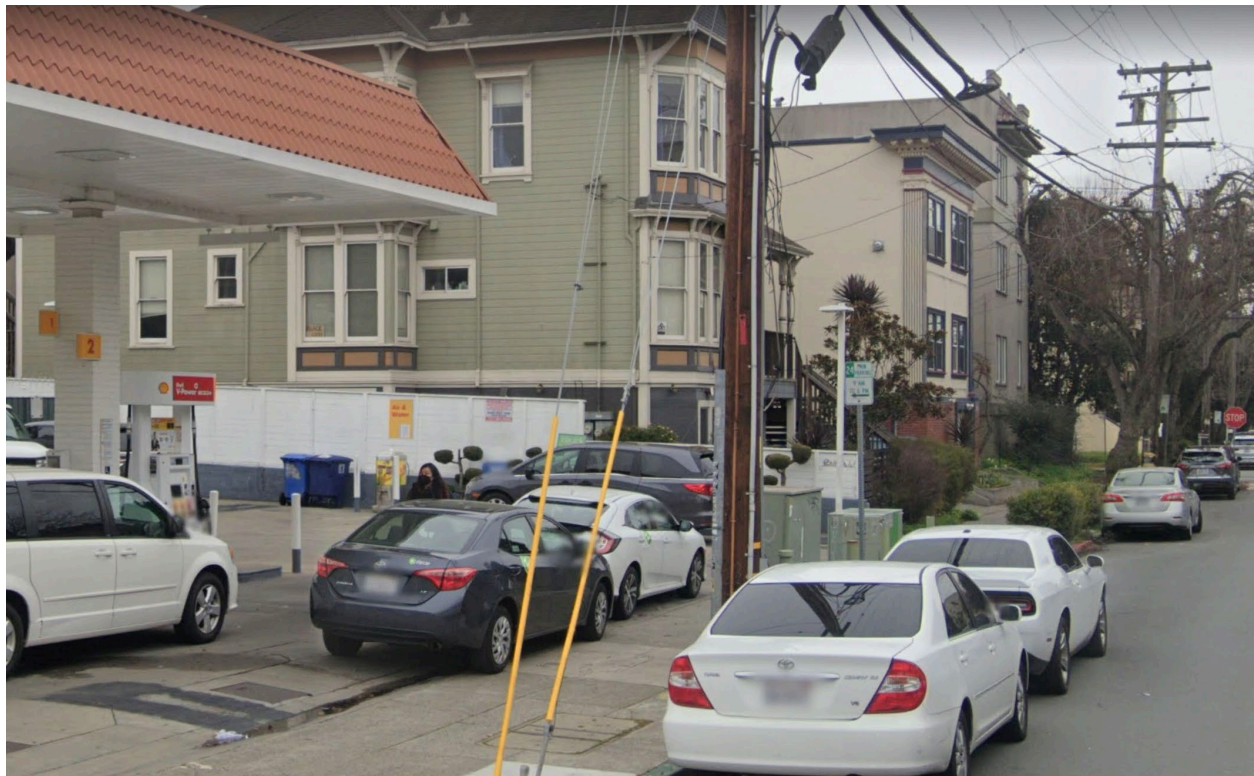


Figure 4.10. Substantial streetscape variability along block face 6E. The first half is comprised of a gas station, while the second half has residential frontages with plantings along the sidewalk. (From *Google Maps*, 2022)

Surprisingly, block face 2W (Figure 4.11), which had the densest concentration of pedestrian-oriented storefronts, elicited relatively little activation based on tonic measurements. Low tonic levels were consistent across subjects, indicating broad agreement in this low-activation response. This finding counters existing theory and evidence about how architecturally engaging spaces are sensorially stimulating for users (Ellard, 2020). While subjects did find this block face preferable, their low activation suggests that they may been experiencing emotional calm rather than excitement. Interestingly, this combination of low EDA and high preference, indicating

calm, was also exhibited along the more park-like block faces 3E and 4E, suggesting an emotional parallel between streetscapes with dense storefronts and those with more natural features, such as large trees. While calm might be expected in more natural contexts (Kaplan, 1995), it was surprising to find that storefronts would elicit a similar response. It is possible that urban streetscapes traditionally interpreted as vibrant and exciting, such as along storefronts, may instead have a dominantly calming effect on walkers, perhaps because their human scale dimensions and interactivity put walkers at ease.



Figure 4.11. View southward along block 2W, with pedestrian-oriented storefronts and sidewalk seating.
(From *Google Maps*, 2022)

4.4.3 SCRs

SCRs, derived from the phasic components of EDA signals, appeared to be less reliable and meaningful as indicators of environmental response than EDA tonic. The four algorithms identified substantially different counts of SCRs from the same data streams, and there was substantial variability in counts between subjects. The Gamboa algorithm identified about 50% more responses per block face than the van Halem (2020) algorithm, which itself identified two to three times as many as the Neurokit and Kim algorithms (Figure 4.12). This inconsistency was likely due to signal noise inherent in the mobile sensor. Movement artifacts, manifesting as sudden dips or peaks, may have been misidentified as SCRs. Errors in peak identification may have been compounded by the E4's 4 Hz EDA sampling frequency, considerably lower than the 60 or 100 Hz sensors that are more common in laboratory settings, for which all of SCR identification algorithms were originally designed. Mobile EDA sensors may require peak identification algorithms customized for their low-sampling rates and propensity for movement artifacts, or they may simply be inappropriate for SCR-based analyses.

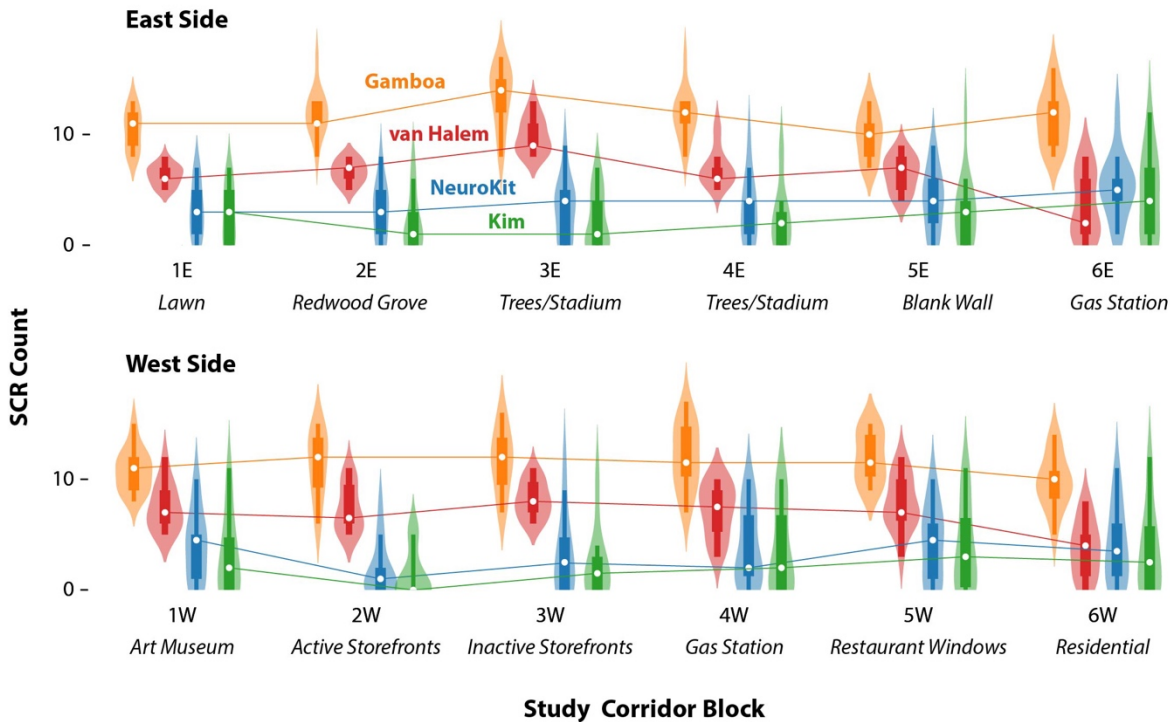


Figure 4.12. Distributions of SCR counts by side and block along the study corridor. Colors distinguish SCR detection methods. Yellow (left-most): Gamboa; red (second from left): van Halem; blue (second from right): NeuroKit; green: (right-most): Kim. Violin plots show kernel density estimations of distributions, which were restricted to positive values to represent counts. White dots show the median. Thick bars show one quartile from the median and thin bars show two quartiles from the median. Data points more than 1.5 times the interquartile range above the upper quartile or below the lower quartile were considered outliers. Hairlines connecting medians show trends between block faces on the same side.

SCR counts within block faces did demonstrate small differences between blocks, but these trends were inconsistent across algorithms and were not a readily interpretable as responses to built environment features. Both the Gamboa and van Halem algorithms identified more SCRs along block face 3E than along others on either side. This potentially reflected a sharp increase in enclosure along this block face, where the frontage transitioned from a retaining wall directly along the sidewalk to a more open, park-like space in front of the stadium. However, this trend was not reflected by the NeuroKit or Kim algorithms. The van Halem algorithm showed a substantial decrease in responses on both sides of block 6, potentially reflecting its relative narrowness and lower traffic volume. None of the other algorithms, however, identified a similar trend. Ultimately, the lack of agreement between detection algorithms and high between-subjects variability suggested that counts of SCRs were an unreliable indicator of subjects' responses to different environments.

Caviedes and Figliozzi (2018) demonstrated greater potential to associate bicyclist's SCRs with features such as bike lanes, which they found to be more activating, and multiuse paths, which were less activating. They do not, however, specify which algorithm they used to detect SCRs, which suggests they may have identified them manually. They also used a different method for evaluating SCRs, measuring how quickly and to what degree subjects responded as opposed to counting the number of responses. This further demonstrates how small differences in

approaches for processing and evaluating biosensory data may substantially impact the meaningfulness of results. It is also possible that SCRs are simply more useful for evaluating more major environment differences, such as on- and off-road paths, among faster-moving users, such as bicyclists, who experience larger and more rapid contrasts in activation. Continuous measures such as EDA tonic, rather than event-based SCRs, may be more appropriate for capturing the often-subtle environmental differences encountered by relatively slow-moving walkers.

4.4.4 HRV

Similar to the SCR measurements, HRV contended with substantial challenges in parsing raw data. It also yielded little variability between block-faces, suggesting that it had minimal value for distinguishing responses to different walking environments. Heartbeat data streams used to calculate HRV were heavily impacted by measurement errors due to motion. The E4's PPG sensor was designed to produce a continuous signal from which heartbeat peaks and the inter-beat intervals (IBIs) could be identified. Signal streams were continuous and exhibited clear beat patterns while subjects were stationary but were highly irregular and had long stretches of missing data while subjects were walking, presumably due to subtle movement of the sensor against the skin. Such motion artifacts are a well-known issue with PPG sensors, especially in non-laboratory settings (Pollreisz & TaheriNejad, 2022).

As a result of these data errors, IBIs could not be reliably identified from substantial portions of the data streams. The E4's built in algorithm identified an average of only 1.9 IBIs per block face across all subjects. The HeartPy algorithm was substantially more successful, yielding an average of 64.2 IBIs per block face. This quantity of IBIs made it possible to calculate HRV as the standard deviation of IBI per block face, though the sample size for these calculations was notably smaller than hundreds or thousands of IBIs that are typically accounted for in HRV studies (Fitch-Polse, 2018).

Unsurprisingly, given the small samples of IBIs, central tendencies in HRV across subjects varied only minimally between block faces. Minor decreases in HRV were located along 3E and 2W, suggesting less stimulation along these block faces than others (Figure 4.13). This was consistent with trends in EDA tonic, but inconstant with SCRs. Large between-subjects variability in HRV, however, substantially limited confidence in these trends.

These null findings contrasted with those from Fitch-Polse (2018), which found higher HRV levels among bicyclists associated with higher-traffic streets, consistent with expectations that HRV would indicate activation from more stressful environments. Comparatively, there may have been insufficient contrast between environmental conditions in the present study to yield measurable HRV differences. Conditions may also have varied over spatiotemporal distances that were too fine-grained to capture with measurement epochs that spanned entire block faces. HRV may have better captured differences between environments that were several blocks in length, similar to Fitch-Polse's comparisons between lower- and higher-traffic corridors. Even as the block-length epochs used in the present study may have been unreasonably coarse for comparison against streetscape-scale features, they would be considered "ultra-short term" within the context of HRV analyses, for which many studies use epochs of at least 15 minutes, and sometimes hours (Salahuddin et al., 2007). Because the precision of HRV measurements improve with large samples of IBIs, and PPG sensors are so sensitive to movement, it may be

best suited for evaluating environments where subjects are fairly stationary and spend a considerable amount of time rather than those they walk past for only a few seconds.

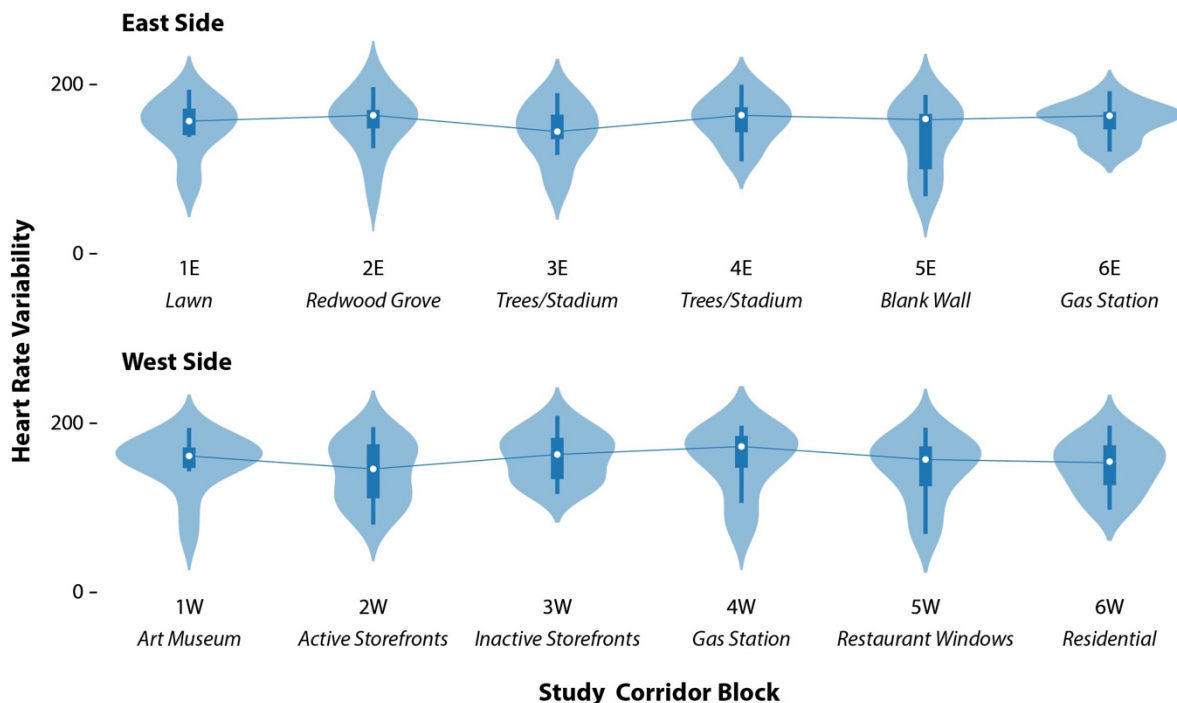


Figure 4.13. Distributions of Heart Rate Variability (HRV) by side and block along the study corridor. Violin plots show kernel density estimations of data distributions. White dots show the median. Thick bars show one quartile from the median and thin bars show two quartiles from the median. Data points more than 1.5 times the interquartile range above the upper quartile or below the lower quartile were considered outliers. Hairlines connecting medians show trends between block faces on the same side.

4.4.5 Skin Temperature

Skin temperature exhibited a downward trend for most subjects as they progressed along both sides of the study corridor (Figure 4.14). The consistency of these trends, especially between the two sides, suggested that skin temperature changed less in response to environmental factors than to exertion or factors associated with walking time or distance. It is possible that decreasing trends in skin temperature were directly caused by increased sweating, as indicated by generally upward trends in EDA tonic. Nonetheless, variability in skin temperature between subjects, revealed by the light blue standard deviation band in Figure 4.14, did fluctuate between block faces. Variability was higher toward the beginning and end of the corridor and notably lower variability near the center of 2E, aligning with the mid-block crossing of Schlessinger Way and the beginning of 4W, immediately after crossing an intersection. It is possible that this lower variability reflected greater activation, with subjects experiencing calm, low activation states at the beginning and end of the corridor, as well as along the park-like area adjacent to 3E, and were more activated in busier areas, particularly intersections. However, these trends were inconsistent across intersections where activation appeared to be high according to EDA tonic, such as between 4E and 5E. Moreover, there is little theoretical justification for how temperature *variability* rather than level might be impacted by activation.

While two studies appear to have collected skin temperature data from urban walkers, neither reported their findings (Chrisinger & King, 2018; Engelniederhammer et al., 2019). This suggests that other researchers have found skin temperature to be an attractive prospect, perhaps because it is straightforward to measure and available from instruments with multiple sensors, such as the Empatica E4, but have similarly found that it offers little meaningful evidence of walkers' emotional responses.

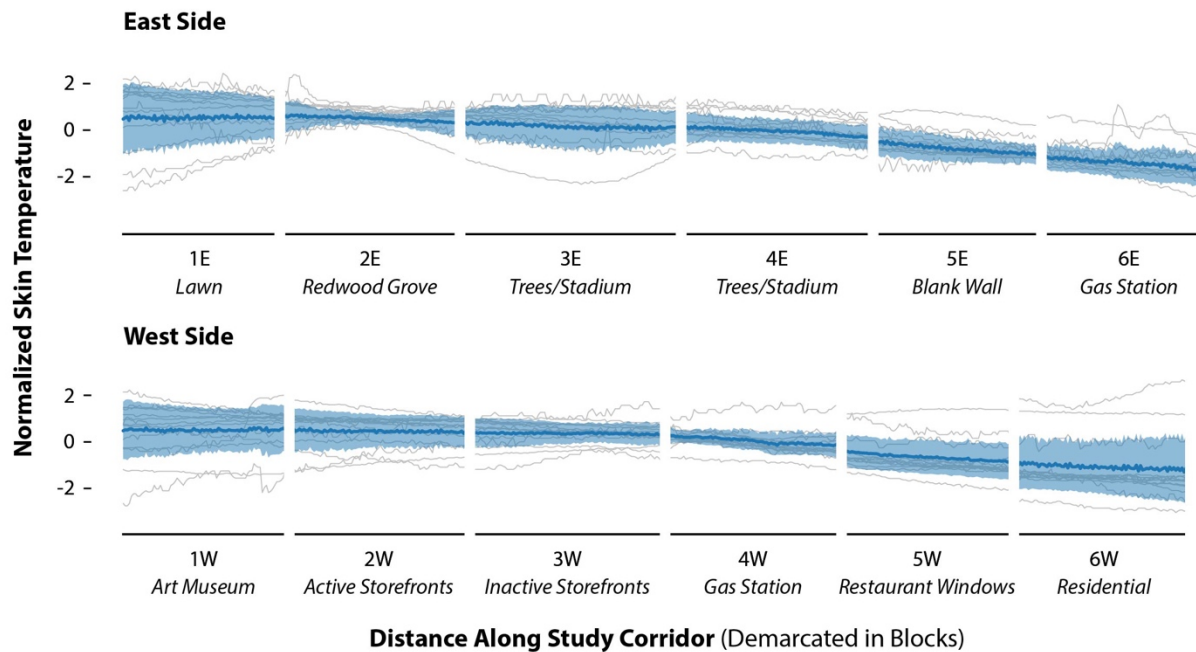


Figure 4.14. Normalized skin temperature levels along the study corridor.

Dark center line shows mean across all subjects on that side. Lighter band shows one standard deviation from the mean. Grey hairlines show each subject. Horizontal axes represent linear distance along each side of the study corridor. The linear extents of each block face are marked and labeled.

4.4.6 Glances

Central tendencies of glance counts across subjects were largely consistent between block faces (Figure 4.15). This offered little evidence that fixations were systematically biased toward more preferred streetscapes, as found by Emo (2014), but was consistent with Noland et al.'s (2017) finding that fixations were balanced between both positive and negative features. Distributions within block faces did indicate substantial variability in glance counts between subjects, especially among glances in the westward direction. This suggests that the park-like areas along the east side may have caught most subjects' attention to similar degrees, while storefronts and architectural features on the west side may have been especially captivating for a subset of subjects, even those walking along the opposite side of the street. Hollander (2018) similarly found higher levels of fixations along more engaging building frontages. These results suggest that manually tracked glances may be a moderately effective proxy for more sophisticated fixation data from eye tracking sensors, but nonetheless provide only a very limited understanding of where walkers are directing their attention.

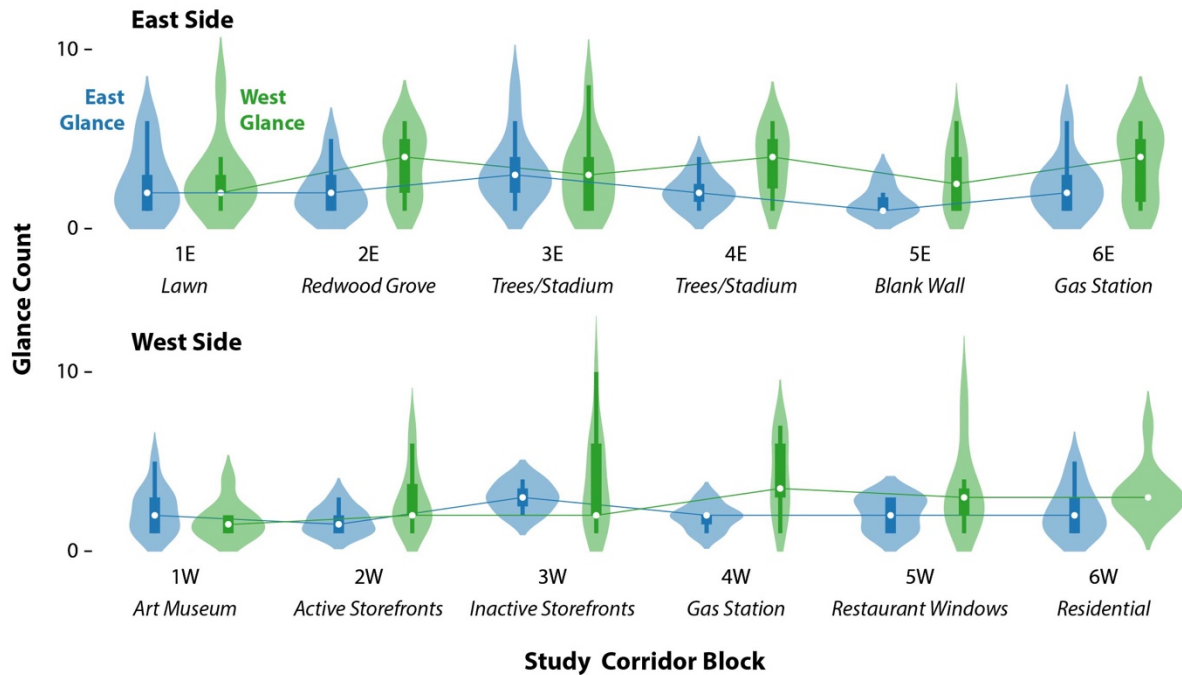


Figure 4.15. Distributions of glance counts by side and block along the study corridor.

Colors distinguish between glances to the left (blue; left-hand) and right (green; right-hand). Violin plots show kernel density estimations of data distributions, which were restricted to positive values to reflect counts. White dots show the median. Thick bars show one quartile from the median and thin bars show two quartiles from the median. Data points more than 1.5 times the interquartile range above the upper quartile or below the lower quartile were considered outliers. Hairlines connecting medians show trends between block faces on the same side.

4.4.7 Walking Speed

Central tendencies and distributions in walking speeds exhibited only minor differences between block faces (Figure 4.16). Some variability in speed was expected due to differences in personal tendency and fitness, but similar distributions between block faces indicated that individual subjects did not substantially change their speeds depending on environmental context. This stands counter to research suggesting that walkers move more slowly in more sensorially engaging and enclosed spaces (Ellard, 2020; Franěk, 2013; Franěk & Režný, 2021).

Nonetheless, several faint trends emerged from walking speed distributions. A small subset of subjects appeared to walk substantially faster along 2E, 3E, and 4E, which were continuous without intersections. Because time waiting at intersections was discounted, this suggests that the unobstructed path might elicit faster speeds from certain walkers, though the majority appear to have continued at a consistent rate. The distribution of speeds along 5E was quite narrow, indicating that those who walked quickly along the previous block faces slowed considerably along this comparatively boring and unpreferred block face that featured a long blank wall. This again conflicted with the expectation that walkers would speed up in less preferred environments (Franěk & Režný, 2021).

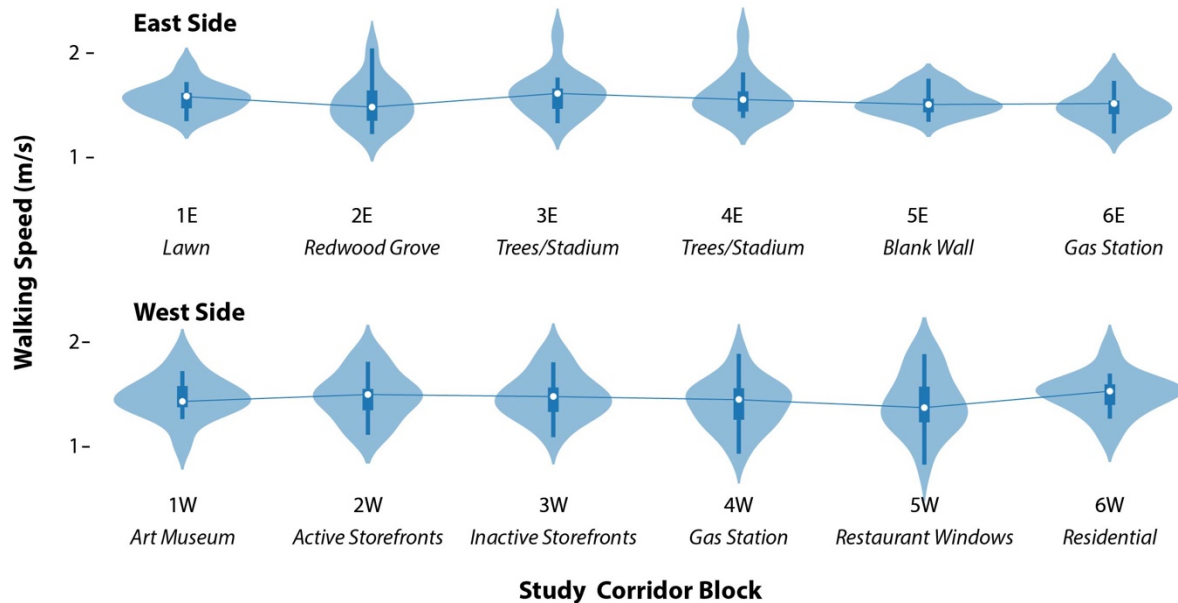


Figure 4.16. Distributions of walking speed by side and block along the study corridor. Violin plots show kernel density estimations of data distributions. White dots show the median. Thick bars show one quartile from the median and thin bars show two quartiles from the median. Data points more than 1.5 times the interquartile range above the upper quartile or below the lower quartile were considered outliers. Hairlines connecting medians show trends between block faces on the same side.

4.4.8 EDA Modeling

Regression models demonstrated significant albeit weak associations between EDA tonic and other biosensory measures as well as built environment characteristics. Three separate models were estimated to evaluate these relationships both with and without conditioning by high and low ratings as an indicator of valence (Table 4.2). Model 1 included all segments, while Models 2 and 3 only include segments along block faces that each subject rated lower or higher than the median rating of six. As such, Model 2 reflected less preferred environments, while Model 3 reflected more preferred ones. Note that the sample sizes of Models 2 and 3 summed to less than the sample size for Model 1 because neither valenced models included block faces with ratings of exactly six. Likewise, Models 2 and 3 had only 26 groups because one subject rated all block faces on the same side as their sensor walk as lower than six; another rated them all higher than six.

Table 4.2. (Next Page) Linear mixed models predicting mean EDA tonic.

Units of analysis for all models were 5-meter segments walked by each subject. HRV and walking speed were constant for each subject along all segments on a given block face. Model 1 accounted for segments along all block faces. Model 2 only included segments along less preferred block faces: those rated lower than six. Model 3 only included segments along more preferred block faces: those rated higher than six. Neither Model 2 nor Model 3 included block faces rated exactly six. All models included subject-level random intercepts. Coefficients that are statistically significant with greater than 90% confidence are bolded.

Response: EDA Tonic	Model 1		Model 2		Model 3	
	Unvalenced (All Block Faces)		Low Valence (Less Preferred Block Faces)		High Valence (More Preferred Block Faces)	
Covariate	β	P	β	P	β	P
Intercept	-0.005	0.752	0.003	0.987	-0.044	0.714
Meters Along Corridor	0.314	<0.001	0.601	<0.001	0.249	<0.001
<i>Biosensory Measures</i>						
HRV (block-level)	0.057	0.001	-0.341	<0.001	0.203	<0.001
Skin Temperature (mean)	0.000	0.996	0.015	0.912	0.179	0.119
Glances to Same Side	-0.018	0.272	-0.036	0.073	-0.023	0.272
Glances to Opposite Side	0.004	0.814	0.007	0.744	0.006	0.749
Walking Speed (block-level)	-0.014	0.424	-0.01	0.838	-0.012	0.748
<i>Streetscape Measures</i>						
Building	-0.032	0.324	-0.043	0.285	0.146	<0.001
Street Tree	0.043	0.083	-0.011	0.722	0.095	0.002
Restaurant Window	0.034	0.077	-0.064	0.008	0.093	<0.001
Active Storefront	-0.027	0.253	0.058	0.052	0.008	0.814
Green Area	-0.140	<0.001	-0.136	<0.001	-0.088	0.008
Parking Lot	-0.059	0.004	-0.089	<0.001	-0.018	0.476
Gas Station	-0.037	0.174	0.003	0.943	0.064	0.048
Opaque Frontage	-0.083	0.006	-0.053	0.172	-0.012	0.745
Blank Wall	0.050	0.018	0.009	0.779	-	-
Ground Floor Window	-0.061	0.041	0.020	0.594	-0.026	0.516
Residential	-0.075	0.008	-0.058	0.127	0.025	0.438
Lawn	0.041	0.115	-0.020	0.451	0.030	0.398
<i>Roadway Measures</i>						
Near Crossing	0.085	<0.001	0.078	<0.001	0.078	<0.001
One Way	0.136	<0.001	-0.060	0.211	0.100	0.014
Bike Lane	0.070	0.006	0.298	<0.001	-0.007	0.850
Street Parking	0.019	0.429	-0.041	0.188	-0.081	0.009
Bus Stop	-0.010	0.631	-	-	-0.071	0.006
<i>Model Summaries</i>						
Observations	2,886		1,261		1,388	
Groups	27		26		26	
Fixed Effects Variance	0.014		0.067		0.048	
Random Effects Variance	0.000		0.602		0.347	
Residual Variance	0.769		0.471		0.528	
Marginal R ²	0.017		0.059		0.052	
Conditional R ²	0.017		0.587		0.427	

All covariates were maintained in all models, even if they were not statistically significant, to facilitate comparison between parameter estimates. All models included intercepts, none of which were significant, and terms controlling for distance along the corridor, which were all significant and positive in all cases. A distance term corrected for the linear increases in EDA tonic likely caused by perspiration due to exertion.

While none of the models exhibited exceptionally strong overall fit based on marginal and conditional R^2 statistics, the valenced models had substantially lower residual variance than the unvalenced model. This indicated that accounting for valence substantially strengthened the predictability of EDA-environment relationships.

Model parameters demonstrated both consistency and contrast with results from similar analyses of EDA among urban walkers. Green areas were negatively associated with EDA tonic, consistent with expectations that they would be calming. LaJeunesse et al. (2021) similarly found forest, park, and campus areas were negatively associated with EDA. On the other hand, street trees were positively associated with EDA tonic in the present study, suggesting that they had an activating effect, potentially due to their visual complexity and movement, as suggested by Arnold (1993). Negative associations with opaque frontages and parking lots were consistent with Chrisinger and King's (2018) negative associations with vacant land uses and office space. These frontages presumably offered relatively low sensory engagement. Conversely, however, I found that blank walls, which Ellard (2015, 2020) suggested would be interpreted as dull and boring, were instead positively associated with EDA tonic, indicating that they were relatively stimulating. Windows into the dining area of a restaurant were positively associated with EDA tonic, suggesting, as expected, that they were visually engaging. Residential frontages, meanwhile, were negatively associated. This contrasted with Chrisinger and King's (2018) positive association between residential uses and EDA. Potentially, residential frontages in their San Francisco study area were relatively more engaging than other environments their subjects encountered, while those in my Berkeley study area were comparatively less engaging.

Both Chrisinger and King (2018) and LaJeunesse et al. (2021) found positive associations between EDA and higher traffic streets. While traffic volumes and speeds were consistent along most of my study corridor, the block with a one-way traffic pattern also had notably lower volumes. Counter to expectations, however, this block exhibited significantly higher EDA, indicating that it was more stimulating despite its lower traffic. This counterintuitive finding suggests that the relationship with traffic may have been confounded by other engaging characteristics of this block. While there are areas of agreement between studies modeling how EDA relates to contextual environments, discrepancies in their results point to the difficulty of defining and labeling environmental features in directly comparable ways, and how study area context may heavily influence which features elicit relatively higher and lower EDA measurements.

Valenced models offered deeper understanding about how emotions may have been associated with environmental factors. Model 2, which only included less preferred, low valence block faces, could be used to differentiate stress (high activation, low valence) from boredom (low activation, low valence). Model 3, by contrast, could be used to differentiate excitement (high activation, high valence) from calm (low activation, high valence). Figure 4.17 shows how streetscape and roadway features mapped onto these circumplex emotions based on results from the valenced models. Buildings, street trees, restaurant windows, gas stations, intersections, and one-way streets appeared to elicit excitement, consistent with the expectation that more visually

engaging, dynamic, and intimate spaces would be considered preferable (Ellard, 2020; Ewing & Handy, 2009). Green areas and street parking, by contrast, appeared to be calming, consistent with expectations that natural features and separation from traffic would reduce stress (Kaplan, 1995; Rodriguez-Valencia et al., 2022). While bus stops also exhibited a negative association with EDA in high valence model, suggesting calm, these estimates were likely confounded by large green spaces adjacent to the bus stops.

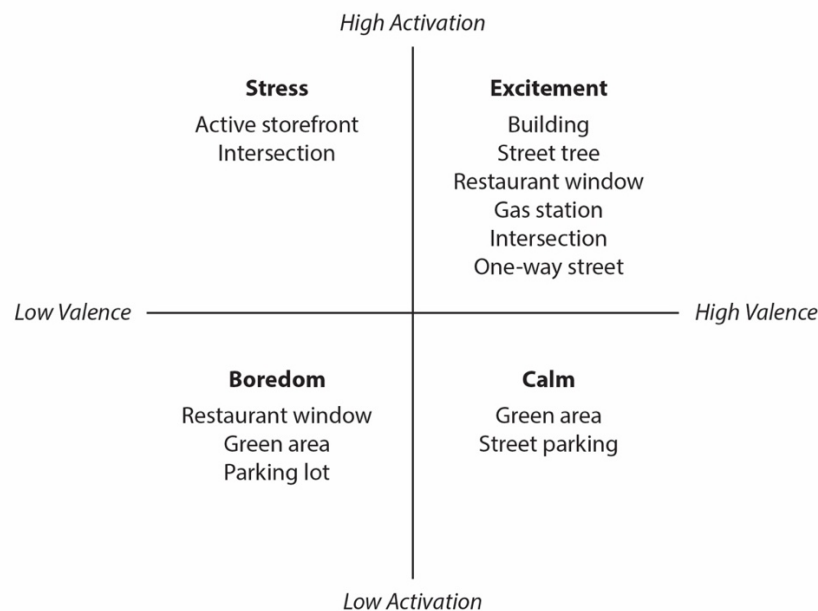


Figure 4.17. Streetscape features associated with circumplex emotions based on valenced modeling results.

Interestingly, the low valence model suggested that several features understood by design experts as contributing to preferable streetscapes may instead have elicited stress or boredom.

Intersections appeared to be stressful, consistent with understandings that proximity to traffic is stressful for walkers and other vulnerable road users (Mekuria et al., 2012; Rodriguez-Valencia et al., 2022). Active storefronts also, however, appeared to be stressful for subjects who found them unfavorable. This suggests that sensorially engaging storefronts may not always be beneficial for walkers. Indeed, as discussed in Chapter 3, a sizable number of subjects specifically disliked retail block faces that felt socially overwhelming or where there was “too much” going on. Biosensory data may help elucidate how these spaces were stressful.

While parking lots, unsurprisingly, appeared to elicit boredom, so did green areas and restaurant windows among subjects who viewed these spaces unfavorably. Ellard (2015) suggests that boredom in street environments may be caused by bland or unidimensional spaces. Parking lots are consistent with this image, but it is also interesting to consider how a green area, such as the large lawn along block face 1E, might be interpreted as vast and uninteresting. It is somewhat less intuitive how windows into a restaurant might be boring, but it is understandable how they might be unappealing *without* being stressful. To the extent that boredom is simply a counterpoint to stress, these results help reinforce how stress is not the only mechanism by which walking environments may be unfavorable. Transportation researchers have recently been heavily focused on “stress” as a framework for understanding the performance of urban environments for walkers and other active users (Faghieh Imani et al., 2019; Fitch et al., 2016;

Harvey et al., 2019; Mekuria et al., 2012, 2017; Rodriguez-Valencia et al., 2022). As Ellard (2015) notes, however, boredom and other negative emotions may be just as powerfully motivating and deserve substantially more attention.

Valanced models provide a window into the complexity of emotional reactions to streetscapes that have been notably absent from many biosensory analyses. By assuming that EDA is a direct indicator of stress, studies may be glossing over the potential for excitement or boredom as alternative high- and low-activation states (Caviades & Figliozzi, 2018; Chrisinger & King, 2018; LaJeunesse et al., 2021). Chrisinger and King (2018) found a strong positive association between EDA and states preferences for features along their study route, suggesting that EDA was useful as an indicator of preference. However, this relationship was inconsistent between subjects, so it may simply have indicated that the relationships between activation and valence was more often positive than negative. Ironically, this positive correlation also suggests that high EDA responses among their subjects tended to indicate excitement, not stress. Reconsidering how they interpreted EDA associations would likely dramatically change their conclusions. The valanced models in the present study were crucial for differentiating between alternative high- and low-activation states. Had I used EDA as a direct indicator of stress, I might have interpreted street trees as stressful rather than exciting, insinuating that they were detrimental for walking environments rather than beneficial. This demonstrates the importance of acknowledging the limitations of EDA for describing valence and drawing on parallel valance measures to develop a more complete picture of emotional response.

One biosensory measure, HRV, demonstrated modest potential as indicator of valence. HRV was associated with EDA tonic in all three models, but associations were four to six times stronger in the valanced models and varied in direction between preferred and unpreferred contexts. When block faces were unpreferred, HRV was negatively associated with EDA tonic, consistent with the expectation that activation is associated with lower HRV (Kim et al., 2018). Along more preferred block faces, however, HRV was positively associated with EDA tonic. This suggests that, counter to theoretical understanding that HRV is primarily an indicator of activation (Fitch-Polse, 2018; Healey, 2015), it might be useful in combination with EDA for discriminating between valences. This potential ought to be more thoroughly investigated with a method that validates HRV measurements against a much larger sample of rated preferences. If valence could be measured alongside activation by combining data streams from multiple sensors, it would substantially reduce barriers to scaling measurement of emotions by eliminating the need to collect data about subjective preferences.

4.5 Conclusions

Biosensors, when implemented and interpreted carefully, have the potential to measure emotional responses to built environments in scalable and quantifiable ways. This may provide a window into responses for which subjects do not have a vocabulary, or are not consciously aware, offering insights into user perceptions that would be inaccessible through qualitative means. Proliferation of biosensors in consumer devices such as smart watches also raise the possibility of collecting data from large volumes of subjects, in highly diverse environments, for relatively low cost. This is an understandably attractive vision for built environment researchers.

The current state of biosensory technology, however, is more sobering. Most biosensory signals tend to be noisy and either too sensitive to confounding stimuli or insufficiently sensitive at the scale of pedestrian environments to be immediately useful for research at this spatial scale.

While there is some empirical evidence of biosensors reflecting emotional valence, the neurological basis for such relationships is poorly understood. This leaves biosensory researchers with, at best, reliable information about activation, only one of two key dimensions in the circumplex model of emotion. The other key dimension, valence, describes favorability or unfavorability, and is essential for distinguishing between stress and excitement, or boredom and calm. Without information about valence, biosensors cannot reliably distinguish between emotions that are critical for planners and designers to understand. Perhaps inconveniently, valence may be even more critical than activation for planning purposes: it likely matters more if people like a space than whether they feel stimulated by it. The current inability of biosensors to reliably identify valence positions them as an immature technology, but with substantial potential for growth. With research improving how their signals are processed and interpreted, they may someday fulfill the futuristic vision of a scalable, objective approach for measuring a broad range of emotions.

Currently, EDA tonic stands out as a promising measure of emotional activation in naturalistic walking environments. The mechanisms by which it reflects activation are well understood, and there are well-developed tools for processing its signals to enable comparison between individuals. EDA tonic signals, once normalized, were substantially more consistent across field study subjects than were other biosensory measures. When aggregated across subjects, they corresponded recognizably with environmental features such as intersections and block face-level streetscapes. Moreover, subject-level tonic was correlated with finely grained features such as buildings, trees, storefronts, and parking lots. EDA's low latency and continuous signal allowed it to be summarized within small spatial units. HRV, by contrast, could only be summarized at the minimal extent of a city block. These characteristics suggest that EDA tonic may be a powerful measure for urban researchers but must still be interpreted carefully to avoid overstating its meaning.

Models predicting EDA tonic, even among only 27 subjects, showed consistent associations with streetscape and roadway characteristics along the corridor. These associations were strongest, however, when models were conditioned by valence, suggesting that subjects with similar preferences for certain features also exhibited similar EDA tonic levels. Conditioning by valence also allows for more complete evaluation of circumplex emotions, including differentiation of excitement from stress, and calm from boredom. Interestingly, subjects appeared to respond with excitement to a substantial number of features, including buildings, street trees, and restaurant windows. In an unvalenced interpretation assuming that activation was a direct indicator of stress, these features might instead have been interpreted as stressful. Parking lots, meanwhile, appeared to be associated with boredom, but without conditioning by valence might have been misinterpreted as calm. These examples demonstrate how critical it may be to interpret EDA measures alongside a parallel measure of valence. Unless progress is made in identifying biosensory indicators of valence, this may remain a substantial limitation to relying solely on biosensory measures without a coincident survey or other method for measuring valences.

These findings encourage cautious optimism about using biosensors to study naturalistic environmental responses, both with the current state of these technologies and into the future. While biosensors may never provide a silver bullet for measuring emotions, they will likely be an increasingly important tool for urban researchers. Those who aim to harness them, however, will likely need to develop more sophisticated understandings both of what they successfully measure and what they do not.

Chapter 5 Do Pedestrian Route Choices Reveal Preferences for Streetscapes?

5.1 Introduction

Urban design theory suggests that streetscape qualities related to spatial enclosure and visual engagement may substantially influence walkability (Ewing & Handy, 2009). There is a dearth of empirical evidence, however, substantiating how these qualities relate to real-world walking behavior. Studies by Ewing et al. (2016) and Park et al. (2019) have found that characteristics related to façade transparency, imageability, and visual complexity were useful for predicting pedestrian volumes in New York City and the Salt Lake City region. But land uses may confound pedestrian volumes in ways that are difficult to control for, limiting their reliability as indicators of preferable streetscapes. A more robust indicator of streetscape preferences may be the routes pedestrians choose. Route choice models, which compare selected routes with viable alternatives, evaluate relationships between route characteristics and the probability of a route being selected. Such models may be used to estimate which streetscape characteristics are associated with preferred routes and the degree of these associations, providing a strong indicator of revealed preference for different streetscapes.

Route choice modeling based on real-world walking routes may also be an apt approach for studying preferences for streetscapes because it relies on revealed preferences rather than conscious interpretations of preferability. Streetscape characteristics are conceptually complex, potentially limiting subjects' ability to articulate true perceptions and preferences. Chapter 3 demonstrated how lay walkers, without expertise in planning or design, often had difficulty describing precisely what about streetscapes they liked or disliked. There may have been discrepancies, therefore, between their conscious interpretations, subconscious perceptions, and potential actions had they walked along the study corridor in real life. Chapter 4 investigated the potential to measure walkers' subconscious responses using biosensors, but found they could not reliably identify preferable streetscapes, only those that were activating. Real-life walking decisions such as route choices may, therefore, provide uniquely reliable windows into pedestrian preferences in ways that are unbiased by constraints on conscious interpretation. A pedestrian may choose to walk along a streetscape even if they don't know precisely why. Route choice models may help unpack the factors associated with this decision.

This chapter uses route choice models to examine whether pedestrian routes in San Francisco reveal preferences for more enclosed and engaging streetscapes. While there is a strong precedent for using route choices to study pedestrian preferences, this literature has often accounted for streetscapes based on tabulations of specific features or characteristics, such as benches, litter, or historic buildings (Basu et al., 2021). Only rarely have they considered the more abstract streetscape qualities described by Ewing and Handy (2009), or related “mesoscale” morphology described by Harvey (2014), which include factors such as width, height, and continuity of building frontages. The notable gap in research about these more abstract qualities may be due, in part, to the challenge of systematically defining and measuring them across large samples of streets (Harvey et al., 2016; Harvey & Aultman-Hall, 2016). This chapter focuses on indicators of such abstract qualities and present methods for efficiently measuring them based on existing spatial datasets.

Results suggest that San Francisco walkers strongly preferred more visually complex, transparent, and enclosed streetscapes. They demonstrated strong preference for more continual enclosure from buildings, and trees, as well as buildings that were taller and less set back.

Modeling results suggested that portions of routes without buildings along either side were perceived as 134% longer, while those with setbacks less than 5 meters from the curb were perceived as 20% shorter. Walkers also preferred routes lined by storefronts, which likely bolstered both complexity and transparency. Portions of routes alongside storefronts appeared to be perceived as 42% shorter than those without storefronts. Furthermore, streetscapes with widths between 15 and 25 meters, and cross-sectional ratios between 1:2 and 3:2 were most preferred, supporting the validity of theories about ideal ranges for these design parameters. These results provide strong evidence that mesoscale streetscape characteristics and perceptual qualities may substantially influence walking behavior, as well as the first known estimates of the extent of these influences. They demonstrate that streetscapes meaningfully influence not only how pedestrians interpret walking environments, but how they make decisions about where to walk, reinforcing how streetscape design may be used to improve urban walkability.

5.2 Background

5.2.1 Streetscapes as Determinants of Pedestrian Preferences

Research on pedestrian route choices has often accounted at least minimally for streetscape-related factors, but studies tend to lack sophisticated interpretation of design qualities and no study has yet emphasized streetscapes as a focus of investigation. Of the 44 pedestrian route choice studies reviewed by Basu et al. (2021), 35 included at least one measure related to streetscapes. Ninety percent of these found that streetscape features were significantly associated with route choice, the vast majority of these findings aligning with understandings that more visually complex, transparent, enclosing, imageable, or human scale streetscapes are more preferable (Ewing and Handy, 2009).

Despite this apparently strong evidence for the importance of streetscapes, the ways they are accounted for and interpreted often appear to be disconnected from broader design principles. Several studies appear to take a laundry list approach, accounting for whatever features might be the objects of pedestrians' attention and readily tabulated along their paths, including benches, fountains, bus stops, public art, plantings, and architectural styles (Foltête & Piombini, 2010; Joseph & Zimring, 2007; Riggs & Gross, 2018; Sevtsuk et al., 2021; Shatu et al., 2019; Shatu & Yigitcanlar, 2018). Others focus on land use characteristics that may relate to preference, including storefronts and what Basu et al. (2021) describe as "pedestrian friendly parcels" (Borst et al., 2009; Guo, 2009; Guo & Ferreira, 2008; Guo & Loo, 2013; Liu et al., 2020; Riggs & Gross, 2018; Tribby et al., 2017). Others account for building age (Bafatakis et al., 2015) and abandonment (Rodríguez et al., 2015). While these types of features may accentuate more general design qualities such as complexity, transparency, and imageability, they instead tend to be interpreted as being preferable in their own right. This raises the question of whether route preferences ought to be conceptualized based on specific streetscape features—are there enough pieces of public art?—or more general design qualities—is there enough visual complexity, to which public art may contribute? Studies examining pedestrian environments outside the sphere of route choice modeling have embraced the latter interpretation, whereby features are selected to serve as proxies for or indicators of more general qualities (Ewing et al., 2016; Park et al., 2019; Purciel et al., 2009). Pedestrian route choice research might borrow this approach to broaden the meaning of its results.

Route choice studies have also largely overlooked what Harvey (2014) describes as the mesoscale morphology of streetscapes, which include factors such as height, width, cross-sectional proportion, and street wall continuity. These factors are key indicators of Ewing and Handy's (2009) qualities of enclosure and human scale. Only two known route choice studies have explicitly evaluated morphological measures: Foltête and Piombini (2010) found that routes along taller residential buildings were not preferred, while Ozbil et al. (2016) found that walkers preferred routes with larger setbacks. Relatedly, Tribby et al. (2017) found positive associations between route preference and land use density, which may serve as a proxy for enclosure, but no known studies have evaluated street wall continuity or cross-sectional proportion, despite urban designers emphasizing their importance for the quality of pedestrian environments (Alexander et al., 1977; Jacobs, 1993). Findings across these studies are also inconsistent—Foltête and Piombini (2010) and Ozbil et al. (2016) suggest preferences for lower enclosure, while Tribby et al. (2017) suggest preferences for higher enclosure—indicating that relationships between streetscape morphology and preference remain highly inconclusive. Furthermore, no known studies have evaluated several morphological characteristics at once, leaving it unclear which may be more strongly preferable than others.

Preference for trees and other green features are a common thread through many pedestrian route choice studies. Out of 18 studies reviewed by Basu et al. (2021) that account for trees, green strips, and vegetation, 72% found significant positive associations with route choices. Trees theoretically contribute to both the spatial enclosure of streetscapes and accentuate qualities such as visual complexity, imageability, and naturalness (Arnold, 1993; Ewing & Handy, 2009; Jacobs, 1993; Nasar, 1998). In more practical terms, they can also provide shade (Arnold, 1993). The multifaceted nature of trees demonstrates how features of streetscapes may contribute to multiple general qualities and reinforces the importance of investigating a broad array of streetscape characteristics to triangulate around which qualities may be most valuable for pedestrians.

5.2.2 Approaches for Modeling Pedestrian Route Choices

Developing a model of pedestrian route choices requires construction of several complex data inputs, including observation of walking routes, synthesizing realistic route alternatives, and measuring characteristics of both observed and alternative routes that may influence pedestrians' decisions about which route to choose. Compiling route measurements across large samples of streets, potentially numbering in the tens of thousands of network links, has posed a practical obstacle to accounting for streetscape characteristics, which are notoriously difficult to define and measure on a large scale (Ewing & Handy, 2009; Harvey & Aultman-Hall, 2016). Advancing methods for precise and replicable measurement of streetscape spaces is crucial for incorporating them into route choice models as well as other large-scale urban analyses (Harvey, 2014).

Streetscapes can be measured either through manual audits or based on existing spatial datasets (Harvey et al., 2016; Purciel et al., 2009). Audits traditionally offer the greatest potential for capturing detailed and nuanced measures, including qualities that may be difficult to define in highly specific terms. The audit used by Rodríguez et al. (2015), for example, captured a measure for “residential ground floor condition,” rated on a three-point scale. Operationalizing this construct based on attributes of a spatial dataset would pose a formidable challenge both theoretically and technically. Audits, however, are extremely time and resource intensive to

conduct, and measurements may be challenging to standardize across multiple auditors (Boarnet et al., 2006; Day et al., 2006). This has spurred efforts to extract environmental characteristics from existing data sources, which is particularly well-suited to route choice analyses that must account for large samples of streets disbursed across broad geographic areas (Ewing et al., 2016; Harvey et al., 2016; Purciel et al., 2009).

Approaches for collecting environmental attributes from existing data sources fall in to three main categories: geolocated records with existing labels, such as parcels with land uses; evaluation of geometric relationships between vector geometries, such as building footprints; and feature extraction from imagery. Geolocated records with labels, which may be aggregated along routes, offer the most straightforward approach for summarizing environmental features, but are limited to characteristics that are already available in municipal, open source (e.g., OSM), or proprietary databases, such as parcels, points of interest, tree canopy areas, or street centerlines. A parcel database is likely to include attributes pertaining to land use, but unlikely to represent morphological attributes such as building setback.

Morphological measures may be collected by geoprocessing widely available vector geometries, such as building footprints, yet relatively little work has been done to-date in this area. In earlier research, I developed tools for automating measurement of characteristics including street wall continuity, width between buildings across the street, and height-to-width cross-section (Harvey, 2014; Harvey et al., 2016). I employ the next generation of this toolset in the present study. Yin (2017) used height-extruded building footprints to evaluate sight lines and three-dimensional visual fields of view from street level. Despite substantial potential to measure streetscapes through vector building geometries that are increasingly ubiquitous, this remains an underdeveloped approach.

Much more attention has gone into extracting features from street-level imagery. Kang et al. (2020) identify 64 papers that have extracted urban environmental features from street-level imagery in public health research, including 13 related to walkable environments. These demonstrate identification of features such as residential land uses, open areas and parking. While many of these features might be available from existing labeled data sources, these methods demonstrate future potential to extract features that are less available, or in areas that lack consistent or updated data. Liu et al. (2017) use machine image interpretation to identify streetscape-related measures that are not commonly available in labeled datasets, including street wall continuity and an index of façade quality, signaling emerging opportunity to assess complex morphological characteristics from imagery. In their recent pedestrian route choice study, Sevtsuk et al. (2021) extract measures of greenness and sky view factor, a measure of spatial enclosure, from Google Street View images. Li et al. (2022) also use computer vision to identify crosswalks and marked crosswalks in Google Street View imagery. The increasing ubiquity of this imagery, and sophistication of machine learning algorithms, will likely make this a mainstay approach for examining streetscapes in years to come. For now, though, many of the same features may be collected more straightforwardly, and potentially more accurately, through other means.

Observation of routes for pedestrian route choice studies has traditionally involved asking subjects to draw current or typical routes on maps (Guo & Loo, 2013; Koh & Wong, 2013; Liu et al., 2020) or outfitting them with GPS receivers (Broach, 2016) to track walking trips throughout day-to-day life. These approaches offer the benefit of direct access to subjects, allowing researchers to readily account for person- and trip-level characteristics, and even to collect

parallel data about perceptions and conscious preferences for walking environments. Recent studies have leveraged smartphone apps integrated with travel surveys or other location-based services to collect large volumes of pedestrians routes (Lue & Miller, 2019; Sevtsuk et al., 2021). While this is a potentially efficient approach to collecting highly naturalistic data, route observations from smartphone apps can be noisy and contain substantial gaps, yielding usable routes from only a small subset of trips. Sevtsuk et al. (2021) were able to model routes for only about 5% of the 280,000 raw trips from their smartphone-derived route dataset. Another limitation of their approach was lack of person- and trip-level characteristics, which were not available alongside route data due to privacy concerns. This demonstrates how many app-based data collection strategies may be trading completeness and richness for larger sample sizes and ease of collection.

Modeling route choice is a discrete choice problem that has often been implemented with multinomial logistic regression (MNL; Prato, 2009). This modeling framework estimates the probability that a route will be selected from a suite of alternatives, typically described as a choice set. Whereas basic MNL implementations evaluate all observations with reference to a consistent choice set—imagine a model predicting diners’ choices from a restaurant menu—route choice models must contend with unique sets of alternatives for each observed route. In essence, each choice is between a unique menu of options, only one of which is definitively known. The other choices—realistic routes between the same origin and destination—must be inferred.

Identifying realistic route alternatives is itself a well-researched aspect of route choice modeling for which there are numerous approaches (Prato, 2012). Prato (2012) identifies two basic categories of algorithms used to build choice sets between known origins and destinations along a network: stochastic and deterministic. Stochastic approaches, including random-walk algorithms (e.g., Broach, 2016), theoretically allow sampling of the entire choice space with limited bias. Their downside is that derived routes may be circuitous or otherwise nonsensical, ultimately requiring heuristic constraints, such as limits on turns or out-of-direction travel, to yield plausible routes, and these constraints somewhat negate the potential benefits of stochasticity. For long routes within complex networks, however, stochastic approaches may be the only viable way to develop a reasonably-sized choice set— n routes—given computational constraints. Determinative approaches, by contrast, identify every available route permutation between an origin and destination. In theory, this could yield hundreds or thousands of alternatives within even a small network, quickly becoming computationally prohibitive and generating a much larger number of potential routes than a person could reasonably comprehend. In practice, deterministic approaches also tend to use heuristic constraints to limit alternatives. The deterministic branch and bound approach used by Prato and Bekhor (2006), for example, constrains routes based on direction, travel time, self-looping, similarity to other routes, and turns. Their research on route generation algorithms indicates that the branch and bound approach produces realistic alternative routes and reproduces observed routes more effectively than other methods.

While some choice set algorithms aim to minimize overlap between identified alternatives, route choice models tend to nonetheless face issues around non-independence of alternative routes. By virtue of limited connectivity within road networks, alternatives within a given choice set almost always overlap along portions of their lengths. There are several common approaches to control for this non-independence (Prato, 2009). Cascetta et al. (1996) propose the C-logit formulation,

which includes a commonality factor representing shared utility between alternatives. Ben-Akiva and Bierlaire (1999) propose a similar approach, path size logit, which has also been used for destination choice modeling (Prato, 2009). Rather than representing commonality between alternatives, as in C-logit, the path size term represents the uniqueness of each alternative on a scale from zero to one, with zero representing a route that entirely overlaps with another, and one representing a route that is entirely unique. Path size is more straightforward to calculate and typically outperforms C-logit (Prato, 2009; Prato & Bekhor, 2006), leading to its wide use in pedestrian and other route modeling applications (Broach, 2016; Liu et al., 2020; Rodríguez et al., 2015; Sevtsuk et al., 2021; Shatu et al., 2019).

Zimmerman and Frejinger (2020) have also been advancing a recursive logit approach that models routes by evaluating alternative links at each intersection rather than creating and comparing alternatives routes. This has the benefit of making alternative generation unnecessary, reducing biases associated with route generation, and dramatically improving route prediction performance. However, estimation software for recursive logit remains underdeveloped, and while this technique may substantially improve prediction performance, it poses challenges for interpreting effects that may be interpreted by users as characteristics of entire routes rather than piecemeal decisions at each intersection. Advanced route modeling techniques are an area of active development but established methods such as path size logit continue to be a useful approach for research that is primarily focused on measuring route-level effects.

5.3 Methods

Path size logit models were used to examine how route-level environmental factors, including those related to streetscapes, were useful for predicting observed pedestrian routes compared with reasonable alternatives. Model estimation required a variety of data inputs, including observed route choices, realistic alternative routes, and environmental factors summarized along each route. Gathering and processing these inputs into a database of comparable route-level records constituted a formidable analytical challenge. In particular, methods for measuring and summarizing streetscape factors along network routes is core to this paper's contribution to urban design and planning literature.

The study was based in San Francisco, which offered detailed pedestrian route observations, built-environment data, and also sufficiently variable built-environmental conditions to facilitate comparisons between route alternatives. Link-level observations of real-world walking routes were available from the 2019 Bay Area Transportation Study, a GPS-enabled travel survey conducted by the San Francisco County Transportation Authority (SFCTA) in conjunction with the Metropolitan Transportation Commission (MTC). Detailed built-environmental data representing features such as building massing, land use, tree canopy, and roadway characteristics throughout the city were available from local agencies, enabling consistent measurement of streetscapes along walking routes. Further, San Francisco's dense and highly connected street network, and variability in streetscape characteristics within and between block faces, was conducive to route modeling because it offered variable alternatives between origin-destination pairs. Such variability is crucial for identifying meaningful estimates with a model that compares potential choices. If there are no reasonable alternatives for an observed route, or the alternatives are highly similar, there is no statistical basis for estimating what makes an observed route preferable. Unlike a laboratory experiment, where alternatives would be curated to ensure variability between them, analysis of real-world choices relies on natural variability

between alternatives. San Francisco provided substantial opportunity for route variability, making it a useful context for evaluating choices between them.

Link-level traces of observed pedestrian routes were foundational for developing choice sets of observed routes and realistic alternatives. SFCTA provided observed routes from the 2019 Bay Area Travel Survey, which they conducted in partnership with the Metropolitan Transportation Commission (MTC), the San Francisco Bay Area's Metropolitan Planning Organization (MPO). The survey was administered by the consulting firm RSG, who recruited participants throughout the nine-county San Francisco Bay Area using random address sampling. Participants installed RSG's proprietary rMove app on their personal smartphones, and the app used GPS and cellular location services to observe each respondents' travel activity for week-long periods—precise dates varied by participant—during the spring of 2019. This yielded timestamped points that formed traces along travel routes. The app predicted travel mode for each trip leg based on factors such as speed and accelerometry, then asked respondents to verify modes with an on-screen prompt after each trip was complete, providing a high degree of confidence in modal classification.

This study was approved by the University of California, Berkeley's Committee for the Protection of Human Subjects (Protocol ID 2020-03-13151).

5.3.1 Observed Routes

I was granted access to a limited and post-processed subset of the survey dataset that represented observed walking routes as lists of network links. SFCTA analysts used `pgrouter`, an open-source extension for PostGIS, to join trace points from walking trips to links along a pedestrian network from OpenStreetMap (OSM), which included all pedestrian-accessible roadways and off-street paths from spring 2019. Walking legs to or from intermediary destinations, such as transit access or egress points, were treated as separate trips. Circular trips, such as recreational trips that started and ended at the same link, were split at the point farthest from the origin, yielding separate trips in each direction. SFCTA's post-processing yielded a database of ordered link identifiers for each pedestrian trip. I considered these links *observed*, though they were technically a derivative of joining point observations to network links. To protect respondent privacy alongside such detailed geoinformation, this dataset did not include additional trip- or traveler-level information.

While the ordered links offered a spatially precise representation of observed routes, they included irregularities such as missing links, duplicate links, and circuitous paths, likely due to sparse and jittery survey points. It was infeasible to examine and clean the routes manually due to their large quantity. Instead, I developed a series of algorithmic processes and filters for correcting routes where possible with a high degree of certainty and excluding those that could not be readily corrected. The algorithm iteratively evaluated shortest paths between links separated by gaps and flipped the directions of links that were oriented against the predominant flow of the route—there were many instances where GPS points appeared to have been joined to directional network links going the unintended direction. Following this automated cleaning process, I manually reviewed the remaining routes and made minor adjustments to ensure that they followed logical trajectories.

Table 5.1. Steps for cleaning observed routes.

Step	Description	Observed Routes Remaining After Step
1	Exclude routes outside San Francisco	18,840
2	Fill gaps between observed links	18,840
3	Exclude routes that contain loops	8,533
4	Exclude routes with fewer than four links	6,474
5	Exclude routes where less than 50% of links or length are observed	732
6	Manually review and exclude routes primarily through parks	694
7	Generate realistic alternatives to construct choice sets	694
8	Exclude routes with no realistic alternatives	547

Table 5.1 outlines the steps of this cleaning process and the number of observed routes remaining after each step. Of the nearly 55,000 pedestrian routes initially provided by SFCTA, routes either partially or fully outside the city of San Francisco were excluded, leaving 18,840 routes. Due to sparse survey points, many routes contained gaps between observed links. I identified shortest paths across each gap as a representation of probable trajectories. Once gaps were filled, I automatically excluded routes based on three criteria. First, I excluded routes containing loops—visiting the same node twice—because they were illogical and likely the product of error in measurements of GPS or cellular point positions or in SFCTA’s post-processing. Secondly, I excluded those with fewer than four links because they were unlikely to offer viable alternative routes, a prerequisite for route modeling. Finally, I excluded routes for which less than 50% of links or overall route length was observed, resulting in low confidence in the actual walking route. These three filters excluded more than 96% of the raw routes available within San Francisco, yielding 732 routes with logical trajectories, viable alternatives, and high proportions of observed links.

Following this automated processing, I manually reviewed and refined or excluded routes to ensure that their trajectories were logical and predominantly traversed developed urban spaces rather than parks. Routes that were severely circuitous or otherwise illogical were excluded. Likewise, routes that were predominantly within parks or along trails were excluded to constrain the study to an urban context where buildings could potentially be developed. Routes that started or ended within a park but were predominantly along urban streets, suggesting that the park was the trip origin or destination, were truncated to the portions outside the park. Routes with minorly illogical trajectories in areas with dense network links, such as circuitry through complex intersections or jumping between sides of double carriageways, were manually straightened to minimize length and turns that likely resulted from measurement of joining errors. Thirty-eight routes were manually excluded, 30 of which were predominantly off-street. Another 57 were manually adjusted. Following this manual review, 694 observed routes were available from which to generate alternatives.

To examine whether excluded routes were non-random, I compared distributions of route lengths between the 18,840 raw routes provided by SCFTA and the 694 cleaned routes. Length calculations for raw routes were complicated by substantial gaps between many observed links, so I instead calculated Euclidean distances between the centers of first and last links. This same

measurement approach was used for both raw and cleaned routes for comparability. Distributions of these lengths were similarly shaped between the raw and cleaned sets, though routes with Euclidean lengths of approximately 500 meters appeared to be somewhat overrepresented in the cleaned dataset (Figure 5.1). Very short routes were not represented in the cleaned dataset because routes with fewer than four links were excluded. Longer routes were less represented, unsurprising given that longer routes offered more opportunities for data collection and processing issues.

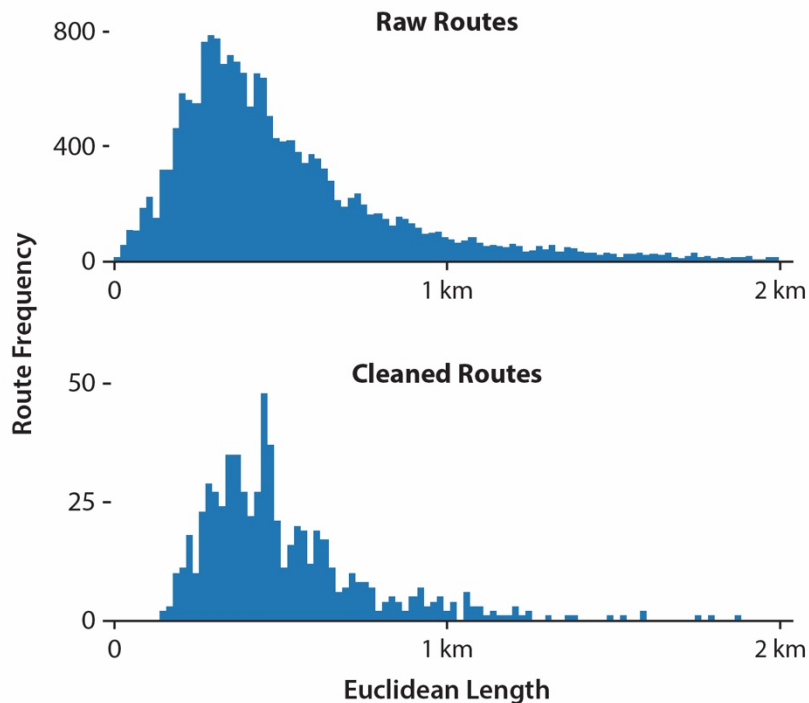


Figure 5.1. Comparison of length distributions between raw and cleaned routes. Lengths were calculated as Euclidean distances between centers of first and last links.

5.3.2 Generating Alternative Routes

Following Rodríguez et al. (2015), I used a branch-and-bound algorithm to generate alternative walking routes based on parameters designed to ensure that alternatives were reasonably direct and distinct from one another. Branch-and-bound algorithms are widely used for efficiently analyzing combinatorial decision spaces (Clausen, 1999). They work by iteratively growing decision paths that branch outward from an origin, using bounding criteria to determine whether potential paths should be maintained or discarded. Applying bounding criteria at each step of path growth limits the number of potential paths that must be evaluated, making it possible to efficiently identify suitable paths within large and complex decision spaces such as street networks.

I adapted Prato and Bekhor's (2006) branch and bound approach with five bounding criteria: *direction*, *length*, *looping*, *similarity*, and *turns*. The algorithm worked in steps, progressively building paths that met the bounding criteria and connected between specified origin (*o*) and

destination (d) nodes. In each step, paths from the previous step ($P_{o,x}$) were branched by appending available links ($L_{x,y}$) to their ends. The resulting candidate paths ($P_{o,y}$) were then evaluated against the bounding criteria. Candidates that met all criteria were carried into the next step. This process continued until all paths reached the destination node while meeting all bounding criteria.

Bounding criteria were conditional functions that compared path characteristics against test factors that controlled the sensitivities of the conditions. The *direction* criterion prevented paths from traveling unreasonably out of direction. It required that the cartesian distance between a path's current endpoint and the destination node ($D_{y,d}$), divided by the cartesian distance between the former endpoint and destination node ($D_{x,d}$), be less than or equal to a test factor ($\Delta_{Direction}$) greater than 1:

$$\frac{D_{y,d}}{D_{x,d}} \leq \Delta_{Direction}$$

The *length* criterion prevented paths from being unreasonably long. It required that path length ($PL_{o,y}$) divided by both the shortest network distance between the origin and the path endpoint ($ND_{o,y}$) and the shortest network distance between origin and destination ($ND_{o,d}$) be less than or equal to a test factor (Δ_{Length}) greater than 1:

$$\frac{PL_{o,y}}{ND_{o,y}} \leq \Delta_{Length}$$

$$\frac{PL_{o,y}}{ND_{o,d}} \leq \Delta_{Length}$$

While the second condition was technically redundant with the first, as y would eventually equal d , testing for it at every step substantially improved algorithmic performance by excluding long paths earlier in the process.

The *loop* criterion excluded paths that traversed the network inefficiently by looping back on themselves. Such loops were identified based on unreasonably long path distances between pairs of path nodes. For all possible pairs ($i, j \in N^2$) of a path's nodes (N), the criterion required that path length between the nodes ($PL_{i,j}$) divided by the shortest network distance between them ($ND_{i,j}$) be less than or equal to a test factor (Δ_{Loop}) greater than 1:

$$\bigwedge_{(i,j) \in N^2} \frac{PL_{i,j}}{ND_{i,j}} \leq \Delta_{Loop}$$

The *similarity* criterion excluded paths that substantially overlapped others while maintaining the shorter alternative. It required that the portion of a path's length that overlapped with any shorter path leading to the same node ($OL_{o,y}$) divided by its overall length ($PL_{o,y}$) be less than or equal to a test factor ($\Delta_{similarity}$) less than 1:

$$\frac{OL_{o,y}}{PL_{o,y}} \leq \Delta_{similarity}$$

The *turn* criterion excluded paths with many more turns than alternatives leading to the same node. It required that the number of turns along a path ($T_{o,y}$) divided by the minimum number of turns among paths reaching the same node ($TM_{o,y}$) be less than or equal to a test factor (Δ_{Turns}) greater than 1.

$$\frac{T_{o,y}}{TM_{o,y}} \leq \Delta_{Turns}$$

Once alternative routes were generated based on these criteria, observed routes were added alongside them to form complete choice sets. Alternatives that were too similar to observed routes based on the similarity criterion were dropped from the sets, ensuring a degree of independence between routes.

Test factor values were determined using an iterative process beginning with the factors used by Prato and Bekhor (2006). They were then tuned to maximize the likelihood of observed paths being reproduced by the algorithm. The final factor values, with which 89% of observed routes were reproduced algorithmically, were:

$$\Delta_{Direction} = 1.1$$

$$\Delta_{Length} = 1.5$$

$$\Delta_{Loop} = 1.6$$

$$\Delta_{similarity} = 0.8$$

$$\Delta_{Turns} = 4$$

These values were also approximately consistent with those used by Rodríguez et al. (2015) and Prato (2012) with similar route generation methods.

Because precise origins and destination points were unknown, origins and destinations were assumed to be located at the midpoints of the first and last links of each observed route. Alternative routes were generated between these midpoints.

5.3.3 Route Variables

Route-level variables used for choice modeling were developed to represent both streetscape characteristics, the main effects of interest, and control characteristics that were potentially influential for route choice but outside the sphere of streetscape design. Streetscape variables were developed to operationalize aspects of each of Ewing and Handy's (2009) five streetscape design qualities: enclosure, complexity, transparency, imageability, and human scale (Table 5.2). Many of these variables were associated with multiple qualities.

Table 5.2. Variables used to operationalize Ewing and Handy's (2009) streetscape design qualities

Design Quality	Associated Variables
Enclosure	Building alongside Building setback from curb Width (between opposing buildings) Height (of building alongside) Cross section (height:width) Tree alongside
Complexity	Tree alongside Land uses alongside (various) Count of buildings alongside Count of parcels alongside
Transparency	Land uses alongside (various)
Imageability	Land uses alongside (various) Storefront alongside Tree alongside
Human Scale	Width (between opposing buildings) Building Height Tree alongside

Route-level variables were based on measurements from sample points spaced at 1-meter intervals along street centerlines, the geometric representations of network links, which provided a consistent and fine-grained spatial unit from which to evaluate streetscape conditions. More than 2.5 million points were evaluated across every pedestrian-accessible network link in San Francisco. Point-level measurements were then summarized along the route-level units used for modeling.

5.3.3.1 Data Inputs

Spatial datasets used to construct streetscape and control variables were gathered from a combination of public and proprietary sources that coordinated with the 2019 vintage of the SFCTA travel survey to the greatest extent possible (Table 5.3). Street centerlines from OpenStreetMap were used as the geometric foundation for sample points and the network links along which observed and alternative routes were defined. Sample points were indexed by a linear referencing system along network links, allowing them to be aggregated in the appropriate order along routes.

Table 5.3. Datasets used to develop route variables

Dataset	Source	Data Vintage
Street Centerlines	OpenStreetMap	2019
Building Footprints and Heights	City and County of San Francisco	2019
Parcel Boundaries and Land Uses	City and County of San Francisco	2019
Tree Canopy Areas	City and County of San Francisco	2019
Curb Lines	City and County of San Francisco	2019
Retail Points of Interest (POIs)	SafeGraph	2019
Retail Points of Interest (POIs)	City Observatory’s Storefront Index	2014
Encampment 311 Cases	City and County of San Francisco	2019
Elevation (5-foot counter lines)	City and County of San Francisco	2019
Marked Crosswalks	(Moran, 2022)	2021

Building footprints, parcels, tree canopy areas, and curb line geometries were collected from the City and County of San Francisco’s Open Data web portal. These datasets enabled consistent citywide measurements related to streetscape enclosure, including the presence of buildings and trees, setback distances, and cross-sectional ratios.

Land use data, used as indicators of streetscape interactivity, were compiled from three sources: municipal parcel data, points of interest (POIs) from SafeGraph, and POIs from City Observatory. The City and County of San Francisco’s parcel dataset, available from their Open Data web portal, identified major land use categories, such as public open space and residential. It did not, however, locate uses such as retail, civic, automotive, industrial, and medical with sufficient precision to represent interactive ground-floor facades. Instead, these land uses were identified by POIs from two third-party datasets—SafeGraph and City Observatory’s Storefront Index—which were spatially joined to the closest parcel within 50 meters. SafeGraph Places data from 2019, acquired directly from SafeGraph through their academic research program, were queried for public-facing locations associated with each of the aforementioned categories based on the North American Industry Classification System (NAICS), yielding 24,606 POIs associated with 12,249 parcels throughout San Francisco. Similarly, POIs from City Observatory’s Storefront Index, which was designed to represent storefront locations in cities throughout the U.S. based on Custom List’s American Business Directory from 2014, were queried with Standard Industrial Classification (SIC) categories, yielding 7,034 POIs associated with 4,830 parcels. There was a large degree of overlap between the two datasets—about 60% of parcels associated with Storefront Index records were the same land use according to SafeGraph—though manual examination suggested that Storefront Index better represented small businesses. SafeGraph, meanwhile, captured a much larger number of business locations. To draw on the strengths of both datasets, parcels were considered to have a retail, civic, automotive, industrial, or medical use if associated with either a SafeGraph or Storefront Index POI of that type. A parcel could be categorized with multiple uses if it contained multiple POIs of different types, such as a museum, a civic use, with a café, a retail use.

5.3.3.2 Distance Measurements

Closest distances between sample points and features to either side—building footprints, parcels, tree canopy areas, and curb lines—were foundational for developing point-level streetscape

measures. Distances were measured in two ways: (1) perpendicular to each side of the street centerline and (2) closest at any angle within the 180-degree arc on each side. Figure 5.2 demonstrates these two types of closest distance from regularly spaced sample points to building footprints. On the left side of the centerline, perpendicular and closest distances are equivalent at points *c* and *d*, but closest distances are shorter at the other points, where the vector to the closest building is not perpendicular. Closest features were identified up to 500 meters from each point and distances were assumed to be infinite beyond this threshold. Perpendicular distances were collected for building footprints, parcels, tree canopy areas, and curb lines to determine the presence and proximity of these features along either side of each street. Closest distances were collected for building footprints and used to determine whether a building was close enough, compared with others on the same side of that street, to be considered “along” a point, as described below.

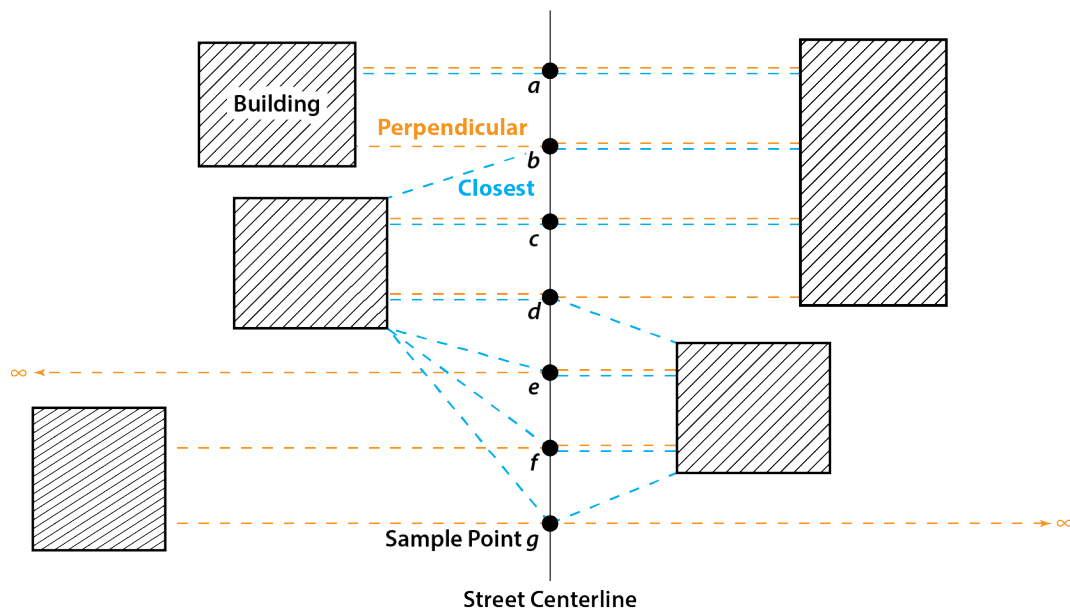


Figure 5.2. Demonstration of closest perpendicular and absolute distances from sample points to buildings.

5.3.3.3 Point-Level Variables

Point-level variables were calculated based on distance measures and other data sources, some representing a specific side of the street and others representing conditions across both sides (Table 5.4). *Building along* indicated whether, for each side of each point, a building was perpendicularly close enough to contribute to a street wall or, conversely, if there was a substantial gap between buildings that degraded the street wall. This was determined by testing whether perpendicular building distances at each point were less than or equal to the maximum of closest building distances on the same side of the block-length street segment: the block face. For example, on the left side of the centerline in Figure 5.2, the maximum closest building distance (blue) is from point *g*. Perpendicular building distances (orange) at points *a*, *b*, *c*, and *d* are shorter than this maximum, so these points are considered to have a building along. Points *e*, *f*, and *g*, however, are not considered to have a building along because their perpendicular

building distances are relatively too large. This method assumed that closer buildings would take precedence in establishing where pedestrians expected a street wall to be located, but that farther buildings could form a street wall in the absence of closer ones on a given block face.

Table 5.4. Point-level variables and definitions

Variable	Definition
<i>Side-Specific</i>	
Building Along (boolean)	If perpendicular building distance $\leq$ maximum closest building distance along street segment
Setback Distance (meters)	Perpendicular building distance – median perpendicular curb distance along street segment
Building Height (meters)	Height of a building that is along; 0 if no building along
Height:Width Cross-Section (ratio)	Building Height:Building-to-Building Width
Retail Along (boolean)	If nearest perpendicular parcel has a non-automotive retail use
Automotive Along (boolean)	If nearest perpendicular parcel has an automotive use (e.g., gas station or car dealership)
Residential Only Along (boolean)	If nearest perpendicular parcel has a solely residential use (e.g., single family or small multifamily)
Open Space Along (boolean)	If nearest perpendicular parcel is public open space (e.g., park or playground)
Civic Along (boolean)	If nearest perpendicular parcel has a civic use (e.g., government, school, or cultural venue)
Medical Along (boolean)	If nearest perpendicular parcel has a medical use (e.g., hospital)
Industrial Along (boolean)	If nearest perpendicular parcel has an industrial use (e.g., factory or warehouse)
<i>Non-Side-Specific</i>	
Building-to-Building Width (meters)	Sum of perpendicular building distances on either side
Curb-to-curb width (meters)	Sum of median perpendicular curb distances across both sides of street segment
Tree Canopy Along (boolean)	If perpendicular tree canopy distance $<$ perpendicular building distance AND perpendicular tree canopy distance $<$ 20 meters on either side
Encampment Along (boolean)	If reported encampment point within 20 meters
Arterial (boolean)	If point is along an arterial street
Collector (boolean)	If point is along a collector street
Local (boolean)	If point is along a local street
Off-Street (boolean)	If point is along an alley, parking lot, off-street path, or very low-traffic street (e.g., <i>woonerf</i> or shared street)
Elevation (meters)	Elevation above sea level

Setback distance was the difference between perpendicular building distance and median perpendicular curb distance along that side of the street segment. The median of perpendicular curb distances was used to approximate curb position despite breaks in curb lines due to driveways and intersections.

Building height was the height of a building along a point on a given side, defaulting to 0 if there was no building along. Building heights were available as tabular attributes of building footprints. This measure represented streetscape scale in the vertical dimension, with lower building heights constituting a more human scale.

Height:width cross section was the ratio between building height on a given side and building-to-building width, described below. This measure represented vertical enclosure, with larger ratios constituting greater enclosure. It was calculated separately on each side to reflect differences in building heights between sides.

Retail, automotive, residential, open space, civic, medical, and industrial along indicated the presence of each land use in the parcel directly perpendicular to a point on a given side. Because parcels could contain multiple POIs with different land uses, it was possible for a point to have multiple land uses along the same side.

Non-side-specific point measures accounted for characteristics that spanned both sides of a street. *Building-to-building width* was the sum the perpendicular buildings distances across both sides, representing the perceptual width of the street corridor between opposing façades. It provided a measure of streetscape scale in the horizontal dimension, with smaller widths being more human in scale.

Curb-to-curb width accounted for the width of a streetscape allocated to the roadway. It was calculated as the sum of median perpendicular curb distances across both sides of a street segment. Because it relied on median curb distances, it was consistent for all points along a street segment but varied between segments.

Tree canopy along indicated the presence of tree canopy area perpendicular to the centerline to either side. Because tree canopy often spanned across streetscape areas, it was inappropriate to differentiate between tree canopy along one side of the street or the other, so this measure simply indicated whether trees were present across the entire cross-section. To ensure that tree canopy was visible from the street, the perpendicular distance to a tree canopy area was required to be less than the perpendicular distance to the nearest building. Tree canopy areas more than 20 meters from the centerline were excluded.

Encampment along indicated proximity to an encampment of tents or other temporary structures erected by unhoused people, a common feature of San Francisco streetscapes. This variable was used as an indicator of disorder that pedestrians might perceive as aesthetically or socially uncomfortable or dangerous. Encampment locations were represented by point locations from encampment reports filed with 311, the City of San Francisco's customer service center, from the first half of 2019, totaling more than 28,000 points. A sample point was considered to have an encampment along it if it was within 20 meters of any reported 311 encampment.

Functional classes—*arterial, collector, local, and off-street*—were used as indicators of traffic volume due to inconsistent availability of more direct measurements across all streets in the study area. A more complex classification system attached to the street network by SFCTA was

summarized into four levels (Table 5.5). Sample points inherited the class of their underlying network links.

Table 5.5. Original functional classes that contributed to summarized classes

Summarized Class	Original Classes
Arterial	Major Arterial, Major Arterial Ramp, Minor Arterial, Minor Arterial Ramp
Collector	Major Collector, Minor Collector, Slip Lane
Local	Local
Off-Street	Alley/Parking, Walking/Bike Path, Private Walk/Square, Stairs, Woonerf

Elevation was attached to sample points to calculate steep grades along routes. Five-foot elevation contours from the City and County of San Francisco’s Open Data Portal were interpolated into raster grid with 1-meter horizontal resolution using a cubic spline. Sample points inherited the elevation of the grid cell they spatially intersected.

5.3.3.4 Route-Level Variables

Point-level variables were summarized along routes, the units of analysis for modeling (Table 5.6). Route-level summaries were primarily calculated as the proportion of route length that met a particular condition. Variables that ranged across continuous scales at the point level were summarized within ranges to create point-level Boolean indicators, then aggregated to represent the proportion of each route meeting the specified condition. Setbacks along the near side, for example, were segmented into the proportions of route length within three ranges: < 5 meters, 5–25 meters, and ≥ 25 meters. Ranges were explored iteratively to identify thresholds around which associations with route choice changed in sign (see Results & Discussion, below). Setback was tabulated along the nearer side at each point, and height and cross section were tabulated along the higher side, to reflect maximum potential for enclosure if buildings were substantially closer or taller along one side than the other. This approach reflected the assumption that enclosure might influence walkers even if it was provided along only one side of a street.

Table 5.6. Route-level variable definitions

Variable	Definition
Length (km)	Count of 1-meter sample points / 1,000
Building Along [x] Sides (proportion of length)	Proportion of sample points with a building along 0, 1, or 2 sides.
Setback Along Near Side [within x range] (proportion of length)	Proportion of sample points with a setback within the specified range. Tabulated along the side with the smaller setback at each sample point.
Width [within x range] (proportion of length)	Proportion of sample points with a building-to-building width within the specified range.
Height Along High Side [within x range] (proportion of length)	Proportion of sample points with a building height within the specified range. Tabulated along the side with the larger building height at each sample point.
Cross Section Along High Side [within x range] (proportion of length)	Proportion of sample points with a height:width cross section within the specified range. Tabulated along the side with the larger cross section at each sample point.
Tree Along [either/neither] Side (proportion of length)	Proportion of sample points with a tree along either or neither side.
Storefront Along [either/neither] Side (proportion of length)	Proportion of sample points with a storefront along either or neither side.
Automotive Along [either/neither] Side (proportion of length)	Proportion of sample points with an automotive use along either or neither side.
Residential Along [either/neither] Side (proportion of length)	Proportion of sample points with a residential use along either or neither side.
Open Space Along [either/neither] Side (proportion of length)	Proportion of sample points with open space along either or neither side.
Civic Along [either/neither] Side (proportion of length)	Proportion of sample points with a civic use along either or neither side.
Medical Along [either/neither] Side (proportion of length)	Proportion of sample points with a medical use along either or neither side.
Industrial Along [either/neither] Side (proportion of length)	Proportion of sample points with an industrial use along either or neither side.
Encampment Along [either/neither] Side (proportion of length)	Proportion of sample points with an encampment along either or neither side.
Arterial (proportion of length)	Proportion of sample points along an arterial street.
Collector (proportion of length)	Proportion of sample points along a collector street.
Local (proportion of length)	Proportion of sample points along a local street.
Off-Street (proportion of length)	Proportion of sample points along an off-street link.
Grade [within x range] (proportion of length)	Proportion of sample points with a rise/run grade within the specified range.
Maximum Grade (decimal %)	Maximum grade across all sample points.
Intersections per Length (count per km)	Count of intersections per km of route length.
Turns per Length (count per km)	Count of turns (> 45 degrees between links) per km of route length.
Crosswalk Availability (crosswalks per intersection)	Proportion of intersections with marked crosswalks.

5.3.4 Choice Modeling

Choices between observed and alternative routes were modeled using a path size logit (PSL) regression framework that incorporated a path size factor into a multinomial logit (MNL) model conditioned on the specific choice sets associated with each observed route. Path size factors adjusted for non-independence between route alternatives by downweighing routes that substantially overlapped with others in the same choice set. Path size factors were calculated as:

$$PS_{in} = \sum_{a \in \Gamma_i} \frac{l_a}{L_i} \frac{1}{\sum_{j \in C_n} \delta_{aj}}$$

where Γ_i was the set of links in a given route (i), l_a was the length of link a , L_i was the total length of the route, C_n was the choice set of alternative routes, and δ_{aj} was equal to 1 if an alternative route (j) included link a . The path size factor equaled 1 if a route had no overlap with alternatives in the same choice set and would equal 0 if it overlapped entirely with an alternative, though constraints on the route generation algorithm prevented this from occurring. Other researchers have included an additional term in their path size formulations that penalized exceptionally long routes (Hoogendoorn-Lanser, 2005; Lue & Miller, 2019; Prato & Bekhor, 2006). However, because the route generation algorithm used in this study already limited the lengths of unobserved alternatives, this term was omitted from the formulation used for this study.

Following Broach et al. (2012) and Tomhave and Khani (2022), the probability of choosing a route (i) that was part of the choice set (C) for an observed route (n) was defined as:

$$P(i|C_n) = \frac{e^{V_{in} + \beta_{PS} \ln(PS_{in})}}{\sum_{j \in C_n} e^{V_{jn} + \beta_{PS} \ln(PS_{jn})}}$$

where V_{in} was a linear combination of regressor-coefficient products representing the utility of choosing alternative route i for observed route n , PS was the path size factor, and β_{PS} was the path size coefficient. Coefficients were estimated using the PyLogit Python package developed by Brathwaite and Walker (2018) using a maximum likelihood approach.

I initially explored associations between streetscape variables and route choice by specifying separate *minimal* models for each variable alongside controls for route length and path size. These minimal models were also used to identify nonlinearities in associations with route choice across different ranges in setback, width, height, cross section, and grade. I iteratively segmented these variables across numerous ranges, beginning with narrow ranges and progressively aggregating them to identify ranges that corresponded with major shifts in directionality or magnitude of association with route choice.

Next, I developed three larger models to examine the marginal effects of streetscape variables while more fully controlling for other factors. The first of these included only streetscape variables, the second only roadway variables along the route, and the third combined both types. The first two were developed using a manual backward stepwise procedure whereby all streetscape or roadway variables were initially entered. Setback, width, height, cross section, and grade variables were entered with the segmentation identified for the minimal models. Within each model, the variable with the highest P value was iteratively dropped until all variables had statistically non-zero coefficients with at least 70% confidence ($P \leq 0.3$). The combined model was then defined as the intersection of variables from the streetscape and roadway models without considering statistical significance. Goodness of fit for the combined model was compared against that for the streetscape and roadway models respectively using likelihood ratio tests.

Effects sizes for covariates were evaluated based on point elasticities, which were calculated using the sample enumeration method, as defined by Louviere et al. (2000, p. 60), following Broach (2016) and Rodríguez et al. (2015).

Marginal rates of substitution (MRS) with route length were used to examine how effects compared with those of route length, yielding *distance equivalents*, as described by Broach (2016). MRS for variables defined as proportions of route length originally represented the route length equivalent for a 100% increase in route length. Distance equivalents were estimated by dividing MRS by the sample mean of route length (1.16 km).

Lastly, effects from the combined model were interpreted by predicting the probability of a route being chosen across varying levels of streetscape variables following the approach by Rodríguez et al. (2015). These predictions were based on a pair of alternatives that were assigned mean values for all covariates except one covariate of interest, which was iteratively manipulated for one of the alternatives. The resulting probabilities of selecting that alternative were then plotted against the input levels.

5.3.5 Computing Environment

All data processing and modeling was scripted with open-source Python packages, including Pandas, GeoPandas, NumPy, Shapely, NetworkX, and PyLogit.

5.4 Results & Discussion

5.4.1 Route Generation and Variable Aggregation

The route generation algorithm developed 5,171 alternatives for 694 observed routes. One hundred forty-seven (147) of these observed routes had no reasonable alternatives. This left a final dataset of 5,718 routes within 547 choice sets. Many of these were relatively short and had straight-line trajectories for which an alternative would require substantial out-of-direction travel. Others were in areas with low street network connectivity, constraining the potential for unique routes. Routes that were most conducive to generating alternatives spanned diagonally across rectilinear street grids, allowing for numerous alternatives with different combinations of turns but similar overall lengths. Longer routes tended to have more alternatives than shorter ones. The route with the maximum number of alternatives, 301, was 2.1 km long and diagonally traversed a gridiron street network. Most observed routes, however, had only one or two alternatives. The median number of alternatives was 3, and the 90th percentile was 19. The

average length of all route alternatives was 1.16 km with a standard deviation of 0.61 km, a minimum of 0.17 km, and a maximum of 3.13 km. The average length of observed routes in the final dataset was 0.6 km, indicating that, as expected, walkers tended to select shorter routes.

Most routes were in the northeast neighborhoods of San Francisco, including Pacific Heights, Presidio Heights, Hayes Valley, and Haight-Ashbury (Figure 5.3). Other well-represented neighborhoods included the Mission, Noe Valley, SOMA, and Dogpatch. Considerably fewer routes were in western neighborhoods such as the Richmond and Sunset Districts, and lower-density southwestern and southern neighborhoods had only a handful of routes.

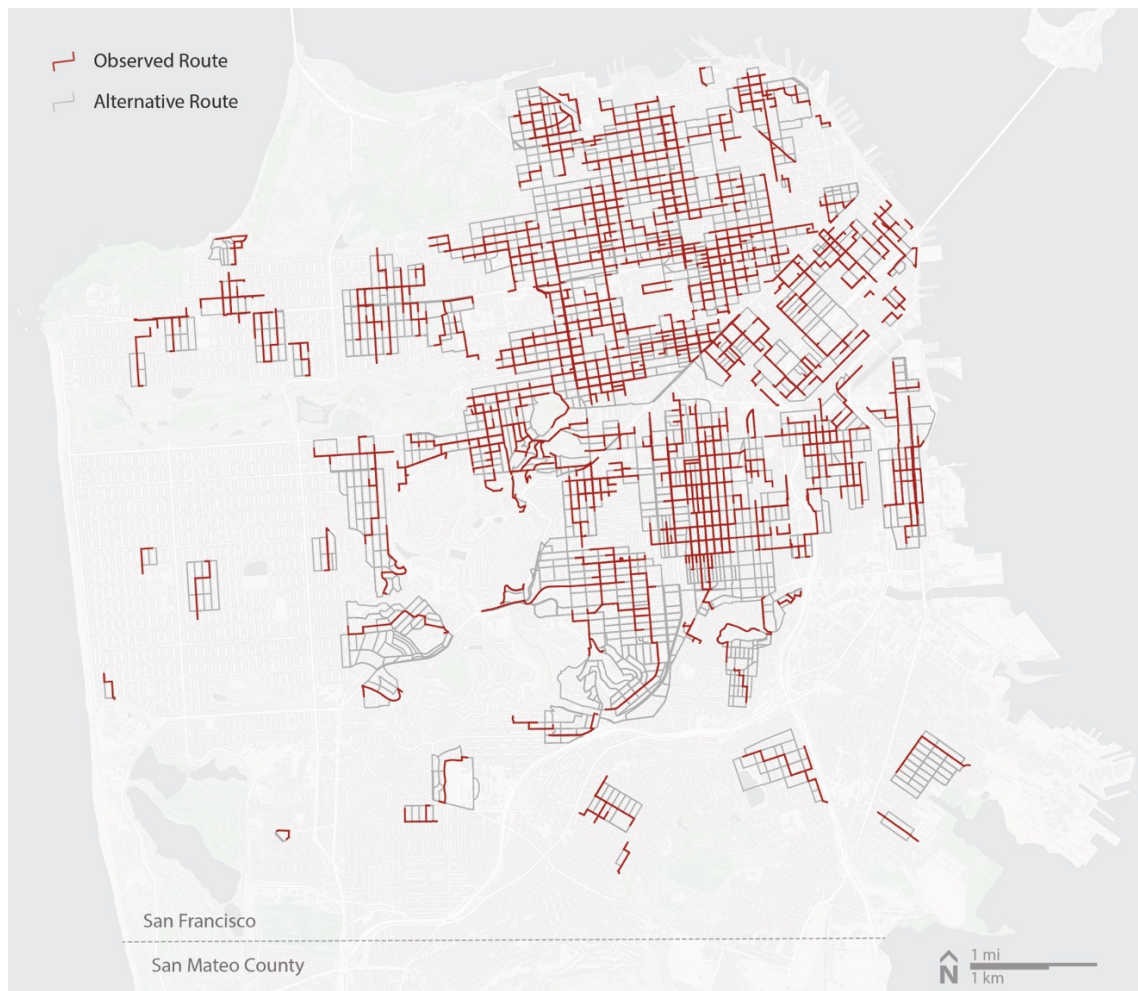


Figure 5.3. Map of observed and alternative routes within San Francisco. Basemap from Carto.

Table 5.7 shows the final aggregations of point-level variables along routes. Setback, width, height, cross section, and grade variables were segmented within ranges that most concisely reflected nonlinearities in their associations with route choice. Descriptive statistics for these aggregations reflect the dense built environment of the study area. On average, more than 80% of route lengths had a building along one or both sides. Setbacks tended to be small—65% of route length on average had a setback less than 5 meters—and storefronts were common—40% of route length on average had a storefront alongside it.

Table 5.7. Descriptive statistics and associations with route choice for streetscape and roadway variables. Separate path size logit models were used to estimate associations for each variable. Separate models are demarcated by horizontal lines in the table. All models controlled for route length and ln(path length) (not shown). Variables were calculated as the proportion of route length with the specified characteristic unless otherwise specified. All models evaluated 547 selected routes and 5,718 total alternatives (selected and not selected).

Outcome for all models: 1= Route Selected; 0= Route Not selected		Descriptive Statistics				Association with Route Choice			
		Mean	S.D.	Min.	Max.	Coeff.	S.E.	P	Elast.
Building Along	Both Sides	0.62	0.10	0.00	0.85	4.18	0.95	<0.01	1.73
	One side	0.21	0.08	0.01	0.61	<i>ref.</i>			
	Neither side	0.17	0.04	0.03	0.57	-17.79	2.66	<0.01	-1.95
Setback Along Near Side	< 5 m	0.65	0.14	0.00	0.91	3.05	0.74	<0.01	1.36
	5–25 m	0.18	0.13	0.00	0.88	<i>ref.</i>			
	≥ 25 m	0.17	0.07	0.02	0.90	-7.53	1.86	<0.01	-0.85
Width	< 15 m	0.03	0.07	0.00	0.80	-5.74	1.18	<0.01	-0.10
	15–25 m	0.42	0.18	0.00	0.84	<i>ref.</i>			
	≥ 25 m	0.55	0.18	0.16	1.00	-3.79	0.55	<0.01	-1.32
Height Along High Side	< 10 m	0.34	0.18	0.06	1.00	-3.69	0.87	<0.01	-0.79
	≥ 10 m	0.65	0.18	0.00	0.94	<i>ref.</i>			
Cross Section Along High Side	< 0.5	0.60	0.19	0.14	1.00	-2.93	0.62	<0.01	-1.11
	0.5–1.5	0.36	0.17	0.00	0.83	<i>ref.</i>			
	≥ 1.5	0.03	0.08	0.00	0.77	-4.90	1.31	<0.01	-0.14
Tree Along	Either side & Width < 25 m	0.83	0.09	0.49	1.00	3.29	0.87	<0.01	0.38
	Neither side or width ≥ 25 m	0.16	0.09	0.00	0.51	<i>ref.</i>			
Residential Along	Either side	0.47	0.28	0.00	1.00	-1.39	0.57	0.01	-0.38
	Neither side	0.53	0.28	0.00	1.00	<i>ref.</i>			
Storefront Along	Either side	0.40	0.27	0.00	1.00	2.40	0.47	<0.01	0.74
	Neither side	0.60	0.27	0.00	1.00	<i>ref.</i>			
Automotive Along	Either side	0.07	0.10	0.00	0.87	-0.18	0.81	0.83	-0.01
	Neither side	0.93	0.10	0.13	1.00	<i>ref.</i>			
Open Space Along	Either side	0.05	0.09	0.00	0.81	-2.97	0.87	<0.01	-0.09
	Neither side	0.95	0.09	0.19	1.00	<i>ref.</i>			
Civic Along	Either side	0.18	0.16	0.00	0.94	-0.86	0.55	0.12	-0.12
	Neither side	0.82	0.16	0.06	1.00	<i>ref.</i>			
Medical Along	Either side	0.10	0.12	0.00	0.92	1.09	0.69	0.11	0.09
	Neither side	0.90	0.12	0.08	1.00	<i>ref.</i>			
Industrial Along	Either side	0.03	0.08	0.00	0.79	0.09	1.03	0.93	0.00
	Neither side	0.97	0.08	0.21	1.00	<i>ref.</i>			
Buildings Along Both Sides (count / m)		0.11	0.04	0.01	0.21	21.30	4.14	<0.01	1.54
Parcels Along Both Sides (count / m)		0.13	0.04	0.02	0.26	9.69	3.49	<0.01	0.80
Encampment Along	Either side	0.27	0.23	0.00	1.00	0.01	0.51	0.98	0.00
	Neither side	0.73	0.23	0.00	1.00	<i>ref.</i>			
Functional Class	Arterial	0.14	0.21	0.00	1.00	-0.74	0.40	0.07	-0.07
	Collector	0.24	0.25	0.00	1.00	<i>ref.</i>			
	Local	0.60	0.30	0.00	1.00	-0.35	0.28	0.21	-0.13
	Off-Street	0.03	0.08	0.00	1.00	-3.65	0.89	<0.01	-0.06
Grade	< 1%	0.20	0.17	0.00	1.00	<i>ref.</i>			
	1–5%	0.22	0.14	0.00	0.87	-0.91	0.82	0.27	-0.14
	5–10%	0.09	0.10	0.00	0.60	-3.25	1.26	0.01	-0.20
	≥10%	0.05	0.08	0.00	0.77	-7.46	1.79	<0.01	-0.21
Maximum Grade (decimal %)		0.13	0.10	-0.01	0.88	-5.92	1.44	<0.01	-0.38
Intersections per Length (count / km)		11.97	3.34	5.28	43.74	-0.31	0.03	<0.01	-2.16
Turns per Length (count / km)		4.45	2.00	0.00	22.30	-0.26	0.03	<0.01	-0.75
Crosswalk Avail. (prop. of intersections)		0.66	0.22	0.00	1.00	1.84	0.38	<0.01	0.87

5.4.2 Univariate Associations with Route Choice

The minimal models indicated strong associations between route choice and many streetscape variables, predominantly indicating preference for streetscapes that were enclosed, where buildings were closer to the roadway, and where there were more sensorially engaging features such as trees and storefronts. Routes more continuously lined with buildings along one or both sides were much more likely to be selected than those with fewer buildings along them. These findings were consistent with design theory and other empirical studies suggesting favorability among walkers for more enclosing streetscapes with the potential to interact with building frontages (Basu et al., 2021; Ewing et al., 2016; Ewing & Handy, 2009). The extreme magnitude of this association—the odds of choosing a route without buildings along its entire length was less than 0.000002%—reflected the lack of variability in this characteristic within the sample; the maximum proportion of route length with no buildings along it was 57%, and the mean was only 17%. Nonetheless, having buildings alongside was strongly favored, and buildings along just one side appeared to have more than four times the marginal effect of buildings along a second side. This result reinforces the Chapter 3 finding that walkers readily experience both sides of a street and substantially benefit from enclosure or other qualities even from what Jacobs (1993) describes as a “one-sided” streetscape, with buildings along just one side and open space along the other. Symmetrical enclosure appears to be considerably less important than having buildings along at least one side.

The minimal model for setback along the near side indicated preference for narrow setbacks, less than five meters, and aversion to wider setbacks, at least 25 meters, compared with distances between these thresholds. This preference for closer buildings was consistent with design theory suggesting preference for more enclosed streetscapes with human-scale dimensions that might allow walkers to interact with building frontages at close range (Ewing & Handy, 2009; S. L. Handy, 1992). Exploration of various setback ranges indicated that five meters was a tipping point after which setbacks were negatively associated with route selection, while the magnitude of negative association increased markedly after 25 meters. This suggests that walkers in San Francisco may prefer setbacks within several meters of the curb, but disfavor those more than 25 meters. Without replicating this study in other locations, it is impossible to disentangle whether this may be due to typical design conditions in San Francisco or reflective of more general preferences. Large setbacks in many parts of San Francisco where routes were concentrated, even in residential neighborhoods, are paved in concrete, which may be interpreted by walkers as vast and sparse (Figure 2.1). In other places, large setbacks might typically be lawns or gardens that would be more attractive for pedestrians. Counter to my results, Ozbil et al. (2016) found that elementary school students in Istanbul preferred routes with larger setbacks, suggesting that the demographics of walkers, their cultural-geographic contexts, and the design characteristics of setbacks may all factor into preferences around setbacks. Examining how preferences are sensitive to such factors will be an important direction for future research about setbacks and other aspects of streetscape design.



Figure 5.4. Large setbacks in many areas of San Francisco are expansive areas of concrete. These setbacks in the Inner Richmond neighborhood are about 8 meters from the curb to building façades, not including stairs. The streetscape is about 27 meters wide from building to building.
(Image source: Google Street View)

The width model indicated preferences for streetscapes with middle-ground widths: neither too wide nor too narrow. Widths below 15 meters and above 25 meters were negatively associated with route selection, suggesting a sweet spot for preferable width within this range. It was unsurprising that walkers may have disliked narrow streetscapes if they were alley-like, which streets of this width in many parts of San Francisco tend to be (Figure 5.5). Guo and Loo (2013) similarly found that walkers in New York City preferred larger, busier streets compared with back alleys, potentially because they provided more of what Jacobs (1961) describes as “eyes on the street.” Conversely, subjects also appeared to dislike streets that were so wide as to degrade enclosure and limit their ability to perceive and interact with buildings to either side. This is consistent with Blumenfeld’s (1971) recommendation that streets be no more than about 20 meters wide to enable recognition of faces and other human-scale features from across the street. The majority of San Francisco’s residential and neighborhood commercial streetscapes are between 20 and 25 meters wide, so preferences for this approximate width may also reflect a bias toward what feels normal among local residents.



Figure 5.5. San Francisco streets less than 15 meters wide tended to be alley-like. This street in the Haight neighborhood is about 10 meters wide from building to building. (Image source: Google Street View)

The model for height along the high side indicated that walkers preferred streetscapes that were at least 10 meters tall, the equivalent of about two stories. This result was consistent with preference for *buildings along* variable because streetscapes without buildings along had heights of zero. It also reinforced design theory suggesting preference for streetscapes with at least moderate vertical enclosure, ideally with surrounding building heights that are no less than a third the width between opposing buildings (Alexander et al., 1977; Jacobs, 1993). For a street approximately 25 meters wide, as are many in San Francisco, this would require buildings at least 8 meters tall, or about two stories, quite similar to the 10-meter preference identified by modeling. Modeling results did not, however, identify a preferred maximum height, counter to observations by Foltête and Piombini (2010) in Lille, France, that pedestrians disliked walking alongside tall residential buildings. Alexander et al. (1977) similarly suggests a limit of four stories to allow pedestrians to interact by voice and sight with occupants in even the top-most levels of buildings. It is possible that maximum preferable heights were not distinguishable in the San Francisco case simply because few streetscapes had buildings taller than four stories. In addition to potential cultural-geographic differences in height preferences, some cities may simply not have enough tall buildings to identify whether walkers dislike them through route choice methods.

The cross-section model did, however, indicate a preferable upper bound for vertical enclosure. Streetscapes with cross sections along the high side between 0.5 and 1.5 were preferable to those with lower and higher cross sections. This indicated that walkers did not necessarily find taller buildings unfavorable if the width was large enough to maintain less than a 3:2 height-to-width ratio. This ratio exceeds the 1:1 ratio that Alexander et al. (1977) describes as an optimal upper limit but is congruent with the theoretical assumption that too much enclosure may be detrimental, making a streetscape feel claustrophobic. In the San Francisco case, such high enclosure tended to be from narrow but only moderately high streetscapes, such as alleys. This finding was consistent, then, with low preference for very narrow streetscapes.

Routes lined by trees were preferred—consistent with expectations that trees would contribute to preferable qualities such as enclosure and visual complexity (Arnold, 1993; Jacobs, 1993)—but only along streetscapes that were less than 25 meters wide. Without conditioning on width, trees were negatively associated due to being confounded with wide streets, which had greater potential for trees due to more ample space between buildings and the roadway. Only accounting for trees along streetscapes with relatively narrow widths removed this confounding effect by ensuring proximity between trees and walkers.

Among land uses, storefronts and medical uses were positively associated with route selection, while residential, civic, and open spaces showed negative associations. Automotive and industrial uses showed no significant associations. This result for storefronts was consistent with theoretical expectations of preference for more transparent and otherwise visually engaging streetscapes (Ewing & Handy, 2009), and empirical findings that walkers preferred more aesthetically pleasing façades (Basu et al., 2021). Medical uses, such as hospitals, may also have had pedestrian-oriented frontages. It was surprising, however, that residential, civic, and open spaces were not similarly preferable, counter to findings from other studies that account for such land uses (Basu et al., 2021). Results from Chapters 3 and 4 also suggested preference for open spaces, especially when they were green. These conflicting findings may reflect peculiarities of the San Francisco context, where open spaces may have been less maintained, or residential land uses may have been less transparent and inviting than in other cities due to the prevalence of garage doors and security-hardened entrances along ground floors. Such discrepancies reinforce how preferences are probably not caused by land uses themselves, but by their dominant forms, which may manifest differently in different places.

Rates of buildings and parcels per route length had strong positive associations with route choice. This was consistent with findings by Appleyard (2010) that smaller parcels encouraged more walking, and with theoretical expectations that more complexity and variability would be preferable to the potentially more monotonous or homogeneous forms of larger buildings with consistent design palettes (Dover & Massengale, 2013; Ewing & Handy, 2009).

Homeless encampments were not significantly associated with route preference, despite strong evidence that visual indicators of homelessness are unfavorable for walkers (Golan et al., 2019), and discussion among subjects in Chapter 3 about the effects of homelessness on environmental preferences. This null relationship may have been the product of imprecise measurement of these ephemeral and highly variable features. The 311 reports used as a data source likely underrepresented actual encampments, may have been imprecisely located, and did not represent the size, duration, or other characteristics of encampments. Moreover, because precise dates were not available for walking route observations, it was unclear whether encampments were yet established, or may have been removed, at the time routes were observed. As such, the lack of an association between route selection and encampments offers only speculative evidence that they were uninfluential.

Several roadway variables were also associated with selected routes. There were substantial differences in favorability between functional classes, which served as a proxy for traffic volumes and speeds, though they were not entirely consistent with theoretical expectations that walkers would prefer less traffic (Rodriguez-Valencia et al., 2022). Arterial streets were less preferable than collectors, but local and off-street links were also less preferable, suggesting that walkers preferred streets with moderate traffic. It is possible that unmeasured land uses related to street types may have confounded this association. However, the observed land use that was

most strongly associated with collector streets, storefronts, was still only weakly correlated with it (Pearson $r = 0.33$). Ultimately, this result suggests that walkers were not deterred by moderate traffic levels. Indeed, they appeared to be most deterred by links through alleys or parking lots, which presumably had the lowest levels of traffic but may have posed confounding concerns, such as fear of crime or inadequate sidewalks (Guo & Loo, 2013; Riggs & Gross, 2018). Notably, this study did not include routes with substantial portions along paths or trails that were entirely inaccessible to vehicles, so these results do not speak to the favorability of such highly separated facilities.

Consistent with findings from many existing pedestrian route choice studies, walkers preferred not to walk uphill (Basu et al., 2021). Steeper grades were considerably less preferred than more gradual ones.

Walkers also tended to choose routes with fewer intersections and greater availability of crosswalks, consistent with expectations that they would prefer less direct interaction with auto traffic (Basu et al., 2021; Rodriguez-Valencia et al., 2022). They also preferred routes with fewer turns, indicating that change of direction posed a psychological impedance. This finding was consistent with space syntax theory, which posits that understandings of spatial connectedness, and therefore distance, are strongly influenced by changes in direction (Shatu et al., 2019).

5.4.3 Marginal Effects of Streetscapes

Multivariate models indicated that streetscapes played a significant additional role in predicting route choices, suggesting that walkers preferred certain streetscape characteristics even after controlling for more practically oriented factors. Seven variables were maintained in the streetscape model, along with controls for length and $\ln(\text{path size})$, all of which were significant with at least 90% confidence and consistent with the minimal models in directionality and relative magnitudes of coefficients (Table 5.8). The width variable fell out as insignificant, likely due to collinearity with setback and the interaction between trees and width. Storefronts were the only land use variable maintained. Parcels per length was dropped due to collinearity with buildings per length. Streetscape variables were initially entered with the same categories developed for the minimal models, though third categories for the building along, setback, and cross section variables were folded into their reference categories because they lacked statistical significance on their own. As a result, while the overall trends demonstrated by multivariate models were consistent with the minimal models, they did not explicitly identify nonlinearities.

Table 5.8. Path size logit regression models predicting observed walking routes. The first model includes only streetscape-related covariates (streetscape model); the second includes only roadway-related covariates (roadway model); the third includes both types (combined model). All models evaluated 547 selected routes and 5,718 total alternatives (selected and not selected). Variables calculated as proportions of route length with that characteristic unless otherwise specified.

Outcome for all models: 1= Route Selected; 0= Route Not selected		Streetscape Model				Roadway Model				Combined Model			
Variable		Coef.	S.E.	P	Elast.	Coef.	S.E.	P	Elast.	Coef.	S.E.	P	Elast.
Building Along	Either Side	<i>ref.</i>								<i>ref.</i>			
	Neither Side	-14.66	2.80	<0.01	-1.56					-10.06	3.08	<0.01	-0.94
Setback Along Near Side	< 5 m	1.15	0.78	0.14	0.48					1.52	0.83	0.07	0.56
	≥ 5 m	<i>ref.</i>								<i>ref.</i>			
Height Along High Side	< 10 m	-2.10	1.01	0.04	-0.41					-1.77	1.09	0.10	-0.31
	≥ 10 m	<i>ref.</i>								<i>ref.</i>			
Cross Section Along High Side	< 1.5	<i>ref.</i>								<i>ref.</i>			
	≥ 1.5	-3.07	1.33	0.02	-0.08					-2.27	1.52	0.14	-0.05
Tree Along	Either Side & Width < 25 m	2.51	0.99	0.01	0.26					0.92	1.09	0.39	0.09
	Neither side or width ≥ 25 m	<i>ref.</i>								<i>ref.</i>			
Storefront Along	Either Side	3.43	0.55	<0.01	0.97					3.14	0.61	<0.01	0.77
	Neither Side	<i>ref.</i>								<i>ref.</i>			
Buildings Along Both Sides (count / m)		20.07	5.07	<0.01	1.34					6.49	5.47	0.24	0.38
Functional Class	Arterial					-0.54	0.43	0.22	-0.04	-0.34	0.46	0.46	-0.02
	Collector					<i>ref.</i>				<i>ref.</i>			
	Local					-0.44	0.31	0.15	-0.15	0.23	0.34	0.51	0.07
	Off-Street					-2.66	0.86	<0.01	-0.04	-1.70	0.94	0.07	-0.02
Grade	<5%					<i>ref.</i>				<i>ref.</i>			
	5–10%					-3.59	1.27	<0.01	-0.19	-2.66	1.33	0.05	-0.13
	≥10%					-8.01	1.90	<0.01	-0.19	-6.61	1.94	<0.01	-0.15
Maximum Grade (ratio)						-4.67	1.82	0.01	-0.25	-3.92	1.89	0.04	-0.20
Intersections per Length (count / km)						-0.32	0.03	<0.01	-2.07	-0.30	0.03	<0.01	-1.85
Turns per Length (count / km)						-0.22	0.03	<0.01	-0.58	-0.19	0.04	<0.01	-0.47
Length (km)		-7.83	0.78	<0.01	-3.37	-6.74	0.82	<0.01	-2.76	-6.50	0.83	<0.01	-2.57
ln(Path Size)		1.47	0.22	<0.01	-0.75	1.18	0.23	<0.01	-0.58	1.19	0.24	<0.01	-0.56
Model Summary													
McFadden's Pseudo R ²		0.18				0.23				0.27			
Log-Likelihood		-761				-711				-678			
Likelihood Ratio χ^2 with combined model				<0.01				<0.01					
AIC		1,540				1,442				1,390			
BIC		1,579				1,485				1,463			

Eight variables, in addition to length and $\ln(\text{path size})$, were maintained in the roadway model. Their signs and relative magnitudes were also consistent with minimal models. Crosswalk availability fell out as insignificant. Arterial and local functional classes were only marginally significant in the multivariate context.

The combined model, which included all variables from both streetscape and roadway models, offered significantly better fit than either of the preceding models. Streetscape variables offered less marginal improvement than roadway variables—McFadden's pseudo R^2 increased nine points between the streetscape and combined model and four points between the roadway and combined model—but both improvements were statistically significant according to likelihood ratio tests ($P < 0.01$).

Multicollinearity was minimal in all the final models, indicating the reliability of error estimates. The maximum variance inflation factor (VIF) was 3.6, for the length variable in the combined model. The vast majority of covariates across all models had VIFs less than 2.0.

By controlling for diverse variables, the combined model offered the most precise estimates of degrees of association between streetscapes and route choice. Elasticities for streetscape variables were similar in magnitude to those for most roadway variables, indicating that they had a comparable degree of influence on predicted outcomes. Consistent with many pedestrian route choice analyses (Basu et al., 2021), route length had the largest effect: a 1% increase in length reduced the likelihood of route selection by nearly 2.6%. The largest effect among streetscape variables, by contrast, was not having a building alongside, with an elasticity of -0.94. Storefronts alongside had a similarly large effect, with an elasticity of 0.77. Notably, elasticities for many streetscape variables were similar or greater in magnitude to those for steep grades, a well-substantiated influence on pedestrian behavior (Basu et al., 2021; Broach, 2016). This indicates that the role of unfavorable streetscapes in shaping pedestrian behavior is non-negligible, but rather may be akin to walking up a substantial slope. A walker might be willing to go out of their way for more preferable streetscapes, just as they might lengthen their route to avoid a hill.

Willingness to add length to a route is a useful way to conceptualize the potential effects of streetscapes and other route attributes. Broach (2016) suggests that MRS between route length and other attributes may be interpreted in terms of equivalent distances, or the rate at which those attributes inflate or deflate “perceived distance.” For example, each additional meter of route length without any building alongside it had, on average, the equivalent effect on probability of route selection as an additional 1.34 meters of route length (Table 5.9). As such, walkers effectively perceived portions of routes without buildings along them as 134% longer than they actually were. Likewise, route portions with setbacks less than 5 meters were perceived as 20% shorter, making them more attractive for walkers. These distance equivalents may be used to parameterize accessibility models that represent how streetscapes may affect impedance along pedestrian networks, easing access to places that could be reached via preferable streetscapes, or posing barriers to places that could only be reached by less preferable ones. While streetscape-based distance equivalents are a novel contribution of this study, it is notable that distance equivalents for intersections and turns identified here are on the same order of magnitude as

those identified by Broach (2016) in Portland, Oregon, indicating a degree of consistency in how these obstacles affected walkers in both cities.³

Table 5.9. Marginal rates of substitution expressed in distance equivalents.

Variable	Distance Equivalent
<i>For each additional meter of...</i>	
Building Along Neither Side	+1.34 m
Setback Along Near Side < 5 m	-0.20 m
Height Along High Side < 10 m	+0.24 m
Cross Section Along High Side ≥ 1.5	+0.30 m
Tree Along Either Side & Width < 25 m	-0.12 m
Storefront Along Either Side	-0.42 m
Off-Street	+0.23 m
Grade 5–10%	+0.35 m
Grade $\geq 10\%$	+0.88 m
<i>For each additional...</i>	
Building Along Either Side	-86 m
Intersection	+41 m
Turn	+26 m

Coefficients in full models were broadly consistent with those from the minimal models, though they tended to be smaller in magnitude owing to variability in route selection being partially explained by other terms. The most substantial change from the minimal models was that tree canopy was positively associated with route choice once other streetscape variables were controlled. In its minimal model, tree canopy had a negative association, counter to design theory suggesting how trees provide preferable qualities such as enclosure, visual complexity, and shade (Arnold, 1993; Jacobs, 1993). This sign flip suggests that the effects of tree canopy may have been more appropriately represented when controlling for building presence and setback, which may have confounded tree canopy measurements due to their role in constraining the physical spaces where trees could be located within the streetscape.

Several variables with significant effects in the roadway and streetscape models—setback, tree canopy, off-street, and crosswalk availability—lacked significance in the combined model, though the approximate magnitudes and directions of their parameter estimates remained consistent. As such, the combined model likely provided the best estimates of how these variables were associated with route selection while controlling for other factors.

³ The present study identified the distance equivalent of turns and all intersections +26 m and +41 m respectively. Broach (2016) identified the distance equivalent for turns as +54 m, for unsignalized arterial crossings as +73 m, and for collectors without a marked crosswalk as +28 m. While not equivalent or comparable, the similar orders of magnitude indicate a validating degree of consistency.

Lack of buildings along both sides remained the most influential streetscape variable. Its point elasticity indicated that a 1% increase in length without a building decreased the likelihood of a route being selected by 1.07%, while its MRS with route length indicated that portions without buildings might be perceived as 391% longer than those with buildings. Likewise, a 1% increase in route length with cross-section greater than 2.0—height greater than twice the building-to-building width—decreased the likelihood of being chosen, but by a much smaller margin, only 0.06%, owing to the relative scarcity of streetscapes with high cross-section within the study area. When it occurred, it appeared to be highly influential, effectively doubling perceived length (MRS with length = 2.06). Portions of routes with storefronts along them, by contrast, had the equivalent effect of reducing length by approximately 96%. Even while controlling for other factors, storefronts appeared to be highly preferential.

These results suggest that an ideal walking route might have been continuously lined by buildings, storefronts, and tree canopy, and with few setbacks greater than 15 meters or cross-sections greater than 2.0. Notably, these characteristics align well with how walkable streetscapes are described by seminal planning and design theorists including Jacobs (1993), Alexander et al. (1977), Gehl (2011), Cullen (1961), Lynch (1981), and the Congress for New Urbanism (1998). Revealed preferences for the suite of characteristics making up walkable streetscapes in San Francisco appeared to be highly consistent with paradigmatic walkable urbanism.

But how might individual characteristics of streetscapes be likely to affect route selection? Predicting route choice with the combined model while varying one characteristic at a time and holding others constant indicated that selection may be highly sensitive to certain factors (Figure 5.6). If nearly all of a route was bordered by buildings on at least one side, the probability of selection approached 100%, but this probably diminished to near zero if only 40% of a route had no buildings along it. The steepness of this curve indicated little tolerance for undeveloped space that might degrade streetscape enclosure. Because a substantial portion of routes spanned intersections—about 15% of observed route lengths were within intersections—this left an effective tolerance of only about 25% of route length within which presence or absence of buildings may have substantially influenced preferability.

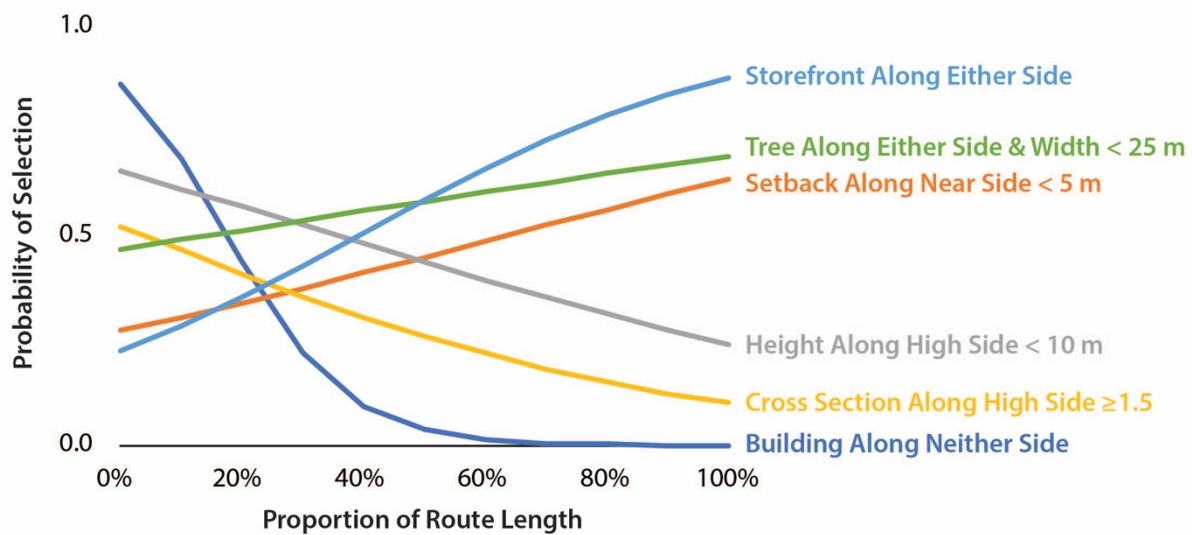


Figure 5.6. Predicted probabilities of selecting a route given varying levels of streetscape characteristics along them. Graphs are based on choice sets of two alternatives. All covariates were set at sample means for both alternatives except the covariate of interest, which was set at the sample mean for one alternative and iterated for the other at 10% intervals between 0% and 100% of the route length. Predictions were made using the Combined Model for all covariates except Cross Section 0.5–1.5 Along High Side and Width <15 m, which were predicted with the Streetscape Model.

Preference for enclosure was reinforced by the probability curves for setback and tree canopy. Setback had only a moderate effect, diminishing probability of selection from 65% to 30% between no areas with large setbacks and 100% of length with large setbacks. Tree canopy appeared to be more influential, increasing probability of selection from 40% to 90% between zero and 100% of route length with trees along both sides.

Predictions at varying levels of the cross-section variable, meanwhile, indicated a strong lack of preference for high vertical enclosure. The probability of selection decreased from about 50% with no cross-sections above 2.0 to near 0% with large cross sections along half of a route. When interpreting this curve, however, it is important to consider that the distribution of large cross-sections within the route sample was narrow (standard deviation = 6% of route length) with a low mean (2% of route length), so there were very few examples of high cross-sections on which to train this effect estimate.

The probability curve for storefronts along either side reinforced the importance of visually complex streetscapes, with the probability of route selection climbing from 15% with no storefronts to 95% if a route were entirely lined by storefronts. Complexity would likely also be reinforced by more buildings and smaller setbacks, which would increase proximity to street-facing windows and other engaging architectural features, as well as trees, with their complex structures and movement (Arnold, 1993). As such, walkers appeared to prefer streetscapes with features that simultaneously supported both enclosure and visual complexity.

5.4.4 Limitations

While this study provides strong evidence of the types of streetscapes walkers found preferable, it offers only limited causal inference. It cannot not conclusively demonstrate that streetscapes influenced route choices, only that certain streetscapes were associated with them. There is good reason to believe that measurable differences between streetscapes would contribute to pedestrians' decision-making, but the real-world contexts of choices evaluated in this study may have been confounded by any number of unmeasured factors. Moreover, interpretations of causality in regression models of choice depend on the somewhat dubious assumptions of complete information about alternatives and rational comparison between them (Ben-Akiva & Lerman, 1985). Route choice modeling has long struggled with developing choice sets that appropriately represent how walkers or other travelers perceive available alternatives (Prato, 2009). Walkers may also be unaware of characteristics partway along routes, and thus face path dependencies after making decisions based on earlier features. I experimented with aggregations of route characteristics that weighted initial blocks more heavily but did not find substantial differences in outcomes compared with equal weighting along entire blocks. There may, however, be ways to represent route-level characteristics that better account for walkers' progressive experiences. Finally, causal interpretations would depend on rationality in decision-making, akin to walkers adding up the characteristics of each alternative and conducting a cost benefit analysis before progressing on their trip. This is clearly an unrealistic assumption. Economists understand that decisions are heavily shaped by habits, heuristics, and biases (Kahneman et al., 1982). Nonetheless, models that mimic rational processes provide a useful shorthand for examining how factors *might* influence decisions that may have actually been shaped by substantially different reasoning processes.

The San Francisco study site offered many benefits, including a robust GPS travel survey dataset and detailed spatial data with which to evaluate streetscape characteristics. Findings, however, are inherently limited to the San Francisco context and the specificities of its residents and built environments. Most of the neighborhoods where routes were concentrated were laid out and initially developed more than 100 years ago, so streets were relatively narrow, land uses diverse, buildings tended to be in the range of two to four stories, and many street trees were mature (Godfrey, 1997). Extremely dense cities such as New York, or sprawling cities like Phoenix, would offer substantially different types of streetscapes to choose from, allowing different preferences to be revealed. The preferences of San Franciscans may also be informed by local environmental norms, so those of New Yorkers or residents of Phoenix might be considerably different. Results from this study, therefore, may not be readily transferrable to other cities, particularly those with strongly contrasting built environments.

While the San Francisco study site provided useful variability in most built environment characteristics, the vast majority of routes were lined by densely spaced buildings along most of their lengths. The average proportion of route length with no buildings along either side was only 17% with a standard deviation of 4%, and the average route had an additional building alongside for every 11 meters of length with a standard deviation of only 4 meters (Table 5.7). Setbacks greater than 25 meters were also unusual. Due to homogeneity in these factors, they served as exceptionally strong predictors of selected routes, with coefficients that were substantially larger than others in both the minimal and multivariate models. The signs and approximate magnitudes of other coefficients in the multivariate models were robust, however, when these factors were excluded, suggesting that they did substantially distort interpretation of other factors. A city with

greater variability in building density might be more opportune for the examining how these factors relate to pedestrian preferences, though such a place might also elicit substantially different preferences.

The study did not account for subject-level and circumstantial factors that may likely have impacted routing decisions. Subject demographics were not provided alongside GPS traces to protect the privacy of subjects. This precluded evaluation of how factors such as gender, age, and racial or ethnic identity may have related to preferences, a notable limitation of this study compared with others that have collected their own route data and, therefore, had direct access to participants (Basu et al., 2021). Other researchers leveraging large anonymized datasets such as cell phone records, however, have faced a similar constraint (Sevtsuk et al., 2021). Other limitations related to anonymization of input data included lack of information about time within the day or week, trip purpose, others accompanying the subject, or other contextual factors such as scheduling constraints or climate conditions that might prompt a subject to prioritize the most direct route or, conversely, enjoy a leisurely stroll. These types of information might conceivably be collected alongside route data by an in-depth travel survey—indeed, the survey from which the data I used originated included diary entries about several of these factors. Unfortunately, however, those records were stripped from the dataset made available for this survey to protect confidentiality. It is notable that raw route choices, even without parallel contextual information, demonstrated substantial preferences for streetscape characteristics, suggesting that there is value in even highly anonymized route traces. Nonetheless, demographic and other contextual factors would be useful for understanding how preferences vary within populations and in different conditions.

The measures by which streetscapes were represented also limited how streetscape qualities could be interpreted, even as they provided a novel opportunity to evaluate these qualities in a route choice context. Ewing and Handy (2009) identified nearly two dozen variables that were significant indicators of their five urban design qualities. This study operationalized these qualities with only about one dozen, about half of which were associated with enclosure (Table 5.2). While the granular measurement of these variables from existing spatial data sources represented a substantial economy compared with more traditional audit-based approaches, they were nonetheless limited in the precision and nuance with which they represented such conceptually complex qualities. They also excluded many factors that would, theoretically, be valuable to account for. Ewing and Handy (2009), for example, note that the number of other people visible on a streetscape is a useful indicator of both complexity and imageability. While active land uses, such as storefronts, may have served as a vague proxy for presence of people, no data sources were available to precisely account for presence of other people, especially at the precise times when survey participants were walking. Data were similarly unavailable for many other factors, including outdoor dining, noise levels, signs, street furniture, public art, planters, proportion of first floor with windows, and number of dominant building colors. Other studies have faced similar difficulty identifying appropriate proxies for such microscale, nuanced, or multisensory factors based on spatial datasets (Harvey, 2014; Park et al., 2019; Purciel et al., 2009). Ultimately, however, certain aspects of streetscapes may simply not be measurable without human investigators in the field. Design researchers will contend with imprecise representations of the conceptual complexity of streetscapes, despite emerging opportunities to measure them more efficiently across a wider variety of places.

5.5 Conclusions

This study provides novel empirical evidence of relationships between mesoscale streetscape design and the revealed choices of real-world walkers. Results indicate strong preferences for streetscapes that are more human scale, spatially enclosed, and sensorially engaging, consistent with prevailing design theory (Ewing & Handy, 2009). Pedestrians demonstrated a willingness to walk out of their way for streetscapes that were more continuously lined by buildings, had smaller setbacks, lower cross-sections, more trees, and more storefronts. Additional analyses of street width and cross-section suggested optimal ranges for these characteristics. Streetscape widths were most favorable between 15 and 25 meters. Likewise, cross-sectional ratios were most favorable when they were greater than 1:2, but less than 3:2. These findings were consistent with design theories citing distance limitations to sensory perception, and preferences for moderately enclosed spaces (Alexander et al., 1977; Blumenfeld, 1971; Ewing & Handy, 2009). While the specific thresholds identified by this study may be particular to the San Francisco context, they demonstrate the potential to empirically identify design sweet spots that validate theoretical understandings of what streetscape dimensions and proportions may be most conducive for pedestrians.

Streetscape variables were significant predictors of route choices even after controlling for roadway variables, adding substantial explanatory power compared with a roadway-only model. This indicates the importance of accounting for streetscapes to understand pedestrian behavior, and the potential role of streetscapes in advancing urban walkability. Every meter of route distance without a building alongside it had an effect similar to adding nearly four meters of route length, and every meter with a storefront had an effect similar to reducing route length by nearly a meter. While these associations are not definitively causal, they indicate that streetscapes may have a substantial influence on pedestrian experiences and provide a mechanism for reducing the perceived costs of walking. Streetscapes might, therefore, be used to steer pedestrians toward particular corridors, or to improve pedestrian experiences more generally, so that walking is perceived as more viable or attractive. While this study did not explicitly investigate mode choices, it did demonstrate how streetscapes may reduce the effective cost of walking, a theoretically important factor in decisions between walking and alternative modes. Because this study demonstrated strong associations between streetscapes and choices about where to walk, there is good reason to believe they may also influence decisions about whether and how much to walk, positioning streetscapes as a meaningful lever for promoting walkability.

The significant roles of streetscape and roadway variables in explaining pedestrians' route choices demonstrates that shortest paths are a poor proxy for real-world walking routes. Nonetheless, there remains much to understand about the full range of factors that contribute to pedestrian preferences. Streetscape and roadway factors ultimately accounted for only a small portion of variability in route choices, indicating the substantial roles of unmeasured environmental, social, and personal factors. This study did not account for sociodemographic differences in environmental preferences, nor did it evaluate more microscale spatiotemporal factors related to environmental qualities such as order and disorder, sun and shade, or wealth and poverty, which likely impact preferences and choices in complex and substantial ways. The study was also limited to representing San Francisco residents who were walking in their home city. There is good reason to believe that pedestrians from other cities may have disparate environmental preferences informed by local architectural or social norms. Investigating these

geographic and sociodemographic differences constitutes a substantial agenda for future research that will be important for informing localized design policies and understanding how preferences vary between groups.

Nonetheless, this study clearly demonstrates that pedestrians are sensitive to streetscapes, and that their preferences are not entirely personal, but are generalizable to a measurable degree within a particular city. Its findings reinforce the possibility of designing streetscapes to tangibly improve experiences of walkability, and validate theoretical understandings that more enclosed, human-scale, and engaging streetscapes tend to be preferred, at least within the San Francisco context. This lends scientific credibility to planners and designers aiming to build more walkable urban places by considering streetscape design in pedestrian planning, reforming design policy to encourage more walkable streetscapes, and consciously developing urban spaces so they are attractive for pedestrians.

Chapter 6 Walkable Streetscapes in Practice

This dissertation strengthens empirical understanding of how streetscapes may contribute to urban walkability. But how can walkable streetscapes be more widely deployed in practice? Even as walking has gained popularity in recent decades, walkable urbanism has remained persistently uncommon in most U.S. cities (Besel & Andreescu, 2013). Why are walkable streetscapes so difficult to build, both in retrofits of existing urban areas and in new development?

Understanding what stands in the way of developing walkable streetscapes is itself a complex research agenda, one that might be the focus of an entire dissertation. It is useful, however, to consider the high-level structural forces that might impede their development to identify opportunities for overcoming them. This short chapter discusses obstacles to development of walkable streetscapes, how results from the studies at the core of this dissertation may inform strategies for improvement, and trajectories for additional research into how streetscape designs influences walkers.

The approaches I present for designing more walkable streetscapes are not revolutionary. Urban designers have long advocated for walkable streetscapes and results from this dissertation broadly support the design qualities they promote, including moderate levels of enclosure, more human scale features, and perceptually engaging frontages. The novel contribution of this dissertation is substantiating the impact that streetscapes may have on real-world walkers and encouraging the transportation field to incorporate streetscapes into its planning toolkit. This will mean strengthening collaboration between transportation, urban design, and land use planning, and acknowledging that development outside the direct control of transportation agencies substantially impacts the quality of transportation systems, particularly for pedestrians. The importance of streetscapes poses a challenge to transportation planning to more broadly conceptualize how it improves walkability, and to more strongly incorporate urban design and land use planning into efforts to promote walking as a viable mode.

6.1 Obstacles to Developing Walkable Streetscapes

A key obstacle to developing walkable streetscapes is the diversity of agents who affect their designs. Whereas transportation planners are used to operating within rights-of-way that are often controlled by a single agency, streetscapes are piecemeal spaces, composed of numerous buildings, trees, and other objects that are often governed by numerous landowners and public agencies. Master-planned development may provide opportunities for a single agent to control streetscape design before properties are transferred to individual owners. Master-planned New Urbanist communities, for example, have been successfully developed with walkable streetscapes spanning their entire street networks (Cysek-Pawlak & Pabich, 2021). But modifying the character of streetscapes within existing urban fabric with piecemeal ownership poses a substantial collective action problem. Meaningfully increasing building enclosure along a streetscape with large setbacks, for example, would require not only modifications to zoning and design regulations, but piecemeal redevelopment led by individual landowners. Organizing or compelling landowners to contribute to such a formidable change will be substantially more complex than adjusting the designs of rights-of-way controlled by a single agency, a process that is more familiar to transportation planners.

Modification of streetscapes may also be impeded by the expense and durability of buildings and other features from which they are composed. The average lifespan of residential buildings in the U.S. is upward of 100 years (Ianchenko et al., 2020). Commercial buildings tend to last between 30 and 60 years (Kneifel, 2010). Even if there is motivation to address streetscape design when properties are redeveloped, there may be few opportunities to do so. Adjusting setbacks along a corridor, for example, might take many decades as individual buildings are modified or replaced, and this assumes that regulations allow for such change. Zoning and design codes often prioritize conforming with existing contexts (Talen, 2012), so meaningful changes to streetscapes may be regulatorily limited even when opportunities arise. The difficulty of making wholesale modifications to existing streetscapes compels planners to ensure that they are developed with walkable designs from the outset, and that occasions to modify large portions of streetscapes, such as construction of large buildings or district-scale redevelopment, are leveraged to their full potential. This may require forethought in implementing design policies that promote walkable streetscapes so that they are already in place during moments that are opportune for development. Once constructed, streetscapes may be a type of technological lock-in that either promote or hinder walking for decades (Avner et al., 2014).

So why do we continue to build streetscapes that limit walkability, even when we have opportunities for change? Major explanations may stem from lack of existing demand for walking, cultural norms that prioritize auto-oriented forms, and zoning and design regulations that perpetuate these norms. While rates of walking in the U.S. have increased marginally in recent years (Le et al., 2019), the proportion of trips made by walking remains low, at just over 10%, and only about 2.5% of workers regularly commute on foot (League of America Bicyclists, 2022). There may be limited political appetite to pursue major changes in urban form that would benefit relatively few existing users. Of course, planning for pedestrians faces a chicken and egg dilemma: should infrastructure development respond to existing demand, or should planners attempt to spur demand through infrastructure improvements? While there is substantial evidence that neighborhoods with more walkable forms are associated with higher rates of walking (Ewing & Cervero, 2010), the causal effects of walkability remain contested (Ewing & Cervero, 2017; Stevens, 2017). People who prefer to walk or otherwise travel less by automobile may simply self-select into more walkable places (Cao & Chatman, 2016). Where rates of walking are especially high, there may be strong economic and political pressure to develop streetscapes and other infrastructures that are conducive to it. In places where this is not already the case, however, substantial planning effort will likely be required to motivate improvements in walkability, and it remains unclear how effective these will be at spurring behavioral change.

Embedded cultural norms that lionize spaciousness in urban form may also stand in the way of developing more walkable streetscapes. Fishman (2011) describes how idealization of open space, rooted in modernist critiques of urban overcrowding, has informed nearly a century of suburbanization in the U.S. and around the world. This paradigm of spaciousness has contributed to proliferation of detached single-family homes that are set back from the street spaced apart from one another, degrading streetscape enclosure and reducing opportunities for interaction between building occupants and passersby. While extremes of crowding and spatial enclosure may be unfavorable—Chapter 5 demonstrates preferences for moderate degrees of enclosure—the openness paradigm has potentially emphasized spaciousness to an unreasonable extreme, causing collateral damage to walkable streetscapes, destination accessibility, and other aspects of sustainable urban design. Homebuyers, despite theoretically desiring aspects of walkable urbanism such as mixed uses, continue to prefer the aesthetic of detached single-family homes, a

paradox that may impede development of more walkable streetscapes in practice (Tian et al., 2015). Zoning and design regulations often compel spaciousness and limit streetscape enclosure through setbacks and height limitations (Talen, 2012). There are also substantial financial incentives embedded in Federal policy and lending practices that favor development of detached, single-family homes (Glaeser, 2011). Reforming these institutional barriers may require shifts in both cultural norms and real estate economics so that more walkable streetscapes are understood as an asset rather than a liability. Luckily, there is mounting evidence that walkable environments are a sound financial investment (Xu et al., 2018), but much work remains to undo systemic barriers to developing them.

6.2 Approaches for Change

Considering the practical and structural obstacles to walkable streetscapes, how might we nonetheless advance their development? Evidence from this dissertation suggests approaches for both short- and long-term change.

While this dissertation primarily focuses on mesoscale aspects of streetscape form, such as enclosure provided by buildings and trees, more microscale features may provide important near-term benefits. Tactical urbanism, an approach for prototyping roadway redesigns using temporary materials such as paint and street furniture, may similarly be applied to experiment with public realm improvements outside the roadway, or to repurpose roadway spaces for pedestrians (Silva, 2016). Street furniture and plantings, which many subjects observed favorably in Chapter 3, may quickly and inexpensively add visual complexity and a degree of enclosure to streetscapes that feel vacant or dull. The widespread expansion of sidewalk dining in many cities during the COVID-19 pandemic demonstrated the relative ease of implementing such changes. In many cases, this was combined with reallocation of roadway spaces, such as parking lanes and traffic lanes, to pedestrian uses, rapidly reshaping streetscapes into more human-scale and pedestrian-accessible spaces (Bereitschaft & Scheller, 2020). Murals and other public art may also add favorable visual complexity and imageability to otherwise blank walls or spaces without expensive changes to building envelopes (Naughton, 2022). While more major changes to buildings, trees, and other mesoscale forms may be needed to support long-term walkability, streetscapes may be usefully activated in the short-term by relatively minor interventions, potentially garnering support for more substantial future changes.

With a slightly greater degree of investment, street trees may be an opportune strategy for reshaping streetscape spaces in the near to medium term, though they may also provide long-term benefits if adequately maintained. Chapters 3 and 5 suggest that trees are powerfully and consistently attractive for walkers, offering sensory qualities of enclosure and complexity while providing numerous other benefits, including shade, protection from vehicle traffic, heat abatement, stormwater management, and other ecological services. Trees may, on their own, convert a street from a vast, exposed space into one that is cohesive and room-like while also offering practical benefits for temperature moderation and air quality at what is likely a lower cost than any other intervention with comparable effects (Jacobs, 1993). While trees do require investments in time and maintenance, planting and removing trees is considerably more economical and straightforward than constructing or demolishing buildings. They are a commitment on the order of decades rather than centuries, allowing for flexibility to shifting needs and making them potentially useful as a stopgap measure to improve streetscapes when changes to buildings are infeasible in the near term.

Perhaps most usefully, trees represent a rare opportunity to shape the vertical dimension of streetscapes from within the right-of-way, providing transportation agencies with a mechanism to improve streetscape walkability on their own. Nonetheless, trees do require allocation of space, for which there may be substantial competition from traffic lanes or more traditional pedestrian infrastructures, such as sidewalks. Fitting trees into urban streets will require creativity and commitment from transportation planners and engineers who have tended more often to remove trees, citing concerns over safety and maintenance, than add them (Dümpelmann, 2019). Street tree spacing and positioning around intersections tend to be heavily restricted, often based on outdated assumptions about dangers they pose as fixed object hazards and sight line obstructions (Macdonald, 2008). The transportation field will need to revisit its cost-benefit analyses of trees to successfully adopt them as a strategy for improving walkability.

Another near-term approach suggested by findings from this dissertation is to increase the transparency and interactivity of ground-floor uses, especially where buildings are already directly adjacent to the sidewalk. Subjects in Chapter 3 consistently responded negatively to blank walls, and nearly as negatively to façades that they interpreted as disingenuous, with windows that teased of transparency but were darked or covered to prevent seeing inside. Such treatments suggest a degree of intentionality to create a pedestrian-facing streetscape, potentially through design regulations that require fenestration, but stop short of following through on the practical value of windows: the ability to see through them. Chapters 4 and 5, meanwhile, suggest that many subjects found transparent storefronts exciting or otherwise preferred them compared with other land uses.

In places where ground floors are underutilized or blocked from view, filling vacancies, or incentivizing landowners to make impermeable façades more transparent may be a way to activate streetscapes without complete redevelopment. While ground floor retail spaces are already often incorporated into mixed use buildings, it can be challenging to fill these spaces with viable tenants, resulting in high rates of vacancy or underutilization, an issue that was further exacerbated by the COVID-19 pandemic (Smith, 2022). Subsidizing or otherwise incentivizing use of vacant ground-floor spaces could substantially enhance streetscape complexity and transparency, as could prohibiting permanent window coverings that block views into interior spaces. Installing additional ground floor windows in otherwise impermeable façades would be resource intensive, but considerably less than reconstruction. With minimal to moderate investment, buildings that currently provide passersby with little opportunity for engagement could be substantially more interactive.

There may also be relatively lightweight approaches for strengthening enclosure through structures that mimic buildings but are considerably less costly and complex to implement. Chapter 5 suggests that walkers substantial prefer streetscapes enclosed by continuous buildings, but permanent infill to patch holes in street walls may be impractical in the near term. In downtown Portland, Oregon, surface parking lots that would otherwise be conspicuous gaps in the densely-enclosed urban fabric have been repurposed as food truck “pods,” providing benefits for economic development and cultural vibrancy as well forming highly effective street walls where trucks park around the perimeters of the lots (Newman & Burnett, 2013). The trucks serve as miniature buildings that together compose block faces. Similarly, temporary dining sheds constructed in many cities during the COVID-19 pandemic intensified streetscapes enclosure, though to an unfavorable extreme in some cases (Timms, 2002). While permanent buildings

likely have maintenance and other advantages in the long run, temporary structures may be a useful way to bolster enclosure and enliven streetscapes in the short run at relatively low cost.

Another strategy for economizing near-term improvements to streetscapes may be to leverage findings from Chapters 3 and 5 indicating that design characteristics may be preferable even when they are limited to a single side. Interview subjects in Chapter 3 often discussed how characteristics of one side added value to their experience from the opposite side. Likewise, routes in Chapter 5 were most preferable when there were buildings and storefronts along at least one side; adding a second side provided relatively little additional value. Prioritizing development of more enclosing or engaging frontages along just one side might have greater benefit than spreading the same resources more thinly across both. Moreover, findings from Chapter 3 suggest potential benefits from sides with contrasting characteristics. Subjects were bifurcated in their preferences for more natural or built settings and were able to accommodate these preferences by choosing sides of the street that best accommodated these preferences. In cases where streetscapes already have substantially different qualities on either side, it may be beneficial to leave these differences in place, both reducing the need for intensive redesign and offering users choices that best suit their preferences.

A similar strategy for controlling the scope of near-term improvements may be to focus on a limited number of features that enhance walkable qualities rather than comprehensively redesigning entire streetscapes. Subjects in Chapter 3 often identified key characteristics—a particular tree, storefront window, hanging flowerpot, sign, or even material texture—that captured their attention and were strong drivers of preference, even within broader contexts that were less desirable. This reinforces how streetscapes do not need to be wholly ideal for walkers to find value in them. Small features, such as a renovated storefront or a new street tree, may have a meaningful impact on how walkers interpret streetscapes, providing a pathway for incremental change. Because walkers inherently explore streetscapes dynamically as they move along them, there may be greater potential to provide a relatively small number of highly favorable features that they may encounter in sequence, like following breadcrumbs along a path. Indeed, this is consistent with Kaplan and Kaplan's (1989) finding that environments providing a sense of unfolding mystery are most strongly preferable. This, of course, requires that engaging features be spaced closely enough to propel walkers between them, and not separated by features that are so unfavorable that they pose barriers. Nonetheless, the effectiveness of even piecemeal contributions may help make it more realistic for cities to pursue more walkable streetscapes through an incremental approach.

The most efficient near-term approach, however, may simply be to preserve walkable streetscapes that already exist. The durability of buildings that form streetscapes is a substantial asset in places where they already dominate. Cities developed before the proliferation of automobiles were built for walking out of necessity, with streetscapes designed around the scale and capabilities of pedestrians. Places that have maintained this urban fabric are some of the most inviting places to walk today (Jacobs, 1993). While none of the studies in this dissertation directly accounted for historic buildings, prior research shows that they tend to be closely associated with more enclosed, complex, and imageable streetscapes (Ewing & Handy, 2009). As a result, historic preservation and redevelopment that is sensitive to historic contexts is likely be a crucial tool for supporting walkable streetscapes (Yoshii, 2016). Preservation efforts should recognize not only the heritage value of historic streetscapes, but the contemporary value they provide by continuing to support walkability.

In the long-term, improving streetscape walkability may be substantially affected by land use policies, such as zoning, that guide the massing of buildings around streets. These policies may incrementally modify existing communities as they undergo redevelopment and infill, or steer ground-up development of new communities toward more walkable forms. There is longstanding precedent for using zoning to control building heights and setbacks, which Chapter 5 suggests substantially influence pedestrian preferences. Zoning codes in U.S. cities, however, have tended to encourage larger setbacks and impose restrictive high limits that degrade enclosure (Talen, 2012), the opposite of what design theory described in Chapter 2 and results from Chapter 5 suggest may be preferable for walkers. The legal mechanism of these codes could instead advance more walkable forms, but it would require a substantial shift in the paradigms they incentivize: closer and taller rather than farther and shorter.

Form based codes may offer even more powerful mechanisms for regulating aspects of design that impact streetscape qualities such as transparency, complexity, and imageability, including fenestration, façade composition, and signage. These types of codes already tend to be motivated by efforts to improve the quality of pedestrian spaces, but not overtly as a component of transportation policy (Parolek et al., 2008). Using research on pedestrian behavior to inform development of both zoning and form-based codes, and then deploying them with the explicit intent of shaping travel patterns, would be a novel application of these land use controls. Such codes could be used to incrementally steer streetscapes toward walkable forms over the long term or more rapidly and comprehensively inform development of new districts.

An important aspect of using zoning and design codes to shape streetscapes will be ensuring that they are well-positioned to affect key moments of change in urban form. This means implementing codes that promote walkable forms, even in places that are not currently experiencing development pressures, so that they are ready to steer projects when they arise. High-level planning for walkable streetscapes might also be used to identify key development needs for strengthening pedestrian networks, such as infill construction that would patch street wall gaps, or renovation of vacant buildings that would enliven streetscapes along prominent corridors. Such projects could be stimulated through public-private partnerships or offered incentives to spur streetscape improvements. Streetscapes might also be incorporated into broader agendas that coordinate improvements across multiple planning spheres. The San Francisco Better Streets Plan, for example, directs City agencies to collaborate around street construction projects so that they simultaneously address goals related to transportation, public life, and ecology (San Francisco Planning, 2010). Projects addressing any of these goals are leveraged as opportunities to make improvements in other areas, including working with private property owners to enhance frontages and public access to ground floor uses. This plan stops short, however, of recommending changes to zoning as a mechanism for improving streetscapes. On one hand, this suggests there may be ample opportunities for improvement that would conform with current codes, at least within the San Francisco context. On the other hand, it acknowledges the difficulty of reforming zoning and its bureaucratic disconnect from other spheres of planning, even in a city with a progressive approach to coordinating these spheres.

While regulations may be required to control certain aspects of how streetscapes develop, market forces may also encourage streetscape walkability in the long term. Walkability is strongly favored in contemporary urban real estate markets (Chernobai & Ma, 2022), so developers may consider walkable streetscapes an important amenity and foster them even without regulatory mandates. Given the current market potential for walkable neighborhoods, an important role for

urban policy may be simply to ensure that market forces promoting walkability are able to act. This may mean loosening zoning regulations that pose obstacles to density or mixed-use development. Planners must also, however, be careful about the gentrification potential of walkable streetscapes, especially in existing low-income communities with walkable built forms (Koschinsky & Talen, 2015). Cities should take advantage of market pressure to develop walkable communities while they are highly demanded, but a regulatory thumb may be necessary to ensure that walkable development is equitable and functional for a broad spectrum of urban residents.

If streetscapes are reshaped to promote walkability on a large scale, it will be important that this process is approached creatively rather than prescriptively, ensuring that their designs continue to relate to their social and physical contexts. Unlike roadway designs specified by engineering standards (AASHTO, 2018), streetscapes are unlikely to be successful if designed in highly standardized ways. Recommendations for rough dimensions or proportions may be useful for shaping the skeletal structures of streetscapes, and qualities such as transparency and complexity may be used as guiding principles, but the details of how these dimensions or qualities are achieved must be worked out creatively and contextually by competent designers. A mandate for walkable streetscapes with certain qualities does not strip agency from the design process, but rather encourages it to be more thoughtful. Formulaic approaches to neighborhood design may reproduce obstacles to walkability by producing monotonous and repetitive streetscapes. There is substantial opportunity to inject more intentional and creative design into spaces that are otherwise boring or uncomfortable for pedestrians. Incentivizing more intensive design and dedicating sufficient resources to it, however, will require advocacy for the importance of walkable streetscapes from a broad range of planning voices, ideally through collaboration between the transportation and design fields. It should also, as Chapter 3 demonstrates, involve diverse community voices who may have different interpretations of what constitutes walkability than do planning experts.

6.3 What More do We Need to Know?

This dissertation demonstrates relationships between streetscape design and the perceptions and behaviors of real-world walkers, links that have so-far been undeveloped in research on walkable urban design. Further, it empirically identifies non-linearities in these relationships, indicating potentially optimal levels in streetscape characteristics within the San Francisco context. While these are important steppingstones to supporting policies and designs that will improve streetscape walkability, there is substantial room for refined understanding of streetscape preferences in ways that are more sensitive to cultural and geographic contexts. Interviews from Chapter 3 demonstrated the variability of personal experiences and preferences that shaped subjects' perceptions and evaluations of streetscapes. These differences were unmeasured in the dataset used in Chapter 5 but were likely central to modeling errors. There is a clear mandate for future research to unpack these unmeasured errors by evaluating differences in preferences across demographics, cultural groups, personal history, and geography. Preferred characteristics are likely to be different between cities, especially those with substantially contrasting built environment norms. It would be unsurprising, for example, to find that more enclosed streetscapes were preferred in a city with a historic core composed of narrow streets lined by multistory buildings, such as New York, while comparably more open spaces might be preferred in a city such as Phoenix, where vernacular streetscapes tend to be lower and wider.

Accordingly, it would likely be inappropriate to import streetscape standards from one city to another. Parameters for walkable streetscapes must be localized by research in numerous cities.

It will also be important to clarify who most benefits from certain streetscape designs. Chapter 3 indicated that men, on balance, tended to prefer streetscapes with fewer people than did women. This suggests that streetscapes with more interactive façades, offering more opportunity for engagement with others, might promote walking among women more than men. On one hand, this might be a favorable compromise because it disproportionately benefits a traditionally marginalized group. On the other hand, reducing perceived walkability among men might have repercussions for advancing walking among this segment of the population. There is also strong potential for differences in normative perceptions across other sociocultural dimensions. More precisely understanding these differences will be crucial for designing streetscapes in ways that avoid reproducing biases toward privileged groups and are also pragmatic about using design to nudge behaviors across populations at-large.

Who it is that has access to walkable streetscapes is another important lens through which to evaluate the design equity of existing and planned development. Because walkability has become a focal point for urban gentrification, there is good reason for concern that low income and other marginalized groups may be losing access to walkable streetscapes, potentially through displacement to more auto-oriented suburbs. Inequitable access to walkable streetscapes may be parallel to, or a component of, issues around inclusivity in sustainable urbanism and urban greening (Anguelovski et al., 2018). Marginalized populations with fewer resources for automobile ownership may be exactly the constituency most in need of walkable urbanism, and yet may not be able to afford to live in these places. Streetscape walkability may be an important but as-yet overlooked criterion by which to gauge equitable allocation of urban resources.

Improved understanding of how streetscapes shape walking behavior may also contribute to refined travel models and related analyses of pedestrian accessibility. Estimates of how streetscapes either facilitate or impede pedestrian travel may be used to develop more precise walksheds and gauge willingness to travel on foot. Traditional travel models that consider distance as the only impeding factor along pedestrian routes may be grossly overestimating the feasibility of walking as a mode choice, causing planners to direct insufficient resources toward strengthening pedestrian infrastructures. Accounting for streetscapes in these models may provide more realistic estimates of where and how far pedestrians are willing to walk and indicate barriers and bottlenecks in pedestrian networks caused not by lack of sidewalks or other traditional infrastructures, but by poorly designed streetscapes. While this application of streetscape research is highly technical, it has the potential to filter into meaningful shifts in how walking contributes to metropolitan-scale travel patterns, directing attention and resources to a mode that has long been poorly represented by transportation analysis and neglected in high-level planning.

While much remains to be understood about the behavioral science of streetscape walkability, it will also be important to investigate the cultural, political, and economic barriers to its development. Given what we already know about their potential benefits, why are walkable streetscapes not already more prolific? The first section of this chapter offers a high-level perspective on factors that may impede meaningful improvements to streetscape design. Further investigating these obstacles and identifying how they might be reasonably overcome will be crucial for allowing technical and theoretical knowledge about walkable streetscapes to be transferred into real-world designs.

A primary goal of walkability research is to advance more energy efficient alternatives to automobility, which is responsible for nearly a quarter of U.S. greenhouse gas emissions (EPA, 2022). This dissertation demonstrates that streetscapes have the potential to influence how pedestrians perceive and choose the routes they walk on. But can streetscapes shift decisions about modes of travel, moving people out of their cars and onto the sidewalk? Could more walkable streetscapes provide a pivotal nudge toward walking to the store instead of driving, or living in a place where this decision is even possible? To move the needle toward walking, it must be a competitive option, enhancing quality of life in ways that overcome the substantial draw of automobility. This is a complex calculus that takes place not only at the scale of individual trips, but in long-term decisions about where people choose to live and work, and feeds back to choices about how cities are built. Important questions remain about the ability of streetscapes to shape urban transportation and curb automobility, but this and other research shows that streetscapes are important to walkers and can contribute to walkability. This is enough evidence to begin incorporating streetscapes into pedestrian planning processes and consider, at the very least, how cities can be more enjoyable places to walk.

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