A Framework for Constructing Elder-Friendly Walking System Based on Living Circle Scale

A. Case Study of the old residential community in Jiangtai, Beijing

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Abstract. Nowadays, the increasing population aging and geriatric health problems have led many scholars to explore the issues of walkability, safety and comfort of walking environment for the old. However, a complete elderly-friendly walking system has not yet been constructed and extended for application. In this paper, considering the travel range and walking characteristics of the elderly, an old community in Beijing's Jiangtai area was selected as a case site. By GIS analysis, field survey and spatial environment notation, our study established a comprehensive evaluation framework in two parts: using walk score to identify the problem, and walking environment evaluation system to identify the influencing factors for elderly mobility. The results indicated that: the walk score differs greatly from north to south of the community, especially in the vegetable market, senior centers and pharmacies; the traffic flow and the pedestrian path patency influence the elderly's choice of walking sections; the density and quality of rest facilities affect the elderly's walking experience. This system can be applied to the analysis of walkability and walking environment in old communities in order to implement more effective improvement measures for sustainable development of old communities.

Keywords: walkability · walking environment · elder-friendly · living circle

1 Introduction

The United Nations Sustainable Development Goals define the development of sustainable cities and human settlements, with a specific emphasis on catering to the geriatric needs by providing safe, inclusive, and green public spaces [1]. In China, the aging population is experiencing a continuous acceleration: by the end of 2022, the number of elderly people aged 60 and above will reach approximately 28, 004 million, accounting for 19.8% of the total population [2]. It is predicted that by 2035, this number will exceed 400 million, comprising over 30% of the population [3]. The proportion of elderly individuals living in old communities in major cities is also increasing. However, current streets in these communities no longer meet the needs of the elderly for a comfortable and safe walking experience. Therefore, it is crucial to explore how to construct a walking system that caters to the seniors' demands.

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Walking is one of the most important forms of health-enhancing exercise for the elderly [4], and the willingness of the elderly to walk is correlated with a good walking environment [5]. Creating an elder-friendly walking space can improve the physical health and well-being of this group. The Walk Score has been widely used to analyze the accessibility of districts [6], the influencing factors of travel environment [7], and the impact of different Housing styles on walking [8]. Currently, it is mainly applied to study the effect on the elderly health or to evaluate the walkability of cities in general. However, the evaluation of the Walk Score of the old communities still need further exploration based on the living circle of the old.

In terms of research on walking environment for the elderly, the scope of research has focused on macroscopic scales of area and or microscopic scales of individual experience. For example, current studies focus on factors promoting elderly walking in terms of environmental characteristics such as residential density, land use mix, and retail commercial area at the macro level [9], as well as sidewalks to assess neighbourhood walkability at the micro level [10]. The walking environment evaluation at the scale of the living circle of the elderly needs to be urgently studied. In terms of walking system, current research mainly uses subjective scoring methods for assessing good walking paths [11], such as evaluating the walkability of rail transit stations from the aspects of distance, time and psychology of walk [12]. It is urgently needed to systematically analyze and construct an elder-friendly walking system from a quantitative perspective.

This study analyzes the walking environment space of the elderly from the perspective of the living circle, and evaluates the elderly walking friendliness of this space by calculating walk score through GIS and identify problematic areas in the current walking environment. The study then determines an evaluation index for the walking environment through a literature review and utilizes correlation analysis to identify factors that affect the walking of elderly individuals. The goal is to construct an evaluation system for an elder-friendly walking, which can guide the aging-friendly renovation of walking systems in older communities and enhance human well-being.

This paper attempts to answer the following research questions: (1) How elder-friendly is the current walking system like within the elderly's living circle? (2) What are the spatial and environmental factors that affect the elderly mobility? (3) During the urban renewal, how to integrate the influencing factors of elder-friendly walking systems and carry out effective elder-friendly retrofitting to meet the needs of elderly groups?

2 Data and Methods

2.1 Research Framework

This study selected representative streets that are closely related to the daily activities of the elderly and divided them into several sections, using entrances and intersections as nodes. Then, we assessed the current walking systems through the Walk Score considering daily destinations of the elderly. After that, we analyzed and evaluated the spatial environment characteristics and elderly mobility by using expert scoring, web data collection. Finally, we used the correlation analysis to explore the influential factors in spatial environment that have a significant impact on elderly flow and proposed initial planning and design during urban renewal (Fig. 1).

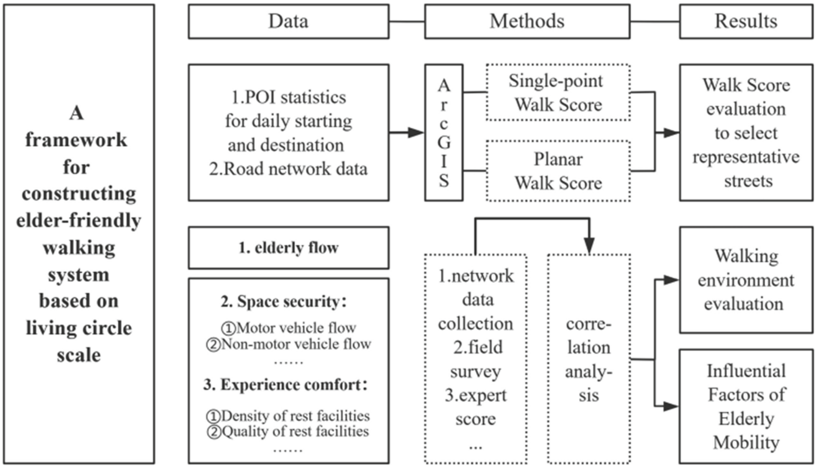


Fig. 1. Research framework

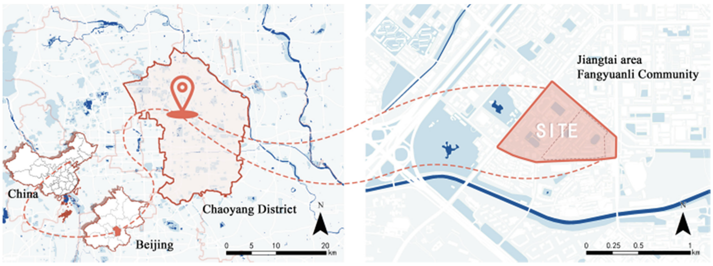


Fig. 2. Schematic diagram of survey community location

2.2 Case Location

In response to the increasing elderly people in the old communities and the particularly prominent health needs, the Fangyuanli Community in the Jiangtai area of Chaoyang District, Beijing was selected for the study. Fangyuanli Community is an old community built in the 1980s. With a resident population of over 8,000, the number of elderly people accounts for nearly 1/3 of the total population, making it a typical aging community for this study (Fig. 2).

2.3 Data Sources

We used the data form www.walkscore.com to calculate the Walk Score. In the process of analyzing walkability based on the Walk Score, we choose the residential buildings in the community is taken as the starting point for analysis in ArcGIS. The data of daily travel destination data comes from POI (Point of Interest) of Amap (https://developer.amap.com). Moreover, we used the road network data from open source maps (https://www.openstreetmap.org) to analyzed their travel trajectory.

Table 1. Walking environment evaluation index

Index classification	Principle Index	Sub-Index
Space security	Traffic security	Motor vehicle flow
		Non-motor vehicle flow
		Human flow
		Relative walking width
		Pedestrian path patency
	Facilities security	Crosswalk rationality
		Street lighting security
Experience comfort	Facilities experience	Density of rest facilities
		Quality of rest facilities
	Service experience of special groups	Blind tracks patency
		Ramp arrangement rationality
	Environmental experience sense	Street greening
		Pedestrian path pavement and neatness
		Open degree of street space
		Street-level interface permeability

In the evaluation of the community walking environment, this paper integrated the relevant studies on the influence of walking environment on walking behavior [13–15], especially the Maslow's Hierarchy of Needs theory. Taking the need of elderly mobility for spatial environment, 15 walking environment evaluation indicators were selected from both space security and experience comfort aspects. The evaluation index are shown in Table 1.

2.4 Methods

1) **Walk Score evaluation**

a) *Weights of Daily destination:*

Based on the existing daily destination weighting system of the Walk Score website [16] and combined with the travel characteristics of the elderly in the communities, this paper localized the daily destination classification table and regarded the places with closer needs of the elderly such as vegetable markets, clinics and activity centers for the elderly as the key points, and made corresponding adjustments to the weights of various types of daily destinations, and finally obtained a daily destination weight classification table of 8 major categories and 20 minor categories (Table 2).

Table 2. Daily destination weight classification

Dimension	Dimension Weight	Index	Index Weight	Final Weight
Education	0.130	Nursery School	0.50	0.065
		Primary school	0.35	0.045
		Middle school	0.15	0.020
Pension benefits	0.080	Activity centers for the elderly	1.00	0.080
Life shopping	0.260	Vegetable market	0.38	0.100
		Convenient store	0.27	0.070
		Supermarket	0.15	0.040
		Shopping malls, department stores	0.08	0.020
		Shops along the street	0.12	0.030
Leisure catering	0.050	Restaurants	1.00	0.050
Health care	0.175	General hospitals	0.29	0.050
		Clinic, community health service centers	0.37	0.065
		Pharmacy	0.34	0.060
Municipal public utilities	0.190	park	0.58	0.011
		Bus station, subway station	0.42	0.080
Cultural entertainment	0.055	Bookstore	0.36	0.020
		Barber shop	0.36	0.020
		Pedicure room, bath room, massage room	0.27	0.015
Others	0.06	Neighborhood committee, street office	0.5	0.030
		Bank, post office	0.5	0.030

b) The decay law of walking distance:

Synthesizing previous studies [17–19] and the approach of Huang Jianzhong [20], this study constructed an actual road network and calculated the distance. We calculated the walking distance for elderly people as 75 m/min, and used a maximum walking distance of about 1500 m, corresponding to a tolerable walking time of 20 min [21]. The decay function was divided into four intervals. The decay neighbourhood is 1.00 for 0–400 m, 0.75 for 400–800 m, 0.45 for 800–1200 m, 0.12 for 1200–1600 m.

c) *Single-point Walk Score:*

This paper utilized tools such as network analysis in ArcGIS to collect different distances from the starting point to daily destination for the elderly. The distances were then substituted into a distance decay function for calculation, resulting in corresponding decay rates. Finally, the weights of each daily destination were added, and the scores were normalized to obtain the walk scores for each starting point, the formula is as follows:

$$WalkScore = \sum_{i=1}^{n} (W_i \times f(D)) \tag{1}$$

W: Class of daily destinations weight; i: different types of daily destinations; n: all types of daily destinations; f (D): the function corresponding to the starting point to daily destination point distance (D).

d) *Planar Walk Score:*

The single-point Walk Score can only reflect the layout of the daily destinations around a starting point and has limited reference value. The planar Walk Score is needed to analyze the Walk Score of the whole area. The Inverse Distance Weight method in ArcGIS was directly applied to generate a more intuitive distribution map of the walk score in the study area.

2) **Walking environment evaluation**

In the study, 30 professionals with urban and rural planning backgrounds were invited to participate in the survey of constructing the walking environment evaluation system. Combined with network data collection, field survey and spatial environment notation, five trained graduated students invested the elderly flows and walking spatial environments (On September 26, 2022 and October 24, 2022). For some indexes that could not be responded to by objective elements, the study used a 7-point Likert scale for scoring. This paper utilized correlation analysis to examine and identify the key variables for the travel of the elderly.

3 Results

3.1 Analysis of Walk Score Results

Combined with the Grading standard of walk score (Table 3), walk score shows a gradually decreasing distribution trend from north to south (Fig. 3). Compared with the buildings on the south side, the buildings 1, 2, 3, 14, etc. near Jiangtai Road in the Fangyuanli community have higher walk score, which have stronger suitability for daily life. The spatial distribution on the south side of the community shows overall commonalities and local differences. Most of the areas on the south side have a poor walk score, local areas such as buildings 19 and 31. Overall, the service facilities suitable for the elderly in the Fangyuanli community are mainly distributed on the north side of Jiangtai Road and Jiuxianqiao Road, resulting in a large difference in walk score between the north and south of the community. In the future, further investigation and data analysis should be carried out on the relevant streets at the micro level to summarize the strategies for improving the walkability of the area.

According to the evaluation results (Fig. 4), daily destinations such as senior centers, vegetable markets, and pharmacies that are frequently used by the elderly have lower walk score. According to interviews, some elderly people in the community still pick up and drop off their children to and from school, but the walk score of primary schools in the area is low. It is difficult to meet such demand only by walking, and other transportation facilities such as bicycles and buses are also needed. Therefore, based on the classification results of the walk score, the community service facility layout can be adjusted and optimized in a targeted manner to better fulfill these needs of the elderly.

Table 3. Grading standard of walk score

Walk Score	Description	Starting Points Quantities	Proportion
90–100	Walker's Paradise: Daily errands do not require a car.	2	6.90%
70–89	Very Walkable: Most errands can be accomplished on foot.	4	13.79%
50–69	Somewhat Walkable: Some errands can be accomplished on foot.	7	24.14%
25–49	Car-Dependent: Most errands require a car.	14	48.28%
0–24	Car-Dependent: Almost all errands require a car.	2	6.90%

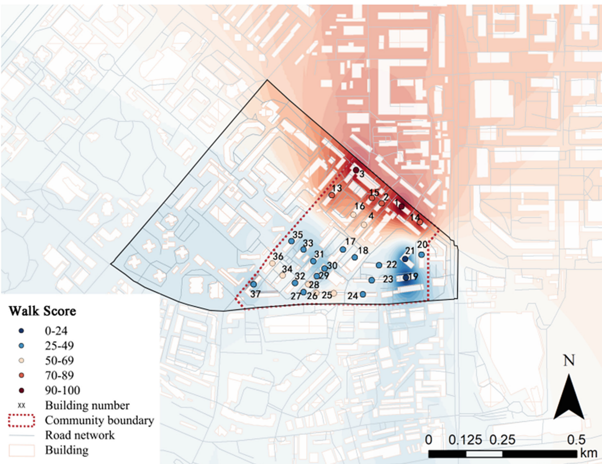
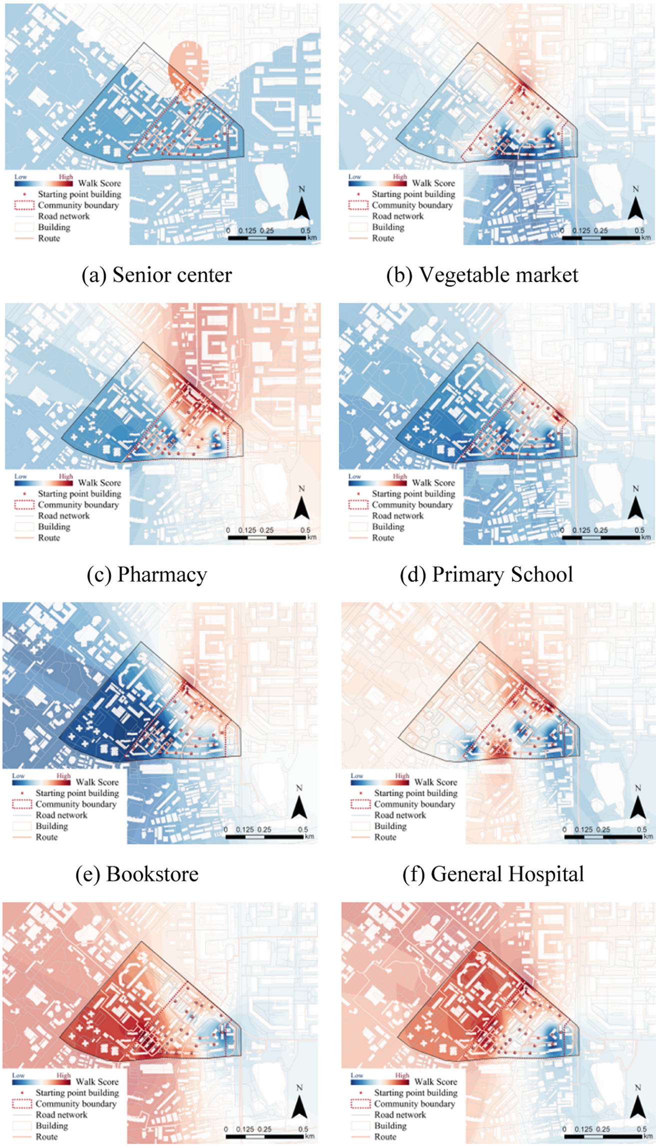


Fig. 3. Community walk score distribution



(a) Senior center (b) Vegetable market

(c) Pharmacy (d) Primary School

(e) Bookstore (f) General Hospital

(g) Convenience Store (h) Barber Shop

Fig. 4. Evaluation results of categorized daily destinations in Fangyuanli Community (Section)

3.2 Analysis of Walking Environment Evaluation Results

The evaluation results of walking environment indexes (Fig. 5) show that: Fangyuan West Road, Jiangtai Road, Jiuxianqiao Road, and Jiangtai West Road have higher traffic flow, with fluctuations in traffic flow in different sections, and more motor vehicles than pedestrians, which are traffic-oriented roads. The traffic flow of Fangyuan South Street is smaller, and the human traffic flow is more than the motor traffic flow, which is a lifestyle-oriented road.

The pedestrian paths with better patency are the AC, CF and GH sections, while the EB and BJ sections have lower scores. The field research found that EB section has a large number of illegal parking of shared bicycles and occupying the road, while BJ section has more utility poles blocking the road.

The study found that the density of rest facilities in different road sections varies greatly. Jiangtai Road and Fangyuan South Street have a high density of rest facilities and distribute a variety of rest facilities, such as seats, fitness facilities and temporary seats in flower beds for people to rest. However, the density of rest facilities in the HI and IJ sections of Jiangtai West Road is 0.

In the service experience of special people, EB, CF, FG, IJ sections have a low score of blind tracks patency, and there are cases of blind tracks being disconnected by poles and manhole covers, etc. AK, DE sections have a low score of ramp arrangement rationality, which means that the sections contain multiple intersections, lack of ramps, and elderly-friendly barrier-free design.

In the street environmental experience sense, AC and FG sections have the highest street greening score, with abundant street greening and pocket parks distributed along the streets. The lower-scoring BJ and IJ sections have only a few street trees, and the road pavement of IJ section is dilapidated and untidy.

In addition, this study also introduces indexes such as sky rate and permeability from the perspective of visual experience of environmental space. Due to the small scale of the study area, the fluctuation of the sky rate is not obvious. Permeability reflects that the closer the road intersection is, the higher the permeability ratio is, and the larger the visual range of the street space can be extended, bringing a richer spatial experience to the pedestrians. (See Fig. 6 for the specific road section division)

3.3 Influential Factors of Elderly Mobility

1) **From a safety perspective** (Table 4)**:**

Motor vehicles flow is significantly negatively correlated with elderly flow ($r = -0.657$). Pedestrian path patency and crosswalk rationality are significantly positively correlated with elderly flow ($r = 0.803$, $r = 0.594$), that is, the more uninterrupted the walk and the more reasonable the layout of sidewalks, the greater the flow of elderly. However, non-motor vehicle flow, human flow, relative walking width, and street lighting security are barely correlated with elderly flow. Therefore, motor vehicles flow, pedestrian path patency, and crosswalk rationality in pedestrian space safety become the key factors affecting elderly mobility. Due to changes in physical conditions, elderly people often have a fear of motor vehicles. In places where there are more motor vehicles and faster

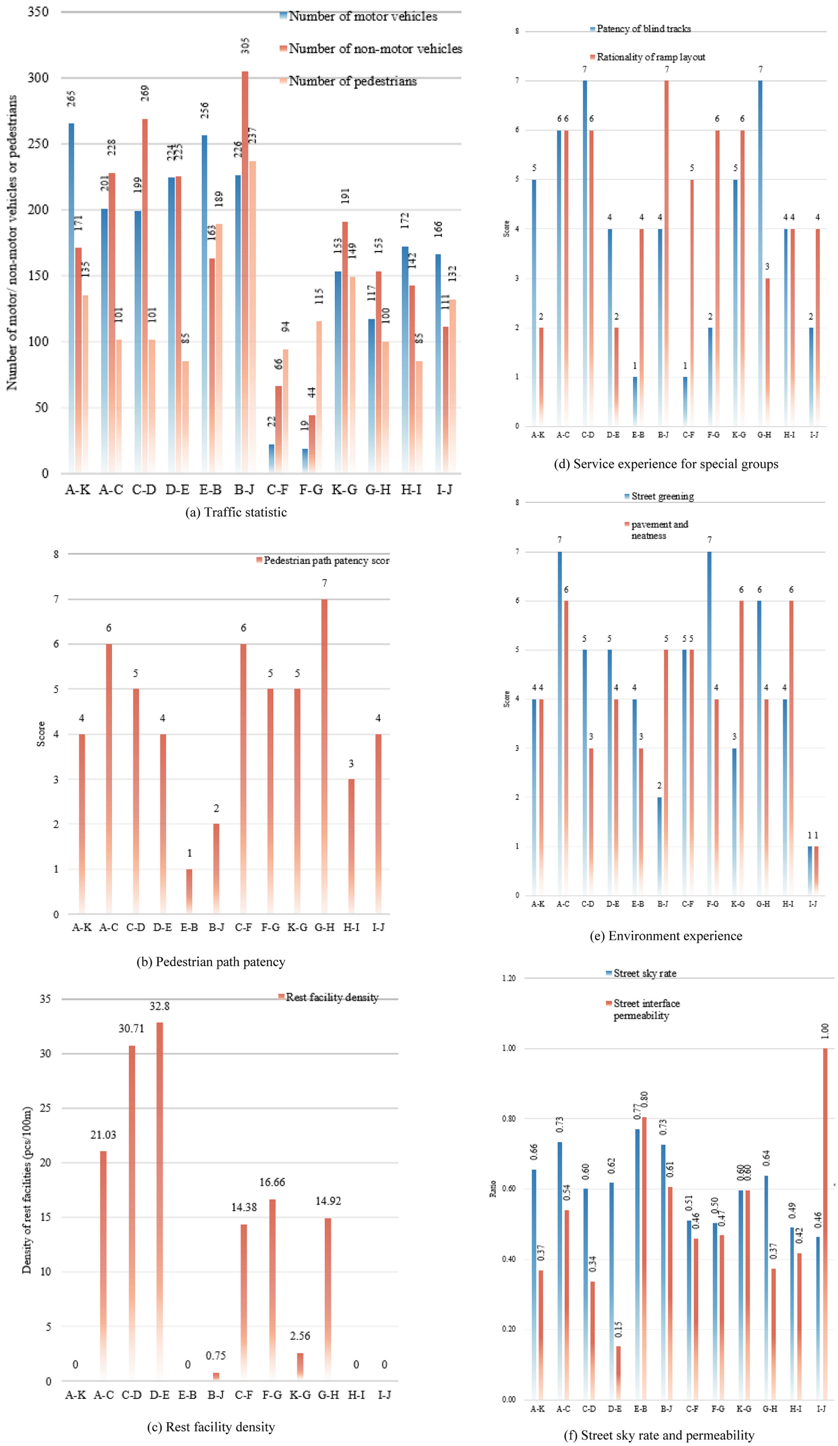


Fig. 5. Evaluation results of walking environment index (Section)

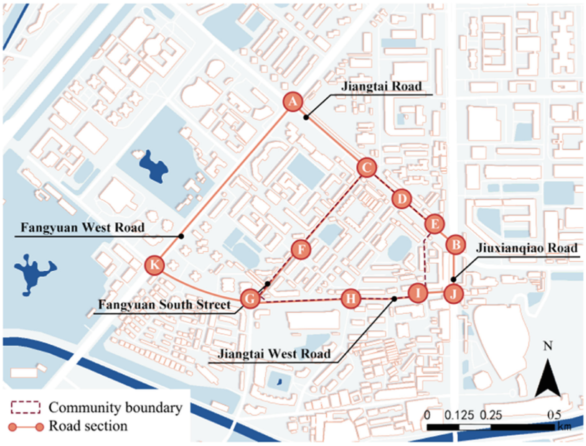


Fig. 6. Schematic diagram of road section division around the community

speeds, traffic and facility intervention measures should be taken to reduce the potential threat of motor vehicles to elderly pedestrians.

2) **From an experiential perspective** (Table 5)**:**

The density and quality of rest facilities, as well as the street greening, are significantly positively correlated with elderly flow ($r = 0.601$, $r = 0.925$, $r = 0.801$). However, blind tracks patency, Ramp arrangement rationality, pedestrian path pavement and neatness, open degree of street space and street-level interface permeability are almost unrelated to elderly flow. Therefore, the density and quality of rest facilities and street greening have become key factors affecting elderly mobility. Among them, rest facilities are one of the most frequently used facilities in walking behaviour. In relatively spacious pedestrian walkways, small communication spaces often appear where rest seats can be set up to provide convenient services for the elderly and other pedestrians, enhance neighbourhood relations, and improve street vitality. Rich and diverse street greening can provide elderly people with sufficient pleasure and comfort. Street-side parks, roadside greenery, lawns, shrubs, and so on will all attract them to walk.

4 Discussion

In areas with degraded residential facilities and obvious ageing, independent departments or working groups need to be set up for systematic management in order to carry out the elder-friendly adaptation of blocks in an orderly manner. In response to:

In terms of walking accessibility, the distance of daily essential walking for the elderly is shortened by increasing the distribution of common service facilities for the elderly in the block. Planning more interactive areas and shops near the residence helps to improve the mobility of the elderly in the neighborhood [22]. For instance, the pharmacy, one of the POI, plays an important role in providing drugs, responsible advice and other services [23]. Increasing the location of drugstores can effectively shorten the walking

Table 4. Correlation analysis of elderly flow and spatial security factors

Relevance		Traffic security					Facilities security	
		Motor vehicle flow	*Non-motor vehicle flow*	*Human flow*	*Relative walking width*	*Pedestrian path patency*	*Crosswalk rationality*	*Street lighting security*
Elderly flow	Pearson correlation	−.657*	−0.322	−0.47	0.135	.803**	.594*	−0.004
	Sig. (Double tail)	0.02	0.308	0.123	0.675	0.002	0.042	0.99
	The number of cases	12	12	12	12	12	12	12

** At the 0.01 level (double tail), the correlation is significant. * At the 0.05 level (double tail), the correlation is significant.

Table 5. Correlation analysis of elderly flow and spatial security factors

Relevance		Facilities experience		Service experience of special groups		Environmental experience sense				
		Density of rest facilities	*Quality of rest facilities*	*Blind tracks patency*	*Ramp arrangement rationality*	*Street greening*	*Pedestrian path pavement and neatness*	*Open degree of Sky Rate*	*Open degree of DH*	*Street-level interface permeability*
Elderly flow	Pearson correlation	.601*	.925**	0.209	0.125	.801**	0.172	−0.091	0.075	−0.482
	Sig. (Double tail)	0.039	0.001	0.514	0.698	0.002	0.593	0.777	0.816	0.112
	The number of cases	12	12	12	12	12	12	12	12	12

** At the 0.01 level (double tail), the correlation is significant. * At the 0.05 level (double tail), the correlation is significant.

distance of buying medicine, make it more convenient to buy drugs and reduce the uncertainty of safety.

In terms of safety, strict standards and regulations for elder-friendly pedestrian blocks need to be formulated. Studies have found that traffic flow and pedestrian path patency, among other things, influence seniors' choice of walking paths. And these need to be guided by strict standards to transform the roadway. In terms of behavioral regulations, strict separation of pedestrians and vehicles is required, limiting the speed of motor vehicles when driving in aging communities, and proposing stricter penalties for motor vehicles occupying pedestrian walkways for parking.

In terms of spatial amenity, the first step is to optimize the rest facilities in the sections with high walking frequency. This initiative is divided into two main aspects: facility density and facility quality. What affects people's walking preferences is the visual and spatial quality that makes walking comfortable [24]. Street rest facilities were often neglected in the construction of early residential areas, which is the reason why old communities are unable to meet the needs of older people for pedestrian rest. Another initiative is to beautify the walking environment. People prefer to walk on streets with continuous, soft edges [8, 23]. We need to improve the visual continuity of walking through street-level storefront management, etc. Adding greenery and creating shade around street rest facilities can increase the comfort of the rest facilities and help the elderly avoid the fatigue of walking for a long time.

5 Conclusions

Triggered by population aging and health problems, this paper established a comprehensive evaluation framework in two parts: using walk score to identify the problem, and walking evaluation system to identify the influencing factors for elderly mobility. Then, we formulated comprehensive optimization measures for community support service facilities and friendly guidance control strategies based on the evaluation results. At this stage, there are still shortcomings in this study: (1) the possible paths that people walk in the site are not completely covered; (2) The feedback of the results after the system is applied is not conducted to identify possible problems within the system. However, for most old communities, the elder-friendly walking system constructed in this paper is typical and can provide a guiding paradigm for elder-friendly construction in most cities that are aging and have a disorderly renewal of old communities, so that old residential areas can be re-energized for sustainable development.

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