

Review

Toward User-Inclusive, Purpose-Specific, and Context-Sensitive Walkability Measurement: A Review of 46 Instruments Through an Adapted Walking-Needs Framework

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Abstract

Walkability measurement has expanded from a small set of generic neighbourhood-level proxies into a heterogeneous field of indices, scored audits, perceived-environment scales, route-based instruments, and context-specific assessment instruments. This expansion has improved the sensitivity of walkability research, but it has also made it increasingly difficult to judge which instruments are appropriate for different users, walking purposes, and urban or environmental contexts. This review addresses this problem by comparing operational walkability instruments through an adapted walking-needs framework derived from the Expanded Hierarchy of Walking Needs (HoWN). Publications from 1990 to 2025 were identified through a structured search and screening workflow covering general walkability measurement, population-sensitive instruments, purpose-specific instruments, climate- and exposure-sensitive instruments, and urban-form-specific instruments. After eligibility assessment and consolidation, 46 walkability instruments were retained for comparative analysis. For this review, the framework is adapted from a behavioural hierarchy into an instrument-level comparative structure, with feasibility re-specified as basic environmental passability. The instruments are then compared across five tiers: feasibility, accessibility, safety, comfort, and pleasurability. The review shows that walkability measurement remains strongly concentrated in lower-order and functionally measurable dimensions, especially pedestrian infrastructure, destination access, connectivity, and traffic safety. By contrast, comfort, pleasurability, environmental exposure, personal security, and user-specific constraints are less consistently formalised and often appear only in specialised instruments. Population-, purpose-, climate-, and urban-form-sensitive instruments do not merely add indicators; they alter which walking needs become foundational in specific assessment scenarios. This review contributes a fit-for-purpose comparative logic for walkability measurement. It shows how a shared walking-needs framework can be used to diagnose coverage imbalance, identify scenario-specific threshold conditions, and guide the selection, adaptation, and transfer of instruments across different users, walking purposes, environmental exposures, and urban forms.

Keywords: walkability instruments; walking-needs framework; context-sensitive assessment; user-inclusive urban design; active mobility



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1. Introduction

Walkability has long been used to describe how the built environment supports walking, but the way it is measured has changed substantially [1,2]. Early and influential instruments established a relatively stable measurement tradition centred on residential density, land-use mix, street connectivity, and destination access [3–5]. These variables helped consolidate walkability as a measurable construct in urban planning, transport, and public health research [1,3]. Over time, however, this generic model proved insufficient for many real walking situations. Later studies introduced microscale audits [6], perception-based tools [7], climate-sensitive measures [8], school-travel assessments [9], station-access tools [10], and instruments tailored to specific groups such as older adults [11], children [12], women [13], or people with disabilities [14]. Walkability measurement has, therefore, evolved from a small set of broadly applicable proxies into a diverse field of operational tools [2,15].

This expansion has created a practical and conceptual problem: different walkability instruments do not merely measure the same construct with different technical choices; they often embody different assumptions about who the walker is, what kind of trip is being made, and which environmental conditions matter most [16–18]. An instrument designed for commuting adults in a generic urban neighbourhood is not equivalent to one developed for winter walking, school travel, or mobility-impaired pedestrians. Yet in both research and practice, such instruments are still often discussed under the single label of “walkability”, with limited guidance on how their differences should be interpreted [2,15]. The result is a field rich in instruments but comparatively weak in comparative logic: many instruments exist, but it remains unclear how they relate to one another, what each actually prioritises, and under what conditions each is appropriate [15,18].

Existing reviews have documented important parts of this landscape by classifying walkability measures according to data source, scale, audit type, or methodological design [1,15]. What remains less clear is how to compare operational instruments when the meaning of a walkable environment changes across users, walking purposes, and contexts [16–19]. This is not a minor issue of categorisation. It affects construct validity, comparability, and instrument selection [16]. The central problem is, therefore, no longer the absence of walkability instruments, but the absence of a coherent framework for comparing increasingly differentiated instruments and judging their fitness for purpose [2,15,18].

This review addresses the problem through an adapted walking-needs framework derived from the Expanded Hierarchy of Walking Needs (HoWN) [20]. Rather than treating walkability as a single, universally stable property, the review treats it as a measurement construct whose operational meaning shifts with user needs and situational conditions [20]. The adapted walking-needs framework is used as a comparative framework for examining how walkability instruments allocate attention across different layers of walking need and across four adaptation dimensions: user group, walking purpose, climate and environmental exposure, and urban-form setting. This review focuses on operational instruments, including composite indices, scored audits, and structured assessment instruments. Its aim is not simply to compile them, but to compare how they are built, what they privilege, and where systematic patterns of omission, imbalance, or adaptation appear.

This paper makes three contributions. First, it brings operational walkability instruments that are usually treated in separate literatures into a common analytical structure, not only by comparing their data sources, spatial scales, or methodological formats, but also by examining the walking needs, user assumptions, trip purposes, and environmental and urban-form conditions they prioritise. Second, it develops an adapted walking-needs framework, derived from the Expanded Hierarchy of Walking Needs (HoWN), as a structure for instrument-level comparison. Third, it develops a comparative basis for fit-for-purpose

instrument selection and local adaptation. It shows why no single walkability measure can serve all users, trip types, and settings equally well, and it identifies three issues that future measurement frameworks need to address: uneven coverage across walking needs, context-specific priorities, and conditional transferability.

Accordingly, this review addresses three research questions. First, how have existing conceptualisations of walkability framed walking needs, trip purpose, user diversity, and environmental and urban-form context? Second, how do operational walkability instruments differ in their indicator structures and in the extent to which they address these dimensions across the adapted walking-needs framework? Third, what comparative principles can support the fit-for-purpose selection or local adaptation of walkability instruments across diverse planning and research scenarios?

The remainder of this paper is structured as follows. Section 2 reviews major conceptualisations of walkability and defines an adapted walking-needs framework from the Expanded HoWN as the analytical framework. Section 3 presents the review method, including search strategy, selection criteria, extraction logic, and coding procedure. Section 4 reports the results of the comparative analysis. Section 5 discusses the implications for walkability theory, measurement, and future instrument design, selection, and adaptation.

2. Conceptual Foundations for Walkability Measurement

Walkability is widely used across urban planning, transport studies, public health, and urban design, but its meaning is not fully stable across these traditions [21–24]. This matters because measurement depends on conceptualisation: how walkability is defined shapes which environmental attributes are treated as relevant, which dimensions are emphasised or neglected, and which walking outcomes a measure is expected to explain [16]. Before comparing specific walkability tools, it is, therefore, necessary to clarify the main conceptual framings that have informed later index construction.

Although definitions of walkability vary across disciplines, most share one basic idea: walkability concerns the extent to which an environment supports walking [21,22,25]. The main difference lies in how such support is defined. The most established approach treats walkability as a property of the built environment itself [22,25]. From this perspective, walkability depends on features such as destination accessibility, street connectivity, pedestrian infrastructure, and other built-form conditions that make walking possible, direct, and convenient [23,25]. This approach underpins many canonical GIS-based indices and helps explain the long-standing emphasis on density, land-use mix, and connectivity in mainstream walkability measurement.

A second framing treats walkability as a perceived or experiential quality of place [26,27]. Here, supportive environments are not defined only by structural access, but also by how they are experienced in terms of safety, comfort, attractiveness, and overall walk-friendliness [27,28]. This perspective has been especially influential in urban design and perceived-environment research, and it helps explain why later instruments increasingly include aesthetics, crime, traffic safety, and environmental quality rather than relying solely on built-form proxies [26–28].

A third framing conceptualises walkability in behavioural terms [3,29]. Rather than treating walkability only as a property of the environment, this perspective defines it through the environment's capacity to enable or encourage walking, active travel, and broader forms of physical activity [26]. It is especially prominent in public health and transport research, where walkability functions not only as a descriptive environmental concept but also as an explanatory or predictive concept linking environmental conditions to behavioural outcomes.

A fourth framing treats walkability as part of a broader urban and policy agenda [24,30,31]. In this literature, walkability is associated with wider goals such as health, sustainability, liveability, neighbourhood vitality, and equity [30,31]. This broader framing has expanded the relevance of walkability, but it has also made the concept more diffuse. When walkability is used to encompass multiple desirable urban outcomes, the boundary between analytical definition, normative aspiration, and policy rhetoric becomes less clear. These four framings are summarised in Figure 1.

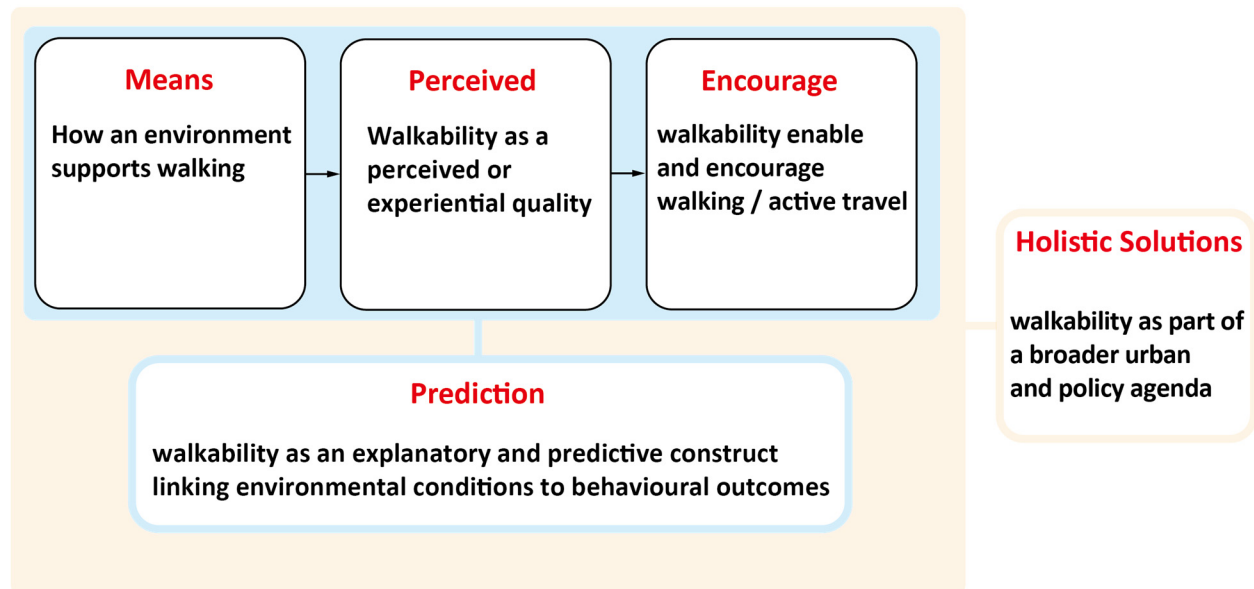


Figure 1. The conceptual framework for walkability.

Taken together, these conceptual framings show that walkability is not a single settled construct, but a family of related formulations organised around a shared core. At the same time, most definitions remain too general to guide the comparison or selection of operational instruments [16,22]. They usually indicate that environments should support walking, but specify less clearly for whom, for what kind of walking, and under what spatial or environmental conditions [24]. This becomes consequential once measurement moves beyond generic neighbourhood assessment. An instrument suitable for utilitarian adult walking may not adequately capture the needs of children, older adults, or mobility-impaired pedestrians, and a measure developed for temperate, mixed-use urban areas may perform poorly in winter cities, hot climates, or low-density settings [16,24].

For the purposes of this review, walkability is, therefore, treated as the extent to which an environment supports walking, while recognising that such support varies by user group, walking purpose, and environmental or urban-form setting. This review adopts a user-inclusive, purpose-specific and context-sensitive understanding of walkability as the conceptual basis for the comparative analysis that follows. The next section translates this position into an analytical framework by introducing the adapted walking-needs framework, which is used to examine how operational walkability instruments distribute attention across feasibility, accessibility, safety, comfort, and pleasurability, and across differences in users, trip purposes, and environmental and urban-form conditions [18–20].

3. Methodology

Building on Section 2, this review adopts the adapted walking-needs framework as the analytical framework for comparing operational walkability instruments. The review was structured as a multi-stage workflow that moved from record identification to instrument-

level coding and final comparative synthesis. Rather than treating publications as the final unit of analysis, this review progressively shifted from records to eligible studies, to extracted instruments, and finally to consolidated walkability instruments suitable for cross-instrument comparison. Records were identified through an Undermind-assisted literature discovery workflow and targeted thematic searches designed to capture general, population-sensitive, purpose-specific, climate-sensitive, and urban-form-sensitive branches of walkability measurement. After title-abstract screening and full-text eligibility assessment, retained studies were examined for distinct operational instruments meeting four requirements: a structured walkability assessment instrument, an explicit or reconstructable indicator system, direct assessment of the walking environment, and mappability to at least one part of the adapted walking-needs framework. Eligible instruments were then extracted, consolidated where close variants were not structurally distinct, and coded to the adapted walking-needs framework to compare how existing measures distribute attention across accessibility, safety, comfort, and pleasurability, as well as across differences in user groups, walking purposes, and environmental or urban-form settings. The following subsections detail the search strategy, eligibility protocol, extraction rules, and coding procedure.

3.1. Search, Screening, and Consolidation Workflow

This review used a structured workflow to identify operational walkability instruments for comparative analysis through the adapted walking-needs framework. The search covered publications from 1990 to 2025 and focused on studies that proposed, adapted, validated, or applied walkability indices, scored audit instruments, composite indicator systems, and other structured instruments for assessing walking environments. The evidence base of the review consisted of published academic studies and documented walkability instruments. No new field, survey, or geospatial data were collected; public spatial datasets were considered only when they formed part of the reviewed instruments themselves.

The search was conducted through an Undermind-assisted literature discovery workflow, which was used to organise thematic search branches and identify candidate studies from the major academic sources. Candidate records and key instrument papers were cross-checked against major academic search platforms, including Web of Science, Scopus, ScienceDirect, and Google Scholar. One baseline search was combined with focused thematic searches. The baseline search captured major methodological families of walkability measurement, including GIS-based composite indices, amenity-access measures, microscale audit instruments, route-based assessments, and perceived walkability scales. Representative search strings included combinations such as “walkability” AND (index OR audit OR scale OR tool OR assessment), “walkability index” AND (measurement OR indicators OR scoring), and “pedestrian environment” AND (index OR audit OR assessment).

Focused searches were conducted for the main adaptation dimensions examined in this review: population, walking purpose, climate and environmental exposure, and urban form setting. These searches linked walkability with terms related to older adults, women or gender-sensitive walking, children and youth, climate-related walking conditions, historic centres, station areas, and utilitarian or leisure walking purposes. Across the confirmed and documented search branches, the identification stage yielded 569 records: 157 from the general walkability instrument branch, 108 from the gender-sensitive branch, 87 from the child- and youth-focused branch, 36 from the climate branch, 112 from the urban-form-specific branch, and 69 from the purpose-specific branch. Duplicate records identified across platforms or search branches were merged before title and abstract screening. These records formed the documented screening pool for this review. After title and abstract screening, 143 records were retained for full-text assessment.

Full-text eligibility was assessed using four criteria. First, the study had to present a walkability index, audit, score, rating, or other structured assessment instrument. Second, it had to provide explicit indicators, scoring, weighting, ranking, or another reconstructable evaluation structure. Third, the instrument had to assess the walking environment itself rather than only walking behaviour, health outcomes, or perceptions without a structured instrument. Fourth, the instrument had to be mappable to at least one part of the adapted walking-needs framework. Applying these criteria yielded 101 retained studies.

After eligibility assessment, the analytical unit shifted from studies to distinct walkability instruments. This step was necessary because one study could contribute more than one instrument, while multiple studies could refer to the same underlying instrument family. The retained studies were, therefore, translated into an instrument-level pool and consolidated for coding and report-level synthesis. Consolidation followed an operational distinction between unchanged applications and substantively distinct variants. Application papers that used an existing instrument without changing its indicator structure, scoring logic, weighting procedure, or target assessment context were absorbed into the parent instrument. Variants were retained as distinct instruments only when they introduced a modified indicator system, revised scoring or weighting logic, a clearly different target population, a new spatial unit, or a substantively different contextual calibration. This process resulted in a final set of 46 consolidated walkability instruments for comparative analysis.

The full identification, screening, eligibility, and consolidation workflow is summarised in the PRISMA flow diagram, as shown in Figure 2.

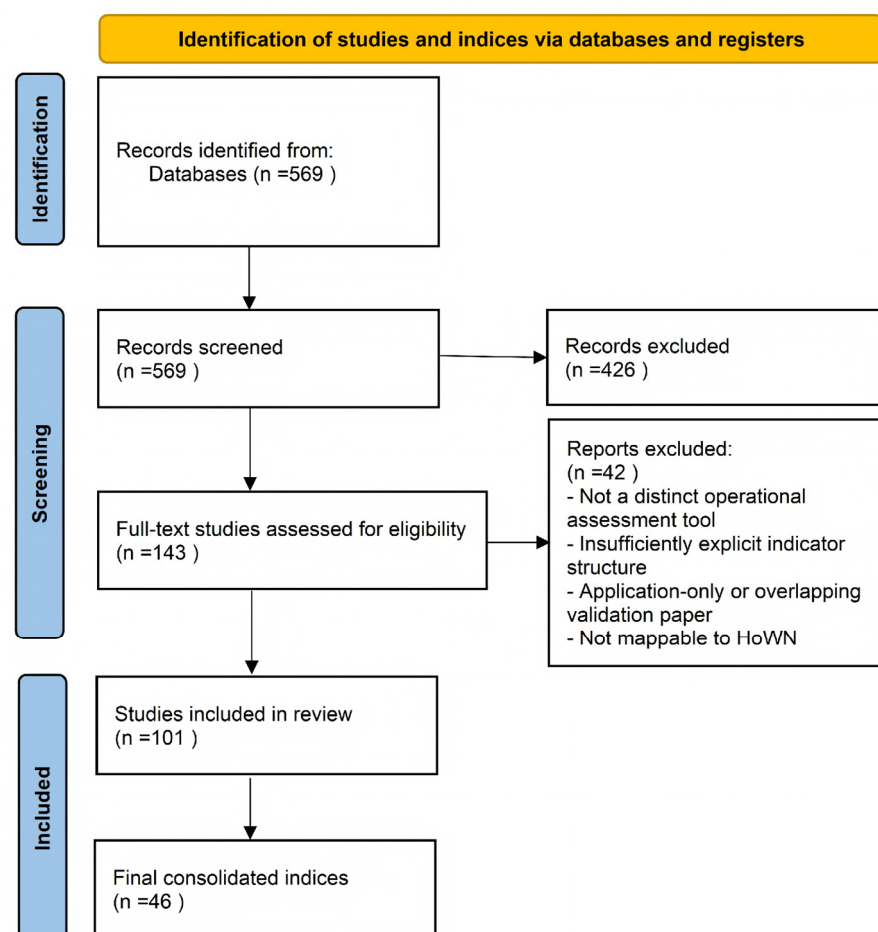


Figure 2. PRISMA flow diagram of documented search, screening, eligibility assessment, and instrument-level consolidation workflow.

3.2. Analytical Framework: An Adapted Walking-Needs Framework

This review adopts an adapted walking-needs framework derived from the Expanded Hierarchy of Walking Needs (HoWN) model as the analytical framework for comparing operational walkability instruments. In Alfonzo's original formulation, HoWN was proposed as a behavioural model of walking choice, in which feasibility, accessibility, safety, comfort, and pleasurability operate as hierarchically ordered antecedents in the decision-making process of whether to walk [20]. It, therefore, emphasised how more basic conditions shape higher-order walking qualities. In the original model, feasibility referred mainly to personal trip viability, including mobility, time, and other responsibilities. HoWN is useful for this review because its five-tier structure provides a clear comparative vocabulary for organising indicators from basic environmental passability to experiential attractiveness. However, since it was originally developed as a behavioural model of walking choice rather than as an instrument-coding framework, this review uses it as an adapted comparative structure rather than testing it as a causal hierarchy.

For this review, the adapted walking-needs framework is used as a classification and comparison framework. It helps examine how different walkability instruments cover five types of walking conditions: feasibility, accessibility, safety, comfort, and pleasurability. It nevertheless retains a central idea of HoWN: in specific contexts, some conditions may become prerequisites for walking.

The adaptation is threefold. First, feasibility is re-specified as the environmental passability of walking because the reviewed instruments mainly assess environmental conditions rather than person-level constraints. It refers to whether pedestrian movement is materially provided for and physically possible within a given setting. Second, the five walking-need tiers are used as coding categories for comparing instrument structures rather than as a single fixed behavioural sequence. Indicators are coded according to the tier they most directly operationalise. Third, the framework is extended by linking the five walking-need tiers to four contextual dimensions: user group, walking purpose, climate and environmental exposure, and urban-form setting. This treatment is consistent with a broader tendency in the later literature to use HoWN as an operational framework for organising walkability dimensions rather than as a strictly tested sequential model [32].

On this basis, the five tiers are specified here in terms suited to the comparative analysis of operational walkability instruments. Feasibility, as the most basic condition of environmental passability, includes pedestrian facility provision, path continuity, effective walking width, terrain and vertical barriers, obstruction and blockage, step-free transitions, and surface conditions affecting route traversability. In climate- or season-sensitive instruments, it may also include snow clearance, surface friction, or sheltered connections where these directly determine whether walking remains possible. Accessibility refers to the reachability of destinations and movement opportunities, including land use, destination proximity, connectivity, route choice, and multimodal access. Safety refers to protection from traffic, crime, and environmental hazards, including crossing protection, buffering, surveillance, and exposure-related risks. Comfort refers to the physical and environmental ease of walking, including urban furniture, greenery, shelter, maintenance, cleanliness, and thermal conditions. Pleasurability refers to higher-order experiential qualities that make walking attractive beyond basic utility, including aesthetic quality, liveliness, transparency, diversity or complexity, and imageability or coherence.

This adapted walking-needs framework provides a common comparative language for analysing how different instruments emphasise, omit, or re-prioritise walking needs across user-inclusive, purpose-specific, climate- and exposure-sensitive, and urban-form-specific assessment scenarios. It also helps identify when certain conditions become basic

thresholds in particular settings, rather than treating all instruments as comparable through a single universal scoring logic. The full framework is illustrated in Figure 3.

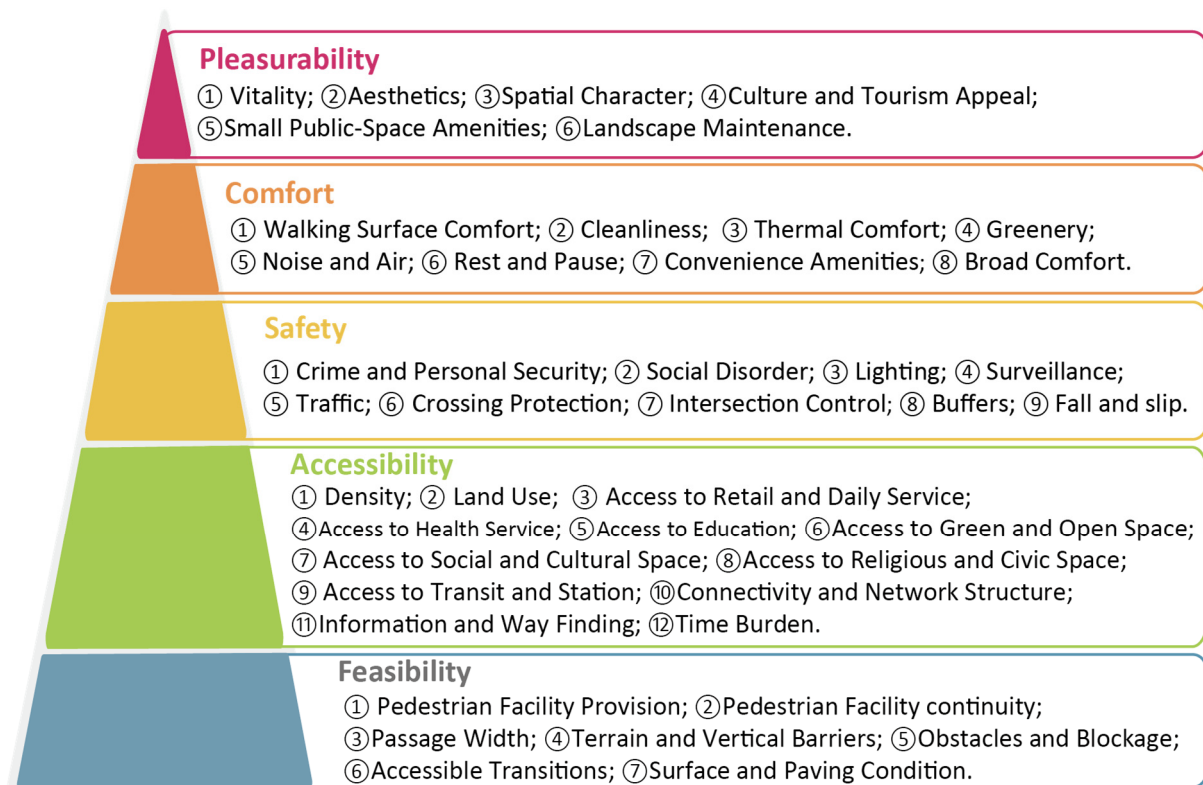


Figure 3. The adapted walking-needs framework derived from the Hierarchy of Walking Needs Model.

3.3. Evaluation Procedure

The evaluation followed a four-step analytical procedure applied to the 46 final consolidated instruments retained for report-level synthesis. For each instrument, the review recorded its indicator structure, scoring rules and weighting, spatial scale, target population, walking scenario, scenario-specific adjustment, and reported verification basis. Instruments were treated as analytically distinct only when they introduced a clearly separable operational structure, such as a modified indicator system, revised scoring logic, different target population, new spatial scale, or a substantively different adaptation logic.

Second, extracted indicators were coded through the adapted walking-needs framework. The five walking-need tiers—feasibility, accessibility, safety, comfort, and pleasurability—were used as coding categories for comparing the internal structure of instruments. Each indicator was assigned to the tier that it most directly operationalised, based on its explicit functional role within the instrument. Where an indicator could plausibly relate to more than one tier, primary coding was determined by its role in the instrument's scoring logic. For example, vegetation-related indicators were coded according to their role in the source instrument. Parks, trees, nature, and general greenness were coded under comfort when they represented environmental ease, shade, natural relief, or landscape support for walking. A garden was coded under pleasurability when it appeared as a small public space amenity, because it functioned more as an attractive, sociable, or place-making feature than as general environmental greenness. When an indicator was related to more than one tier, it was counted only once under its primary tier. Any additional relevance to other tiers was noted in the interpretation but not included as a separate code. This avoided double-counting the same indicator.

Third, the coded instruments were compared across four evaluative dimensions: (1) breadth of walking-need coverage, (2) dominant emphasis, (3) adaptation sensitivity, and

(4) reported verification basis. Breadth of walking-need coverage referred to the number of walking-need tiers represented within an instrument. Dominant emphasis referred to the tiers receiving the clearest substantive or weighted attention in the instrument structure. Adaptation sensitivity captured whether an instrument was explicitly designed for a particular population group, walking purpose, climate and environmental-exposure condition, or urban-form setting. Reported verification basis referred to whether the source study provided reliability testing, validity assessment, empirical application, expert assessment, pilot testing, or other documented evidence supporting the instrument's operational use. This dimension was used descriptively to interpret the robustness and transferability of the reviewed instruments.

Fourth, the coded results were synthesised at a comparative level to identify broader patterns across instrument families and thematic branches. This synthesis examined recurring distributions of indicators across walking-need tiers, common areas of over- or underrepresentation, and differences in adaptation sensitivity across population-specific, purpose-specific, climate-sensitive, and urban-form-sensitive instruments. To improve coding consistency, indicator assignments were checked against the tier definitions and the source instrument's own scoring logic. Ambiguous cases were revisited during the synthesis stage so that similar indicators were interpreted consistently across instruments. In this way, the evaluation moved beyond a single-instrument description toward a structured interpretation of how walkability has been operationalised across different analytical settings. The detailed indicator coverage maps generated from this coding procedure are reported in Appendix A, Figures A1–A5.

4. Results

4.1. Composition of the Reviewed Instruments

The categories in Table 1 were constructed according to the primary design intention and operational logic of each instrument. General instruments refer to instruments designed for broad walkability assessment without a dominant user-, purpose-, climate-, or urban-form-specific calibration. Population-specific instruments were classified by the user group that shaped the tool design; purpose-specific instruments by the walking activity or walking purpose prioritised; climate-sensitive instruments by the role of heat, cold, seasonal maintenance, or environmental exposure in indicator selection; and urban-form-specific instruments by the spatial or morphological context for which the tool was designed. When an instrument could plausibly fit more than one category, it was assigned to the category that most directly shaped its indicator structure, scoring logic, or intended application context.

As shown in Table 1, the final analytical sample comprised 46 consolidated walkability instruments and represented a differentiated measurement landscape rather than a single generic index tradition. General-purpose baseline instruments formed one part of the final corpus, but these themselves reflected several distinct measurement traditions, including canonical GIS-based composite indices such as the Frank walkability index family [3], amenity-access scores such as the Walk Score family [5,33], perceived-environment scales such as NEWS [26], and microscale audit instruments such as MAPS [6]. Even at this baseline level, the reviewed instruments did not converge on one common operational model but varied in whether walkability was defined primarily through neighbourhood accessibility, destination structure, route quality, streetscape conditions, or perceived environmental attributes.

Table 1. Selected walkability instruments.

Dimension	Sub-Category	Selected Instruments	Official Abbreviation	Abbreviation Used in This Review
General	Walk Score family	Walk Score [5,33]	Walk Score	Walk Score
	Perceived baseline	Neighbourhood Environment Walkability Scale [26]	NEWS	NEWS
	Microscale audit baseline	Microscale Audit of Pedestrian Streetscapes [6]	MAPS	MAPS
	Canonical GIS composite indices	Frank walkability index [3,4]	/	Frank WI
User group	Gender-sensitive	1. Women’s Walkability Index [13] 2. Walkability for Women Index [34] 3. Women to Rail Transit Station Walkability Index [35] 4. Gender-sensitive Technical Walkability Index [36]	1. WWI 2. / 3. / 4. /	1. WWI 2. WFWI 3. WRTS-WI 4. GSTWI
	Older adults	1. Walkability Index for Elderly Health [37] 2. Objective Walkability Index for Older Adults [38] 3. Older Adults Walking Accessibility Index [39] 4. Age-Friendly Approach Index [40] 5. 15 min Age-Friendly Walkability [41]	1. WIEH 2. OWI 3. OWAI 4. W-AFAI 5. AFW	1. WIEH 2. OWI 3. OWAI 4. W-AFAI 5. AFW
	Child and youth	1. Children’s Neighbourhood Walkability Index for Active Transport [12] 2. School Walkability Index [9] 3. MAPS-SRTS [42] 4. MAPS Global-SN [43] 5. NEWS-Y IPEN [44] 6. Child Friendliness Index [45]	1. / 2. / 3. MAPS-SRTS 4. MAPS Global-SN 5. NEWS-Y IPEN 6. CFI	1. CNWI-AT 2. SWI school 3. MAPS-SRTS 4. MAPS Global-SN 5. NEWS-Y IPEN 6. CFI
Purpose	Utilitarian	1. Walkability Index across Trip Purposes [46] 2. Commute Walk Calibrated Indicator Model [47] 3. First and Last Mile Quality Index [48]	1. / 2. / 3. /	1. WI-TP 2. Commute WI 3. FLM-QI
	Leisure	1. Tourist Walkability Index [49] 2. Tourist Route Prioritisation Tool [50] 3. Path Environment Audit Tool, PEAT [51] 4. Park access [52]	1. / 2. / 3. PEAT 4. ParkIndex	1. TWI tourist 2. TRPT 3. PEAT 4. ParkIndex
Climate	Heat and climate-sensitive	1. Comfort and Time-Based Walkability Index [53] 2. Comfort Walkability Index [8] 3. Street Walkability and Thermal Comfort Index [54] 4. Pedestrian Walkability and Comfort Index [55] 5. Walkability under Climate Pressure [56]	1. / 2. CWI 3. SWTCI 4. ICCP 5. /	1. CTBWI 2. CWI 3. SWTCI 4. ICCP 5. WCP
	Winter and cold-climate	1. Winter Walkability Audit Tool [57] 2. Sidewalk Maintenance Assessment Tool [58] 3. Snow and Rain Walkability Tool [59]	1. / 2. / 3. /	1. WWAT 2. SMAT 3. Snow-Rain NWI
Urban form	Transit-oriented	1. TOD Walkability Assessment [60] 2. Walkability Indicators for TOD Sites [61] 3. Sustainable Walkability Indices for TOD [62] 4. Path Walkability [10] 5. Walk Access to Transit SAQI and CI [63]	1. / 2. / 3. / 4. / 5. SAQI&CI	1. TOD-WA 2. TOD indicators 3. SWI-TOD 4. Path WI 5. SAQI&CI
	Historic fabric	1. Walkability Index for World Heritage Cities [64] 2. Comprehensive Walkability Index for Historical Centres [65]	1. / 2. /	1. WHC-WI 2. CWI-HC
	Compact mixed	1. Walking Suitability Index of the Territory, T-WSI [66] 2. Contextualised Spatial Network-Based Walkability Index [67]	1. T-WSI 2. CSNW	1. T-WSI 2. CSNW
	Dispersed	1. Rural Pedestrian Environmental Audit Instrument [68] 2. Car-Dominated Campus Walking Route Assessment [69] 3. Large Parking Lot Walkability Assessment [70]	1. / 2. / 3. /	1. RPEAI 2. CDC-WRA 3. LPL-WA

Note: / indicates that no official abbreviation was identified.

Beyond this baseline set, the final corpus was organised around several specialised branches. Population-specific instruments addressed women [13,34–36], older adults [37–41], children and youth [9,12,42–45], and, in a smaller number of cases, accessibility needs associated with reduced mobility. Purpose-specific instruments covered utilitarian walking, commuting, school travel, transit access, leisure, tourism, and park or

path walking [46–52]. Environmental exposure formed another distinct branch, including instruments focused on heat and thermal comfort [8,53–56] as well as cold-weather and winter conditions such as maintenance, snow, and rain exposure [57–59]. Urban-form-specific instruments were likewise retained for transit-oriented development and station areas [10,60–63], historic centres [64,65], compact mixed urban settings [66,67], and dispersed or low-density settings such as rural and car-dominated environments [67–70].

At the profile level, the reviewed corpus was differentiated along four main adaptation dimensions: user group, walking purpose, environmental exposure, and urban-form setting. As summarised in the classification table, the final set combined a relatively small baseline group with a broader range of specialised instruments calibrated to specific user groups, walking purposes, climatic conditions, and urban forms. This profile provides the basis for the adapted walking-needs framework mapping reported in the following subsection.

4.2. Coverage of Walking-Need Tiers Across Instruments

Indicator mapping across the adapted walking-needs framework revealed an uneven distribution of coverage across the five walking-need tiers. Table 2 summarises the binary coding results for the 46 reviewed instruments. It distinguishes between two complementary forms of coverage: tier presence and subcategory representation. Tier presence shows how many instruments included at least one indicator subcategory within a given walking-need tier, while subcategory representation shows how extensively each tier was covered across its standardised indicator subcategories.

Table 2. Summary of walking-need coverage across the 46 reviewed instruments.

Walking-Need Tier	Number of Indicator Subcategories	Instruments Covering ≥ 1 Subcategory	Included Instrument–Subcategory Pairs	Mean No. of Covered Subcategories per Instrument	Share of Possible Pairs Covered
Feasibility	7	37/46 (80.4%)	139	3.02	43.2%
Accessibility	12	43/46 (93.5%)	188	4.09	34.1%
Safety	9	37/46 (80.4%)	138	3.00	33.3%
Comfort	8	36/46 (78.3%)	105	2.28	28.5%
Pleasurability	6	33/46 (71.7%)	68	1.48	24.6%

Note: An instrument–subcategory pair refers to one instrument covering one standardised indicator subcategory within a walking-need tier. For example, feasibility includes $46 \times 7 = 322$ possible instrument–subcategory pairs; 139 of these pairs were coded as covered. The mean number of covered subcategories per instrument is calculated as included pairs divided by 46. The share of possible pairs covered is calculated as included pairs divided by all possible pairs within that tier.

Table 2 shows that accessibility had the widest tier presence, appearing in 43 of the 46 instruments, while feasibility and safety each appeared in 37 instruments. The instrument–subcategory counts further indicate that accessibility, feasibility, and safety formed the most repeatedly represented measurement base. Comfort and pleasurability were also present across the corpus, but they were represented through fewer subcategories on average, especially in the case of pleasurability. The detailed instrument-by-subcategory matrices supporting these summary statistics are provided in Appendix A, Figures A1–A5.

These results indicate that the reviewed instruments were strongest in the lower and more functionally measurable tiers, while higher and more experiential tiers were less consistently formalised as comparable measurement domains. The following paragraphs explain how each tier was operationalised across the reviewed instruments.

Feasibility was coded in this review as basic environmental passability rather than as personal time constraints or individual mobility capacity. Across the sample, it was most commonly operationalised through pedestrian facility provision, path continuity, effective walking width, terrain and vertical barriers, obstruction or blockage, step-free

transitions, curb ramps, and surface condition. In this sense, feasibility functioned as a gate condition: it captured whether walking was physically possible before higher-order qualities could be assessed. In climate-sensitive and winter-focused instruments, this tier was further extended to seasonal passability, including snow clearance, surface friction, sheltered connections, icy surfaces, and related maintenance conditions [57–59].

Accessibility showed the highest degree of recurrence and standardisation across the corpus. Common indicators included destination proximity, land-use mix, service access, street connectivity, intersection density, route directness, route choice, sidewalk-network coverage, and multimodal access through transit connections [3,46,48]. General GIS-based composites and amenity-access instruments were especially concentrated in this tier, where walkability was predominantly operationalised as reachability and spatial opportunity. Even in more specialised instruments, accessibility remained a core layer, often linking population-specific or context-specific priorities back to destination access, network structure, and access-chain logic [9,39–41,48].

Safety was broadly represented but internally fragmented across traffic safety, personal security, and a smaller set of environmental-condition risks. Traffic-oriented safety indicators were common in school-travel, transit-access, and audit-based instruments, and typically included crossing safety, traffic speed, traffic volume or exposure, buffering, separation from vehicles, traffic calming, driveway conflicts, and signal or crossing design [9,42,43,48]. Personal-security indicators were more prominent in women-focused and other socially sensitive instruments, where safety was operationalised through lighting, surveillance, eyes on the street, active frontage, fear of crime, social disorder, and harassment-related concerns [13,34–36]. These two strands did not overlap evenly: women-focused instruments tended to privilege personal security and visibility, whereas child and school-travel instruments more often emphasised traffic exposure, school-frontage protection, crossing infrastructure, and route supervision. Environmental-condition safety, such as slip risk or winter hazard, appeared far less often and was concentrated in climate-sensitive or user-sensitive instruments.

Comfort was present across the corpus, but it was less systematically structured than accessibility and safety. Frequently coded indicators included benches, shelters, urban furniture, shade, cleanliness, surface maintenance, noise, and signs of physical disorder. Thermal comfort variables such as wind, humidity, solar radiation, heat exposure, and related composite measures appeared mainly in climate-sensitive instruments rather than in mainstream walkability ones [8,53–56]. Greenery occupied an intermediate position in this tier. In the present coding, parks, trees, nature, and general greenness were assigned to comfort when they represented environmental ease, shade, natural relief, or landscape support for walking. A garden was assigned to pleasurability only when it appeared as a small public-space amenity, where its function was closer to place-making, sociability, or walking attractiveness than to general environmental greenness.

Pleasurability was the least stable tier in the mapping. It appeared through indicators such as aesthetics, public art, heritage features, visual interest, liveliness, active frontages, transparency, diversity or complexity, imageability, coherence, and place identity, but these were unevenly distributed and rarely standardised across instruments. They were more common in urban design, tourism, historic-centre, and streetscape-audit tools than in generic GIS composites, where experiential qualities were often reduced to a small number of proxy variables or omitted altogether [6,49,50,64,65]. The result was not the absence of pleasurability, but its inconsistent treatment: it was commonly present in selective or isolated form, yet much less often incorporated as a stable and comparably structured domain.

Taken together, the adapted walking-needs framework mapping showed that the reviewed instruments were strongest in measuring walking as passable, reachable, and safe, but weaker in measuring walking as comfortable, socially meaningful, and experientially attractive.

4.3. Adaptation Sensitivity and Variation in Walking-Need Priorities

Adaptation sensitivity appeared in four main forms across the reviewed corpus: population sensitivity, purpose sensitivity, climate or environmental-exposure sensitivity, and urban-form sensitivity. To examine how these branches differed in their coverage of walking-need tiers, Table 3 cross-tabulates the four adaptation dimensions against the five walking-need tiers. Each cell reports two values: the share of possible instrument–subcategory pairs covered within that branch and tier, and the number of instruments covering at least one subcategory within that tier. This allows the comparison to capture both the extent of subcategory coverage and the presence of each walking-need tier across instruments.

Table 3. Adaptation dimension by walking-need tier: share of possible pairs covered and tier presence.

Adaptation Dimension	Number of Instruments	Feasibility	Accessibility	Safety	Comfort	Pleasurability
Population-sensitive	15	40.0%; 13/15	39.4%; 15/15	40.0%; 14/15	24.2%; 11/15	21.1%; 13/15
Purpose-specific	7	55.1%; 7/7	35.7%; 7/7	44.4%; 7/7	44.6%; 7/7	42.9%; 6/7
Climate- and exposure-sensitive	8	37.5%; 6/8	25.0%; 6/8	15.3%; 5/8	34.4%; 8/8	14.6%; 4/8
Urban-form-specific	12	50.0%; 9/12	27.8%; 11/12	29.6%; 9/12	21.9%; 8/12	25.0%; 8/12

Note: Values before the semicolon report the share of possible instrument–subcategory pairs covered within each adaptation dimension and walking-need tier. Values after the semicolon report tier presence, namely, the number of instruments in that context dimension covering at least one subcategory within the corresponding tier. General baseline instruments are not included in this table because the purpose of the cross-tabulation is to compare the four adaptation-sensitive branches.

The cross-tabulation shows that adaptation sensitivity did not operate as a uniform expansion of all walking-need tiers. Instead, each adaptation branch displayed a distinct coverage profile. Purpose-specific instruments showed the broadest cross-tier coverage, with high coverage across all five tiers. Climate- and exposure-sensitive instruments were distinguished by the universal presence of comfort-related indicators, reflecting the central role of thermal and seasonal conditions in this branch. Population-sensitive and urban-form-specific instruments remained more strongly tied to feasibility, accessibility, and safety. These patterns support the central finding that specialised instruments do not merely add specialised indicators; they alter the relative emphasis placed on walking-need tiers.

Population-sensitive instruments most clearly shifted the minimum threshold of walkability. Older-adult instruments gave greater weight to slope, stairs, surface evenness, resting places, benches, crossing burden, slower walking speeds, access to daily services, and supportive public-space features [37–41]. Child and youth tools, especially school-travel instruments, concentrated more strongly on crossing protection, traffic exposure, route continuity, school frontage, supervision, and parental or perceived safety concerns [9,12,42–44]. Women-focused instruments placed greater emphasis on lighting, visibility, harassment risk, fear of crime, surveillance, activity presence, and the avoidance of isolated or weakly supervised routes [13,34–36]. Accessibility-sensitive provisions directed toward disability or reduced-mobility needs, where explicitly represented, prioritised continuous accessible routes, curb ramps, step-free transitions, surface quality, tactile or auditory cues, wheelchair passability, and crossing barriers [41]. In these instruments, user specificity redefined minimum adequacy: the same sidewalk, crossing, or route could be acceptable for a generic adult but insufficient for older adults, children, women, or mobility-impaired pedestrians.

Purpose-sensitive instruments changed the dominant balance among walking-need tiers. Utilitarian walking measures tended to privilege destination access, network directness, route efficiency, transit access, and service proximity [46–48]. Commuting and first or last-mile instruments sharpened this logic further through access-chain continuity, transfer burden, walking time, crossing delay, and multimodal integration [47,48,63]. School-travel tools combined purpose sensitivity with population sensitivity by linking child users to school-route protection and supervised access [9,42,43]. By contrast, leisure, tourism, park, and recreational walking tools gave greater prominence to comfort, landscape, aesthetics, route attractiveness, public-space quality, and experiential continuity [49–52]. Purpose, therefore, changed the balance between efficient movement and experiential support: commuting and first/last-mile tools prioritised access-chain efficiency, whereas leisure, tourism, park, and recreational tools gave greater weight to comfort and pleurability.

Climate-sensitive instruments moved environmental exposure from background conditions into the measurement core. Hot-climate and thermal-comfort instruments incorporated shade, solar exposure, air temperature, humidity, wind, surface heat, tree canopy, shelter, and rest opportunities as central variables rather than contextual modifiers [8,53–56]. Cold-climate and winter tools instead prioritised snow and ice clearance, surface friction, seasonal maintenance, wind exposure, daylight conditions, sheltered paths, and the year-round usability of routes [57–59]. In these instruments, climate and environmental exposure were not external modifiers of walkability scores; they directly reshaped feasibility, safety, and especially comfort. The comparative result was that the same route could perform differently depending on weather, season, or temporal exposure conditions.

Urban-form-sensitive instruments also changed measurement logic rather than simply relocating a generic instrument. TOD and station-area instruments relied more heavily on route and access-chain logic, with particular attention to transit proximity, station-approach quality, crossing burden, sidewalk continuity, and multimodal connectivity [10,60–63]. Historic-centre and tourism-oriented instruments incorporated heritage, imageability, enclosure, public-space character, visual quality, and route attractiveness [49,50,64,65]. Rural and low-density instruments foregrounded basic pedestrian infrastructure deficits, long distances, absent sidewalks, road-edge walking, and vehicle exposure [68–70]. Compact mixed urban-form instruments, by comparison, retained stronger emphasis on permeability, continuity, contextualised network structure, and the relation between everyday access and urban morphology [66,67]. Urban-form sensitivity, therefore, often changed the spatial unit, route logic, or evaluative frame of measurement rather than merely applying a generic instrument to another setting.

Taken together, the comparison showed that adaptation specificity was not a marginal supplement to walkability measurement. It reshaped which walking-need tiers became central, which indicators became decisive, and which instruments were suitable for a given planning or research scenario.

4.4. Operational Patterns, Verification Bases, Spatial Units, and Transferability

Beyond differences in walking-need coverage and adaptation sensitivity, the reviewed instruments also differed in how walkability was operationalised. These differences appeared in four main aspects: instrument lineage, evidence base and reported verification basis, spatial unit, and scoring or aggregation logic. The reviewed instruments fell into several recognisable operational lineages, including GIS-based composite indices, amenity-access and destination-access scores, perceived-environment scales, microscale street-audit tools, route-based or access-chain tools, climate and winter exposure tools, and population-specific or equity-sensitive instruments. These lineages differed not only in indicator content but also in what they treated as measurable walkability. GIS compos-

ites and access scores primarily operationalised walkability as spatial opportunity and network structure [3], whereas audit tools treated it as observable street-level support or constraint [6,42,43]. Perception-based instruments emphasised experienced walkability, including fear, comfort, and perceived environmental support [44], while climate-sensitive and population-sensitive tools redefined walkability around exposure, vulnerability, or threshold adequacy in specific user or environmental contexts [8,13,37,56,57].

The instruments also varied in their evidence bases and reported verification bases. GIS-based instruments were grounded mainly in spatial datasets, land use, density, intersections, network structure, destination proximity, and service access [3,46]. Audit-based instruments drew on observed street attributes such as sidewalks, crossings, buffers, furniture, lighting, disorder, greenery, and frontage conditions [6,42,43]. Perception-based scales captured subjective access, fear, satisfaction, safety, and environmental experience [44]. Climate-sensitive instruments incorporated variables such as temperature, shade, solar radiation, wind, humidity, snow, ice, and seasonal maintenance [8,53,56,58,59]. Across these lineages, the reported verification basis took different forms, including reliability testing, validity assessment, empirical application, expert assessment, pilot testing, or documented use in a specific planning or research context. This review used these records descriptively rather than to rank instruments by quality. The purpose was to clarify the kinds of evidence supporting each instrument's operational use and to interpret the conditions under which its logic could be transferred to other contexts.

Operational differences were equally evident in spatial units. The reviewed instruments worked at the level of neighbourhoods, buffers, census areas, street segments, blocks, routes, school catchments, station access chains, parks, trails, and tourist corridors. Neighbourhood-scale indices were better suited to broad comparison and benchmarking because they summarised spatial opportunity across larger areas [3]. Segment-, route-, and access-chain instruments were more diagnostic, allowing fine-grained identification of crossing problems, continuity failures, waiting conditions, or route-specific burdens [10,42,48,63]. These units were not interchangeable. A strong neighbourhood-level score could conceal weak or discontinuous route conditions, while a detailed route or segment audit might capture local barriers without representing wider destination access or area-level opportunity.

Scoring and aggregation were also highly variable. Some instruments provided explicit formulas, weighting procedures, threshold rules, or scoring rubrics, especially among GIS composites and access models [3,39,48]. Others relied more on checklist-style counting, categorical ratings, expert-derived weights, participatory assessment, or context-specific scoring rules. This variation was not merely a technical difference. It affected how instruments could be compared, reproduced, and transferred. More formula-driven instruments were generally easier to reproduce across places, but they often captured a narrower set of experiential or microscale conditions. Audit-, perception-, and climate-sensitive instruments captured richer local detail, but they usually required more intensive data collection, observer judgement, user input, or context-specific calibration. Weighting procedures were frequently context-dependent, and their portability across cities, climates, user groups, and walking purposes was often limited rather than assumed.

Transferability, therefore, appeared as conditional rather than automatic. Instruments developed for one population, urban setting, climate, or mobility scenario often required adjustment of thresholds, weights, indicator definitions, spatial units, or input data before use elsewhere [40,41,56]. General-purpose instruments remained useful for baseline comparison across settings, but specialised instruments were better suited when evaluation focused on vulnerable users, school travel, station access, thermal exposure, tourism, or unusual urban morphology [48,49,57,65,68]. In this sense, the issue was not whether general

or specialised instruments were inherently superior, but whether the instrument's evidence base, spatial unit, scoring logic, and reported verification basis matched the walking scenario being assessed. These operational differences indicate that fit-for-purpose selection cannot depend only on which walking-need tiers are covered. It also requires attention to how the instrument is constructed, what kind of evidence it uses, at what spatial unit it operates, and under what conditions its results can be meaningfully transferred.

5. Discussion

5.1. Structural Bias in Walkability Measurement

The differentiated but uneven pattern identified in Section 4 is not only a matter of incomplete coverage. It points to a deeper structural bias in how walkability has been measured and stabilised as a research and policy construct. Walkability measurement did not simply grow by neutrally accumulating better indicators. It stabilised around a core set of variables that were easy to count, easy to map, easy to compare across places, and easy to insert into transport, health, and planning workflows. The quantitative mapping in Sections 4.2 and 4.3 shows that accessibility, feasibility, and safety form the most repeatedly represented measurement base, whereas comfort and especially pleasurability remain less consistently formalised. Density, connectivity, land-use mix, and destination accessibility became dominant not only because these factors matter, but because they fit the epistemic and institutional machinery through which walkability became knowable and governable [2,16,29,71,72]. This has produced a durable asymmetry. Experiential dimensions such as thermal comfort, affect, perception, attractiveness, fear, and walking pleasure have not been absent from the literature, but they have usually entered later, more weakly, and more often as corrective additions than as part of the canonical core. The problem is, therefore, deeper than a simple gap in coverage. Mainstream instruments privilege variables that can be extracted from archival spatial datasets and recombined into composite scores with apparent objectivity, whereas more experiential dimensions are harder to operationalise, more temporally unstable, more context-sensitive, and less compatible with benchmarking logics. The result is not that experiential qualities are unknown, but that they are systematically downgraded in what counts as a credible walkability metric.

The repeated centrality of density, connectivity, and access has a clear methodological and institutional logic. GIS and archival datasets make density, land-use mix, and street-network structure feasible at large scale [29,73]. These variables also fit the dominant transport and public-health research traditions, in which the 5Ds and related accessibility logics became the backbone of much walkability research [71,72]. Reviews repeatedly note the resulting dominance of objective mesoscale built-environment attributes [71,74,75]. Such variables are reproducible, comparatively easy to benchmark across cities and studies, and readily converted into legible composite scores for modelling and policy communication [16,29,72]. Decision-support systems further reinforce this tendency because they privilege transparency, reproducibility, and usability for non-experts [15,76]. This helps explain why the same indicator families recur even when the stated concept of walkability broadens. Their persistence reflects not only empirical relevance but also available data structures, inherited research routines, and governance uptake. The deeper point is that repeated use does not automatically mean conceptual sufficiency. The recurrent core is durable because it is the easiest part of walkability to stabilise into comparable numbers. In this sense, measurement does not merely represent walkability; it helps define what counts as walkability.

This bias is reinforced by the broader institutional history of planning, transport, and public-health research. Pedestrian environments have long been evaluated through instrumental rationalities that privilege what can be audited, modelled, compared, and

governed [77,78]. Brownson et al. explain why GIS-based measures became central: they offer a feasible way to generate objective environmental measures across large study areas from administrative datasets already available [29]. The broader indicator literature clarifies why this narrowing is not accidental. Kitchin et al. show how urban indicators and benchmarking systems govern cities by privileging what can be rendered comparable and continuously tracked [76]. Applied to walkability, this gives disproportionate authority to variables with stable data pipelines and clear scalar outputs, while experiential qualities that resist easy commensuration become secondary, optional, or invisible. Although perceived-environment scales, microscale audits, participatory assessment, thermal-comfort metrics, and other experiential approaches have steadily expanded the field [8,27,79,80], they have generally remained thinner, more fragmented, and more context-specific branches of the literature rather than displacing the mainstream metric core. They often qualify, supplement, localise, or challenge dominant instruments, but rarely become the backbone of large-scale indicator systems. The result is, therefore, not only uneven measurement but a field in which corrective strands are conceptually rich yet institutionally weaker.

This institutional and methodological asymmetry also explains why comfort, perception, and affect struggle to enter the metric core. These qualities are more temporally unstable, context-sensitive, and user-dependent than density or intersection counts. Shade, noise, heat exposure, wind, and social atmosphere vary by hour, season, weather, and route segment [8,53]. Experience is often route-specific or segment-specific rather than well captured by neighbourhood averages [81]. Perceptions also vary across user groups, histories, and local social conditions [27,80]. As a result, surveys, audits, participatory methods, and sensor-based approaches are often more expensive and less scalable than archival GIS variables [15,82], and they fit less easily within dashboard-oriented governance systems that favour standardised and continuously trackable metrics [76–78]. Ewing et al. mark an important hinge in this discussion by explicitly distinguishing the gross qualities that earlier active-living research could readily measure, such as density and connectivity, from subtler urban-design qualities such as imageability, enclosure, human scale, transparency, and complexity [83]. Comfort research shows a similar corrective pattern: Labdaoui et al. argue that many walkability instruments do not account for comfort indicators at the neighbourhood microscale and that thermal comfort has generally been left out [8]. Shammass et al. state that comfort-related factors such as noise, shade, and sun exposure were often excluded because of limited data or computational capacity [53]. Johansson et al. show that affective and sensory experience can be studied systematically, but these methods remain less standardised and less portable than conventional GIS measures [84]. These studies suggest that experiential dimensions were not excluded because they were irrelevant, but because they were harder to measure consistently, compare across contexts, and absorb into established indicator systems.

Taken together, the literature supports a multi-layered explanation for this structural bias. There is an epistemic bias, because what is easier to count is more easily accepted as real, and built-form proxies acquire authority because they can be repeatedly observed, normalised, and correlated with outcomes [16,29]. There is a methodological bias, because dominant techniques such as GIS, buffer analysis, catchment models, and composite indices work best with variables that are spatially discrete, archived, and stable [2,15]. There is a governance bias, because policy systems privilege variables that can be audited, benchmarked, and defended in interjurisdictional comparison [15,76]. There is also a representational bias, because the dominant metric tradition tends to represent space as a system of access rather than walking as a lived, embodied, and socially mediated practice [24,77]. Experiential dimensions are underrepresented not because they are less important, but because they are harder to operationalise, standardise, and integrate into widely used measurement systems. Current walkability measurement should, therefore, be understood

not as a neutral reflection of all walking conditions, but as a field shaped by what can be more readily measured, compared, and transferred across contexts.

5.2. Fragmentation in Walkability Measurement

Walkability measurement is no longer only diversifying. The literature increasingly suggests a stronger diagnosis: the field is showing signs of fragmentation. Differentiation by itself would imply that instruments are becoming more differentiated while remaining broadly comparable within a shared conceptual and methodological frame. Fragmentation is different. It means that instrument proliferation is outpacing efforts to standardise concepts, justify indicator selection, harmonise spatial units, and maintain comparability across studies and planning contexts [2,15–17]. The problem is, therefore, not simply that there are many walkability tools. The problem is that diversity is increasingly combined with weak integration. Indicators, weights, scales, and validation strategies vary so widely that cumulative knowledge becomes harder to build, cross-study comparison becomes less secure, and practical tool selection becomes more uncertain [75,85]. In this sense, the field is no longer facing only a problem of expansion. It is facing a problem of coordination.

One of the clearest signs of this fragmentation is the inconsistency of indicator systems. Walkability instruments often rely on different variable sets without a robust shared rationale. Shashank and Schuurman show that different health-oriented walkability instruments can produce different scores for the same place and argue that many canonical variables are included by assumption rather than by strong justification [16]. Venerandi et al. reach a similar conclusion at the review level, noting that many instruments still lack adequate justification for metric selection and weighting, so that indicator choice often appears shaped as much by data structures, embedded biases, and inherited agendas as by settled theory [2]. This means that inconsistency is not merely a side effect at the edge of the field. It is built into how many instruments are assembled. What appears as methodological variety is often also a sign that the field lacks a sufficiently stable basis for deciding which variables belong to walkability, why they belong, and how they should be combined. The result is that different tools do not simply provide different windows onto the same construct. They often operationalise partially different constructs under the same label.

A related issue is weak standardisation. The field has repeatedly recognised the need for common definitions, detailed measurement protocols, and standardised classification systems, yet the persistence of these calls is itself evidence that such goals have not been achieved [73,75]. This is not a minor technical matter. It directly affects whether results can be compared across studies in a meaningful way. Lefebvre-Ropars and Morency show that results vary not only by the measure chosen but also by the size of the catchment area and the spatial unit of analysis, raising the basic question of which measure to use, where to measure it, and how [17]. Method-comparison studies point in the same direction. Different assessment approaches may agree on broad categories, but diverge substantially on finer, more dynamic, or more socially contingent attributes [86]. Comparability, therefore, becomes partial and attribute-specific rather than general. The field still produces measurements, but it does not always produce measurements that are reliably commensurable across tools, datasets, and contexts.

Fragmentation is further reinforced by divergent weighting and aggregation logics. Some indices simply sum standardised scores, while others apply selective or context-dependent weighting systems, often without robust and transferable justification [2]. Blečić et al. show how far this heterogeneity extends, documenting variation in compensatory and non-compensatory models, profiling strategies, calibration approaches, and output scales, and explicitly concluding that the field's variety has produced a lack of uniformity that makes comparison difficult [15]. Spatial fragmentation compounds the problem. Different

instruments operate at the level of neighbourhoods, census tracts, blocks, street segments, nodes, routes, or even sub-street elements [15,75]. Transferability studies likewise show that an instrument calibrated in one setting does not necessarily travel cleanly to another [85]. As a result, walkability measurement no longer varies only in content; it also varies in the very units, scales, and aggregation rules through which content is made measurable. This weakens the possibility that findings from different studies can accumulate into a more coherent shared knowledge base. The field has not merely become more diverse in what it measures. It has become more heterogeneous in how measurement itself is constituted.

Several reviews now come very close to diagnosing fragmentation directly, even when they do not always use that exact term. Shashank and Schuurman show that the same place can receive different walkability scores depending on the index applied [16]. Venerandi et al. identify methodological heterogeneity, weak justification for metric selection and weighting, and continued dependence on catchment-area logic as central limitations of the field [2]. Blečić et al. conclude that the wide variety of approaches has led to a lack of uniformity that makes comparison difficult [15]. Wang and Yang call for a standardised classification system [74]. Taken together, these studies suggest that the field is not simply producing a family of complementary instruments within a shared architecture. It is producing partially overlapping but often weakly commensurable lineages of indices, audits, perceived-environment instruments, and hybrid models. This is why fragmentation is a more precise diagnosis than simple diversification. Diversity becomes fragmentation when specialisation expands faster than the frameworks needed to keep that specialisation analytically connected.

This distinction matters because differentiation can be a sign of maturation, whereas fragmentation signals a coordination problem. Some degree of differentiation is clearly necessary: walkability instruments should vary by user group, walking purpose, climate, urban form, and data environment [75]. The problem arises when such variation is not matched by a coherent integrative framework. Under these conditions, diversification weakens cumulative knowledge, complicates practical instrument selection, and encourages parallel lineages rather than integration [2,15–17]. A fragmented field can still appear vibrant because it contains many instruments and many innovations, but if these additions do not connect through shared definitions, translation rules, or comparability standards, pluralism becomes difficult to use analytically. The stronger conclusion, then, is not simply that walkability measurement has become more varied. It is that productive differentiation has not been matched by adequate harmonisation and is, therefore, increasingly functioning as fragmentation.

5.3. *Beyond Fragmentation: Toward Composable Frameworks for Walkability Measurement*

The preceding analysis suggests that the next step in walkability measurement cannot simply be the production of another standalone instrument for another user group, walking purpose, climate, or urban form. The field already contains a large and growing supply of indices, audits, scales, scores, accessibility models, and pedestrian assessment tools. The more fundamental problem is that productive differentiation has not been matched by adequate harmonisation. Instruments have become more context-sensitive, but the field still lacks shared ways to compare indicator choices, spatial units, weighting logics, evidence types, and transferability conditions across settings. The difficulty is that specialisation has often been handled by producing another standalone instrument. This expands coverage, but it does not resolve the integrative problem: the field becomes broader without necessarily becoming more cumulative. The case for composable frameworks, therefore, follows directly from this review's findings: walkability measurement needs a way to preserve contextual specificity without losing cumulative comparability.

These findings point to several design requirements for future walkability measurement. Structural bias requires a framework that keeps the limits of access-based baseline

indicators visible and makes room for comfort, perception, exposure, and experiential qualities when they matter. Fragmentation requires shared indicator categories, transparent scoring and weighting rules, explicit spatial units, and documented transferability conditions. Context sensitivity requires modular user-, purpose-, climate-, and urban-form-specific components rather than separate instruments that cannot be compared. In this sense, composability is not proposed here as a fashionable technical solution, but as a response to the specific problems identified in this review: uneven walking-need coverage, weak commensurability, and insufficient integration across specialised instruments. Under these conditions, the more productive response is not further proliferation, but a composable framework that retains a shared analytic backbone while allowing structured variation where context genuinely requires it [87–90].

What composability offers is not a return to a single universal score. It implies a framework in which a stable common core can be combined with user-, purpose-, climate-, and urban-form-specific modules, profiles, scenarios, or parameter sets. In walkability measurement, this would involve a shared analytic backbone for comparison across places or studies, explicit modules for user groups, walking purpose, climate, and urban form. It would also require configurable weighting rules, multi-scale interoperability, and the capacity to combine objective spatial data, audit data, perceptual data, and environmental exposure data. Composability, therefore, treats scenario variation not as a reason to build disconnected instruments, but as something to be located within a shared structure of modules, parameters, scenarios, and reporting rules.

This shift is already visible in several strands of recent research. Some studies build taxonomies and classification schemes rather than yet another metric, recognising that heterogeneous methods must first be made legible within a shared comparison structure [15,75]. Others move from one-off indices toward reusable computational backbones, including generalised, open-source, configurable, and multi-scalar frameworks [87,90,91]. A further strand advances configurable accessibility and multi-activity structures, showing that different destination types, activity structures, and user-defined weights can be combined within one framework rather than requiring entirely separate instruments [88,92]. Other approaches move from universal scoring toward structured recombination across scenarios and evidence types, including user-specific scenarios and combinations of objective and subjective dimensions [89,93]. These studies differ in terminology, using terms such as generalised, open-source, extensible, customizable, integrated, multi-activity, or multi-scenario rather than composable. However, they converge on the same architectural principle: future progress lies less in multiplying isolated instruments than in building frameworks that can be configured, recombined, and translated across settings.

This is not only a technical development, but a theoretical one. The case for composability rests on a broader change in what walkability is taken to be. If walkability is understood as a relational, multi-domain, and context-dependent construct rather than a fixed property reducible to a small set of built-form variables, then measurement cannot plausibly rely on one stable formula across all users, places, and conditions [24]. The literature now makes two claims at once: first, contextual validity matters, because different groups and situations require different priorities [44,89]; second, cumulative comparison and policy benchmarking also matter [87,90]. A field that accepts both claims cannot rely on a single universal index, but it also cannot remain a patchwork of disconnected bespoke instruments. Composable frameworks address this tension because they preserve a common structure for comparison while placing variation into explicit modules, scenarios, parameters, or profile settings. Composability is, therefore, not the abandonment of comparability. It is the condition for comparability under real heterogeneity.

For this review, the implication is that future progress in walkability measurement depends less on producing additional generic or standalone instruments than on organising specialisation within a shared and extensible architecture. The field has already generated enough evidence to show that context matters, but it has not yet fully built the frameworks needed to make that contextual sensitivity cumulative rather than fragmentary. What walkability measurement now requires is, therefore, not simply more tools, but better ways of relating instruments to one another: a common language for reporting walking-need coverage, modular structures for context-specific adaptation, transparent rules for weighting and aggregation, and documented conditions for transferability.

5.4. Illustrative Use for User-, Purpose-, and Context-Sensitive Instrument Selection

The preceding findings suggest that the adapted walking-needs framework can support instrument selection and adaptation, not only instrument comparison. Its practical value lies in making three decisions explicit: whether a candidate instrument covers the walking-need tiers required by a defined assessment scenario, which tiers become critical in that scenario, and what additional modules or weighting adjustments are needed. The following scenario is, therefore, used as an illustrative application derived from this review's findings, rather than as a new empirical case study.

Consider a walkability assessment in a hot-climate historic centre used by older residents, tourists, and public-transport users. A conventional GIS-based walkability index may provide a useful starting point because it captures baseline accessibility, such as density, street connectivity, destination proximity, and transit access. However, the findings of this review suggest that such an instrument should not be treated as sufficient by default. Table 2 showed that comfort and pleasurability were less consistently covered than feasibility, accessibility, and safety. Table 3 further showed that different adaptation branches change the relative emphasis placed on walking-need tiers. The first task is, therefore, to diagnose the mismatch between the candidate instrument's coverage and the walking needs of the assessment scenario.

In this example, the adapted framework would indicate that different walking-need tiers should play different roles. For older residents, feasibility and safety would function as basic thresholds: high destination accessibility would not indicate walkability if routes were discontinuous, surfaces were uneven, crossings were unsafe, or resting opportunities were absent. For tourists, accessibility would need to include not only destination proximity but also route legibility and continuity between attractions, while pleasurability would become more important because heritage character, visual interest, and route attractiveness are part of the walking experience. Because the area is hot and climatically exposed, comfort would also become a necessary context-sensitive component, including shade, shelter, seating, and thermal exposure.

The framework would, therefore, guide a composable assessment strategy. The GIS-based index could be retained as the shared analytical backbone for accessibility and network comparison. A microscale audit component would be added to assess feasibility and safety conditions, such as sidewalk continuity, surface quality, crossings, and traffic exposure. A climate-sensitive component would be added to capture heat exposure and shade. User-sensitive adjustments would give greater priority to resting places, surface evenness, accessible transitions, and crossing difficulty for older pedestrians. Purpose-specific adjustments would add route legibility, heritage experience, and public-space attractiveness for tourism-related walking.

This example shows that the framework does not simply recommend adding more indicators. It provides a rationale for selecting, combining, and adapting instruments according to the relationship between walking-need coverage and assessment context.

Each added component or weighting adjustment is justified by a specific walking-need tier and adaptation dimension. In this sense, the adapted walking-needs framework supports user-, purpose-, and context-sensitive instrument selection while preserving comparability through a shared reporting structure.

6. Conclusions

This review examined how operational walkability instruments conceptualise and measure walking environments across different users, purposes, climates, and urban contexts. By applying an adapted walking-needs framework derived from the Hierarchy of Walking Needs (HoWN) to 46 consolidated instruments, this study shows that walkability measurement is not a neutral accumulation of indicators, but a structured field shaped by different assumptions about what makes walking possible, safe, comfortable, and desirable. In this framework, feasibility is interpreted as environmental passability, and the five walking-need tiers are used as comparative categories for examining instrument coverage and adaptation rather than as a fixed universal scoring sequence.

The main finding is that existing instruments remain unevenly distributed across walking needs. Feasibility, accessibility, and safety are more consistently represented because they are easier to observe, map, standardise, and connect to transport or public-health outcomes. Comfort and pleurability are more weakly institutionalised, not because they are irrelevant to walking, but because they are more experiential, temporally variable, context-sensitive, and difficult to translate into stable indicators. The quantitative comparison reported in this review further shows that comfort and pleurability have lower instrument–subcategory coverage than the more basic or more easily standardised tiers. This imbalance helps explain why many mainstream tools remain useful for broad benchmarking but insufficient for evaluating route-level vulnerability, thermal exposure, gendered safety, child mobility, older adults' needs, disability access, or leisure-oriented walking experience.

This review also shows that different adaptation branches change the relative emphasis placed on walking-need tiers. For older adults, slopes, surface quality, resting places, and crossing burden may become threshold conditions. For children, route supervision, school-frontage safety, traffic exposure, and parental perceptions become central. For women, lighting, visibility, harassment risk, and social surveillance receive greater weight. In hot, cold, historic, transit-oriented, rural, or car-dominated settings, climate exposure, maintenance, route continuity, heritage quality, access-chain logic, or basic pedestrian provision can become decisive. These differences mean that user-inclusive, purpose-specific, and context-sensitive measurement cannot be treated as simple extensions of a generic index. They often require re-prioritising indicators, adding modules, or adjusting weights according to the walking needs of a defined assessment scenario.

The contribution of this review is, therefore, both conceptual and methodological. Conceptually, it clarifies walkability as a user-inclusive, purpose-specific, and context-sensitive construct rather than a universal property of place. Methodologically, it demonstrates how an adapted walking-needs framework can be used to compare instrument coverage, reveal structural imbalance, and support fit-for-purpose instrument selection. Practically, the findings support a fit-for-purpose approach to instrument selection and adaptation: generic instruments can provide a common baseline, but they should be supplemented by modules sensitive to user group, walking purpose, climatic exposure, spatial scale, and local urban form. The illustrative scenario presented in this review further shows how the framework can guide this process by diagnosing what a candidate instrument covers, identifying which walking-need tiers become critical, and specifying which modules or weighting adjustments are needed.

Future walkability measurement should move beyond the search for one best index. The more important task is to develop composable frameworks that preserve comparability while allowing structured adaptation. Such frameworks should combine baseline indicators with explicit user-, purpose-, climate-, and urban-form-specific modules. This shift is essential if walkability assessment is to support not only efficient movement, but also safe, equitable, comfortable, and meaningful pedestrian environments across different users, purposes, and environmental settings.

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Abbreviations

The following abbreviations are used in this manuscript:

HoWN	Hierarchy of Walking Needs
NEWS	Neighbourhood Environment Walkability Scale
MAPS	Microscale Audit of Pedestrian Streetscapes
Frank WI	Frank walkability index
WWI	Women's Walkability Index
WfWI	Walkability for Women Index
WRTS-WI	Women to Rail Transit Station Walkability Index
GSTWI	Gender-sensitive Technical Walkability Index
WIEH	Walkability Index for Elderly Health
OWI	Objective Walkability Index for Older Adults
OWAI	Older Adults Walking Accessibility Index
W-AFAI	Age-Friendly Approach Index
AFW	15 min Age-Friendly Walkability
CNWI-AT	Children's Neighbourhood Walkability Index for Active Transport
SWI school	School Walkability Index
MAPS-SRTS	MAPS-SRTS
MAPS Global-SN	MAPS Global-SN
NEWS-Y IPEN	NEWS-Y IPEN
CFI	Child Friendliness Index
WI-TP	Walkability Index across Trip Purposes
Commute WI	Commute Walk Calibrated Indicator Model
FLM-QI	First and Last Mile Quality Index
TWI tourist	Tourist Walkability Index
TRPT	Tourist Route Prioritization Tool
PEAT	Path Environment Audit Tool, PEAT
ParkIndex	Park access
CTBWI	Comfort and Time-Based Walkability Index
CWI	Comfort Walkability Index
SWTCI	Street Walkability and Thermal Comfort Index

ICCP	Pedestrian Walkability and Comfort Index
WCP	Walkability under Climate Pressure
WWAT	Winter Walkability Audit Tool
SMAT	Sidewalk Maintenance Assessment Tool
Snow-Rain NWI	Snow and Rain Walkability Tool
TOD-WA	TOD Walkability Assessment
TOD indicators	Walkability Indicators for TOD Sites
SWI-TOD	Sustainable Walkability Indices for TOD
Path WI	Path Walkability
SAQI&CI	Walk Access to Transit SAQI and CI
WHC-WI	Walkability Index for World Heritage Cities
CWI-HC	Comprehensive Walkability Index for Historical Centres
T-WSI	Walking Suitability Index of the Territory, T-WSI
CSNW	Contextualised Spatial Network-Based Walkability Index
RPEAI	Rural Pedestrian Environmental Audit Instrument
CDC-WRA	Car-Dominated Campus Walking Route Assessment
LPL-WA	Large Parking Lot Walkability Assessment

Appendix A

Indicators	Pedestrian Facility Provision - sidewalk presence - sidewalk density - sidewalk on both sides etc.	Pedestrian Facility Continuity - completeness - sidewalk continuity etc.	Passage Width - sidewalk width - footpath width - clear width etc.	Terrain and Vertical Barriers - slope - stairs - overpass etc.	Obstacles and Blockage - fixed obstacles - encroachment - barrier - snow management - sheltered connection etc.	Accessible Transitions - curb ramp - aligned curb/ramp - wheelchair-accessible pavement etc.	Surface and Paving Condition - surface quality - flat and neat - smoothness - non-slip etc.
Indices							
General							
Walk Score	☐	☐	☐	☐	☐	☐	☐
NEWS	☒	☐	☐	☐	☐	☐	☐
MAPS	☒	☐	☒	☒	☒	☒	☒
Frank WI	☐	☐	☐	☐	☐	☐	☐
Population							
Gender-sensitive							
WWI	☐	☐	☐	☐	☐	☒	☐
WFWI	☒	☐	☐	☐	☐	☐	☐
WRTS-WI	☒	☐	☒	☒	☐	☐	☐
GSTWI	☒	☐	☐	☐	☐	☒	☐
Older Adults							
WIEH	☒	☐	☒	☒	☒	☐	☒
OWI	☐	☐	☐	☐	☐	☒	☐
OWAI	☐	☐	☐	☐	☐	☐	☐
W-AFAI	☐	☐	☐	☒	☐	☐	☐
AFW	☐	☐	☐	☐	☐	☒	☒
Child and Youth							
CNWI-AT	☒	☒	☐	☒	☐	☐	☐
SWI school	☒	☒	☐	☐	☐	☐	☐
MAPS-SRTS	☒	☒	☒	☒	☐	☒	☐
MAPS Global-SN	☒	☐	☐	☒	☐	☐	☐
NEWS-Y IPEN	☒	☐	☐	☒	☐	☐	☐
CFI	☐	☐	☐	☐	☐	☐	☐
Purpose							
Utilitarian							
WI-TP	☒	☒	☒	☐	☒	☒	☒
Commute WI	☐	☒	☒	☐	☒	☒	☒
FLM-QI	☐	☒	☒	☐	☒	☐	☐
Leisure							
TWI tourist	☐	☐	☐	☒	☐	☐	☐
TRPT	☒	☒	☒	☐	☒	☐	☒
PEAT	☐	☐	☒	☒	☒	☐	☒
ParkIndex	☒	☐	☐	☐	☐	☐	☐
Climate							
Heat & Hot-Climate							
CTBWI	☐	☐	☐	☐	☐	☐	☐
CWI	☒	☐	☒	☒	☐	☒	☒
SWTCI	☐	☐	☐	☐	☐	☐	☐
ICCP	☒	☒	☒	☒	☐	☐	☐
WCP	☒	☐	☐	☐	☐	☐	☐
Winter & Cold-climate							
WWAT	☒	☒	☐	☐	☒	☐	☐
SMAT	☐	☐	☐	☐	☐	☐	☒
Snow-Rain NWI	☐	☐	☐	☐	☒	☐	☐
Urban Form							
Transit-oriented							
TOD-WA	☒	☐	☒	☐	☐	☐	☒
TOD Indicators	☐	☐	☐	☐	☐	☒	☐
SWI-TOD	☒	☐	☒	☐	☒	☒	☐
Path WI	☒	☒	☐	☒	☒	☒	☒
SAQI & CI	☐	☐	☐	☐	☐	☐	☐
Historic Fabric							
WHC-WI	☐	☐	☐	☐	☐	☐	☐
CWI-HC	☒	☐	☒	☐	☒	☒	☐
Compact mixed							
T-WSI	☒	☐	☒	☒	☒	☐	☒
CSNW	☒	☐	☒	☒	☒	☐	☐
Dispersed							
RPEAI	☒	☒	☐	☐	☒	☒	☒
CDC-WRA	☒	☐	☐	☐	☒	☒	☒
LPL-WA	☒	☒	☒	☐	☒	☒	☐

Legend: Whether the index include the attribute
☐ Not included ☒ Included

Figure A1. Coverage of feasibility-related indicators across the reviewed walkability instruments under the adapted walking-needs framework.

Indicators	Indices											
	Density - housing density - population density	Land Use - mix - proximity - diversity	Access to Retail and Daily Service - grocery - market - bank - hairdresser etc.	Access to Health Service - hospital - healthcare - clinic etc.	Access to Education - school - educational institution - public school etc.	Access to Green and Open Space - park - public space etc.	Access to Social and Cultural Space - museum - galleries - cinemas - cafes - restaurants etc.	Access to Religious and Civic Space - church - cemetery - town hall - police - government etc.	Access to Transit and Station - stop - train - bus - metro etc.	Connectivity and Network Structure - intersection density - cul-de-sac - route choice - permeability etc.	Information and Way Finding - info sign - info booth - direction sign - bus info - pedestrian signage etc.	Time - walk time - 15 min - 400/500 - 800 meter service area etc.
General												
Walk Score	☐	☐	☒	☐	☒	☒	☒	☐	☐	☐	☐	☒
NEWS	☒	☒	☒	☐	☐	☐	☒	☐	☐	☒	☐	☒
MAPS	☐	☐	☒	☒	☒	☒	☒	☒	☒	☐	☒	☐
Frank WI	☒	☒	☒	☐	☐	☐	☐	☐	☐	☒	☐	☐
Population												
Gender-sensitive												
WWI	☐	☐	☒	☐	☒	☒	☒	☐	☐	☐	☐	☐
WFWI	☐	☐	☒	☒	☒	☒	☐	☒	☐	☐	☐	☐
WRTS-WI	☐	☐	☒	☐	☒	☒	☒	☐	☒	☐	☐	☐
GSTWI	☐	☒	☐	☐	☐	☐	☐	☐	☒	☒	☒	☒
Older Adults												
WIEH	☐	☒	☐	☐	☐	☐	☐	☐	☒	☐	☒	☐
OWI	☐	☐	☒	☐	☐	☒	☐	☐	☒	☒	☐	☐
OWAI	☒	☒	☒	☒	☐	☒	☒	☐	☐	☒	☐	☒
W-AFAI	☐	☒	☒	☒	☐	☒	☒	☒	☐	☐	☒	☐
AFW	☐	☐	☒	☒	☒	☒	☒	☒	☒	☐	☒	☐
Child and Youth												
CNWI-AT	☐	☐	☒	☐	☒	☒	☐	☐	☒	☒	☐	☒
SWI school	☒	☐	☐	☐	☒	☒	☐	☐	☒	☒	☐	☐
MAPS-SRTS	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐
MAPS Global-SN	☐	☐	☐	☐	☒	☐	☐	☐	☒	☐	☐	☐
NEWS-Y IPEN	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CFI	☒	☒	☒	☐	☒	☒	☐	☐	☒	☒	☐	☐
Purpose												
Utilitarian												
WI-TP	☒	☒	☒	☐	☐	☐	☐	☐	☒	☒	☐	☐
Commute WI	☐	☒	☒	☐	☐	☒	☐	☐	☒	☒	☐	☒
FLM-QI	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☒	☐
Leisure												
TWI tourist	☒	☒	☐	☐	☐	☒	☒	☐	☒	☒	☐	☐
TRPT	☐	☒	☒	☐	☐	☒	☒	☐	☒	☒	☐	☐
PEAT	☒	☐	☒	☐	☐	☐	☒	☐	☒	☐	☐	☐
ParkIndex	☐	☐	☐	☐	☐	☒	☐	☐	☒	☐	☐	☐
Climate												
Heat & Hot-Climate												
CTBWI	☒	☒	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐
CWI	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
SWTCI	☒	☒	☒	☐	☐	☒	☐	☐	☒	☒	☐	☐
ICCP	☐	☒	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐
WCP	☒	☐	☒	☒	☐	☒	☐	☐	☒	☐	☐	☐
Winter & Cold-climate												
WWAT	☐	☒	☒	☐	☐	☐	☐	☐	☐	☒	☐	☐
SMAT	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Snow-Rain NWI	☒	☐	☒	☐	☐	☐	☐	☐	☒	☒	☐	☒
Urban Form												
Transit-oriented												
TOD-WA	☐	☒	☒	☐	☐	☒	☐	☐	☒	☒	☐	☐
TOD Indicators	☒	☒	☒	☐	☐	☐	☐	☐	☒	☒	☐	☒
SWI-TOD	☒	☒	☒	☐	☐	☐	☐	☐	☒	☒	☐	☐
Path WI	☐	☒	☒	☐	☐	☐	☐	☐	☐	☐	☐	☒
SAQI & CI	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐	☐
Historic Fabric												
WHC-WI	☐	☐	☒	☐	☐	☒	☒	☐	☐	☒	☐	☒
CWI-HC	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Compact mixed												
T-WSI	☐	☒	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
CSNW	☐	☒	☐	☐	☒	☐	☐	☐	☐	☒	☐	☐
Dispersed												
RPEAI	☐	☒	☒	☐	☐	☒	☐	☐	☒	☒	☐	☐
CDC-WRA	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☐	☐
LPL-WA	☐	☐	☐	☐	☐	☐	☐	☐	☐	☒	☒	☒

Legend: Whether the index include the attribute

☐ Not included ☒ Included

Figure A2. Coverage of accessibility-related indicators across the reviewed walkability instruments under the adapted walking-needs framework.

Indicators	Crime and Personal Security Social Disorder Lighting Surveillance Traffic Crossing Protection Intersection Buffers Fall and slip								
	- crime - assault - robbery - sex offenses - harassment - child security etc.	- encampment - carts - needles - human waste - graffiti - abandoned building etc.	- lamp - light density - light quality - street visibility etc.	- eye on the street - visible police - CCTV monitor - emergency call - safety emergency facilities etc.	- speed limit - slow zone - traffic calm - traffic exposure - parking - road width - traffic lanes etc.	- priority intersection - strip visibility - refuge island - curb extension - guard rail etc.	- Signal - Sign - push buttons etc.	- seperated sidewalk - barrier - parking lane etc.	- trip hazard - slip risk - fall risk - icy hazard - non-slip surfaces etc.
Indices									
General									
Walk Score	☐	☐	☐	☐	☐	☐	☐	☐	☐
NEWS	☒	☐	☒	☐	☒	☒	☒	☒	☐
MAPS	☐	☒	☐	☒	☒	☒	☒	☒	☒
Frank WI	☐	☐	☐	☐	☐	☐	☐	☐	☐
Population									
Gender-sensitive									
WWI	☒	☒	☐	☐	☒	☐	☐	☐	☐
WfWI	☒	☐	☐	☐	☒	☒	☐	☐	☐
WRTS-WI	☐	☐	☒	☐	☐	☒	☒	☐	☐
GSTWI	☐	☐	☒	☐	☒	☒	☒	☐	☐
Older Adults									
WIEH	☐	☐	☒	☐	☐	☐	☐	☐	☐
OWI	☒	☒	☒	☒	☐	☒	☒	☐	☐
OWAI	☐	☐	☐	☐	☒	☐	☐	☐	☐
W-AFAI	☐	☐	☐	☐	☐	☐	☐	☐	☐
AFW	☐	☐	☒	☐	☐	☐	☒	☐	☒
Child and Youth									
CNWI-AT	☒	☐	☐	☐	☒	☒	☐	☐	☐
SWI school	☒	☒	☒	☒	☒	☒	☒	☒	☐
MAPS-SRTS	☒	☒	☐	☐	☒	☒	☒	☒	☒
MAPS Global-SN	☒	☒	☒	☐	☒	☐	☐	☐	☐
NEWS-Y IPEN	☒	☐	☒	☒	☒	☐	☒	☒	☐
CFI	☐	☐	☐	☐	☒	☐	☒	☐	☐
Purpose									
Utilitarian									
WI-TP	☐	☐	☒	☐	☒	☒	☒	☐	☐
Commute WI	☒	☐	☒	☐	☒	☒	☒	☐	☐
FLM-QI	☒	☐	☒	☒	☐	☒	☐	☒	☐
Leisure									
TWI tourist	☒	☐	☐	☒	☐	☐	☐	☐	☐
TRPT	☐	☐	☒	☐	☒	☒	☐	☐	☐
PEAT	☐	☐	☒	☒	☐	☒	☒	☐	☐
ParkIndex	☐	☒	☒	☒	☒	☐	☒	☐	☐
Climate									
Heat & Hot-Climate									
CTBWI	☐	☐	☐	☐	☐	☐	☐	☐	☐
CWI	☐	☐	☒	☐	☒	☒	☐	☒	☐
SWTCI	☐	☐	☐	☐	☐	☐	☐	☐	☐
ICCP	☐	☐	☒	☐	☒	☒	☐	☐	☐
WCP	☐	☐	☐	☐	☐	☐	☐	☐	☐
Winter & Cold-climate									
WWAT	☐	☐	☒	☐	☒	☐	☐	☐	☐
SMAT	☐	☐	☐	☐	☐	☐	☐	☐	☒
Snow-Rain NWI	☐	☐	☐	☐	☐	☐	☐	☐	☒
Urban Form									
Transit-oriented									
TOD-WA	☐	☐	☒	☐	☒	☒	☐	☐	☐
TOD Indicators	☐	☐	☐	☐	☐	☐	☐	☐	☐
SWI-TOD	☒	☐	☒	☒	☒	☒	☒	☐	☐
Path WI	☒	☐	☒	☐	☒	☒	☐	☐	☐
SAQI & CI	☐	☐	☐	☐	☐	☐	☐	☐	☐
Historic Fabric									
WHC-WI	☐	☐	☐	☐	☐	☐	☐	☐	☐
CWI-HC	☐	☐	☐	☐	☒	☒	☐	☒	☐
Compact mixed									
T-WSI	☐	☐	☒	☐	☒	☒	☐	☐	☐
CSNW	☐	☐	☒	☒	☒	☒	☐	☒	☐
Dispersed									
RPEAI	☐	☐	☒	☐	☒	☐	☐	☐	☐
CDC-WRA	☐	☐	☐	☐	☒	☒	☒	☐	☐
LPL-WA	☐	☐	☒	☐	☒	☒	☐	☐	☐

Legend: Whether the index include the attribute
☐ Not included ☒ Included

Figure A3. Coverage of safety-related indicators across the reviewed walkability instruments under the adapted walking-needs framework.

Indicators	Walking Surface Comfort	Cleanliness	Thermal Comfort	Greenery	Noise and Air	Rest and Pause	Convenience Amenities	Broad Comfort
	- flat - neat - smoothness - drainage etc.	- garbage - bulky waste - trash can - litter - fouling etc.	- shade & shadow - heat stress - temperature - solar radiation - wind chill - cold stress etc.	- park tree - nature etc.	- traffic noise - air quality - low pollution etc.	- seating - shelter - waiting area etc.	- toilet - digital support - vending machine - working telephone etc.	- comfort score - route level comfort etc.
Indices								
General								
Walk Score	☐	☐	☐	☐	☐	☐	☐	☐
NEWS	☒	☐	☐	☒	☐	☐	☐	☐
MAPS	☒	☒	☒	☒	☐	☒	☒	☐
Frank WI	☐	☐	☐	☐	☐	☐	☐	☐
Population								
Gender-sensitive								
WWI	☐	☒	☐	☒	☐	☐	☐	☐
WFWI	☐	☐	☐	☒	☐	☐	☐	☒
WRTS-WI	☐	☐	☐	☐	☐	☐	☒	☒
GSTWI	☐	☐	☒	☐	☐	☒	☒	☐
Older Adults								
WIEH	☒	☐	☐	☒	☐	☒	☐	☐
OWI	☒	☐	☒	☒	☐	☒	☐	☐
OWAI	☐	☐	☐	☒	☐	☐	☐	☐
W-AFAI	☐	☐	☐	☐	☐	☐	☐	☐
AFW	☐	☒	☐	☒	☒	☒	☐	☐
Child and Youth								
CNWI-AT	☐	☐	☐	☐	☐	☐	☐	☐
SWI school	☒	☒	☐	☒	☒	☐	☐	☒
MAPS-SRTS	☐	☐	☐	☐	☐	☒	☐	☐
MAPS Global-SN	☐	☒	☐	☒	☐	☐	☐	☐
NEWS-Y IPEN	☐	☐	☐	☐	☐	☐	☐	☐
CFI	☐	☐	☐	☐	☐	☐	☐	☐
Purpose								
Utilitarian								
WI-TP	☐	☒	☒	☒	☐	☒	☐	☐
Commute WI	☐	☒	☒	☒	☐	☒	☐	☐
FLM-QI	☒	☒	☐	☐	☐	☒	☒	☐
Leisure								
TWI tourist	☐	☐	☐	☒	☐	☐	☐	☐
TRPT	☐	☒	☒	☐	☐	☒	☐	☐
PEAT	☐	☒	☐	☒	☒	☒	☒	☐
ParkIndex	☐	☒	☐	☒	☒	☐	☒	☐
Climate								
Heat & Hot-Climate								
CTBWI	☐	☐	☒	☐	☒	☐	☐	☐
CWI	☒	☐	☒	☒	☐	☒	☒	☐
SWTCI	☐	☐	☒	☒	☐	☐	☐	☐
ICCP	☒	☐	☒	☒	☒	☐	☐	☐
WCP	☐	☐	☒	☒	☐	☐	☐	☐
Winter & Cold-climate								
WWAT	☐	☒	☒	☒	☐	☒	☐	☐
SMAT	☒	☒	☐	☐	☐	☐	☐	☐
Snow-Rain NWI	☐	☐	☒	☐	☐	☐	☐	☐
Urban Form								
Transit-oriented								
TOD-WA	☐	☒	☐	☐	☐	☒	☐	☐
TOD Indicators	☐	☐	☐	☐	☐	☐	☐	☐
SWI-TOD	☒	☒	☐	☒	☐	☒	☐	☐
Path WI	☐	☐	☒	☐	☐	☒	☐	☐
SAQI & CI	☐	☐	☐	☐	☐	☐	☐	☐
Historic Fabric								
WHC-WI	☐	☐	☐	☐	☐	☐	☐	☐
CWI-HC	☒	☒	☐	☐	☐	☒	☐	☐
Compact mixed								
T-WSI	☐	☐	☐	☒	☐	☒	☐	☐
CSNW	☐	☐	☒	☐	☒	☐	☐	☐
Dispersed								
RPEAI	☒	☒	☒	☒	☐	☐	☒	☐
CDC-WRA	☐	☐	☐	☐	☐	☐	☐	☐
LPL-WA	☒	☐	☐	☐	☐	☐	☐	☐
Legend: Whether the index include the attribute								
☐ Not included ☒ Included								

Figure A4. Coverage of comfort-related indicators across the reviewed walkability instruments under the adapted walking-needs framework.

Indicators	Vitality	Aesthetics	Spatial Character	Culture and Tourism Appeal	Small Public-Space Amenities	Landscape Maintenance
	- food - socialization - active frontage etc.	- visual interest - pulic art - matched pave - attractiveness etc.	- enclosure - urbanity - setback - building height etc.	- destinations - scenery - POIs - heritage etc.	- squares - parklets - waterfronts - gardens - play spaces etc.	- hardscape - softscape - material - color etc.
Indices						
General						
Walk Score	☐	☐	☐	☐	☐	☐
NEWS	☐	☒	☐	☐	☐	☐
MAPS	☒	☒	☒	☐	☒	☒
Frank WI	☐	☐	☐	☐	☐	☐
Population						
Gender-sensitive						
WWI	☒	☐	☐	☐	☐	☐
WfWI	☒	☒	☐	☐	☐	☐
WRTS-WI	☒	☐	☐	☐	☐	☐
GSTWI	☒	☐	☒	☐	☐	☐
Older Adults						
WIEH	☐	☐	☒	☐	☐	☐
OWI	☐	☒	☐	☐	☐	☐
OWAI	☐	☐	☐	☐	☐	☐
W-AFAI	☐	☐	☐	☐	☒	☐
AFW	☒	☒	☐	☒	☒	☐
Child and Youth						
CNWI-AT	☐	☐	☐	☐	☒	☐
SWI school	☐	☒	☐	☐	☐	☐
MAPS-SRTS	☐	☐	☐	☐	☐	☐
MAPS Global-SN	☐	☐	☒	☐	☐	☐
NEWS-Y IPEN	☐	☒	☐	☐	☐	☐
CFI	☒	☐	☐	☐	☒	☐
Purpose						
Utilitarian						
WI-TP	☒	☒	☐	☐	☒	☐
Commute WI	☒	☒	☐	☐	☒	☐
FLM-QI	☐	☐	☐	☐	☐	☐
Leisure						
TWI tourist	☐	☒	☐	☒	☒	☐
TRPT	☐	☒	☒	☒	☒	☐
PEAT	☐	☒	☐	☐	☒	☒
ParkIndex	☐	☒	☐	☐	☒	☐
Climate						
Heat & Hot-Climate						
CTBWI	☐	☐	☐	☐	☐	☐
CWI	☐	☐	☐	☐	☐	☒
SWTCI	☐	☐	☐	☐	☐	☐
ICCP	☐	☒	☐	☐	☒	☐
WCP	☒	☐	☐	☐	☐	☐
Winter & Cold-climate						
WWAT	☒	☒	☐	☐	☒	☐
SMAT	☐	☐	☐	☐	☐	☐
Snow-Rain NWI	☐	☐	☐	☐	☐	☐
Urban Form						
Transit-oriented						
TOD-WA	☐	☒	☐	☐	☒	☐
TOD Indicators	☐	☐	☐	☐	☐	☐
SWI-TOD	☒	☒	☐	☐	☒	☐
Path WI	☒	☒	☒	☐	☐	☐
SAQI & CI	☐	☐	☐	☐	☐	☐
Historic Fabric						
WHC-WI	☐	☒	☐	☒	☒	☐
CWI-HC	☐	☐	☐	☒	☐	☐
Compact mixed						
T-WSI	☐	☒	☒	☐	☐	☐
CSNW	☐	☒	☒	☐	☐	☐
Dispersed						
RPEAI	☐	☒	☐	☐	☒	☐
CDC-WRA	☐	☐	☐	☐	☐	☐
LPL-WA	☐	☐	☐	☐	☐	☐
Legend: Whether the index include the attribute						
☐ Not included ☒ Included						

Legend: Whether the index include the attribute
☐ Not included ☒ Included

Figure A5. Coverage of pleurability-related indicators across the reviewed walkability instruments under the adapted walking-needs framework.

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