Applied Spatial Analysis and Policy (2026) 19:86
https://doi.org/10.1007/s12061-026-09863-7

RESEARCH

How Streetscape Design Shapes Everyday Street Vitality: The Mediating Role of Commercial Satisfaction within a Servicescape Framework

Chao Luo[1,2] · Yiwei Mo[1,2] · Yunzhong Wang[1,2] · Yuxiao Jiang[3] · Wenxin Zhang[4,5]

Received: 3 December 2025 / Accepted: 23 March 2026

Abstract

Everyday streets are fundamental social–spatial units of urban life that support residents, workers, and commuters through routine small-scale commercial services and the social interactions associated with them. The vitality of such streets—manifested primarily in high-frequency consumption-related activities and associated pedestrian presence—constitutes a key component of sustainable and livable cities, particularly in daily-life-oriented urban environments. However, prior research has often treated the impact of streetscape design on street vitality as a direct effect, paying limited attention to the perceptual and cognitive pathways through which physical environments shape commercial activity patterns and pedestrian behavior. Drawing on servicescape theory, this study investigates everyday streets within Wuhan's Third Ring Road and integrates multiple sources of urban big data—including OpenStreetMap, Baidu Street View images, Dazhong Dianping platform data, and China Unicom signaling data—to construct and test a mediation model linking streetscape design, commercial satisfaction, and commercially driven everyday street vitality. The results indicate that moderate vertical complexity at the streetscape skeleton level enhances commercially driven everyday street vitality via higher commercial satisfaction, whereas excessive enclosure reduces pedestrian activity. At the streetscape skin level, natural elements and pedestrian infrastructure tend to foster vitality when effectively coupled with commercial functions. Among perceptual factors, perceived beauty emerges as the primary perceptual driver, while perceived safety appears to function primarily as a threshold condition. By extending servicescape theory to open urban street environments, this study identifies commercial satisfaction as a critical cognitive–affective nexus linking streetscape design to collectively expressed, consumption-oriented everyday street vitality. The findings offer planning-relevant insights for designing vibrant, human-centered everyday streets oriented toward routine urban consumption.

Extended author information available on the last page of the article

Published online: 31 March 2026

Keywords Everyday Streets · Street Vitality · Streetscape Design · Servicescape Theory · Commercial Satisfaction · Mediation Pathways

Introduction

Urban streets function not only as transportation corridors connecting different urban functions, but also as vital public spaces for human activity. Street vitality is widely recognized as a defining feature of sustainable and livable cities, and is commonly understood as a relational and emergent property of street environments, becoming observable through recurring patterns of human activity. In empirical research, street vitality is often manifested through a range of pedestrian activities, including discretionary and social walking (i.e., non-commuting walking), as well as static activities such as lingering, resting, socializing, and consuming (Gehl, 2003).

While street vitality is frequently discussed as a broad social concept encompassing diverse forms of movement, interaction, and public life, everyday streets operate under a more specific behavioral logic. On such streets, vitality is primarily generated through routine, small-scale commercial activities embedded in daily life, which produce high-frequency pedestrian presence, repeated visits, and associated behaviors such as lingering and informal social interaction. Accordingly, this study focuses on a specific subtype of street vitality—commercially driven everyday street vitality—rather than the full spectrum of urban social vitality.

Embedded in the daily routines of residents, workers, and commuters, everyday streets typically accommodate small-scale commercial services such as food and beverage, retail, and entertainment. Through continuous ground-floor commercial spaces, active frontages, outdoor seating, and the informal vending (Istrate, 2025; Salazar-Miranda et al., 2022), they function as sites of routine economic exchange, meanwhile act as "generators of social life" (Gehl, 2003; Mehta, 2013). In this sense, commercial activity does not merely represent an economic function but provides a contextually grounded and behaviorally specific observational lens for examining everyday street vitality. Therefore, commercial activity is treated not as a surrogate for all social life on streets, but as a behaviorally grounded proxy for routine street use closely intertwined with everyday commercial practices.

As a context-specific manifestation of street vitality, everyday street vitality is theoretically rooted in a broader body of research examining how the built environment shapes patterns of pedestrian activity. Street vitality is an inherently multifaceted and scale-sensitive concept. At the macro level, particularly within planning and transportation research, vitality is often operationalized as accessibility-driven activity intensity, such as pedestrian volume or other density-based indicators of activity potential. Influential theories, like the 5D framework (density, diversity, design, destination accessibility, and distance to transit), have demonstrated association between morphological, accessibility-related, and affordance-based attributes of the built environment and the intensity and distribution of pedestrian activities (Ewing & Cervero, 2010). Although the 5D framework is behavior-neutral and does not distinguish activity purposes, its design-related dimensions are particularly relevant for understanding routine, consumption-oriented street use in everyday contexts. At the meso- and micro-levels, however, street vitality is more commonly understood through the characteristics of pedestrian activity itself, including activity type, duration, frequency, density, and the presence of static and social behaviors. These dimensions reflect not only movement but also the quality and persistence of street use, capturing how streets are experienced and inhabited in everyday life. Classic urban theories—such as mixed land-use emphasized by Jacobs (1961), image of the city proposed by Lynch (1964), and the human-centered design principles advanced by Whyte (1980) and Gehl (2003)—have long established the linkage between urban form and pedestrian activities through qualitative research. With the rapid development of multi-source urban big data—such as mobile phone signaling, street-view imagery, place of interest (POI) data, and OpenStreetMap (OSM) datasets—recent studies have advanced the empirical measurement of urban form and commercially relevant street vitality with unprecedented spatial and temporal resolution (Ewing & Handy, 2009; Jiang et al., 2025). These data-driven approaches have enabled fine-grained analyses linking pedestrian activity patterns associated with routine street use to human-scale urban form, particularly streetscape design features (Ye et al., 2018; Zhang et al., 2023).

Despite these methodological advances, a critical theoretical gap remains in explaining how streetscape design translates into street vitality, especially in the context of everyday streets. Much of the existing literature conceptualizes the impact of streetscape design as a direct effect, positioning spatial form as an external constraint or preference shaping pedestrian activity patterns. As a result, everyday street vitality is often interpreted as a spatial projection derived from "black-box" correlations, with limited attention to the perceptual and cognitive processes mediating this relationship. Empirical work in this vein has primarily focused on two primary dimensions of streetscape design: the streetscape skeleton (the three-dimensional spatial framework formed by buildings, trees, and other large adjacent elements) (Harvey & Aultman-Hall, 2016; Zhang et al., 2023) and the streetscape skin (the finest grain of details that texture the medium-scale skeleton) (Zhou et al., 2022).

Servicescape theory proposed by Bitner (1992) provides a compelling lens for modeling and explaining the mediating pathways between streetscape design and everyday street vitality. Originally developed to explain how physical cues in indoor commercial settings (e.g., stores, restaurants) influence users' cognition, affect, and behavioral responses (e.g., consumption, staying, repeat visits, word-of-mouth), the theory establishes a structured framework linking physical environment to behavioral outcomes via psychological processes. Recent studies have extended servicescape theory to outdoor urban environments (C. Han et al. 2025a, b; Koo et al. 2023), suggesting that adjacent streetscapes function as open service settings that influence users' affective and cognitive experiences throughout walking and static activity stages, thus shaping approach or avoidance tendencies. In the context of everyday streets, where pedestrian activity is closely intertwined with small-scale, routine commercial use, several contextual characteristics are particularly salient: the relative homogeneity of commercial structures (small-scale daily services), the stability of user groups (e.g., local residents, workers, and commuters), and the high level of environmental familiarity (frequent interactions) (Gehl, 2003; Mehta, 2013). Under such conditions, commercial satisfaction—reflecting users' integrated affective and cognitive evaluations of routine street-based commercial experiences—may serve as a key psychological mediator linking streetscape design to observable patterns of commercially driven street use. Prior research has shown that commercial satisfaction is closely associated with staying behavior, repeat visits, and recommendation intentions (Cronin Jr et al., 2000; C. Han et al. 2025a, b), suggesting its relevance for understanding the persistence and continuity, rather than the momentary presence of everyday street vitality.

Building on these insights, this study employs servicescape theory as the conceptual framework to construct and evaluate a mediation model linking streetscape design, commercial satisfaction, and commercially driven everyday street vitality. Focusing on everyday street segments within Wuhan's Third Ring Road, we integrate multi-source urban big data—including OpenStreetMap, Baidu Street View images, Dazhong Dianping platform data, and China Unicom signaling data—to comprehensively quantify the elements within the mediation model and examine the entire theoretically informed structure at scale. The goal is to provide a unified, efficient, and human-centered analytical perspective for the design and activation of everyday streets.

This study makes three contributions. First, theoretically, it extends servicescape theory from indoor commercial environments to open street spaces, offering a structured framework for explaining the psychological pathway underlying everyday street vitality and enriching the conceptualization of the "space–perception–behavior" relationship. Second, empirically, through multi-source big data integration and mediation analysis, it demonstrates the mediating role of commercial satisfaction between streetscape design and everyday street vitality, advancing street vitality research beyond correlational description toward pathway-oriented explanation. Third, practically, the findings provide planning-relevant insights for urban planning and everyday street design by highlighting how the configuration of both the streetscape skeleton and streetscape skin is associated with higher commercial satisfaction and, in turn, supports sustained everyday street vitality with a human-centered and evidence-informed design perspective.

Literature Review

Direct Evidence from Urban Form to Street Vitality

Built Environment and Street Vitality in Everyday Contexts

The relationship between the built environment and street vitality lies at the core of urban planning and design, transport studies, behavioral geography, and environmental behavior research, with street vitality commonly examined through observable patterns of pedestrian use and activity intensity. Classical urban theories have long emphasized that frequent pedestrian presence and spatial use associated with routine, small-scale commercial activities constitute observable manifestations of street vitality, particularly at the neighborhood and everyday street scales (Gehl, 2003; Jacobs, 1961; Montgomery & John, 1998; Ye et al., 2018). In everyday, life-oriented urban contexts, street vitality is often commercially driven, and is expressed through walking, lingering, and other low-threshold activities embedded in routine daily practices, reflecting the degree to which streets support continuous use, consumption-related presence, and opportunities for social encounter.

Early empirical studies, drawing on travel behavior research, highlighted the importance of density, diversity, and design—the 3D elements—in shaping aggregated pedestrian activity patterns. High-density, mixed-use, and well-designed built environments were shown to reduce automobile dependence and encourage walking and public transit use, thereby increasing everyday street-level activity (Robert et al., 1997). Subsequent work incorporated destination accessibility and distance to transit, forming the widely applied 5D framework linking built environment attributes to street-level activity intensity, which has often been interpreted as a proxy for street vitality in a broad, behavior-aggregated sense (Ewing & Cervero, 2010). Within the 5D framework, vitality is generally conceptualized as a composite outcome of functional affordances (e.g., FAR, POI density, building coverage, functional mix measured by POI entropy), transportation accessibility (e.g., population and employment densities, spatial location, street network connectivity), and design features, without explicit differentiation of activity purposes or behavioral motivations. Empirically, vitality is reflected not only in walking trips but also in discretionary and social behaviors such as strolling, window shopping, chatting, resting, and consuming—activities that collectively constitute everyday street life, particularly on streets shaped by routine, small-scale commercial use (Gehl, 2003).

While the above literature typically conceptualizes street vitality in a broad sense, encompassing multiple forms of social, recreational, and mobility-related activities, recent studies increasingly suggest that, on everyday neighborhood streets, routine consumption-related activities form a dominant and structurally embedded component of observed vitality. Regular visits to food services, retail shops, and daily service facilities generate high-frequency pedestrian presence and repeated street use, thereby structurally sustaining lingering, informal social interaction, and non-commuting movement. Accordingly, this study focuses on a specific subtype of street vitality—commercially driven everyday street vitality, defined by the intensity and continuity of street use generated through routine commercial practices—rather than the full spectrum of urban social vitality. This conceptual narrowing aligns the theoretical framework with empirical indicators derived from consumption-related behavioral data.

It is important to note that the 5D framework itself is largely behavior-neutral and has been widely applied to explain overall pedestrian activity without systematically distinguishing between activity purposes. However, its design-related dimensions are particularly relevant for understanding how physical environments support routine, consumption-oriented street use in everyday contexts. As such, the present study draws on the 5D tradition as an explanatory framework, while explicitly situating street vitality within the domain of commercially driven everyday activity.

Streetscape Design Features Related to Pedestrian Activity

At the street level, human-scale built environment attributes are referred to as the streetscape, defined as the spatial arrangement of architectural and landscape features, street furniture, and visual appearance as perceived from the street view (Tucker et al., 2005). As the most immediate interface between people and the built environment, streetscape design plays a critical role in shaping everyday street use, particularly activities associated with walking, lingering, and routine consumption embedded in daily practices.

Research on the influence of streetscape design on pedestrian activity can be traced back to humanistic critiques of rationalist planning. Jacobs (1961) emphasized small blocks, "eyes on the street" and mixed uses as essential conditions for vibrant street life, while Lynch (1964) introduced the five-element framework—nodes, landmarks, districts, paths, and edges—to demonstrate how street morphology affects legibility, aesthetics, urban imageability, and wayfinding. Subsequent studies proposed more specific indicators, such as building–street relationships and aspect ratios (Ashihara, 1986), informal seating opportunities along active edges (Whyte, 1980), and active frontages and comfort-enhancing elements such as shading and wind protection (Gehl, 2003). Together, these classic contributions collectively established a foundational understanding of how streetscape design supports everyday street use and vitality, with pedestrian activity serving as a primary observable manifestation of street vitality at the everyday scale.

In recent decades, advances in multi-source urban big data have enabled researchers to "measure the unmeasurable." Through video-based documentation and expert ratings, Ewing and Handy (2009) identified five streetscape design qualities significantly associated with walkability: imageability, enclosure, human scale, transparency, and complexity. Subsequent work has further refined the empirical understanding of how streetscape design influences street-level activity across different spatial scales.

(1) Meso-scale: The Streetscape Skeleton.

At the meso-scale, streetscape design is often conceptualized as the streetscape skeleton, referring to the three-dimensional structural framework formed by buildings, trees, and other large adjacent elements that define the spatial enclosure of the street (Harvey & Aultman-Hall, 2016; Zhang et al., 2023). Empirical studies show that reducing building setbacks, continuous street walls, and the presence of mid- to high-rise buildings and street trees contribute to more enclosed street spaces that evoke the sense of being in an "outdoor room," enhancing comfort and attractiveness (Ewing & Handy, 2009; Liu et al., 2025).

Such enclosed and visually complex streetscapes have been shown to not only improve perceived safety but also encourage slower movement, discretionary walking, and longer staying times—behavioral patterns that are closely aligned with routine consumption-oriented pedestrian activity (Dumbaugh & Rae, 2009; Harvey et al., 2015). Moreover, three-dimensional variations in building height, facade articulation, and street curvature significantly encourage non-commuting walking and exploratory movement (Ewing & Handy, 2009; Zhou et al., 2022). These characteristics are particularly relevant for commercially oriented everyday streets, where visual interest and spatial enclosure enhance storefront visibility, walking continuity, and the likelihood of spontaneous consumption.

(2) Micro-scale: The Streetscape Skin.

At the micro scale, streetscape design is conceptualized as streetscape skin, referring to fine-grained texture elements that overlay the streetscape skeleton, including natural features, surface materials, and pedestrian infrastructure (Zhou et al., 2022). A growing body of research indicates that natural elements can promote non-commuting walking and lingering under specific functional and spatial conditions. Higher green-view index (GVI) enhance visual pleasure, reduce stress, and increase lingering and slow-movement and staying behaviors (Kumakoshi et al., 2020). Similarly, appropriate sky view index (SVI) improves natural lighting and perceived safety, further supporting everyday walking and street use (Sakamoto et al., 2023). Water features have been associated with increased recreational walking, longer staying time, and enhanced perceived accessibility (Gascon et al., 2017). However, these effects are highly context-dependent and may vary across street functions, commercial intensity, and user groups.

In parallel, pedestrian infrastructure—such as sidewalk width and continuity, traffic signals, buffers between sidewalks and roadways, and streetlights—has been consistently shown to improve walking comfort and perceived safety (Painter, 1996; Stutts et al., 1996). In contrast, high traffic volumes and vehicle speeds reduce pedestrians' perceived safety and willingness to walk, and are associated with increased injury and fatality risks, thereby suppressing walking, lingering and consumption-related street activities (Soto et al., 2022).

Overall, existing studies demonstrate that both the streetscape skeleton and the streetscape skin shape pedestrian experiences through perceived safety, visual quality, and comfort (Alfonzo, 2005; Owen et al., 2004; R. Wang et al. 2025a, b, c). These experiential qualities are especially important for commercially driven everyday street vitality, as routine consumption relies on repeated visits, slow-paced movement, and short-term staying behaviors. Nevertheless, much of the existing research continues to focus on the direct link between streetscape design and aggregated measures of street vitality (Zhang et al., 2018, 2023; Zhou et al., 2022), often treating vitality as a spatial projection of physical form revealed through spatial regression or machine-learning models (Gebru et al., 2017; Ma et al., 2019; Zhou et al., 2022). Such approaches tend to overlook the psychological mediation patterns through which perception and cognition translate streetscape design into specific patterns of commercially oriented street use—a gap that the present study seeks to address.

Streetscape as Servicescape: A Satisfaction-based Mediation Pathway

The S–O–R Framework and Servicescape Theory

Unlike the traditional stimulus–response (S–R) paradigm commonly adopted in urban planning, urban design and transportation studies, research in environmental psychology and behavioral geography emphasizes the indirect and mediated nature of space–behavior relationships. Rooted in the Stimulus–Organism–Response (S–O–R) model (Mehrabian & Russell, 1974), early studies highlighted an affect-first pathway, suggesting that environmental cues primarily trigger affective responses, which subsequently shape cognitive evaluations and behavioral intentions. Later arguments stressed that individuals may also form cognitive judgements prior to affective reactions (Lazarus, 1991; Oliver, 1993), constituting a cognition-first pathway. More recent perspectives increasingly acknowledge that affective and cognitive processes interact or operate in parallel, jointly influencing behavioral outcomes across different temporal scales, behavioral types, and situational contexts (Kahneman, 2011). This evolving understanding provides a robust theoretical basis for modeling satisfaction as an integrative cognitive–affective mediator between environmental stimuli and behavioral responses.

Servicescape theory extends the S–O–R framework to commercial service environments (Bitner, 1992). The term "Servicescape" refers to the physical and symbolic environmental cues that shape users' perceptions, evaluations, and behaviors within service settings. Research has traditionally focused on indoor physical attributes—such as aesthetics, cleanliness, spatial layout, music, sound, temperature, scent, and lighting—that fall within managerial control (Ryu & Han, 2010). These physical features influence satisfaction through both affective atmospherics and functional evaluations (Cronin Jr et al., 2000; Mari & Poggesi, 2013). Affective perceptions capture immediate emotional experiences (e.g., safety, pleasure, beauty), while functional cognition reflects rational evaluations of utility, order, and value. The two processes are mutually reinforcing: positive affect enhances perceived environmental quality, and coherent functional organization further strengthens affective experience (Lin & Mattila, 2010). Together, they shape overall satisfaction, which mediates approach or avoidance behaviors such as staying, revisiting, and recommending (Bitner, 1992). Through this affect–cognition co-construction pathway, satisfaction becomes a key mediator linking servicescape attributes and behavioral outcomes.

Streetscape as an Expanded Servicescape: An Indirect Framework from Form to Everyday Street Vitality

Landscape may be conceptualized narrowly as an interior or bounded setting, or more broadly at the scale of cities and towns (Hall, 2014). As essential public activity spaces, urban streets can be regarded as an expanded and open form of servicescape. Throughout the stages of initiation, continuation, and termination of pedestrian activity, the streetscape shapes users' affective experiences and functional evaluations, which jointly influence behavioral tendencies such as approaching, lingering, routine consuming, or avoiding.

Cross-disciplinary research bridging service marketing and urban planning first examined the link between streetscape and customer satisfaction. Survey-based studies show that streetscape design affects perceived product quality, shopping enjoyment, and consumption intentions (Yüksel, 2013). Hahm et al. (2019) further demonstrate that high-quality streetscapes enhance behavioral intentions not only directly but also by increasing permeability and accessibility to adjacent ground-floor commercial uses. With the growing availability of multi-source urban big data, recent studies have begun to quantitatively test the applicability of servicescape theory in outdoor street contexts. For example, Koo et al. (2023) show that enclosed street views, greenery, and buffered sidewalks promote customer satisfaction and enhance local commercial attractiveness, while C. Han et al. (2025a, b) find that customers' satisfaction with dining establishments reflects the combined influence of interior aesthetics, adjacent streetscape, and neighborhood characteristics. These studies collectively provide empirical support for extending servicescape theory to open street settings and for modeling indirect pathways linking streetscape design to commercial activity outcomes.

In the context of everyday streets—life-oriented street segments embedded in residents', workers', and commuters' daily routines—commercial functions play a structurally central role in shaping street use. Such streets are typically characterized by relatively homogeneous small-scale commercial formats, stable user groups, and high environmental familiarity. Everyday streets function not only as transactional spaces but also as "generators of social life" (Gehl, 2003; Mehta, 2013). Continuous ground-floor commercial frontage, open facades, sidewalk dining, and the presence of informal vendors blur the boundary between public and private realms, allowing walking, lingering, socializing, and consumption to interweave (Istrate, 2025; Salazar-Miranda et al., 2022). Unlike landmark or tourist streets, whose vitality is often driven by episodic events or symbolic attraction, vitality on everyday streets arises primarily from repetitive, purposive, and socially embedded commercial practices. Its intensity is therefore closely tied to the frequent use of daily commercial functions and the social interactions they generate (Gehl, 2003; Mehta, 2013), forming stable and observable patterns over time (Istrate, 2025; Zheng et al., 2024).

While affective perceptions and functional cognition may fluctuate at the individual level, their aggregated expressions at the collective level on everyday streets—where commercial structures are similar, user composition is stable, and repeated exposure is common—tend to exhibit structural regularity. In this sense, street-level commercial satisfaction can be interpreted as an accumulated outcome of dynamic affective and cognitive processes over repeated encounters. It reflects residents', commuters', and workers' integrated evaluations of commercial services, spatial ambiance, and product quality. This collective evaluative outcome in turn conditions purposive visitation, repeated consumption, and local word-of-mouth diffusion, thereby influencing the continuity and persistence of commercially driven everyday street vitality.

Unlike residential neighborhoods or long-term place-based community environments, everyday streets are open and fluid public spaces in which pedestrian activities are frequent yet highly situational. Satisfaction in this context is therefore better understood as an evaluative response to repeated service encounters rather than as an expression of deep place attachment or identity formation (Sirgy & Cornwell, 2002). Accordingly, the psychological pathways examined in this study emphasizes situational affective perception and accumulated functional cognition associated with street-level commercial experiences, rather than long-term emotional bonding with place.

Multi-source Urban Big Data and Computational Advances Supporting Streetscape–everyday Street Vitality Research

In recent years, the integration of open digital maps, street-view imagery, spatial big data, and behavioral data—together with breakthroughs in spatial and perceptual computing—has made it possible to examine both the direct and indirect relationships between streetscape design attributes and everyday street vitality at large scales. These developments enable the systematic quantification of physical form, perceptual experience, and consumption-related behavior within a unified analytical framework.

Systematic Extraction of Streetscape Design Features

As the material foundation shaping both the pedestrian behavior and psychological perceptions on streets, the features of the streetscape design have become increasingly accessible through the combination of open spatial data and deep-learning methods. Research drawing on OSM, POI, and municipal geospatial platforms has enabled systematic characterization of street-level density (e.g., POI density), functional diversity (e.g., Shannon entropy), accessibility (e.g., proximity and connectivity), and three-dimensional attributes of the Streetscape skeleton (Zhang et al., 2023; Zhou et al., 2022).Meanwhile, deep-learning analysis of street-view imagery allows fine-grained quantification of streetscape skin variables such as green-view index, sky openness, visual dominance of motor vehicles, and visibility of water bodies (Nice et al., 2020; Wang et al., 2019; Zhou et al., 2022).

These developments enable human-scale built-environment characteristics to be measured systematically, thereby providing objective physical inputs and comparable spatial indicators for empirical studies on streetscape design–everyday street vitality relationships.

Large-scale Measurement of Spatial Perception and Commercial Satisfaction

Perception and cognition constitute the core psychological processes within the S–O–R framework. Early environmental psychology and behavior studies relied mainly on surveys and interviews to measure environmental perception and satisfaction. With the rise of data mining, computer vision, and perceptual computing, researchers can now model collective psychological responses across broader spatial and temporal scales. Street-view images from platforms such as Google Street View and Baidu Street View has facilitated large-sample assessments of perceived beauty, safety, and visual quality through crowdsourced ratings and machine-learning predictions (Dubey et al., 2016; Naik et al., 2014; Zhang et al., 2018). Meanwhile, user-generated content (UGC) from commercial review platforms—such as Dazhong

Dianping and Yelp—has been widely used to capture aggregated commercial satisfaction, reflecting users' integrated evaluations of service quality, ambiance, and functional performance (Koo et al., 2023; Tripathi et al., 2022; Zhang et al., 2023).

Empirical evidence suggests that such UGC-based satisfaction measures are strongly associated with revisit intention, dwell time, and consumption intensity, and thus provide effective proxies for collective cognitive–affective evaluations of street-level commercial environments (Wang et al. 2025a, b, c).

Measuring Everyday Street Vitality Using Behavioral Data

On the behavioral side, location-based services (LBS), together with social media check-ins, comments, sensor monitoring, and Wi-Fi connection logs, provide multi-source datasets describing pedestrian volume, visitation frequency, and consumption-related activity at the street scale. These indicators primarily capture consumption-oriented and visitation-based activity, rather than the full spectrum of social or civic street vitality. Compared with traditional surveys or manual counts, these data capture everyday street use with higher spatial and temporal resolution and are widely regarded as reliable proxies for commercially driven everyday street vitality in contemporary urban research (Liwei et al., 2025; Long & Huang, 2019; Ye et al., 2018).

When interpreted within clearly defined conceptual boundaries, consumption-related behavioral indicators—such as review density or visitation frequency—offer contextually valid measures of commercially driven everyday street vitality.

Taken together, advances in multi-source urban big data and computational science have created unprecedented opportunities to move beyond correlational analysis and to uncover the indirect psychological pathways through which streetscape design influences commercial satisfaction and, in turn, everyday street vitality.

Research Hypotheses

Grounded in servicescape theory, this study examines whether pedestrian-oriented streetscape design under everyday street conditions enhances commercial satisfaction and, through this cognitive-affective pathway, contributes to commercially driven everyday street vitality. Rather than conceptualizing vitality in a broad social or civic sense, this study defines vitality as the intensity and continuity of routine, consumption-related street use embedded in daily urban life. Accordingly, the hypotheses are formulated as follows.

(1) H1: Pedestrian-oriented streetscape design is positively associated with street-level commercial satisfaction.

   H1a: Greater enclosure of the streetscape skeleton is associated with higher street-level commercial satisfaction.
   H1b: Higher geometric articulation of the streetscape skeleton is associated with higher street-level commercial satisfaction.

H1c: The presence of natural elements in the streetscape skin is associated with higher street-level commercial satisfaction.
H1d: Better pedestrian infrastructure in the streetscape skin is associated with higher street-level commercial satisfaction.
H1e: Higher perceived safety generated by streetscape design is associated with higher street-level commercial satisfaction.
H1f: Higher perceived beauty generated by streetscape design is associated with higher street-level commercial satisfaction.

(2) H2: Pedestrian-oriented streetscape design exerts an indirect effect on commercially driven everyday street vitality through increased street-level commercial satisfaction.

H2a: Enclosure of the streetscape skeleton is indirectly associated with commercially driven everyday street vitality through commercial satisfaction.
H2b: Geometric articulation of the streetscape skeleton is indirectly associated with commercially driven everyday street vitality through commercial satisfaction.
H2c: Natural elements of the streetscape skin are indirectly associated with commercially driven everyday street vitality through commercial satisfaction.
H2d: Pedestrian infrastructure of the streetscape skin is indirectly associated with commercially driven everyday street vitality through commercial satisfaction.
H2e: Perceived safety generated by streetscape design is indirectly associated with commercially driven everyday street vitality through commercial satisfaction.
H2f: Perceived beauty generated by streetscape design is indirectly associated with commercially driven everyday street vitality through commercial satisfaction.

Materials and Methods

Research Framework

Grounded in servicescape theory, this study investigates everyday street segments within the Third Ring Road of Wuhan, China. By integrating multi-source and heterogeneous urban big data—including OSM, Dazhong Dianping POI and user ratings data, Baidu Street View images, and China Unicom mobile signaling data—we develop and empirically test a mediation framework linking streetscape design, street-level commercial satisfaction, and commercially driven everyday street vitality (Fig. 1). This framework emphasizes the perceptual-cognitive pathways through which the built environment shapes routine consumption-oriented street, in contrast to event-driven or landmark urban spaces where vitality often arises from episodic gatherings, tourism, or large-scale public events.

In everyday streets, which primarily serve nearby residents, workers, and commuters, vitality emerges from habitual consumption activities rather than occasional social spectacles. Frequent visits to food services, retail shops, and local daily service

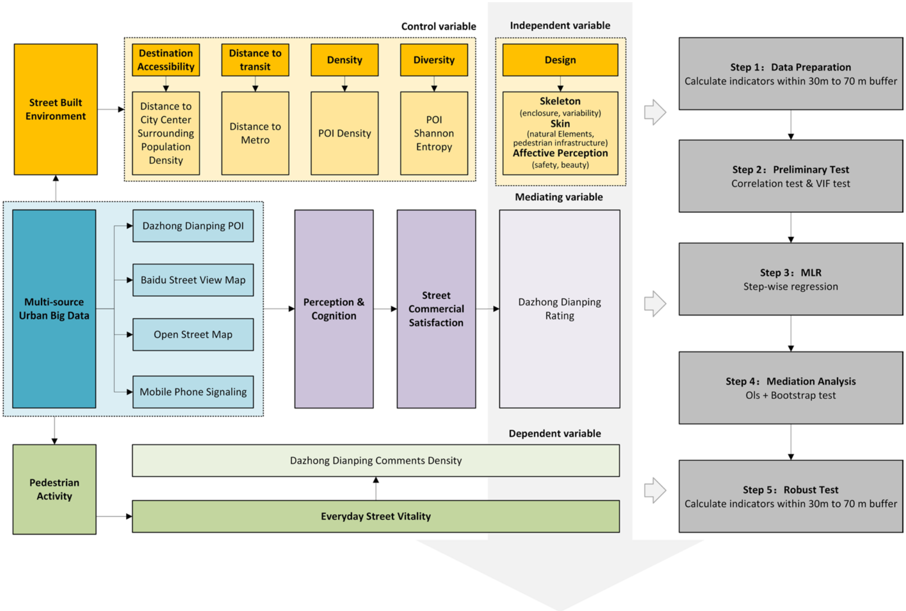

Fig. 1 Research Framework

facilities generate high pedestrian presence and repeated street use, thereby structuring non-commuting walking, lingering, and informal social interactions. Accordingly, commercially driven everyday street vitality is operationalized as the spatial density of user reviews for lifestyle-oriented POIs within each street-buffer area, capturing the intensity and continuity of routine consumption-oriented activity in high density urban contexts.

Street-level commercial satisfaction is conceptualized as a post-experience evaluative judgment integrating both functional appraisal and affective impressions of commercial environments, rather than an immediate emotional reaction. Within the S–O–R framework, commercial satisfaction functions as a higher-order evaluative mediator, aggregating perceptual and cognitive responses to streetscape design. In everyday street contexts, repeated exposure and habitual use produce collective evaluations that influence purposive visitation, repeated consumption, and social interaction patterns, thereby sustaining commercially driven street vitality over time.

Independent variables are systematically quantified across two streetscape dimensions:

(1) Streetscape skeleton (meso-scale structural framework): enclosure (building average height on both sides of the street, cross–section ratio, street wall continuity, streetscape enclosure index, and building number per unit street length) and geometric variability (variability of building height on both sides, variability of cross–section ratio, variability of the street width, and street sinuosity).

(2) Streetscape skin (micro-scale texture layer): natural elements (green view index, sky view index, and waterscape visibility) and pedestrian infrastructure (visual pavement ratio and visual vehicle ratio).

In addition, perceived safety and perceived beauty derived from Baidu Street View images are included as affective attributes, reflecting experiential responses to streetscape design.

To account for accessibility- and affordance-related influences, control variables include POI density, functional diversity, distance to city center, surrounding population density, and distance to the nearest metro station. Multicollinearity among predictors is assessed using Pearson correlation coefficients and variance inflation factors (VIF). Street-level review density is computed across multiple buffer radii (30, 40, 50, 60, and 70 m) to examine the spatial robustness of effects, and ordinary least squares (OLS) regression combined with bootstrap procedures is employed to test the mediation patterns through commercial satisfaction.

Given the cross-sectional nature of the data, the mediation analysis does not establish temporal causality. Rather, it examines whether observed associations among streetscape design features, commercial satisfaction, and commercially driven everyday street vitality are consistent with a theoretically grounded S–O–R-mediated framework, with causal interpretations made cautiously.

Study Area

This study focuses on everyday street segments located within the Third Ring Road of Wuhan, Hubei Province. The area represents the core of Wuhan's urban development, forming an integrated spatial entity across historical, geographical, cultural, economic, and social dimensions (Fig. 2).

Based on the current land-use dataset, street centerlines, and Dazhong Dianping POI data, a total of 2,684 everyday street segments were identified within the study boundary through spatial analysis. Segments such as elevated expressways, tunnels, greenways, bridges, fully pedestrianized commercial streets, tourist streets, and internal roads of large institutional compounds were excluded. However, under-viaduct corridors that host everyday commercial activities were retained. The spatial distribution of the final sample street segments is illustrated in Fig. 3.

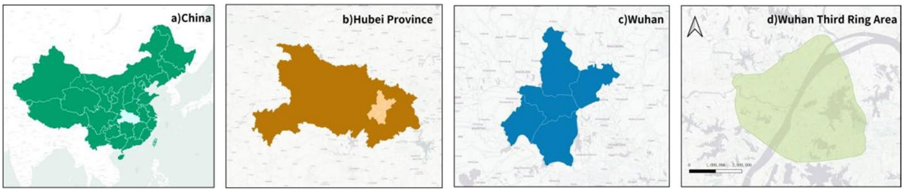

Fig. 2 Multi-scale Spatial Context of the Study Area: (**a**) National Context; (**b**) Hubei Provincial Context; (**c**) Wuhan Metropolitan Context; (**d**) Core Area within Wuhan's Third Ring Road

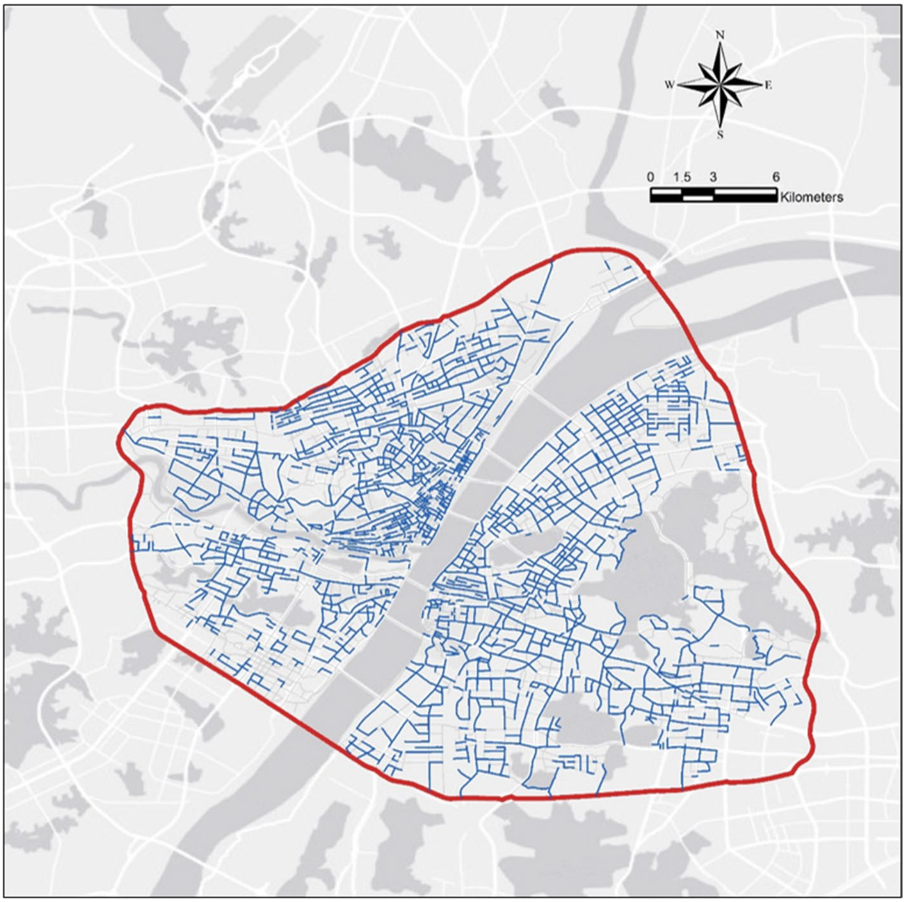

Fig. 3 Spatial distribution of everyday street segments within the Third Ring Road of Wuhan

Variable and Data Selection

Dependent Variable

The dependent variable, commercially driven everyday street vitality (Str_Vitality), is operationalized as the density of Dazhong Dianping user reviews for lifestyle-oriented POIs (food services, retail, and local daily services) within each street-buffer area. Dazhong Dianping is one of China's most influential platforms for evaluating on-site consumption, and review patterns have been shown to strongly correlate with offline consumption behaviors (Long & Huang, 2019; Zhang et al., 2023). While review density does not fully capture non-consumptive pedestrian activities such as informal social interaction or passive lingering, prior research suggests these behaviors often co-occur spatially and temporally with commercial activity (Gehl, 2003; Liwei et al., 2025; Long & Huang, 2019; Mehta, 2013; Ye et al., 2018). In everyday streets—where pedestrian movement, short-term staying, and consumption activities are highly intertwined—review density provides a contextually appropriate and empirically grounded proxy for routine, consumption-oriented street vitality.

Data were collected via the platform's API, including POI categories, geographic coordinates, review counts, and user ratings, followed by cleaning to remove duplicates and invalid entries. To mitigate biases related to buffer size or street-segment length, circular buffers with radii of 30, 40, 50, 60, and 70 m were constructed for each segment, and review densities were calculated for comparative analyses to identify the optimal spatial scale.

Independent Variables

Independent variables capture streetscape design features known to influence pedestrian activity, following the streetscape skeleton–skin framework and including affective perceptions of safety and beauty (Ewing & Handy, 2009; Zhang et al., 2023; Zhou et al., 2022).

Using OSM centerline and building-footprint data, Baidu Street View images, GIS-based spatial computation, and semantic segmentation via PSPNet trained on the ADE20K dataset, we quantify skeleton characteristics including enclosure (building average height on both sides of the street, cross–section ratio, street wall continuity, streetscape enclosure index, and building number per unit street length) and geometric variability (variability of building height on both sides, variability of cross–section ratio, variability of the street width, and street sinuosity) (Ewing & Cervero, 2010).

Features of the streetscape skin are quantified through natural elements (green view index, sky view index, and waterscape visibility) and pedestrian infrastructure (visual pavement ratio, visual vehicle ratio) (Koo et al., 2023; Zhou et al., 2022).

To extract affective perceptions, Baidu Street View images were further analyzed using the MIT Place Pulse dataset and a ResNet50 model to obtain perceived safety and beauty scores (Dubey et al., 2016; Naik et al., 2014).

Detailed computational formulas and procedures are summarized in Table A1, Appendix A.

Control variables

To account for functional affordances and accessibility, the following control variables are included:

(1) Destination accessibility, measured by:① straight-line distance from the street mid-point to the city center (Di_CC) (Duranton & Overman, 2005; Glaeser et al., 2001); ② surrounding population density (Popu_Dens), derived from China Unicom mobile signaling data within a 500 m buffer, averaged for non-holiday weekdays between 9 am and 10 pm.
(2) Distance to transit, measured by straight-line distance from the street mid-point to the nearest metro station (Di_Metro) (Zhang et al., 2023).
(3) Functional density, defined as Dazhong Dianping POI density within 50 m of the street centerline (Func_Dens) (Zhang et al., 2023).

(4) Functional diversity, calculated by reclassifying Dazhong Dianping POIs into six categories—food services, retail, on-site lifestyle services, transport facilities, cultural/entertainment, and other public services—and obtaining standardized proportions within a 50 m buffer (Func_Div) (Wu et al., 2021; Zhang et al., 2023).

Mediating Variable

The mediating variable, street-level commercial satisfaction (Func_Sa), is operationalized as the average user rating of lifestyle-oriented POIs within each street buffer. Ratings reflect cumulative evaluative judgments integrating functional appraisal and affective impressions of the commercial environment, rather than discrete emotional states. (Koo et al., 2023; Zhang et al., 2018).

In the S–O–R framework, commercial satisfaction serves as a higher-order evaluative mediator, linking streetscape design (stimulus) to aggregated pedestrian behavior (response). This conceptualization aligns with everyday street contexts, where repeated exposure and habitual use produce collective evaluations that influence purposive visitation, repeated consumption, and social interaction patterns.

By integrating multi-source urban big data, this study systematically quantifies all components of the proposed mediation model and conducts large-scale empirical testing of the theoretically posited association structure linking streetscape design, commercial satisfaction, and commercially driven everyday street vitality. The framework provides a unified, efficient, and human-centered approach for understanding how pedestrian-oriented streetscape design supports everyday streets vitality through commercially mediated pathway.

Result

Data processing

Descriptive statistics of all scalar variables are presented in Table 1. Prior to regression analysis, the distributions of key variables were examined using histograms and boxplots. Several variables—including average building height on both sides (Bui_Hei), street wall continuity (StrW_C), street sinuosity (Str_Sin), cross-section ratio (Cr_sec)—exhibited right-skewed and long-tail distributions. To improve model reliability and better satisfy the normality assumption underlying OLS regression, a log transformation of the form log([VAR] + 1) was applied to these variables. All subsequent analyses were conducted using the transformed values.

Preliminary Test

Pearson correlation coefficients and variance inflation factors (VIF) were used to assess multicollinearity among the explanatory variables. All pairwise correlation coefficients were below 0.8, and all VIF values were below 5 (see Appendix A Table

Table 1 Descriptive Statistics of Key Study Variables (N=2,684)

Variable Type	Variable	Data Source	Mean	SD	Unit
Dependent Variable	Str_Vitality				
	Buffer 30 m	Dazhong Dianping	48,730.59	146,363.67	#/km²
	Buffer 40 m	Dazhong Dianping	53,812.89	148,171.31	#/km²
	Buffer 50 m	Dazhong Dianping	55,733.32	149,001.91	#/km²
	Buffer 60 m	Dazhong Dianping	56,029.75	147,660.56	#/km²
	Buffer 70 m	Dazhong Dianping	53,562.08	140,111.74	#/km²
Independent Variables	Skeleton – Enclosure				
	Bui_Hei (Building Height)	OSM	43.66	26.95	m
	Cr_Sec (Cross Section Ratio)	Baidu Street View	374.49	256.16	%
	VIS_Enc (Landscape Enclosure)	Baidu Street View	12.18	13.92	%
	StrW_C (Street Wall Continuity)	OSM	20.80	24.30	%
	Bui_Num (Number of Buildings per length)	OSM	15.31	12.27	#/100m
	Skeleton – Geometric Variability				
	Str_Sin (Street Sinuosity)	OSM	99.42	2.30	%
	V_Str_wi (Street Width Variation)	OSM	23.63	25.27	%
	VHB (Building Height Variation)	OSM	20.78	18.61	%
	V_Cr_Sec (Cross Section Ratio Variation)	OSM	113.47	93.82	%
	Skin – Natural Elements				
	GVI (Green View Index)	Baidu Street View	14.74	10.63	%
	SVI (Sky View Index)	Baidu Street View	28.53	10.76	%
	VIS_Wat (Waterscape Visibility)	Baidu Street View	0.18	1.47	%
	Skin – Pedestrian Infrastructure				
	VIS_Pav (Visual Pavement Ratio)	Baidu Street View	6.68	56.79	%
	VIS_Veh (Visual Vehicle Ratio)	Baidu Street View	11.76	9.05	%
	Affective Perception				
	Emo_Beauty (Perceived Beauty)	Baidu Street View	4.85	0.07	–
	Emo_Safety (Perceived Safety)	Baidu Street View	3.06	0.09	–
Control Variables	Di_CC (Distance to City Center)	OSM	7.20	3.25	km
	Di_Metro (Distance to Metro Station)	OSM	695.66	552.97	m
	Popu_Dens (Population Density)	China Unicom Mobile Signal	12,608.77	9,518.96	#/km²
	Func_Dens (Functional Density)	Dazhong Dianping	9,282.26	9,613.45	#/km²
	Func_Div (Functional Diversity)	Dazhong Dianping	0.5695	0.2066	–
Mediating Variables	Func_Sa (Commercial Satisfaction)	Dazhong Dianping	3.69	0.27	–

N=2,684

A2), indicating that multicollinearity was not a concern and that the regression specifications were statistically acceptable.

Multistep Linear Regression

Before conducting mediation analysis, the robustness of buffer radius selection was evaluated with respect to spatial segmentation and the calculation of online review density. As shown in Table 2, multistep regression results indicate that enlarging the buffer radius from 30 m gradually increases the number of streetscape variables significantly associated with review density. The number stabilizes around a radius of 50 m. Specifically, when the radius increases from 50 m to 60 m, improvements in R^2 and adjusted R^2 are marginal; however, expanding the radius to 70 m reduces model fit and introduces noticeable fluctuations, suggesting potential spatial noise and spillover effects from adjacent street segments.

Based on these results—and to balance spatial sensitivity with statistical stability—this study adopts 50 m as the primary buffer radius for the construction of streetscape indicators. The results for 30 m, 40 m, 60 m, and 70 m are retained for subsequent robustness testing.

Mediation Path Analysis

To clarify the interpretation of mediation effects, this study distinguishes between partial and full mediation based on the statistical significance of the indirect and direct pathways estimated through bootstrap procedures. Following standard mediation analysis conventions (Hayes, 2013), a full mediation pattern is identified when the indirect effect through commercial satisfaction is statistically significant while the direct effect of the independent variable on commercially driven everyday street vitality becomes statistically insignificant. Partial mediation is identified when both the indirect and direct effects remain statistically significant. When neither pathway is statistically significant, no mediation relationship is considered to exist.

OLS regression combined with bootstrap procedures was employed to examine whether features of the streetscape skeleton and streetscape skin influence commercially driven everyday street vitality through street-level commercial satisfaction (Table 3; Fig. 4). The results are summarized below.

(1) Streetscape Skeleton.

Enclosure-related variables generally show negative associations with commercial satisfaction, with the strongest and statistically significant effects observed for average building height and building number per length. In the mediation tests, average building height demonstrates significantly negative indirect, direct, and total effects,

Table 2 Model Fit across Spatial Scales: R^2 and Adjust R^2 Values for Regression Models at Varying Buffer Radii (30 m, 40 m, 50 m, 60 m, 70 m)

N=2684	30 m buffer	40 m buffer	50 m buffer	60 m buffer	70 m buffer
R^2	0.207	0.266	0.293	0.297	0.321
Adjust R^2	0.201	0.260	0.287	0.292	0.315

Table 3 Mediating Effect of Commercial Satisfaction on the Relationship between Streetscape Design and Commercially Driven Everyday Street Vitality

Mediation Path	Standardized Indirect Effect	95% CI	Direct Effect	95% CI	Total Effect	95% CI
Skeleton – Enclosure						
Bui_hei -> Func_Sa -> Str_Vitality	-0.0156*	[-0.0288, -0.0036]	-0.0839**	[-0.1403, -0.0316]	-0.0995***	[-0.1573, -0.0452]
Cr_Sec -> Func_Sa -> Str_Vitality	-0.0040	[-00164, 0.0083]	-0.0023	[-0.0551, 0.0530]	-0.0064	[-0.0597, 0.0491]
VIS_Enc -> Func_Sa -> Str_Vitality	-0.0055	[-0.0141, 0.0023]	-0.0259	[-0.0659, 0.0165]	-0.0314	[-0.0717, 0.0115]
StrW_C -> Func_Sa -> Str_Vitality	-0.0058	[-0.0116, 0.0001]	-0.0048	[-0.0428, 0.0329]	-0.0106	[-0.0496, 0.0275]
Bui_Num -> Func_Sa -> Str_Vitality	-0.0105*	[-0.0203, -0.0018]	-0.0420	[-0.0893, 0.0088]	-0.0524*	[-0.1007, -0.0016]
Skeleton – Geometric Variability						
Str_Sin -> Func_Sa -> Str_Vitality	-0.0052	[-0.0117, 0.0010]	-0.0027	[-0.0213, 0.0161]	-0.0079	[-0.0263, 0.0114]
V_Str_wi -> Func_Sa -> Str_Vitality	0.0017	[-0.0041, 0.0083]	0.0333	[-0.0071, 0.0764]	0.0350	[-0.0057, 0.0779]
VHB -> Func_Sa -> Str_Vitality	0.0318***	[0.0203, 0.0446]	0.0277	[-0.0249, 0.0807]	0.0595*	[0.0056, 0.1157]
V_Cr_Sec -> Func_Sa -> Str_Vitality	0.0172**	[0.0077, 0.0282]	-0.0048	[-0.0551, 0.0464]	0.0124	[-0.0380, 0.0641]
Skin – Natural Elements						
GVI -> Func_Sa -> Str_Vitality	-0.0049	[-0.0131, 0.0024]	-0.0053	[-0.0769, 0.0179]	-0.0338	[-0.0828, 0.0126]
SVI -> Func_Sa -> Str_Vitality	-0.0104*	[-0.0207, -0.0010]	-0.0747	[-0.1487, -0.0073]	-0.0851*	[-0.1576, -0.0168]
VIS_Wat -> Func_Sa -> Str_Vitality	-0.0005	[-0.0059, 0.0055]	-0.0137*	[-0.0249, -0.0014]	-0.0143*	[-0.0258, -0.0007]
Skin – Pedestrian Infrastructure						
VIS_Pav -> Func_Sa -> Str_Vitality	-0.0022	[-0.0065, 0.0038]	-0.0202 **	[-0.0353, -0.0051]	-0.0224**	[-0.0371, -0.0078]
VIS_Veh -> Func_Sa -> Str_Vitality	-0.0035	[-0.0107, 0.0032]	-0.0532*	[-0.0888, -0.0169]	-0.0567**	[-0.0921, -0.0201]
Affective perception						
Emo_Safety -> Func_Sa -> Str_Vitality	-0.0038	[-0.0106, 0.0026]	0.0281	[-0.0060, 0.0649]	0.0243	[-0.0106, 0.0619]
Emo_Beauty -> Func_Sa -> Str_Vitality	0.0082*	[0.0013, 0.0156]	0.0164	[-0.0231, 0.0565]	0.0246	[-0.0157, 0.0662]

*$p<0.05$

**$p<0.01$

***$p<0.001$

indicating a negative partial mediation pattern via commercial satisfaction. Building number per length shows significant negative indirect and total effects, while its direct effect is negative but statistically insignificant, suggesting a full mediation pattern through commercial satisfaction. For landscape enclosure, cross-section ratio,

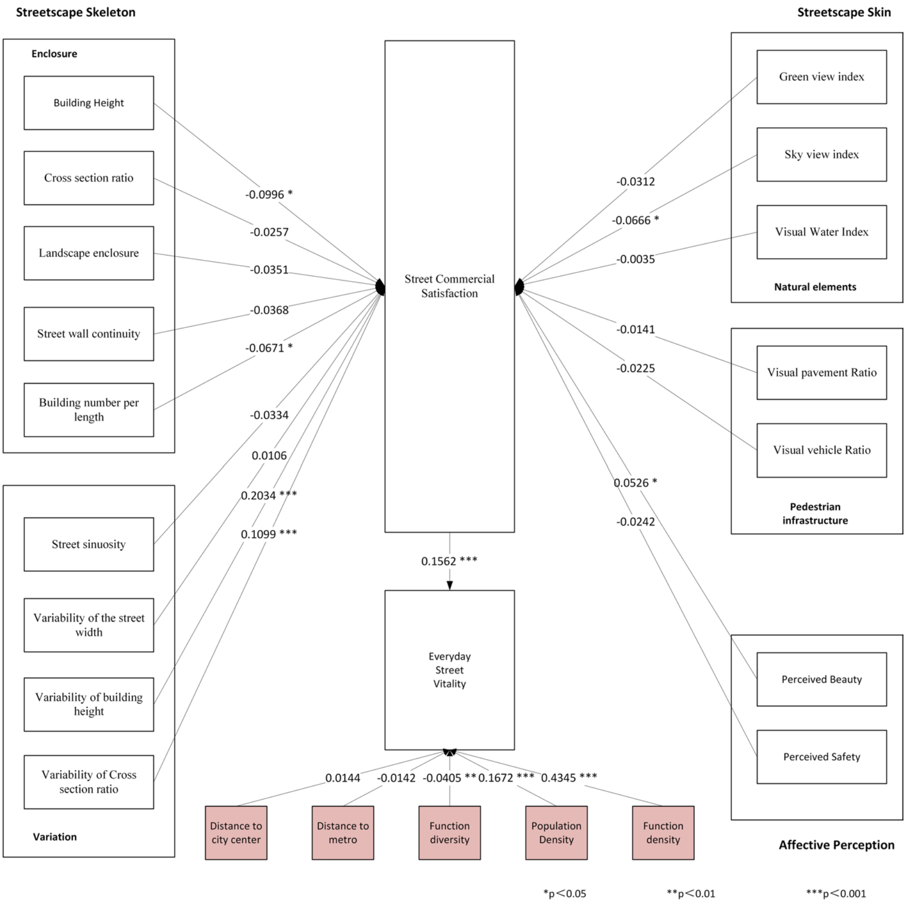

Fig. 4 Conceptual Path Model: The Mediating Role of Commercial Satisfaction between Streetscape Design Features and Commercially Driven Everyday Street Vitality

and street wall continuity, the indirect, direct, and total effects are negative but statistically insignificant, indicating no significant mediation relationship.

Among the geometric variability variables, building-height variation and cross-section ratio variation exhibit significant positive effects on commercial satisfaction, while the remaining variables are not statistically significant. In the mediation analysis, the indirect effects of street sinuosity and street-width variation are insignificant, indicating no mediation relationship. By contrast, the indirect effects of building-height variation and cross-section ratio variation are significantly positive, while their direct effects are insignificant, indicating full mediation.

Overall, streetscape skeleton characteristics exhibit a clear structural differentiation: enclosure-related attributes tend to suppress commercial satisfaction and thereby indirectly reduce commercially driven everyday street vitality, whereas vertical variability functions as a positive contributor, primarily through indirect pathways mediated by commercial satisfaction.

(2) Streetscape Skin.

Variables related to natural elements and pedestrian infrastructure generally show limited associations with commercial satisfaction. Among them, the sky view index exhibits a significant negative effect, whereas the other variables are not statistically significant. In the mediation analysis, the sky view index shows a significantly negative indirect effect with an insignificant direct effect, indicating a full negative mediation pattern through commercial satisfaction. For the green view index and waterscape visibility, the indirect effects are statistically insignificant. Although waterscape visibility exhibits a significant negative direct effect on vitality, the absence of a significant indirect effect indicates no mediation pathway through commercial satisfaction. Similarly, visual pavement ratio and visual vehicle ratio show insignificant indirect effects but significant negative direct and total effects, suggesting that their influences operate primarily through direct environmental constraints rather than mediated pathways.

Taken together, streetscape skin variables display weak or inconsistent mediation effects through commercial satisfaction, while several traffic- and openness-related indicators exert direct negative influences on commercially driven everyday street vitality.

(3) Affective Perception.

The two affective-perception variables exhibit contrasting patterns. Perceived beauty shows a significant positive association with commercial satisfaction, whereas perceived safety does not. In the mediation analysis, perceived beauty demonstrates a significantly positive indirect effect, while its direct and total effects are positive but statistically insignificant, indicating a full mediation pattern. For perceived safety, the indirect, direct, and total effects are all statistically insignificant.

These results indicate a clear divergence in the affective pathway: aesthetic perception enhances commercially driven everyday street vitality indirectly by elevating commercial satisfaction, whereas perceived safety does not function as either a mediating or a direct driver.

Overall, the results reveal a differentiated structure in how streetscape design characteristics relate to commercially driven everyday street vitality. Streetscape skeleton variables show the most consistent mediation patterns: enclosure-related attributes generally suppress commercial satisfaction and vitality, whereas vertical variability tends to enhance them, primarily through indirect pathways mediated by commercial satisfaction. By contrast, streetscape skin variables display weaker and more inconsistent mediation effects. Most natural and pedestrian-related indicators show limited associations with commercial satisfaction, while several openness- or traffic-related variables exert direct negative influences on vitality. In comparison, perceptual variables demonstrate a clearer psychological pathway. Perceived beauty significantly promotes vitality indirectly through commercial satisfaction, whereas perceived safety does not exhibit a comparable mediating or direct effect. Taken together, these findings suggest that structural spatial configurations mainly influence vitality through shaping commercial satisfaction, surface-level environmental features often operate through direct environmental constraints, and aesthetic perception functions as a key affective mediator linking streetscape environments to commercially driven everyday street vitality.

Robust Test

To further verify the stability of the mediation patterns, review-density measures derived from buffer radii of 30 m, 40 m, 50 m, 60 m, and 70 m were tested. As shown in Appendix A Table A3, the mediation effects of cross-section ratio variation, building-height variation, sky view index, average building height, building number per length, and perceived beauty remain consistently significant across different dependent-variable specifications, confirming the robustness of the findings.

Discussion

Overall, the empirical findings provide partial support for the proposed hypotheses and reveal differentiated pathways linking streetscape design, commercial satisfaction, and commercially driven everyday street vitality. Among the streetscape skeleton variables, geometric articulation—particularly vertical variation in building height—shows a positive association with commercial satisfaction and a significant indirect effect on vitality, supporting H1b and H2b. In contrast, enclosure-related attributes exhibit negative or insignificant relationships, offering partial but significant support for H2a while contradicting H1a. For the streetscape skin, neither natural elements nor pedestrian infrastructure demonstrate consistent positive effects on commercial satisfaction or mediated vitality, providing limited support for H1c–H1d and H2c–H2d. Among affective perceptions, perceived beauty significantly enhances vitality through commercial satisfaction, supporting H1f and H2f, whereas perceived safety shows no significant effects, failing to support H1e or H2e. Together, these results suggest that commercially driven everyday street vitality is shaped more strongly by spatial complexity and aesthetic perception than by enclosure intensity, natural visibility, or pedestrian infrastructure alone.

Dual Impacts of the Streetscape Skeleton: Complexity as a Driver and Enclosure as a Constraint

The results indicate a dual pathway by which streetscape skeleton attributes shape commercially driven everyday street vitality, encompassing both stimulation and constraint.

Vertical complexity emerges as an important indirect contributor to commercially driven everyday street vitality, primarily through its association with commercial satisfaction. Variations in building height appear to enhance commercial satisfaction by introducing visual rhythm, facade articulation, and perceptual richness along commercial frontages. Consistent with classic environmental preference theory, moderate complexity signals environmental intrigue and legibility, encouraging exploratory behavior and prolonged engagement (Kaplan & Kaplan, 1989; Zhou et al., 2022). In everyday street contexts, these visual cues translate into more favorable evaluations of commercial environments and, ultimately, higher commercially mediated vitality. By contrast, horizontal geometric variations—such as street sinuosity or width fluctuation—seem less influential at the pedestrian scale. The absence of statistically significant effects suggests that these features may be less perceptible during routine walking, or that their symbolic or functional meanings are not consistently recognized by everyday users, echoing recent evidence that vertical elements exert stronger perceptual salience in street-level experience (Florio et al., 2024; Usui, 2024).

Enclosure-related attributes, in contrast, primarily function as constraints. Excessive enclosure—manifested through high building density, tall continuous street walls, or compressed cross sections—appears to undermine commercial satisfaction and thereby indirectly reduce commercially driven everyday street vitality. This pattern aligns with the notion of an "optimal enclosure threshold," whereby spatial definition enhances comfort up to a point, beyond which perceived pressure, reduced daylight, limited ventilation, and diminished storefront visibility begin to dominate (Zhou et al., 2022). In everyday streets characterized by frequent, habitual use, overly compact spatial configurations may therefore exceed users' comfort thresholds, leading to unfavorable evaluations of both commercial services and the overall street environment (Yilmaz et al., 2025). These results suggest that commercially driven vitality is fostered not by maximal enclosure, but by a balanced combination of spatial definition and openness.

Limited and Context-dependent Role of Natural Elements in the Streetscape Skin

Within the streetscape skin, traffic-related visual dominance emerges as a clear suppressor of commercially driven everyday street vitality. A higher visual presence of motor vehicles is associated with a direct negative effect on commercially driven everyday street vitality, independent of commercial satisfaction, reinforcing the importance of pedestrian-oriented environments (Nia, 2021; Soto et al., 2022). Notably, this effect does not operate primarily through commercial satisfaction, suggesting the presence of alternative pathways—such as reduced perceptual comfort, heightened stress, or a weakened willingness to linger—through which traffic-related disturbances erode commercially mediated street use. Similarly, the expansion of pedestrian space alone does not necessarily translate into higher commercial satisfaction (Koo et al., 2023). On everyday streets structured around routine consumption and commuting, sidewalk width appears to function as a necessary but insufficient condition. In contexts of limited functional intensity, excessively wide pedestrian spaces may even generate a form of spatial hollowing, reducing social density and weakening opportunities for interaction (Ewing & Handy, 2009; Mehta, 2013).

Natural elements—including greenery, sky openness, and waterscape visibility—do not exhibit uniformly positive effects on commercially driven everyday street vitality. Rather than implying their ineffectiveness, these results point to context-dependent and potentially nonlinear relationships. Prior research suggests that greenness may follow an inverted U-shaped association with pedestrian engagement, where both scarcity and excess dampen activity (Chen et al., 2024). Similarly, increased sky openness interacts with enclosure and microclimatic conditions; beyond certain thresholds, excessive openness may erode spatial definition and weaken commercially oriented street engagement (Arif & Yola, 2021). Waterscape visibility, while beneficial in leisure-oriented settings, may exert neutral or negative effects on commercially oriented streets if it disrupts pedestrian flow or competes with active ground-floor interfaces (Gascon et al., 2017; Sitohang et al., 2024).

Overall, these findings caution against linear or universal assumptions regarding natural elements. On everyday streets, their contribution to commercially driven vitality depends less on visibility alone than on functional integration, scale, and alignment with routine commercial and social practices. When deployed as isolated or ornamental features detached from pedestrian circulation or commercial interfaces, natural elements may inadvertently introduce spatial discontinuities, thereby diluting commercially driven everyday street vitality (Yu et al., 2024).

Divergent Roles of Affective Perception: Aesthetic Attraction and the Threshold Nature of Safety

Analysis of affective perception uncovers a clear divergence in its underlying pathway shaping commercially driven everyday street vitality.

Aesthetic perception functions as an active psychological driver, indirectly enhancing vitality through elevated commercial satisfaction. Perceived beauty increases emotional pleasure and environmental attractiveness, promoting approach-oriented behaviors—strolling, repeated visitation, and prolonged presence—which reinforce commercially mediated street use. This pathway aligns with approach–avoidance theory (Bitner, 1992; Mehrabian & Russell, 1974) and prior evidence linking aesthetic appraisal to pedestrian engagement (Dubey et al., 2016; Seresinhe et al., 2017; Zhang et al., 2018).

In contrast, perceived safety exhibits a threshold-like function. Safety serves primarily as a prerequisite: once a basic level is achieved, additional increments do not substantially increase commercially driven vitality (Marquet & Miralles-Guasch, 2015; Maslow, 1943). In familiar, everyday streets, safety is often taken for granted, shifting attention toward more rewarding cues such as aesthetic quality and functional satisfaction (Gehl, 2003). Consequently, aesthetic perception and commercial satisfaction emerge as principal psychological drivers, while safety operates as a necessary but non-salient condition.

These implications should be understood as typologically grounded design heuristics that inform street-scale intervention strategies, rather than as prescriptive or universally applicable regulatory standards.

Limitations and Future Directions

Despite its contributions, this study has several limitations that warrant further exploration.

(1) Limitations in data sources.

The study relies on Dazhong Dianping user ratings and reviews to approximate commercial satisfaction and indicators of commercially driven everyday street vitality. Such crowdsourced data are susceptible to systematic biases related to user demographics and usage patterns. Platform users tend to be younger, digitally literate urban residents, which may underrepresent primary everyday street users, such as nearby residents, commuters, and workers (L. Wang et al. 2025a, b, c). Temporal discrepancies in rating records may introduce noise and reduce measurement accuracy. Future research could integrate multiple complementary data sources—such as Weibo check-ins, mobile signaling data, credit-card transactions, and video-based pedestrian counts—and adopt temporal modeling strategies to capture both instantaneous and longitudinal patterns of commercially driven everyday street vitality (Huang et al., 2020).

(2) Cultural and demographic biases in perceptual data.

Affective indicators were derived from the Place Pulse dataset, whose training samples are primarily from Western cities. Consequently, cultural differences in aesthetic preference and perceived safety may limit the applicability of these models to Chinese urban contexts (Dubey et al., 2016; Naik et al., 2014). Streetscape perception is also inherently observer-dependent; different social groups (e.g., gender groups, age cohorts, commuters, and residents) may differ systematically in their judgments of safety, beauty, and comfort (Rui & Cai, 2025; Yao et al., 2019). Future work should establish culturally adapted perception models based on locally sourced training data and integrate subjective surveys with objective indicators to develop a mixed measurement framework with broader applicability and deeper explanatory power.

(3) Potential non-linear and threshold effects.

Although the present study identifies statistically significant linear associations between streetscape attributes and commercially driven everyday street vitality, the modeling strategy adopted here does not allow for explicit testing of non-linear or threshold-based relationships. Several environmental features—particularly natural elements such as greenery, sky openness, and waterscape visibility—may exert effects that are contingent, non-monotonic, or subject to upper and lower thresholds, rather than following a simple linear pattern. The weak or negative coefficients observed for certain natural elements should therefore be interpreted with caution. Rather than indicating a universally suppressive role, these results may reflect context-specific trade-offs or saturation effects that cannot be disentangled within a linear framework. In this sense, the current findings are suggestive rather than confirmatory with respect to potential threshold mechanisms. Given the street-segment scale of analysis and the aggregation of perception-related indicators into collective evaluative proxies, introducing higher-order terms without independent perceptual measurements may risk overfitting and spurious inference. Future research should explicitly address this limitation by employing non-linear modeling strategies, such as quadratic terms, segmented regression, interaction effects, or machine-learning-based approaches capable of capturing complex response patterns. Longitudinal or quasi-experimental designs would further enable the identification of critical thresholds at which environmental features shift from facilitating to constraining everyday street vitality.

(4) Theoretical modeling and causal inference limitations.

Although the mediation model links streetscape design, commercial satisfaction, and commercially driven everyday street vitality, cross-sectional data limit causal inference. Reciprocal dynamics may exist, where highly vital streets attract more commercial engagement and higher satisfaction, consistent with space–behavior co-construction perspectives. Longitudinal or panel-based studies, combined with quasi-experimental designs—such as before-and-after evaluations of streetscape upgrades or façade renovations—are needed to disentangle bidirectional effects. Further research should also differentiate between momentary affect (Hahm et al., 2019; Mattila & Wirtz, 2008; Muhammad et al., 2023) and accumulated cognition (Gülertekin & Genc, 2021; Majdah Makkiyah & Indrawati, 2025) in shaping commercially driven everyday street vitality.

(5) External validity and applicability.

The study focuses on everyday streets within Wuhan's Third Ring Road. The pathways observed here may differ in tourist, office, or transport-oriented streets. Cross-city and cross-type comparative studies could clarify the generalizability of findings across diverse socio-cultural and functional contexts, advancing a more comprehensive "space–psychology–behavior" framework for urban street vitality (Belaroussi et al., 2024; Kamani Fard & Paydar, 2024).

In sum, despite these limitations, the study provides empirical insights into how streetscape design supports commercially driven everyday street vitality through perceptual and cognitive pathways and offers conceptual and methodological guidance for extending servicescape theory to open urban environments.

Conclusion

This study advances both the theoretical and empirical application of servicescape theory in open urban environments by integrating multi-source urban data with streetscape perception models at the street-segment scale. The findings reveal how the physical environment shapes commercially driven everyday street vitality through a psychological chain of affective perception, cognitive evaluation, and behavioral response, highlighting commercial satisfaction as a central cognitive–affective nexus linking streetscape morphology to routine activity intensity.

Key findings include:

(1) Dual impacts of the streetscape skeleton. Moderate vertical complexity—manifested as controlled building-height variation and articulated skyline profiles—enhances commercial satisfaction and everyday street vitality through increased visual interest and perceptual richness. Excessive enclosure and

over-densification, by contrast, suppress vitality by reducing visual permeability, storefront exposure, and psychological comfort. Vitality is maximized under an intermediate spatial condition balancing enclosure, visibility, and experiential quality.

(2) Context-dependent role of natural elements in the streetscape skin. Greenery, sky openness, and waterscapes do not automatically enhance commercial satisfaction or everyday street vitality. Their contributions appear to be threshold-sensitive and contingent on functional integration with pedestrian circulation and commercial interfaces. When deployed in isolation or ornamentally, natural elements may disrupt frontage continuity, pedestrian flow, or spatial definition, potentially weakening vitality.

(3) Differentiated roles of affective perception. Aesthetic perception acts as a primary driver, stimulating lingering behavior and repeated use through emotional and environmental appeal. Perceived safety appears to function as a threshold-like condition, functioning as a necessary precondition rather than a continuous incentive. Once a basic safety level is met, additional improvements yield diminishing returns, with users increasingly guided by aesthetic and functional cues.

Building on these findings, the study provides more operational and typologically grounded guidance for the planning and renewal of everyday streets in high-density urban contexts, particularly in Chinese cities characterized by compact block structures, dense mixed-use development, and highly active street-level commercial interfaces:

(1) Operationalizing moderate vertical complexity. Rather than pursuing uniform building heights or excessive landmarking, planners may consider encouraging controlled height variation and façade modulation at the block or segment scale. For everyday streets, a fine-grained rhythm of storefront widths, articulated façades, and limited height differentials between adjacent buildings can enhance visual stimulation without fragmenting spatial coherence, an approach particularly relevant to the dense commercial frontages and small-parcel development patterns commonly observed in Chinese inner-city neighborhoods.

(2) Defining optimal enclosure as a relational condition. "Optimal enclosure" should be understood not as maximum openness, but as a balanced height–width relationship that preserves both spatial definition and visual permeability. Street sections that avoid extreme canyon effects while maintaining continuous street walls are more conducive to pedestrian comfort, storefront visibility, and social interaction, a consideration especially important in high-density Chinese urban districts where rapid redevelopment and high floor-area ratios often intensify street enclosure.

(3) Reframing openness as functional rather than purely geometric. Openness should be evaluated in terms of pedestrian accessibility, interface continuity, and activity support rather than sky exposure alone. Excessively wide sidewalks or setbacks, when unaccompanied by active frontages or functional intensity, may lead to spatial hollowing and reduced vitality, a phenomenon increasingly observed in some large-scale urban renewal or street-widening projects in Chinese cities.

(4) Integrating blue–green elements as enabling infrastructures. Greenery and waterscapes should be embedded within activity-supportive micro-spaces—such as shaded seating, café extensions, or pause points along pedestrian flows—so that natural elements reinforce rather than compete with commercial and social functions. This shifts blue–green design from decorative enhancement toward infrastructural support for everyday street life, particularly in dense urban environments where public space is limited and multifunctional design is required.

Overall, this study enriches theoretical understanding of the "space–psychology–behavior" mediation pathway, extends the scope of servicescape theory, and demonstrates an integrated analytical approach combining multi-source urban data with perceptual models. By translating abstract spatial concepts into operational design principles, the research offers actionable guidance for enhancing commercially driven vitality on everyday streets in high-density cities, such as those widely found in contemporary Chinese metropolitan regions. Future research should further test the stability of these pathways across sociocultural contexts, temporal conditions (e.g., day–night and seasonal variations), and street typologies, contributing to a more generalizable and dynamic theory of street vitality.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12061-026-09863-7.

Acknowledgements The authors sincerely acknowledge the funding support from the National Social Science Foundation Arts Project of China (22CG182), Scientific Research Start-up Fund of Hubei Institute of Fine Arts (KYQDJ-2023-006), National Natural Science Foundation of China (No. 52508086), Sichuan Provincial Natural Science Foundation (Grant No. 2026NSFSC1300) and Chengdu Cultural and Economic Research Center (No. CE202501). We extend our heartfelt gratitude to Professor Bai Ge of Huazhong University of Science and Technology for his invaluable guidance on the research design. We also thank Professor Wu Ping and Associate Professor Chen Hui for constructive feedback on the early draft of this paper. Special appreciation goes to all participants who shared their insights and made this study possible.

Author Contributions All authors contributed to the study in distinct roles. Chao Luo was responsible for the conceptualization and methodological design of the research and prepared the original draft. Yiwei Mo carried out the software implementation and validation. Yunzhong Wang led the mediation analysis. Yuxiao Jiang contributed to the review and revision of the manuscript and conducted the visualization work. Wenxin Zhang was in charge of data curation and undertook the investigation and resource acquisition. All authors reviewed the final manuscript.

Data Availability The data used in this study were obtained from third-party platforms and are subject to usage restrictions. As these data will be used for subsequent research, they cannot be fully shared publicly. However, a portion of the processed datasets can be made available upon reasonable request. Interested researchers should contact the corresponding author in advance to obtain access.

Declarations

Competing Interests The authors declare no competing interests.

References

Alfonzo, M. A. (2005). To walk or not to walk? The hierarchy of walking needs. *Environment and behavior*, *37*(6), 808–836.

Arif, V., & Yola, L. (2021). The impact of sky view factor on pedestrian thermal comfort in tropical context: A case of Jakarta sidewalk. In L. Yola, U. Nangkula, O. G. Ayegbusi, & M. Awang (Eds.), *Sustainable Architecture and Building Environment: Proceedings of* the *ICSDEMS 2020* (pp. 27–33). Springer. https://doi.org/10.1007/978-981-16-2329-5_4

Ashihara, Y. (1984). *The aesthetic townscape (L. E. Riggs, Trans.)*. MIT Press.

Belaroussi, R., Sitohang, I., González, E. M. D., & Martín-Gutiérrez, J. (2024). Cross-cultural aspects of streetscape perception. *VITRUVIO-International Journal of Architectural Technology and Sustainability*, *9*(1), 114–129.

Bitner, M. J. (1992). Servicescapes: The impact of physical surroundings on customers and employees. *Journal of marketing*, *56*(2), 57–71.

Cambra, P., & Moura, F. (2020). How does walkability change relate to walking behavior change? Effects of a street improvement in pedestrian volumes and walking experience. *Journal of transport & health*, *16*, 100797.

Chen, C., Wang, J., Li, D., Sun, X., Zhang, J., Yang, C., & Zhang, B. (2024). Unraveling nonlinear effects of environment features on green view index using multiple data sources and explainable machine learning. *Scientific Reports*, *14*(1), 30189.

Cronin Jr, J. J., Brady, M. K., & Hult, G. T. M. (2000). Assessing the effects of quality, value, and customer satisfaction on consumer behavioral intentions in service environments. *Journal of retailing*, *76*(2), 193–218.

Dubey, A., Naik, N., Parikh, D., Raskar, R., & Hidalgo, C. A. (2016). Deep learning the city: Quantifying urban perception at a global scale. In *Proceedings of the European Conference on Computer Vision* (pp. 196–212). Springer.

Dumbaugh, E., & Rae, R. (2009). Safe urban form: Revisiting the relationship between community design and traffic safety. *Journal of the American Planning Association*, *75*(3), 309–329.

Duranton, G., & Overman, H. G. (2005). Testing for localization using micro-geographic data. *The Review of Economic Studies*, *72*(4), 1077–1106.

Ewing, R., & Cervero, R. (2010). Travel and the built environment. *Journal of the American Planning Association*, *76*(3), 265–294.

Ewing, R., & Handy, S. (2009). Measuring the unmeasurable: Urban design qualities related to walkability. *Journal of Urban design*, *14*(1), 65–84.

Florio, P., Leduc, T., Sutter, Y., & Brémond, R. (2024). Visual complexity of urban streetscapes: human vs computer vision. *Machine Vision and Applications*, *35*(1), 7.

Garber, M. D., Benmarhnia, T., Mason, J., Morales-Zamora, E., & Rojas-Rueda, D. (2024). Parking and public health. *Current Environmental Health Reports*, *12*(1), 2.

Gascon, M., Zijlema, W., Vert, C., White, M. P., & Nieuwenhuijsen, M. J. (2017). Outdoor blue spaces, human health and well-being: A systematic review of quantitative studies. *International journal of hygiene and environmental health*, *220*(8), 1207–1221.

Gebru, T., Krause, J., Wang, Y., Chen, D., Deng, J., Aiden, E. L., & Fei-Fei, L. (2017). Using deep learning and Google Street View to estimate the demographic makeup of neighborhoods across the United States. *Proceedings of the National Academy of Sciences*, *114*(50), 13108–13113.

Gehl, J. (2011). *Life between buildings: Using public space.* Island Press.

Glaeser, E. L., Kolko, J., & Saiz, A. (2001). Consumer city. *Journal of economic geography*, *1*(1), 27–50.

Gülertekin, S., & Genc, V. (2021). The effect of servicescape on revisit intention in restaurants: the mediating effect of brand familiarity. *Journal of Tourism Leisure and Hospitality*, *3*(1), 18–25.

Hahm, Y., Yoon, H., & Choi, Y. (2019). The effect of built environments on the walking and shopping behaviors of pedestrians; A study with GPS experiment in Sinchon retail district in Seoul, South Korea. *Cities*, *89*, 1–13.

Hall, P. (2014). Cities of tomorrow: An intellectual history of urban planning and design since 1880 (4th ed.). Wiley.

Han, C., Lieu, S. J., Hwang, U., & Guhathakurta, S. (2025a). Do streetscapes still matter for customer ratings of eating and drinking establishments in car-dependent cities?. *Journal of Urban Design*. Advance online publication. https://doi.org/10.1080/13574809.2025.2541953

Han, T., Tang, L., Liu, J., Jiang, S., & Yan, J. (2025b). The Influence of multi-sensory perception on public activity in urban street spaces: An empirical study grounded in landsenses ecology. *Land,* 14(1), 50. https://doi.org/10.3390/land14010050

Harvey, C. W. (2014). Measuring streetscape design for livability using spatial data and methods (Master's thesis, The University of Vermont). https://scholarworks.uvm.edu/graddis/268

Harvey, C., & Aultman-Hall, L. (2016). Measuring urban streetscapes for livability: A review of approaches. *Professional Geographer*, *68*(1), 149–158.

Harvey, C., Aultman-Hall, L., Hurley, S. E., & Troy, A. (2015). Effects of skeletal streetscape design on perceived safety. *Landscape and Urban Planning*, *142*, 18–28.

Hayes, A. F. (2013). *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach*. Guilford Press.

Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P., & Wang, R. (2019). Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. *Environment international*, *126*, 107–117.

Huang, B., Zhou, Y., Li, Z., Song, Y., Cai, J., & Tu, W. (2020). Evaluating and characterizing urban vibrancy using spatial big data: Shanghai as a case study. *Environment and Planning B: Urban Analytics and City Science*, *47*(9), 1543–1559. https://doi.org/10.1177/2399808319828730

Istrate, A. L. (2025). Street vitality: what predicts pedestrian flows and stationary activities on predominantly residential Chinese streets, at the mesoscale? *Journal of Planning Education and Research*, *45*(1), 66–80.

Jacobs, J. (1961). The Death and life of great American cities. Vintage Books.

Jiang, Y., Sun, Z., Wei, D., Zhao, P., Yang, L., & Lu, Y. (2025). Revealing the spatiotemporal pattern of urban vibrancy at the urban agglomeration scale: Evidence from the Pearl River Delta, China. *Applied geography*, *181*, 103694.

Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus and Giroux.

Kamani Fard, A., & Paydar, M. (2024). Place attachment and related aspects in the urban setting. *Urban Science*, *8*(3), 135.

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge University Press.

Koo, B. W., Hwang, U., & Guhathakurta, S. (2023). Streetscapes as part of servicescapes: Can walkable streetscapes make local businesses more attractive? *Computers Environment and Urban Systems*, *106*, 102030.

Kumakoshi, Y., Chan, S. Y., Koizumi, H., Li, X., & Yoshimura, Y. (2020). Standardized green view index and quantification of different metrics of urban green vegetation. *Sustainability*, *12*(18), 7434.

Lazarus, R. S. (1991). *Emotion and adaptation*. Oxford University Press.

Lin, I. Y., & Mattila, A. S. (2010). Restaurant servicescape, service encounter, and perceived congruency on customers' emotions and satisfaction. *Journal of hospitality marketing & management*, *19*(8), 819–841.

Liu, D., Lu, Y., & Jiang, Y. (2026). Exploring the environmental justice of street tree provision: Adding biodiversity to automatic assessment of street-level greenery. *Urban Forestry & Urban Greening*, 115, 129184. https://doi.org/10.1016/j.ufug.2025.129184

Liwei, Z., Wei, X., Kang, P., Wen, Z., & Yanfei, L. (2025). Measurement of Urban Vitality and Its Relationship with the Built Environment Based on Multi-Source Big Data: A Case Study of Hefei. *China City Planning Review*, *34*(1), 75–87.

Long, Y., & Huang, C. (2019). Does block size matter? The impact of urban design on economic vitality for Chinese cities. *Environment and Planning B: Urban Analytics and City Science*, *46*(3), 406–422.

Lu, Y. (2019). Using Google Street View to investigate the association between street greenery and physical activity. *Landscape and Urban Planning*, *191*, 103435.

Lynch, K. (1960). *The image of the city*. MIT Press.

Ma, R., Wang, W., Zhang, F., Shim, K., & Ratti, C. (2019). Typeface reveals spatial economical patterns. *Scientific Reports*, *9*(1), 15946.

Majdah Makkiyah, G., & Indrawati, N. K. (2025). The effect of servicescape on consumer revisit intention through fine dining restaurant satisfaction and reputation in Malang City. *International Journal of Research in Business and Social Science (2147–4478)*, *14*(2), 70–78. https://doi.org/10.20525/ijrbs.v14i2.3912

Mari, M., & Poggesi, S. (2013). Servicescape cues and customer behavior: a systematic literature review and research agenda. *The Service Industries Journal*, *33*(2), 171–199.

Marquet, O., & Miralles-Guasch, C. (2015). Neighbourhood vitality and physical activity among the elderly: The role of walkable environments on active ageing in Barcelona, Spain. *Social Science & Medicine*, *135*, 24–30.

Maslow, A. (1943). A theory of human motivation. *Psychological Review google schola*, *2*, 21–28.

Mattila, A. S., & Wirtz, J. (2008). The role of store environmental stimulation and social factors on impulse purchasing. *Journal of services marketing*, *22*(7), 562–567.

Mehrabian, A., & Russell, J. A. (1974). *An approach to environmental psychology*. MIT Press.

Mehta, V. (2013). *The street: A quintessential social public space*. Routledge.

Montgomery, & John. (1998). Making a city: Urbanity, vitality and urban design. *Journal of Urban design*, *3*(1), 93–116.

Muhammad, A. S., Adeshola, I., & Isiaku, L. (2023). A mixed study on the wow of impulse purchase on Instagram: insights from Gen-Z in a collectivistic environment. *Young Consumers: Insight and Ideas for Responsible Marketers*, *25*(1), 128–148. https://doi.org/10.1108/yc-04-2023-1728

Naik, N., Philipoom, J., Raskar, R., & Hidalgo, C. (2014). Streetscore:Predicting the perceived safety of one million streetscapes. In *Proceedings of the IEEE conference on computer vision and pattern recognition workshops (pp. 779–785)*.

Nia, H. A. N. (2021). The role of urban aesthetics on enhancing vitality of urban spaces. *Khulna University Studies*, *18*(2), 59–77. https://doi.org/10.53808/KUS.2021.18.02.2112-E

Nice, K. A., Wijnands, J. S., Middel, A., Wang, J., Qiu, Y., Zhao, N., Thompson, J., Aschwanden, G. D., Zhao, H., & Stevenson, M. (2020). Sky pixel detection in outdoor imagery using an adaptive algorithm and machine learning. *Urban Climate*, *31*, 100572.

Oliver, R. L. (1993). Cognitive, affective, and attribute bases of the satisfaction response. *Journal of Consumer Research*, *20*(3), 418–430.

Owen, N., Humpel, N., Leslie, E., Bauman, A., & Sallis, J. F. (2004). Understanding environmental influences on walking: review and research agenda. *American journal of preventive medicine*, *27*(1), 67–76.

Painter, K. (1996). The influence of street lighting improvements on crime, fear and pedestrian street use, after dark. *Landscape and Urban Planning*, *35*(2–3), 193–201.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D:Transport & Environment, 2*(3), 199–219.

Rui, J., & Cai, C. (2025). Plausible or misleading? Evaluating the adaption of the place pulse 2.0 dataset for predicting subjective perception in Chinese urban landscapes. *Habitat International*, *157*, 103333.

Ryu, K., & Han, H. (2010). Influence of the quality of food, service, and physical environment on customer satisfaction and behavioral intention in quick-casual restaurants: Moderating role of perceived price. *Journal of Hospitality & Tourism Research*, *34*(3), 310–329.

Sakamoto, S., Kogure, M., Hanibuchi, T., Nakaya, N., Hozawa, A., & Nakaya, T. (2023). Effects of greenery at different heights in neighbourhood streetscapes on leisure walking: a cross-sectional study using machine learning of streetscape images in Sendai City, Japan. *International journal of health geographics*, *22*(1), 29.

Salazar-Miranda, A., Heine, C., Duarte, F., Schechtner, K., & Ratti, C. (2022). Measuring the impact of slow zones on street life using social media. *Cities*, *131*, 104010.

Seresinhe, C. I., Preis, T., & Moat, H. S. (2017). Using deep learning to quantify the beauty of outdoor places. *Royal Society open science*, *4*(7), 170170.

Sirgy, M. J., & Cornwell, T. (2002). How neighborhood features affect quality of life. *Social indicators research*, *59*(1), 79–114.

Sitohang, I., Belaroussi, R., Adelé, S., & Imine, H. (2024). The effect of access to waterbodies and parks on walking and cycling in urban areas. *Infrastructures*, *9*(12), 235.

Soto, G. W., Whitfield, G. P., Webber, B. J., Omura, J. D., Chen, T. J., Zaganjor, H., & Rose, K. (2022). Traffic as a barrier to walking safely in the United States: perceived reasons and potential mitigation strategies. *Preventive medicine reports*, *30*, 102003.

Stutts, J. C., Hunter, W. W., & Pein, W. E. (1996). Pedestrian crash types: 1990s update. *Transportation Research Record*, *1538*(1), 68–74.

Tripathi, S., Deokar, A. V., & Ajjan, H. (2022). Understanding the Order Effect of Online Reviews: A Text Mining Perspective. *Information Systems Frontiers*, *24*(6), 1971–1988. https://doi.org/10.1007/s10796-021-10217-6

Tucker, C., Ostwald, M. J., Chalup, S., & Marshall, J. (2005). *A method for the visual analysis of the streetscape (Version 1)* [Research report]. Open Research Newcastle. https://hdl.handle.net/1959.13/35551

Usui, H. (2024). Relative Variability in Streetscape Skeletons and Spatial Association: Application for Identifying Harmonious and Inharmonious Streetscape Skeletons in Tokyo. *Geographical Analysis*, *56*(2), 358–383.
Wang, Y., Chau, C. K., Ng, W., & Leung, T. (2016). A review on the effects of physical built environment attributes on enhancing walking and cycling activity levels within residential neighborhoods. *Cities*, *50*, 1–15.
Wang, R., Lu, Y., Zhang, J., Liu, P., Yao, Y., & Liu, Y. (2019). The relationship between visual enclosure for neighbourhood street walkability and elders' mental health in China: Using street view images. *Journal of transport & health*, *13*, 90–102.
Wang, L., Xu, M., Zhang, Q., Shi, Y., & Wu, Q. (2025a). Causal disentanglement for regulating social influence bias in social recommendation. *Neurocomputing*, *618*, 129133. https://doi.org/10.1016/j.neucom.2024.129133
Wang, M., Zhao, J., Zhang, D., Xiong, Z., Sun, C., Zhang, M., & Fan, C. (2025b). Assessing urban vitality in high-density cities: a spatial accessibility approach using POI reviews and residential data. *Humanities and Social Sciences Communications*, *12*(1), 1119. https://doi.org/10.1057/s41599-025-05459-7
Wang, R., Jiang, Y., Liu, D., Peng, H., Cao, M., & Yao, Y. (2025c). Is perceived safety a prerequisite for the relationship between green space availability, and the use and perceived comfort of green space? *Wellbeing Space and Society*, *8*, 100247.
Whyte, W. H. (1980). *The social life of small urban spaces*. Project for Public Spaces, INC.
Wu, W., Niu, X., & Li, M. (2021). Influence of built environment on street vitality: A case study of West Nanjing Road in Shanghai based on mobile location data. *Sustainability*, *13*(4), 1840.
Yao, Y., Liang, Z., Yuan, Z., Liu, P., Bie, Y., Zhang, J., Wang, R., Wang, J., & Guan, Q. (2019). A human-machine adversarial scoring framework for urban perception assessment using street-view images. *International Journal of Geographical Information Science*, *33*(12), 2363–2384.
Ye, Y., Li, D., & Liu, X. (2018). How block density and typology affect urban vitality: An exploratory analysis in Shenzhen, China. *Urban Geography*, *39*(4), 631–652.
Yilmaz, N. G., Lee, P. J., Heimes, A., & Galbrun, L. (2025). The influence of natural features and height-to-width ratios on psycho-physiological responses to urban street canyons. *Building and environment*, *276*, 112851.
Yin, L., & Wang, Z. (2016). Measuring visual enclosure for street walkability: Using machine learning algorithms and Google Street View imagery. *Applied geography*, *76*, 147–153. https://doi.org/10.1016/j.apgeog.2016.09.024
Yu, J., Zhang, H., Dong, X., & Shen, J. (2024). The impact of street greenery on active travel: A narrative systematic review. *Frontiers in Public Health*, *12*, 1337804.
Yüksel, F. (2013). The streetscape: Effects on shopping tourists' product/service quality inferences and their approach behaviors. *Journal of Quality Assurance in Hospitality & Tourism*, *14*(2), 101–122.
Zhang, F., Zhou, B., Liu, L., Liu, Y., Fung, H. H., Lin, H., & Ratti, C. (2018). Measuring human perceptions of a large-scale urban region using machine learning. *Landscape and Urban Planning*, *180*, 148–160.
Zhang, E., Xie, H., & Long, Y. (2023). Decoding the association between urban streetscape skeletons and urban activities: Experiments in Beijing using Dazhong Dianping data. *Transactions in Urban Data Science and Technology*, *2*(1), 3–18.
Zheng, Y., Ye, R., Hong, X., Tao, Y., & Li, Z. (2024). What factors revitalize the street vitality of old cities? A case study in Nanjing, China. *ISPRS International Journal of Geo-Information*, *13*(8), 282.
Zhou, H., He, S., Cai, Y., Wang, M., & Su, S. (2019). Social inequalities in neighborhood visual walkability: Using street view imagery and deep learning technologies to facilitate healthy city planning. *Sustainable Cities and Society*, *50*, 101605.
Zhou, H., Gu, J., Liu, Y., & Wang, X. (2022). The impact of the skeleton and skin for the streetscape on the walking behavior in 3D vertical cities. *Landscape and Urban Planning*, *227*, 104543.

Authors and Affiliations

Chao Luo[1,2] · Yiwei Mo[1,2] · Yunzhong Wang[1,2] · Yuxiao Jiang[3] · Wenxin Zhang[4,5]

✉ Yuxiao Jiang
jiangyx0710@swjtu.edu.cn

Chao Luo
luochao@hifa.edu.cn

Yiwei Mo
moyiwei0426@gmail.com

Yunzhong Wang
wangyunzhong@hifa.edu.cn

Wenxin Zhang
wenxin_zhang@whu.edu.cn

1 School of Visual Arts Design, Hubei Institute of Fine Arts, Wuhan, China

2 Center for Design & Culture Research, Hubei Institute of Fine Arts, Wuhan, China

3 School of Architecture, Southwest Jiaotong University, Chengdu, China

4 School of Urban Design, Wuhan University, Wuhan, China

5 Research Center for Digital City, Wuhan University, Wuhan, China