

## A Study on Measuring the Walkability of the Built Environment in Communities for an Ageing Society

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**ABSTRACT:** This study investigates several ageing communities in Daqing City with differing facility layouts and street network morphologies to evaluate their walkability. We develop a comprehensive walkability measurement model at macro and micro scales and apply the analytic hierarchy Process (AHP) to perform qualitative and quantitative assessments of the influencing indicators. At the meso scale, we employ a walkability index to analyze facility distribution and accessibility. Results indicate that the comprehensive walkability model and the walkability index effectively reflect community walkability. Factors such as land-use mix, street network configuration, facility distribution, and the quality of the pedestrian environment all influence the walkability of communities. Recommendations for practice include: establish rational street network structures, increase diversity of community land uses, and create high-quality pedestrian environments to enhance older adults' walking comfort and enjoyment in community planning; reconfigure road space, optimize parking areas and parking strategies, and improve the system of community eldercare facilities in existing communities.

**KEY WORDS:** ageing; walkability; older adults; community; walkability index

### Introduction

China is currently experiencing an increasingly severe ageing trend. According to national research and projection data, by the middle of the 21st century the population aged 60 and over in China will reach 487 million, accounting for approximately 35% of the total population, and the country will transition into a severely ageing society. In recent years, the emergence of concepts such as "walkable" and "green travel" has reflected growing attention to building walkable cities[1]. Community walkability directly affects older adults' convenience in ac-

cessing community services and their satisfaction with those services[2], so measuring community walkability with respect to older adults is of great significance.

The term "walkability" denotes the degree to which an environment is friendly to pedestrians. Its main influencing factors include the types and spatial distribution of destinations, walking distances, and the pedestrian environment[3]. Internationally, two principal approaches to evaluating walkability have been promoted: (1) perception-based methods, such as the UK-originated Pedestrian environment review system (PERS); and (2) pedestrian accessi-

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bility-based methods that emphasize destination diversity and spatial layout, among which the most widely used is the walkability index proposed in the United States in 2007[4]. Duncan et al. demonstrated a substantial correlation between the walkability index and walkability[5]. It was introduced to China by LU Yintao in 2013[6], and HUANG Jianzhong et al. have used the walkability index together with older adults' walking characteristics to explore service-facility layouts that would facilitate older adults' walking[7]. Michael Ochs found that attributes of the walking network are related to walkability, and that small-scale, high-density pedestrian networks can improve street connectivity[8]. Allan B. Jacobs, in *Great Streets*, evaluates street-network quality using connectivity indicators[9]. Some scholars categorize walkability measurement into community spatial morphology at the macro scale and pedestrian spatial experience in micro scale[10]. Regarding the effects of the built community environment on older adults' walking, several studies have examined service-facility distribution and road connectivity. Li Harmer et al. found that higher land-use mix is associated with greater convenience and frequency of walking trips among older adults[11]. Frank et al. showed that community land-use mix and street-network connectivity influence older adults' walking behavior[12]. At the micro scale, Gallagher et al. argue that the safety and comfort of the community pedestrian environment promote walking activities among older adults[13]. Although there is substantial domestic research on walkability in residential communities, comprehensive qualitative and quantitative studies specifically focused on older adults remain limited. Focusing on the Northeast region of China, which is characterized by a rapidly aging population, this study comprehensively evaluates community walkability by integrating the specific needs and travel characteristics of older adults. Building upon existing research, we develop a comprehensive walkability measurement model that bridges both macro- and micro-perspectives to provide valuable insights for the planning and development of age-friendly, walkable communities.

## 1 Research methodology

This study examines the built environment of com-

munities from three perspectives: overall community planning at macro scale, service-facility layout at meso scale, and the quality of community pedestrian space at micro scale. It analyzes community issues and proposes walkability optimization strategies for both planned (unbuilt) and existing communities. Regarding the layout of community service facilities, the walkability index method is applied. At the macro level, analyses are conducted separately for land development and road network structure. At the micro level, questionnaire surveys are used to assess the pedestrian environment. Indicators at the macro and micro levels are weighted using the Analytic Hierarchy Process (AHP).

### 1.1 Walkability measurement model for macro community planning and micro pedestrian environment

#### 1.1.1 Community planning at the macro level

##### (1) Land development and use

The land development and use dimension primarily includes floor-area ratio (FAR) and land-use mix. FAR reflects a community's comfort level. Land-use mix indicates the degree of mixed uses of different land types; higher land-use mix in the neighborhood is conducive to encouraging older adults to walk[14]. The formula for calculating land-use mix is given in Equation (1).

$$H = \sum_{i=1}^k \frac{p_i \times N_i}{\text{MAX}(P_i)} \quad (1)$$

Where  $H$  is the diversity value,  $P_i$  is the number of the  $i$ th type of service facility within the community boundary, and  $N_i$  is the weight of service facilities commonly used by older adults.  $H$  ranges from 0 to 1, and larger  $H$  indicates greater land-use mix. We adopt service-facility weights commonly accessed by older adults from existing studies[15].

##### (2) Street-network structural attributes

Higher street-network connectivity is associated with greater walking frequency. Connectivity is mainly represented by intersection density, entrance/exit accessibility, and street-network density. A reasonable number and placement of entrances/exits reduce unnecessary detours for older adults. The entrance/exit accessibility is objectively quantified following[16]. Older adults' cognition of complex overall space is inferred from their memory of local spatial fragments[17]. The intelligibility in space

syntax expresses how easily older adults can infer unknown spaces from known local segments. Intelligibility is calculated using axial-line analysis in space syntax to obtain a street-network legibility parameter. Indicator calculations are summarized in Table 1.

**Table 1** Calculation methods for the street network structure indicators

| Evaluation indicators     | Computational method                                                                                                                                  |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|
| Intersection density      | Number of street intersections within the community/sample area (intersections per km <sup>2</sup> )                                                  |
| Street-network density    | Total length of streets within the community/area (km/km <sup>2</sup> )                                                                               |
| Street-network legibility | The correlation coefficient between the overall connectivity values of street networks at each level within the community and the global integration. |

### 1.1.2 Pedestrian environment quality at the micro level

This level comprises pedestrian service level and pedestrian environment quality. The questionnaire targets community residents aged 60 and above and consists of a pilot survey and a formal survey. During the pilot survey, candidate indicators were identified from related literature and then screened according to the needs perceived by the surveyed older adults. In

the end, indicators including accessibility, safety, comfort, and pleasantness were retained for the formal study. In the formal survey, questionnaires collected basic personal information, walking frequency, and satisfaction with service facilities and the pedestrian environment. A total of 325 questionnaires were distributed, with an effective response rate of 95.6%. Satisfaction was quantified using a five-point Likert scale (very satisfied, satisfied, neutral, dissatisfied, very dissatisfied) with corresponding scores 5, 4, 3, 2, and 1.

### 1.1.3 Construction of the walkability measurement indicator system

Experts in urban planning and gerontological psychology were consulted to score the evaluation indicator weights for older adults. The final weighting scheme assigns a weight coefficient of 0.7 to the expert panel and 0.3 to the older adult respondent group. The measurement evaluation indicators (Table 2) comprise 22 evaluation indicators in 4 goal levels and 9 criterion layers. Using yaahp, the AHP hierarchical model analysis software, we selected questionnaires that passed the consistency test ( $CR < 0.1$ ) to determine indicator weights.

**Table 2** Walkability evaluation indicator weight table

| Objective level A                       | Criterion level B        | Evaluation indicator C                                            | Comprehensive weight W |
|-----------------------------------------|--------------------------|-------------------------------------------------------------------|------------------------|
| Land development and use A1             | Development intensity B1 | Plot ratio C1                                                     | 0.0241                 |
|                                         | Land-use mix B2          | Land-use mix C2                                                   | 0.0318                 |
| Street-network structural attributes A2 | Connectivity B3          | Intersection density C3                                           | 0.0405                 |
|                                         |                          | Entrance/exit accessibility C4                                    | 0.0560                 |
|                                         |                          | Street-network density C5                                         | 0.0445                 |
|                                         | Legibility B4            | Street-network intelligibility C6                                 | 0.0689                 |
| Pedestrian service level A3             | Accessibility B5         | Street-network directness C7                                      | 0.0634                 |
|                                         |                          | Arrangement of transfer facility for public-transport services C8 | 0.0264                 |
|                                         |                          | Arrangement of signage and directional guidance C9                | 0.0405                 |
|                                         | Safety B6                | Social security C10                                               | 0.0491                 |
|                                         |                          | Traffic safety C11                                                | 0.0675                 |
|                                         |                          | Arrangement of nighttime streetlight C12                          | 0.0280                 |
|                                         |                          | Arrangement of accessibility facilities C13                       | 0.0474                 |
|                                         | Comfort B7               | Arrangement of sheltering facilities C14                          | 0.0215                 |
|                                         |                          | Environment quality (air, greenery, noise, etc.) C15              | 0.0577                 |
|                                         |                          | Walkway width C16                                                 | 0.0560                 |
|                                         |                          | Walkway continuity C17                                            | 0.0577                 |
|                                         |                          | Walkway pavement quality C18                                      | 0.0556                 |

(Continued)

| Objective level A                 | Criterion level B | Evaluation indicator C                              | Comprehensive weight W |
|-----------------------------------|-------------------|-----------------------------------------------------|------------------------|
| Pedestrian environment quality A4 | Enjoyment B8      | Arrangement of rest and activity space C19          | 0.0454                 |
|                                   |                   | Street cleanliness C20                              | 0.0604                 |
|                                   |                   | Landscape C21                                       | 0.0297                 |
|                                   | Diversity B9      | Well-articulated street-facing building façades C22 | 0.0290                 |

## 1.2 Walkability index method for assessing facility distribution and accessibility at meso scale

The walkability index was adapted for older adults, and the assessment was based on road-network data and points of interest (POIs) representing daily service facilities used by older adults. Field measurements indicate an average walking speed for older adults of approximately 60 m/min. First, each study area was divided into a uniform grid and the grid cell centroids were used as origin points. Using ArcGIS network analysis, an OD cost-matrix was constructed. The weights assigned to community service facilities commonly used by older adults were adopted from Ref.[7]. These weights were then adjusted according to the distance-decay function (Figure 1). The attenuated weights for all facility types were summed to produce a base walkability index. Next, the base index was adjusted by decay indices for intersection density and block length to account for street-network effects. Finally, ordinary kriging was applied for spatial interpolation; the scores at

all grid centroids were summed and averaged to yield the final walkability index score.

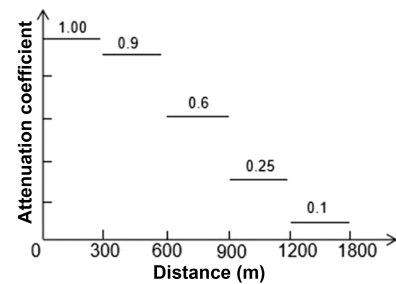


Figure 1 Attenuation pattern of older adults' walking speed

## 2 Case Study

### 2.1 Overview of the case communities

The survey selected three ageing communities in Daqing City, Heilongjiang Province: Wanbao Community (hereafter Wanbao), Lianghu Community (hereafter Lianghu), and Hubin Community (hereafter Hubin). Differences in facility layout, street-network characteristics, and building fabric among the case communities are shown in Figure 2.

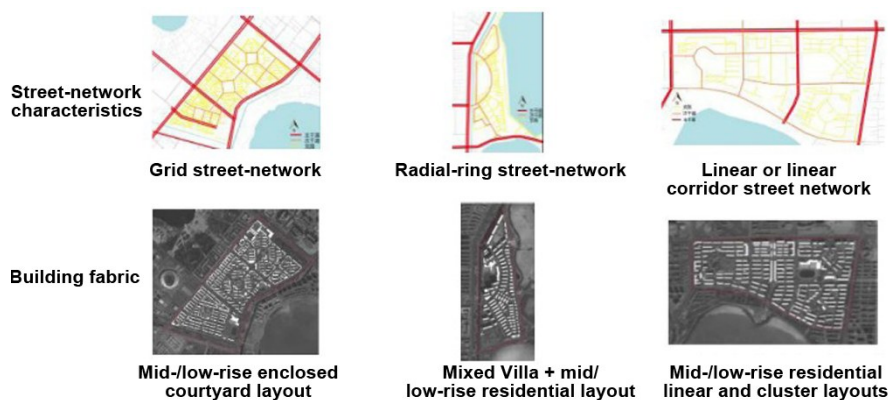


Figure 2 Overview of the communities

### 2.2 Current walkability measurement

#### 2.2.1 Community planning

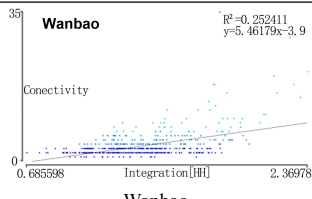
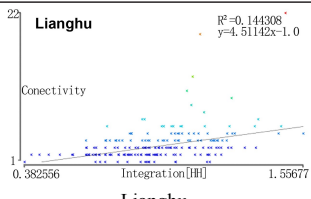
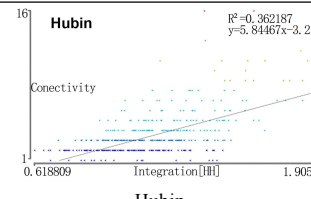
The planning-related indicator parameters for each community are listed in Table 3. Lianghu Community has the highest floor-area ratio but relatively low land-use mix and intersection density. It has few entrances/exits with

moderate entrance/exit accessibility. Hubin Community exhibits high land-use mix. It has entrances/exits on all four sides with a moderate number of access points, and shows relatively good entrance/exit accessibility. Wanbao Community has a relatively high intersection density and many entrances/exits, but some intersections are not con-

nected, resulting in only moderate entrance/exit accessibility. Both Wanbao and Hubin Communities have a street-network density  $\geq 8$  km/km<sup>2</sup>, indicating relatively high street-network density, whereas Lianghu Community has a lower street-network density. The street-network legibility

values are 0.34 for Hubin, 0.25 for Wanbao, and 0.14 for Lianghu. Lianghu's street-network has low legibility and it is difficult to infer orientation while walking; the spatial morphology of Hubin and Wanbao is more suitable for older adults' walking.

Table 3 Community Planning Indicators and Parameters Table

|                                                       |                    | Wanbao Community                                                                  | Lianghu Community                                                                  | Hubin Community                                                                     |
|-------------------------------------------------------|--------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Indicators of land development and use                | FAR                | 1.0                                                                               | 1.43                                                                               | 1.0                                                                                 |
|                                                       | Land-use diversity | 0.47                                                                              | 0.35                                                                               | 0.51                                                                                |
| Intersection density (intersections/km <sup>2</sup> ) |                    | 402                                                                               | 295                                                                                | 388                                                                                 |
| Entrance/exit accessibility                           |                    | Fair                                                                              | Fair                                                                               | Good                                                                                |
| Street-network density (km/km <sup>2</sup> )          |                    | 9.76                                                                              | 7.68                                                                               | 10.7                                                                                |
| Street-network legibility                             |                    |  |  |  |
|                                                       |                    | Wanbao                                                                            | Lianghu                                                                            | Hubin                                                                               |
| Space syntax analysis of street-network by community  |                    |                                                                                   |                                                                                    |                                                                                     |

## 2.2.2 Service-facility layout

### (1) Facility inventory and quantity analysis

Based on a survey of the types of daily community service facilities used by older adults, this study classifies the facilities into six major categories. The facility composition for each community is shown in Figure 3. The proportional mixes of facility types are similar across communities: shopping and food service facilities account for a large share; medical and public service facilities occupy a moderate share; recreation and eldercare facilities account for a very small proportion.

### (2) Kernel-density analysis of community service facilities

Using satellite imagery and field inspection, we produced kernel-density maps to show facility distribution (Figure 4). Wanbao shows relatively high kernel density and an overall reasonable layout; all facility types are evenly distributed and facility coverage is comprehensive. The northwest sector of Lianghu exhibits relatively high facility kernel density, whereas other parts show low density. Facilities are clustered along the western arterial road while internal provision is sparse. The surrounding area of the community lacks major shopping, leisure/recreation, and eldercare service facilities. The density of service facilities in Hubin

is moderate overall, with a pronounced concentration in the central zone. Facilities are relatively evenly distributed overall, with a higher concentration in the central area.

### (3) Walkability index

The walkability index scores for each study area were obtained (Figure 5) after ordinary kriging interpolation. Hubin achieved a walkability score of 86.2. Much of the neighborhood is classified as highly walkable, resulting in the highest mean walkability among the study areas. The central area exhibits particularly high walkability, and the spatial distribution of walkability displays a pronounced centripetal pattern. Wanbao obtained a walkability score of 80.83. High-walkability zones are concentrated in the northeastern sector. The index values decline from north to south. The community's overall walkability is moderate. Lianghu obtained a walkability score of 75.0. Areas adjacent to the arterial urban road exhibit relatively higher walkability, while the community's average walkability remains moderate. Overall, Hubin's dispersed distribution of service facilities yields higher walkability and pedestrian accessibility. By contrast, Wanbao, whose facilities are concentrated in specific areas, and Lianghu, whose facilities aligned along the street frontage, exhibit relatively lower pedestrian accessibility.

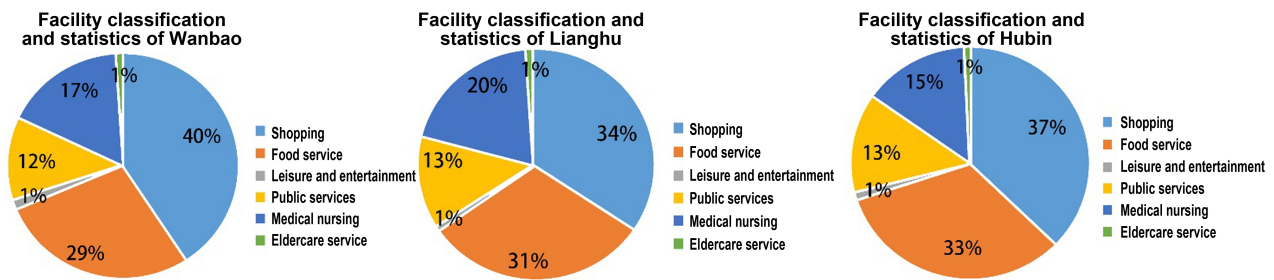


Figure 3 Facility classification and statistics of the communities

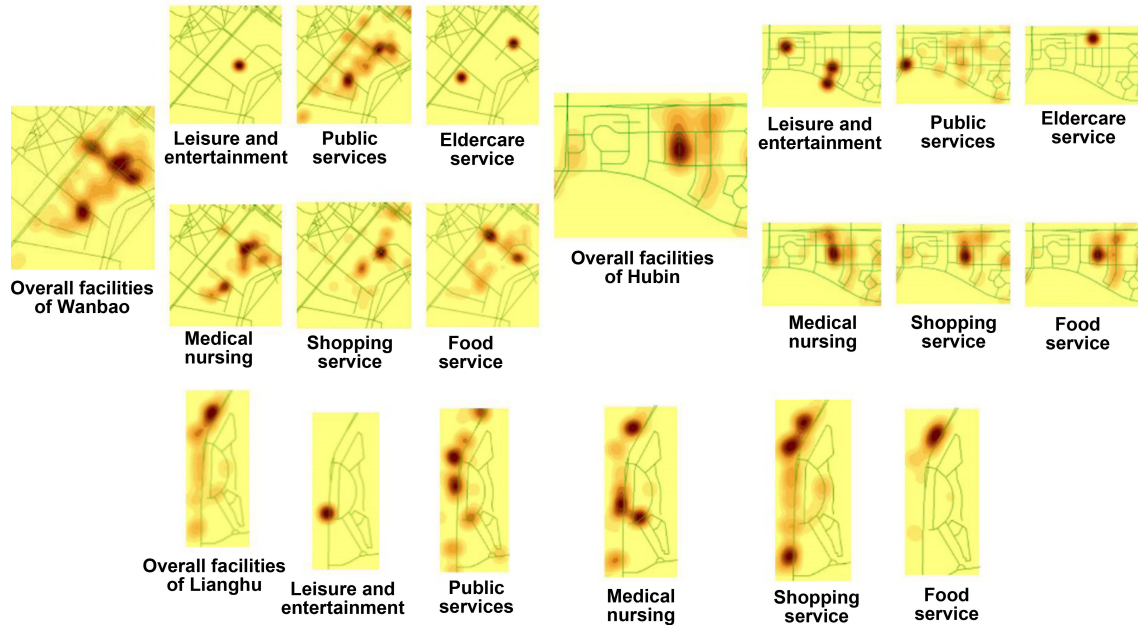


Figure 4 Kernel-density analysis of community service facilities

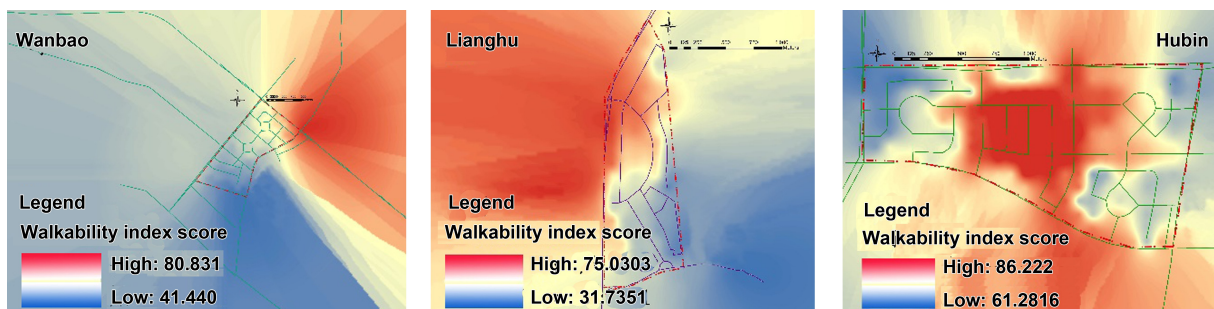


Figure 5 Distribution of walkability index values of the communities

### 2.2.3 Pedestrian Environment Quality

Survey results indicate that walking is the predominant travel mode among older adults, followed by public transit. Relatively few respondents choose private car or bicycle. Cold weather does not significantly reduce trip frequency. Purposeful walking denotes trips with a specific objective, such as shopping, attending to errands, and escorting family members, whereas non-purposeful walking

denotes walking for recreation or leisure, such as strolling and leisure walking. 84.75% of respondents walk 1-2 times per day, and 70.87% report daily walking durations of 1-2 hours. When trips are for leisure, both walking frequency and duration increase (Figures 6-7).

Satisfaction data collected via questionnaires and interviews are summarized in Table 4. Scores for satisfaction with surrounding community facilities (quantity and layout

rationality) rank as follows: Hubin 4.55 > Wanbao 3.89 > Lianghu 3.75. Lianghu is perceived as aesthetically pleasing, safe, well-planned for parking, and conveniently served by transport, but its walkways are indirect and convoluted, spatial legibility is poor, signage is scarce, and nighttime lighting is inadequate. Hubin exhibits high pedestrian-network accessibility. However, overall environ-

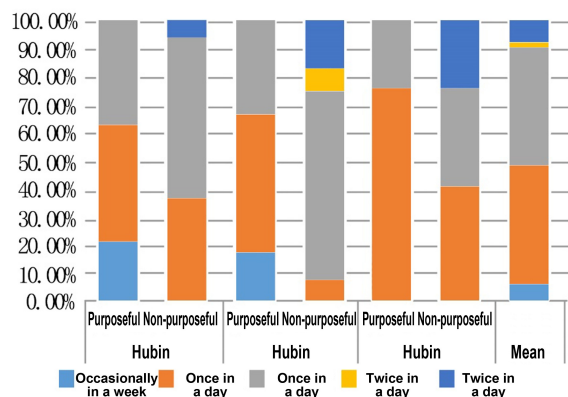


Figure 6 Average daily walking trip count of older adults in the communities

mental hygiene is only average, greening is insufficient, and pavement surfaces are prone to water accumulation during rain and snow. Wanbao has good street network accessibility and a high concentration of older residents. But it suffers from poor cleanliness, substandard pavement quality, and limited greenery, resting areas, and parking spaces.

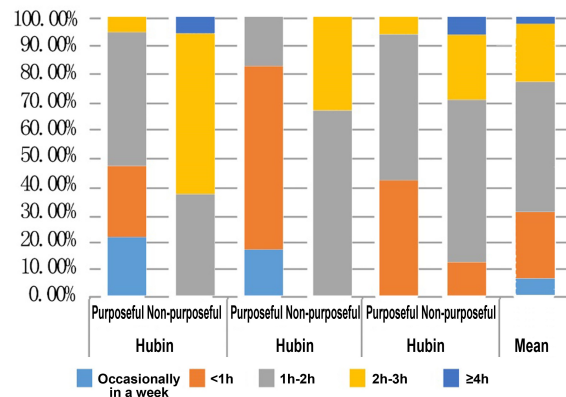


Figure 7 Average daily walking time of older adults in the communities

Table 4 Satisfaction survey results by community

| Indicator | C5   | C6   | C7   | C8   | C10  | C11  | C12  | C13  | C14  | C15  | C16  | C17  | C18  | C19  | C20  | C21  | C22  |
|-----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Wanbao    | 4.68 | 4.89 | 4.11 | 4.79 | 4    | 3.95 | 3.53 | 3.89 | 3.32 | 3.79 | 3.89 | 3    | 3.26 | 3.26 | 3.63 | 4.63 | 4.68 |
| Lianghu   | 3.92 | 4.58 | 3.5  | 4.75 | 4.75 | 3.83 | 3.42 | 4.25 | 4.5  | 4.33 | 4.42 | 4    | 3.8  | 4.5  | 4.67 | 4.67 | 3.92 |
| Hubin     | 4.29 | 4.76 | 4.12 | 4.35 | 4.24 | 3.94 | 3.88 | 4.35 | 4.18 | 4    | 4.29 | 3.82 | 3.5  | 3.94 | 4.29 | 4.53 | 4.29 |

## 2.3 Integrated analysis of measurement results

### 2.3.1 Problem analysis of case communities

Selected indicators were processed according to the scoring standards (Table 5). Ten experts in architecture and planning rated FAR, land-use mix, and entrance/exit accessibility. Combining these expert scores with the previously determined indicator weights produced walkability scores at the indicator, criterion, and objective levels (Figures 8-10). At the indicator level, Lianghu scored poorly on street-network legibility but performed well on traffic safety, environmental quality, pedestrian walkway width, and walkway cleanliness. Hubin scored markedly higher on entrance/exit accessibility and street-network legibility. Wanbao achieved a high score for street-network directness, indicating that its street layout allows pedestrians to travel along direct routes with minimal detours, but showed clear weaknesses in environmental quality, walkway width, walkway continuity, pavement quality, and walkway cleanliness. At the criterion level, the three com-

munities differ substantially on connectivity, legibility, and comfort. Lianghu's scores for development intensity, land-use diversity, connectivity, legibility, and accessibility are lower than those of the other two communities, while its scores for safety, comfort, and pleasantness are relatively high. Wanbao's overall score is significantly lower than the other two communities due to poorer environmental conditions. At the objective level, results are as follows: in land development and use, Hubin = Wanbao > Lianghu; in road-network attributes, Hubin > Wanbao > Lianghu; in pedestrian service level and environment quality, Lianghu > Hubin > Wanbao.

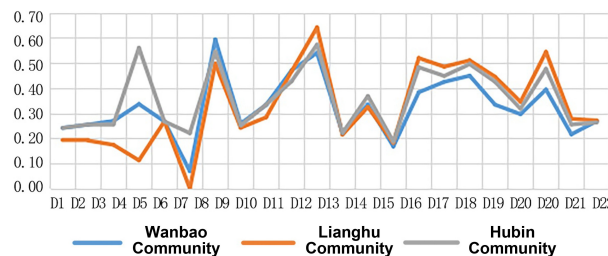


Figure 8 Summary of walkability indicator level scores by community

Table 5 Scoring standards for objective indicators

| Evaluation indicators       | Indicator meaning                                                                                              | Scoring standards                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-----------------------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Plot FAR                    | The ratio of the total above-ground building floor area within the plot to the plot area                       | For good residential communities, the FAR for high-rise housing should not exceed 4.0; for low-/mid-rise housing it should not exceed 1.5. Generally, higher FAR is associated with lower residential comfort.                                                                                                                                                                                                                                                                                                                                       |
| Intersection density        | Number of street intersections within the community/area of the community (intersections per km <sup>2</sup> ) | When $x \geq 1000$ , $P(x) = 10$ ; when $x \leq 100$ , $P(x) = 0$ ; when $1000 > x > 100$ , $P(x) = 0.011 \times (x - 100)$                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Street-network density      | Ratio of total length of streets to area within the community (km/km <sup>2</sup> )                            | When $x \in [0, 4)$ , $P(x) = 2$ ; when $x \in [4, 8)$ , $P(x) = 4$ ; when $x \in [8, 12)$ , $P(x) = 6$ ; when $x \in [12, 16)$ , $P(x) = 8$ ; when $x \geq 16$ , $P(x) = 10$                                                                                                                                                                                                                                                                                                                                                                        |
| Street-network legibility   | Correlation coefficient between connectivity and global integration                                            | When $x \geq 0.7$ , $P(x) = 10$ ; when $x \leq 0.2$ , $P(x) = 0$ ; when $0.7 > x > 0.2$ , $P(x) = 20 \times (x - 0.2)$                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Entrance/exit accessibility | Community entrance/exit count and layout rationality                                                           | Community has entrances/exits on all 4 sides adjacent to urban roads, and bus stops are within 300 m walking distance (5 points); Community has entrances/exits on 3 sides adjacent to urban roads, and bus stops are within 500 m walking distance (3 points); Community has entrances/exits on 2 sides adjacent to urban roads (1 point); intermediate scores are determined by actual conditions (in accordance with the "Code for planning of city and town facilities for the aged" and the "Code for design of building for elderly persons"). |

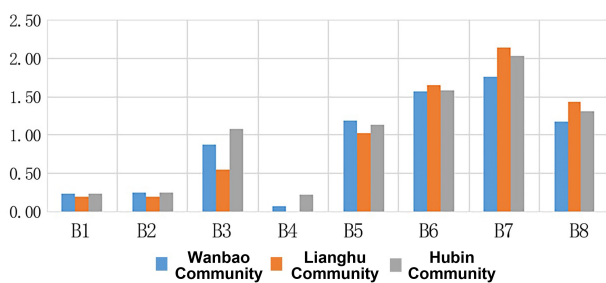


Figure 9 Summary of walkability criterion level scores by community

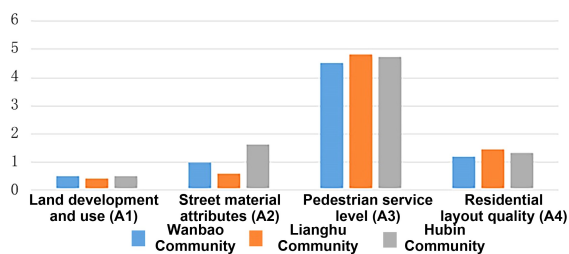


Figure 10 Summary of walkability objective level scores by community

### 2.3.2 Common problems in existing ageing communities

(1) Mixed pedestrian-vehicle traffic, intersecting street pattern, and unclear navigational cues from road signage. The community exhibits mixed pedestrian-vehicle circulation. As older residents walk slowly and may not yield promptly to motorized traffic, points of pedestrian-vehicle interaction present elevated safety risks. In a street network characterized by winding, intersecting roads, older adults have difficulty with spatial orientation, and are more likely to get lost or fail to locate destinations. This diminishes both the ease and the motivation for them to

undertake trips. A rectilinear, well-connected street network combined with legible, wayfinding signage enhances pedestrian convenience for older adults and supports their travel activity.

(2) Incomplete eldercare service systems in modern communities. Recreational and eldercare facilities account for only about 2% of community facilities. Community eldercare service facilities are inadequate. The limited provision of recreational and care facilities reduces the number of accessible leisure destinations for older adults, constrains their activity opportunities and negatively impacts their physical and psychological well-being[7].

(3) Pedestrian environment quality varies with community age and property management. Newer communities generally have smoother, recently paved roads and better property management, so that pedestrian-environment quality is higher. In certain long-established residential communities, the quality of the pedestrian environment is relatively low. Due to their age, sections of the roadway exhibit cracking and subsidence. Combined with inadequate property management and delayed waste collection, these conditions lead to deteriorated air quality and a diminished pedestrian experience for older adults. Inadequate and poorly arranged parking leads to roadside private vehicle parking that encroaches on pedestrian space, which reduces accessibility and compromises older adults' walking safety.

### 3 Recommendations for improvement

#### 3.1 Community planning and design

For communities that have yet to be built, the following recommendations are proposed at the planning stage.

(1) Design a coherent, high-connectivity street network for the community that favors grid or strip-shaped street networks, and implement effective pedestrian-vehicle separation.

Design a dense, highly connected street network and locate bus stops according to service radii. Other than radial-ring patterns, grid or linear street-network forms provide higher intelligibility and facilitate orientation and walking among older adults. Because age-related declines in hearing ability may reduce older adults' ability to detect approaching vehicles, pedestrian-vehicle separation and one-way or two-way lane arrangements should be set appropriately based on traffic volumes. Use space-syntax integration analysis to avoid designating highly integrated streets as primary vehicular thoroughfares (for example, Reyuan Street at Wanbao Community).

(2) Increase land-use mix and raise the proportion of eldercare facilities to enrich community functions.

Control building heights appropriately for the local climate zone. Subdivide a community into smaller blocks through facility placement and street network design to enable a greater variety of functions within each block. Shorten travel distances and improve access to facilities that older adults need. Offer more options to increase the likelihood that older adults will choose walking for daily trips. In new developments, allocate a larger share of land to facilities with higher evaluation weights during the initial planning phase.

(3) Create a high-quality pedestrian environment to improve comfort and enjoyment among older adults.

Incorporate landscape elements such as covered walkways and pavilions in the community, and enhance ground-level greening at building entrances to enrich visual layers and increase green coverage. Choose non-slip, wear-resistant paving materials, ensure even, tidy surfaces with proactive upkeep and effective drainage for wet and snowy conditions, thereby embodying age-friendly design principles. To improve the comfort and enjoyment of

walking for older adults, introduce landscape amenities—for example, decorative lighting and tree-stump-like seats—along pedestrian routes leading to the lakeside promenade. These interventions increase the attractiveness and experiential richness of walking corridors and supply convenient, comfortable rest opportunities for older adults.

#### 3.2 Existing community environment

For communities that are already constructed, the following retrofit recommendations are proposed.

(1) Optimize parking space and parking arrangements to support pedestrian-vehicle separation.

Provide additional above- or below-ground parking and standardize parking practices to prevent encroachment on walkways. Locate parking where pedestrian flows are low. On shared streets, introduce measures such as planted buffers to separate pedestrians and vehicles, traffic-calming to reduce vehicle speeds, parallel and time-limited parking, and deceleration signage at turns and high-pedestrian locations. Upgrade road and parking facilities to be age-friendly.

(2) Reconfigure existing street space and add convenient pedestrian shortcuts.

Recognizing that older adults have distinct trip purposes, community streets are typically differentiated into two functional types—through streets for direct movement and leisure streets for recreational walking. Because older adults often prefer direct routes for shopping trips, primary streets should minimize detours and be organized around frequently used service facilities with regular and direct street-network forms (for example linear, strip-shaped, or grid street-network patterns rather than convoluted ring roads) while maintaining adequate roadway widths of primary streets. For leisure walking, arrange winding recreational loops around community squares or landscape spaces, and integrate greenery and resting seats along these circuits.

(3) Adjust facility layout by service radii to improve the community eldercare service system.

Ensure a sufficient variety and number of service facilities within the community and avoid clustering all services on one side. Inventory commonly used facilities for older adults and tier them by usage frequency. Account

for different walking-distance thresholds of older adults, facility scale, and service radii, and organize facilities into graded tiers so that each facility type is spatially distributed according to appropriate walking-distance thresholds and service radii. For example, shopping and leisure facilities should, as far as possible, be located within a five-minute walking range; other, less frequently used facilities can be placed within a ten-minute walking range. Adopt a hybrid spatial strategy that combines decentralized and centralized facility distribution. Provide a community center in each cluster that concentrates high-frequency elder-care and daily-use facilities, thereby maximizing the proportion of older adults' needs that can be satisfied within walking distance[18].

(4) Strengthen property management, install wayfinding signs, and improve accessibility facilities

As older adults value a comfortable and secure pedestrian environment above other considerations, community management should enhance coordinated security and surveillance, eliminate monitoring gaps, and implement rigorous access control and registration at community entrances/exits. Provide highly visible wayfinding signs and distinctive spatial markers at intersections and curves, and employ contrasting pavement colors and materials to improve wayfinding and the legibility of the street network. Develop a comprehensive accessibility infrastructure by installing anti-slip ramps and signage at grade changes, eliminating gaps in lighting coverage, and integrating functional lighting with landscape fixtures to both meet accessibility standards and improve visual amenity.

## 4 Conclusions and outlook

### 4.1 Conclusions

This study employed a mixed qualitative-quantitative approach to develop a comprehensive assessment of walkability in aging communities and applied the method to case analyses. The following conclusions were drawn: community walkability must be assessed from multiple dimensions, and planning, the spatial distribution of service facilities, and the quality of the pedestrian environment all influence overall walkability.

(1) Land-use mix and street-network configuration in community planning and layout affect older adults' travel

experience. A richer diversity of functions and more direct street alignments increase older adults' willingness to walk outdoors.

(2) The distribution of service facilities and their coverage areas influence walkability metrics: areas with a more uniform distribution of facilities and broader service coverage achieve higher walkability index values, indicating superior walkability.

(3) Street-network accessibility, pavement condition, parking design, availability of healthcare and shopping, greenery, and property management collectively determine the quality of the pedestrian environment in a community and thereby shape older adults' satisfaction with that environment.

To address the issues identified above, the following optimization strategies are proposed:

1) Planning and design considerations for undeveloped communities:

Adopt safe and convenient street-network forms. Prefer grid or linear corridor street patterns and avoid designating streets with high elderly pedestrian use as vehicle thoroughfares. Enrich community functions. Subdivide activity spaces into smaller blocks to accommodate diverse activities for older adults. Ensure resting space and pedestrian safety. Provide ample seating in pedestrian areas and use smooth, durable paving materials.

2) Optimization based on current conditions for existing communities:

Optimize pedestrian space. Add above- or below-ground parking where appropriate and install speed-reduction signage at high-pedestrian areas and turning points. Improve current street network: Introduce small, convenient shortcut paths near areas where older adults gather. Increase seating/resting benches in main walking areas. Adjust service facility: Prioritize high-frequency amenities such as retail and recreational facilities so they are reachable within a five-minute walk, and organize lower-frequency facilities into tiers according to their frequency of use. Improve barrier-free facilities: install highly visible wayfinding and accessibility signage at intersections, curves, and locations of accessible facilities. Install handrails on steps, ramps, and other accessible facilities. Ensure

the community lighting system provides full area coverage.

#### 4.2 Limitations and outlook

This study developed a macro-level quantitative and micro-level qualitative measure of walkability for aging societies based on older adults' walking characteristics and needs, and validated the measurement approach from both objective and subjective perspectives. It also proposed targeted optimization strategies from the perspectives of community planning and existing communities. By integrating multiple perspectives rather than a single dimension, the research offers useful guidance for future planning and construction of age-friendly, walkable communities.

The study's limitations are that the optimization recommendations emphasize qualitative, macro-scale guidance for community planning; specific parameterization of street layouts, node design, and other detailed interventions remains underdeveloped. The study also did not account for the climatic and regional characteristics of Daqing as a cold-region city. Future research should integrate regional climate conditions, local community planning patterns, and older adults' travel behaviors to derive concrete design parameters, perform a more granular walkability assessment, and construct a walkability assessment framework suitable for older adults in cold regions.

#### Sources of Figures and Tables

Figure 1 was redrawn based on an image from Ref.[2]; all other figures and tables were prepared by the authors.

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