Microscale Walkability Assessment in Historic Cities: Preliminary Results of a Framework Centred on Pedestrian Experience

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Abstract

Microscale walkability assessment has become increasingly important for understanding how detailed street conditions shape pedestrian experience, especially in historic districts where constrained spatial forms and mixed patterns of use complicate conventional evaluation. This paper develops an analytical framework that links physical street features, perceived qualities, and overall walkability. Accessibility, safety, comfort, and attractiveness are treated as interrelated dimensions of perception, while environmental indicators are operationalized at spatial ranges corresponding to the ways pedestrians encounter them. The framework is initially implemented in Pingjiang Historic District, Suzhou, by integrating on-site ratings with street level 3D point cloud data acquired through mobile mapping, together with geospatial data. Preliminary mapping reveals clear differences among streets and continuous clusters of high and low scores, indicating that perceived walkability varies spatially across the district. Future work will complete the extraction and spatial matching of environmental indicators and examine how physical street features shape perceived accessibility, safety, comfort, and attractiveness, and how these perceptions contribute to overall walkability.

1. Introduction

Improving the quality of urban walking environments is an important way to promote public health, support daily mobility, and strengthen urban vitality (Alves et al., 2021; Kelly et al., 2017). Effective improvement, however, is not limited to upgrading physical facilities. It also requires understanding how pedestrians perceive and evaluate streets, because satisfaction with the walking environment influences their future willingness to walk (Kim et al., 2014). This issue is particularly relevant in historic urban areas, where streets must accommodate daily movement, tourism, and cultural activities within spatial conditions that are often difficult to alter. Improving walkability is therefore essential to maintaining the continued use and vitality of historic streets.

Over the past two decades, walkability research has developed a rich set of concepts and assessment methods. Early studies mainly examined walkability at the neighbourhood or urban scale, using built-environment variables such as density, diversity, design, destination accessibility, and distance to transit to explain walking behaviour (Cervero and Kockelman, 1997; Ewing and Cervero, 2001). These macroscale approaches are useful for comparing urban areas and identifying walking potential. However, they provide limited explanation of how pedestrians experience street environments. In response, microscale assessment tools, such as SPACES, MAPS, and the Irvine–Minnesota Inventory, have been developed to record detailed features, including sidewalks, crossings, frontage conditions, traffic safety, and street furniture (Day et al., 2006; Millstein et al., 2013; Pikora et al., 2002). These tools have shifted the focus of walkability assessment from accessibility conditions to the qualities of streets as experienced by pedestrians.

Recent advances in street-view imagery (SVI) have made microscale assessment more scalable and operational by enabling the large-scale extraction of visual indicators such as greenery, sky openness, and street enclosure (Koo et al., 2023; Li et al., 2015). However, geometric measurements can be affected by occlusion and perspective distortion, while the identification of small-scale elements depends on image quality and resolution (Yin et al., 2015). These problems are particularly relevant in historic districts, where narrow lanes, irregular street interfaces, and restricted vehicle access often result in incomplete or uneven image coverage. In addition to these limitations in spatial representation, many assessment tools further aggregate heterogeneous indicators through additive weighting. Although convenient for mapping and comparison, this structure allows favourable conditions, such as greenery or visual attractiveness, to compensate for deficiencies in more fundamental conditions, such as route continuity or safety (Chan et al., 2021). Together, these representational and aggregation choices limit the ability of current methods to reconstruct the pedestrian viewpoint and to explain how physical street conditions are translated into walking experience.

This paper develops a three-level framework for microscale walkability assessment in historic cities, comprising physical features, perceived qualities, and overall walkability. Applied in Pingjiang Historic District, Suzhou, the framework examines how street conditions are associated with accessibility, safety, comfort, attractiveness, and the overall evaluation of walking. Rather than combining environmental information into a composite score at the outset, it retains perceived qualities as an intermediate analytical layer. This structure provides a more interpretable basis for identifying local problems and supporting detailed renewal in historic streets.

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2. Literature review

2.1 From traditional walkability to microscale pedestrian experience

Early walkability research mainly examined walking potential at the neighbourhood or urban scale, with a focus on how the built environment affects travel behaviour, physical activity, and public health. Representative frameworks include the 3D variables proposed by Cervero and Kockelman (1997), namely density, diversity, and design, and the later 5D framework developed by Ewing and Cervero (2001). These studies commonly rely on geographic information system (GIS) data, land-use patterns, street-network structure, facility accessibility, and destination distribution to assess whether an area provides spatial conditions that support walking. Geography-based indices such as Walk Score follow a similar logic, using distance to amenities as a proxy for walking convenience at the neighbourhood level (Carr et al., 2010). These approaches are useful for comparison across areas, broad planning diagnosis, and policy communication. However, their main concern is whether destinations can be reached easily, rather than how pedestrians experience the street while walking.

Compared with this traditional understanding, microscale walkability places greater emphasis on street-level perception, bodily effort, and environmental appraisal. Its objects of analysis are not limited to neighbourhood density, land-use mix, and network connectivity. They also include finer-grained features such as sidewalk width, surface continuity, traffic conflicts, street frontages, shade, greenery, street furniture, visual enclosure, legibility, and street activities. Street audit tools such as SPACES and MAPS record microscale walking environments through systematic field observation, while NEWS measures residents' perceived neighbourhood walking environments through questionnaires (Millstein et al., 2013; Pikora et al., 2002). The theoretical shift was further supported by Alfonzo's (2005) hierarchy of walking needs and Ewing and Handy's (2009) work on urban design qualities. Together, these studies moved walkability research beyond spatial accessibility alone and framed it as a relationship among physical environment, perceived qualities, and behavioural responses. In this sense, microscale walkability is not simply a smaller-scale version of traditional walkability. It examines how pedestrians perceive and evaluate the street environment during walking.

As walkability research has moved from macro-level spatial structure to experience-oriented assessment, more attention has been paid to perceived dimensions such as safety, comfort, attractiveness, and legibility (Bartzokas-Tsiompras et al., 2023; Blecic et al., 2020; De Vos et al., 2023). This shift broadens the assessment focus from whether space supports walking to how space shapes the walking experience. Built-environment features do not necessarily determine overall walkability directly. Instead, they may first influence perceived qualities, which then affect pedestrians' overall evaluation and behaviour (Ewing and Handy, 2009). Therefore, experience-oriented walkability assessment requires more than adding microscale indicators. It also requires an analytical framework that can explain the relationships among physical features, perceived qualities, and overall walkability.

2.2 Measurement and analytical methods

Methods for microscale walkability assessment have developed from manual audits toward digital measurement. Early tools relied on field observation or questionnaire surveys. These methods can capture many street-level details, but they are labour-intensive, and their results may be affected by differences among observers. In recent years, SVI and computer vision have been widely used to extract visual indicators such as green view, sky openness, street enclosure, building frontages, and street facilities. This has greatly improved the efficiency of large-area microscale assessment (Koo et al., 2023; Li et al., 2015; Lu and Chen, 2024). However, SVI does not always correspond to the pedestrian viewpoint. As a two-dimensional image source, it is also affected by occlusion, image date, perspective distortion, and uneven data coverage. As a result, SVI alone remains limited for measuring geometric and spatial features such as street width, frontage height, visual obstruction, obstacles, viewshed, and spatial layering. To address these limitations, 3D point clouds, mobile mapping, and multi-source spatial data have been introduced to complement GIS data and SVI, allowing street geometry, occlusion, and pedestrian viewsheds to be represented more accurately (Treccani et al., 2021; Xia et al., 2024; Yin, 2017).

Aggregation methods have also evolved from simple summation to more complex aggregation approaches. Early street audit tools often summed standardized item scores to produce an overall suitability score, for example by combining measures of sidewalk continuity, pavement condition, and crossing facilities (Emery et al., 2003). Later studies developed weighted additive models. Their weights may be derived from distance-decay logic, as in Walk Score; from participatory or user-preference approaches, as in the IAAPE framework proposed by Moura et al. (2017); or from multi-criteria decision analysis, as in Garau et al. (2024). These methods are more refined than simple summation, but many of them still rely on a linear compensatory assumption. In other words, a high score in one dimension can offset a low score in another. However, weighted summation is often applied without sufficient attention to its underlying methodological assumptions, creating a risk of misuse or biased interpretation (Malczewski, 2006). Comparisons of alternative aggregation rules have shown that different approaches can produce substantially different assessment results. In particular, linear additive models may systematically overestimate the walkability of areas that perform well on a limited number of attributes while still having serious deficiencies in more fundamental conditions (Chan et al., 2021). This compensatory logic may therefore obscure the behavioural thresholds that determine whether pedestrians regard a walking environment as acceptable.

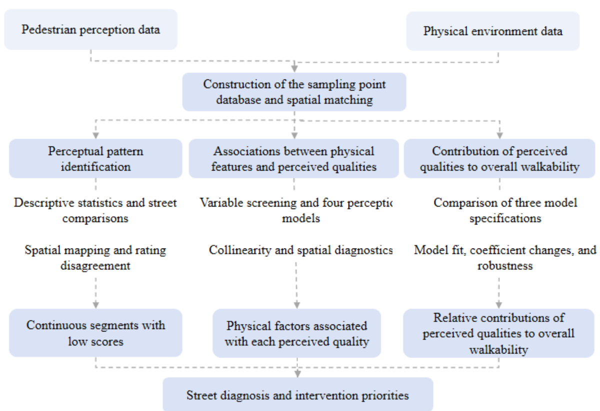

Figure 1. Analytical framework for microscale walkability assessment

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3. Method

3.1 Analytical structure construction

Existing walkability studies often combine standardized environmental indicators into a weighted composite index. This approach is useful for comparison and mapping, but a single score may limit the diagnostic value of the assessment. In a linear weighting framework, different dimensions are assumed to be mutually compensatory. As a result, strong performance in greenery or streetscape attractiveness may mask basic problems such as insufficient walking space or low perceived safety (Chan et al., 2021). To avoid reducing walking experience to an opaque overall score, this study adopts a three-level analytical structure: physical features, perceived qualities, and overall walkability (**Errore. L'argomento parametro è sconosciuto.**).

The structure follows a progression from objective street conditions to subjective perception and then to overall evaluation (Alfonzo, 2005; Ewing and Handy, 2009):

- Physical features: measurable street conditions derived from 3D point clouds, GIS, point of interest (POI) data, and field records.
- Perceived qualities: pedestrians' on-site ratings of accessibility, safety, comfort, and attractiveness at each sampling point.
- Overall walkability: pedestrians' integrated evaluation of the walking experience at the same point.

This structure allows the analysis to examine how physical conditions shape multiple perceptual dimensions and how these dimensions contribute to overall walkability.

3.2 Indicator system and variable selection

Candidate physical features were identified through three complementary steps. First, established walkability theories and conceptual frameworks were reviewed to define the main environmental domains relevant to walking experience. Second, indicators previously used or empirically examined in walkability studies and street-audit tools were compiled to form an initial candidate list. Third, this list was adapted through field observations in Pingjiang Historic District. Features characteristic of the local historic street environment were retained or added, whereas variables that were absent, difficult to measure reliably, redundant with other indicators, or showed little meaningful spatial variation across the study area were excluded. The remaining indicators were then screened according to their relevance to pedestrian experience, measurability with the available data, and usefulness for planning intervention. This process resulted in 10 macroscale variables and 26 microscale variables, as shown in Table 1.

Perceived qualities are used to explain the intermediate process between physical features and overall walkability. Based on the literature review and coding of representative walkability assessment tools, and considering the operational design of the questionnaire, this study adopts four dimensions of perceived quality: accessibility, safety, comfort, and attractiveness.

- Accessibility: the perceived ease of reaching and passing through the street and connecting to nearby activity opportunities.
- Safety: perceived exposure to traffic conflicts, limited visibility, and other walking risks.
- Comfort: bodily ease in relation to walking space, surface conditions, shade, resting opportunities, and pedestrian flow.
- Attractiveness: affective evaluation of visual quality, historic atmosphere, and sense of place.

These dimensions are not treated as isolated categories. The same physical feature may affect several perceived qualities at the same time. For example, greenery may improve comfort while also increasing attractiveness.

Spatial scale	Indicator group	Indicators
Macro scale	Land use and activity opportunities	Land-use mix; floor area ratio; density and diversity of public service facilities; density and diversity of commercial facilities
	Public transport accessibility	Bus-stop accessibility; metro-station accessibility
	Street-network structure	Street-network connectivity; intersection density
Micro scale	Walking and traffic conditions	Motor vehicle traffic volume; pedestrian volume; pedestrian pavement material; walking-surface evenness; effective walking-space width; walking-space continuity and obstruction; longitudinal slope; curb-ramp provision; street cleanliness
	Street form, frontage, and activity	Street-vendor density; mean building height; street width-to-height ratio; sky view factor; visual depth; ground-floor facade transparency; upper-floor facade transparency; frontage continuity; semi-outdoor transitional spaces; active ground-floor frontage ratio
	Green-blue environmental conditions	Mean tree-canopy diameter; green view index; continuous shaded walking length; waterfront accessibility
	Street amenities	Waste-bin density; public-toilet accessibility; seating density

Table 1. Candidate physical environment indicators for walkability assessment in historic cities

3.3 Data collection and spatial matching

Suzhou's Pingjiang Historic District is used as the main empirical case (**Errore. L'argomento parametro è sconosciuto.**). The study focuses on the core part of the historic district. Streets affected by construction or other temporary, unrepresentative conditions during the survey period were excluded. A comparative case in Mantua is planned for future work to examine whether the proposed indicator measurement and data-matching workflow can be transferred to another historic urban context (**Errore. L'argomento parametro è sconosciuto.**). Therefore, Mantua is treated as a future methodological extension rather than as part of the empirical analysis reported in this paper.

Figure 2. Study area location in Suzhou, the main empirical case.

Figure 3. Study area location in Mantua, planned for subsequent validation of the methodological workflow.

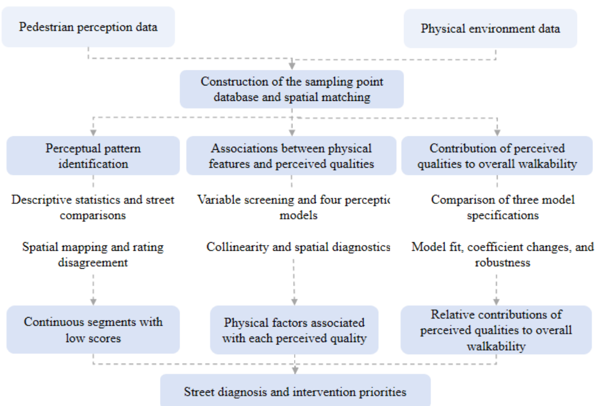

Figure 4. Analytical workflow for microscale walkability assessment.

Subjective perception data were collected through on-site questionnaires. At each sampling point, about 10 passers-by were randomly invited to rate accessibility, safety, comfort, attractiveness, and overall walkability. Objective environmental data include 3D point clouds, geospatial vector data from OpenStreetMap, and field records. The point clouds were collected using handheld laser scanning devices based on simultaneous localization and mapping (SLAM). The Suzhou case used the CHCNAV RS10, while the planned Mantua case will use the Stonex X70GO.

The data processing stage builds a database organized by sampling point that links questionnaire ratings with corresponding environmental features. The measurement extent varies according to how each environmental feature is perceived. Conditions involving direct physical contact are measured near the sampling point. Continuous exposures are measured along the street segment, visual indicators within the pedestrian field of view, and functional accessibility within a short walking distance. In this way, environmental variables are not placed within a single uniform buffer. Instead, they are operationalized according to the spatial scale at which they are perceived, improving the correspondence between indicator measurement and on-site walking experience.

3.4 Analytical strategy and spatial relationship testing

The analytical workflow is summarized in Figure 4. Questionnaire ratings and environmental features are first organized and matched at the sampling-point level. The analysis then proceeds through three stages: identifying the distribution and spatial variation of perceived walkability, examining the relationships between physical features and the four perceived qualities, and assessing how these qualities contribute to overall walkability. Network-based spatial diagnostics are used as a conditional check on perception scores and model residuals rather than as an independent analytical stage.

First, the study describes the overall distribution and spatial variation of the five on-site ratings: accessibility, safety, comfort, attractiveness, and overall walkability. Means, standard deviations (SD), and distributional patterns will be calculated. Differences across streets and street types will also be compared. At the sampling-point level, the spatial distribution of each rating will be mapped to identify high-scoring points, low-scoring points, and continuous low-scoring segments. The SD of ratings will be used as supplementary information to indicate disagreement among respondents. A point with a low mean score and limited disagreement may suggest a stable environmental problem. A point with a moderate mean score but strong disagreement may indicate that perception is more sensitive to user differences or local conditions.

Second, the study examines the relationship between physical features and perceived qualities. Accessibility, safety, comfort, and attractiveness are treated as dependent variables. Environmental variables extracted from 3D point clouds, open geospatial data such as OpenStreetMap, and field records are used as explanatory variables. Since the candidate variables may overlap, variable selection will combine theoretical judgement, correlation checks, and collinearity diagnostics. Priority will be given to variables that are relevant to walking experience in historic streets, stable in measurement, and meaningful for planning intervention. The main analysis uses sampling points as the unit, linking the mean rating of each point with its corresponding environmental features. The analysis will then check whether perception scores and model residuals show spatial continuity along the street network. If clear neighbourhood dependence is found, the model will include perception information from adjacent sampling points. This helps test whether a perceived quality is shaped not only by local physical features, but also by the perceived atmosphere of nearby street segments.

Finally, the study tests the role of the four perceived qualities in explaining overall walkability. Three model specifications will be compared: a model with only physical features, a model with only perceived qualities, and a combined model including both. Changes in model fit and coefficient patterns will be used to assess whether physical features influence overall walkability mainly through accessibility, safety, comfort, and attractiveness. If perception scores or model residuals show spatial dependence, network-based neighbourhood relationships between adjacent sampling points will be considered as an exploratory robustness check rather than as an independent dynamic experiment.

4. Current Progress and Preliminary Discussion

Fieldwork for the initial application of the framework has been completed in Pingjiang Historic District. The survey covered 12 streets and 157 sampling points spaced approximately 30 m apart, yielding 1,558 valid rating records (**Errore. L'argomento parametro è sconosciuto.**). Street-level 3D point cloud data have also been acquired, providing a basis for extracting fine-grained physical indicators such as street width, frontage characteristics, visible range, occlusion relationships, and walking-space conditions. This paper therefore reports the initial implementation of the framework, data usability, and field observations rather than a full test of the proposed relationships.

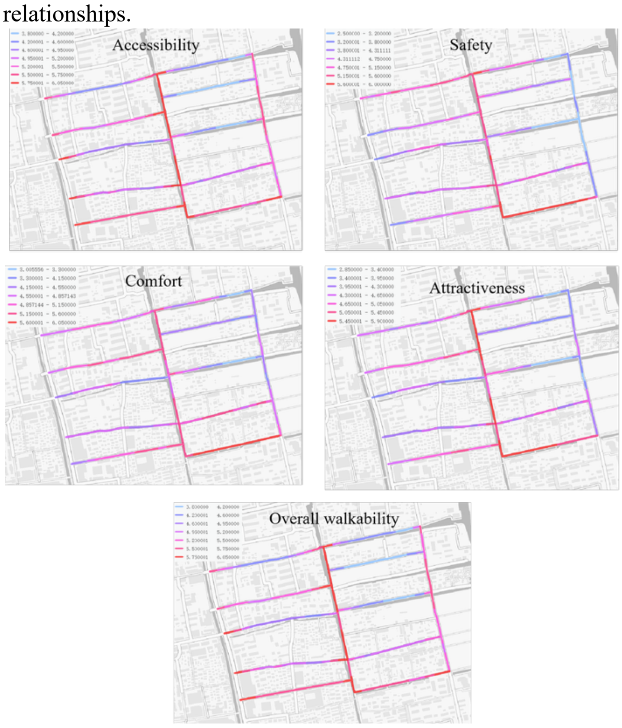

Figure 5. Spatial distribution of mean scores for perceived qualities and overall walkability in Pingjiang.

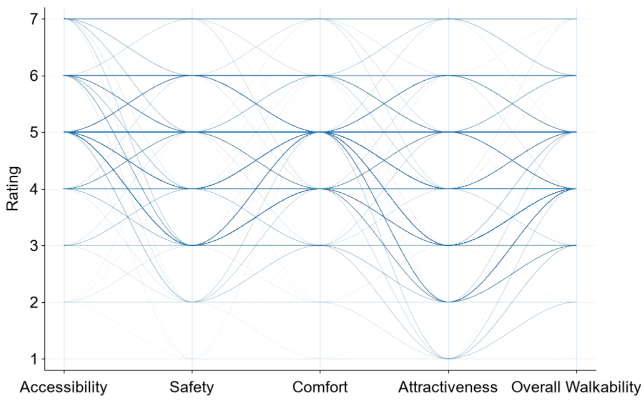

Figure 6. Parallel-coordinate plot of the five ratings from 1,558 valid questionnaire responses. Each curve represents one complete response.

Preliminary mapping shows that the five perception scores are not evenly distributed across the study area. Instead, they vary across streets and form continuous clusters of high and low scores along some street segments (Figure 5). Figure 6 visualizes the five-dimensional rating profile of each of the 1,558 valid questionnaire responses. Each curve connects the accessibility, safety, comfort, attractiveness, and overall walkability scores given in one questionnaire response. Accessibility received the highest average rating and was relatively concentrated around a score of 5 (mean = 5.17, SD = 1.11). Comfort showed a similarly concentrated distribution (mean = 4.80, SD = 1.08). In contrast, attractiveness had the lowest mean and the widest dispersion (mean = 4.14, SD = 1.60), while safety and overall walkability occupied intermediate positions. These results indicate that accessibility was evaluated relatively consistently and positively, whereas attractiveness showed greater heterogeneity in the collected responses. This variation may reflect differences among street environments as well as variation in individual appraisal. When combined with the spatial distribution shown in Figure 5, low or highly variable attractiveness scores may help identify locations where experiential quality is uneven or particularly sensitive to local street conditions. However, these descriptive patterns do not establish which perceived dimension contributes most strongly to overall walkability.

Field observations further suggest that Pingjiang Historic District is not environmentally homogeneous. Spatial characteristics are generally continuous within the same street, while differences between streets are more evident. Even streets with similar functions differ in commercial intensity, pedestrian and tourist activity, frontage conditions, and spatial form. For example, Luxia Lane is characterized by mature street trees, a slower pedestrian pace, and a relatively diverse mix of street-front commercial activities (Figure 7a). By contrast, Zhongzhangjia Lane has more recently renewed building frontages, a narrower range of commercial uses, and a greater concentration of pedestrians stopping to take photographs (Figure 7b). Although these observations are descriptive, they confirm that the study area contains sufficient environmental variation for subsequent analysis. They also support the inclusion of variables related to greenery and shade, commercial activity, pedestrian volume, frontage characteristics, and street form.

a b

Figure 7. Representative street environments in Luxia Lane (a) and Zhongzhangjia Lane (b).

The field survey also suggests that stopping conditions may have influenced participation. Pedestrians appeared more willing to respond at shaded locations where stopping was physically comfortable. This may have produced some spatial variation in response availability and should be considered when interpreting the survey results. Shade and thermal exposure therefore have a dual relevance in this study: they are environmental conditions that may shape walking comfort, but they may also have affected where questionnaires could be collected more easily.

5. Conclusion

This paper develops a framework for microscale walkability assessment in historic cities that distinguishes physical street features, perceived qualities, and overall walkability. Accessibility, safety, comfort, and attractiveness are treated as distinct but interrelated dimensions of perceived quality. This allows each dimension to retain its specific meaning without assuming that the dimensions operate independently or reducing them immediately to a single composite score.

The framework uses the sampling point as the unit of analysis and matches pedestrian ratings with 3D point clouds, OpenStreetMap data, and field records. The measurement extent is adjusted to the way each feature is encountered, including immediate contact, exposure along a street segment, the pedestrian visual field, and short walking access. This avoids applying a single buffer to variables with different perceptual ranges.

The Suzhou fieldwork covered 12 streets and 157 sampling points and yielded 1,558 valid ratings. Preliminary maps and field observations show clear differences among streets and locally continuous patterns in several ratings, indicating that Pingjiang provides sufficient spatial variation for the next stage of analysis. The present paper reports the framework and its initial implementation. Future work will complete indicator extraction and spatial matching, test the relationships among physical features, perceived qualities, and overall walkability, and evaluate the transferability of the methodological workflow in Mantua, Italy.

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