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EDITED BY

Yang Zhang,
Chengdu University of Technology, China

REVIEWED BY

Jing Xia,
Hefei University of Technology, China
Pan Hu,
Southeast University, China

*CORRESPONDENCE

Jiayu Chen,
✉ jychen@whut.edu.cn

[†]These authors have contributed equally to this work and share first authorship

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The fine evaluation and optimization strategy of barrier-free public activity systems from the perspective of a county-level city: Xinle, Hebei Province

Sen Zhang^{1†}, Ke Zhang^{2†}, Haoge Zhao^{3†}, Jiahao Zhang³ and Jiayu Chen^{1*}

¹School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, China,

²Department of Built Environment, Eindhoven University of Technology, Eindhoven, Netherlands,

³School of Architecture, Tianjin University, Tianjin, China

Introduction: Compared with prefecture-level cities and other large cities, county-level cities in China have significant differences in composition of public service facilities, population size characteristics, and social awareness. Thus, it is necessary to conduct refined research on barrier-free design and evaluation in county-level cities.

Methods: We used Xinle as an example based on the composition of vulnerable groups and people's spatio-temporal activity data from the perspectives of public service facilities, tactile paving systems, and activity areas to explore the construction approach and current situation of barrier-free public activity systems (PAS).

Result: The main vulnerable groups in Xinle those who are the elderly, visually impaired, and mobility-impaired individuals. Among these groups, common needs characteristics can be found in the area of shopping consumption and company and enterprise, non-common characteristics centered around food and beverages, life services, healthcare, and parking lots. Then the spatial distribution of related public service facilities is vital for building barrier-free environments. At the same time, the tactile paving system in Xinle has weak correlation with key facilities and poor construction standards.

Discussion: From this, optimization strategies for a barrier-free PAS is construct in this research and to provide theoretical and technical references for county-level cities to carry out related work.

KEYWORDS

county-level city, vulnerable group, urban public service facilities, activity area, barrier-free environments

1 Background

Currently, China has 394 county-level cities. Based on China's seventh national population census and the local statistical bulletins from 2023, the total population of county-level cities is estimated to be approximately 400 million, accounting for 25%–30%

of the country's total population. However, significant regional differences exist in the quality of urban environmental construction and public service levels among county-level cities in China (Xiong et al., 2018; Wang et al., 2020; Sun et al., 2022). County-level cities in developed regions such as Jiangsu, Zhejiang, and Guangdong have well-developed infrastructure, good environmental governance, and public services that are close to (or even exceed) the level of prefecture-level cities. However, county-level cities in underdeveloped areas face problems, such as lagging infrastructure and insufficient public services (Li et al., 2015; Zhang et al., 2019). Overall, the quality of county-level cities in China is fairly low, with insufficient supervision, refined evaluation and optimization strategy of urban environments, particularly for the construction of barrier-free environments (BFEs) (Sun et al., 2023; Yang et al., 2024; Tan and Chen, 2025). Since the Management Measures for Creating National Demonstration Cities (Counties) for Barrier-free Construction were released in 2022, the barrier-free construction of county-level cities has begun to receive attention. Although the 2023 Law of the People's Republic of China on the Construction of Barrier-free Environments has effectively promoted the renovation of barrier-free facilities nationwide, enforcement efforts in county-level cities are generally weaker than those in prefecture-level cities (Sun et al., 2023). The construction of BFEs in many city centers and old urban hubs in county-level cities is still in the early stages. Meanwhile, because of comprehensive factors such as uneven resource allocation, economic pressure, traditional beliefs, group discrimination, and social services, the actual living experiences and quality of life of people with disabilities, the elderly, and those with mobility impairments in county-level cities vary greatly (Zhang and Ge, 2017), and their daily activities are complex and challenging (Deng and Zhou, 2022). Exploring a refined evaluation and optimization strategy path for accessible environments that is suitable for county-level cities based on the layout features of urban functional facilities, the daily activity needs of the population, and environmental conditions is of great significance for promoting social equity and inclusiveness in county-level cities (Tang and Dong, 2022). At the same time, conducting research on accessible design strategies from the perspective of county-level cities can supplement the lack of guidance for the construction of accessible environments in county-level cities and further improve the spatial as well as regional allocation systems of accessible facilities in urban and rural parts of China. Thus, we used the city of Xinle in Hebei Province as an example to perform in-depth research on strategies and practical paths for building accessible environments in central urban areas.

2 From evaluation to optimization

Currently, the construction of BFEs has led to the establishment of systematic norms and procedural requirements for developed nations (Dai et al., 2023; Tucker et al., 2023; Zhao et al., 2014). For example, Japan regards accessibility as a holistic system and has refined matching rules between facility configuration and crowd activities through legislation (Deng and Zhang, 2015). In Japan's urban hierarchy, prefectures are responsible for formulating regional accessibility policies and coordinating accessibility planning across cities, towns, and villages. Meanwhile, cities, towns, and villages

focus on refining accessibility requirements according to local regulations, and some places have set stricter standards. In Europe, the Netherlands officially implemented the 'Omgevingswet' in 2024, which provides a legal and digital unified platform for all spatial construction, proposes institutional foundations for accessible facilities, and encourages people with disabilities to participate in the research and development of accessible policies at the community level based on the implementation of local inclusive policies at the provincial, administrative, and municipal levels (Henderson-wilson et al., 2022; Van Hoven et al., 2024). The accessibility system in Germany consists of federal laws, administrative regulations, and enforcement mechanisms at the state and municipal levels, comprising a multi-level governance model. The federal level sets basic obligations and technical standards through legislation (such as DIN 18040), and state governments can develop local regulations in accordance with legislation to promote the integration of accessibility principles into land-use planning and urban design processes. Simultaneously, based on this, state governments refine the technical requirements in the regulations for urban construction management, whereas municipalities implement them in actual construction projects (Manley, 1996; Loeschcke and Pourat, 2022). In the US, with federal laws at the core, states, counties, and municipalities refine enforcement through additional regulations, thus forming a multi-level standard system. At the state level, the focus is on implementing the Disability Act, developing state-building codes, and overseeing state-owned facilities. At the county level, requirements are refined through local regulations that focus on managing areas that have not been incorporated into municipalities (including relevant rural zones) to ensure that various public service facilities comply with the Disability Act (Eisenberg et al., 2020; Wen and Zhang, 2020; Tan and Chen, 2025).

China uses the Law of the People's Republic of China on the Construction of Barrier-free Environments, implemented in 2023, as a guideline to promote the progress of building urban BFEs. However, compared with the international experience, the creation and governing of accessible environments in urban areas at all levels in China generally relies on extensive promotion. The current practice of building BFEs is more traditional in county-level cities, most of which focus on enhancing facility coverage guided by administrative assessment and the quality improvement of single-material facilities (such as tactile paving and pedestrian crossing facilities); county-level cities have not formed a systematic construction model (Chen et al., 2020; Ye and Su, 2021).

In addition, county-level cities in different regions also reflect different construction orientations in the construction of accessible environments. For example, county-level cities in the Yangtze River Delta and Pearl River Delta (such as Kunshan and Yiwu) consider barrier free construction as the key to improving urban quality and soft power. Its practice pays attention to high standard special planning, and integrates the development of smart cities. Its achievements are not only reflected in high-density and high-quality hardware facilities (such as tactile paving and ramps), but also include barrier free electronic maps, government information barrier free refined disability services, realizing the exploration from physical barrier free environment to information barrier free environment (China Press for Persons with Disability, 2025). In contrast, the construction of county-level cities in North China (such as Hebei) is more reflected in "policy driven

and key breakthroughs,” with the core goal of responding to higher-level assessments (Wang, 2025). Policy promotion relies on administrative instructions and special rectification. Although there has been a significant improvement in the accessibility rate of key venues, it is limited by funding, traditional concepts, and insufficient supervision in the later stage (Xu, 2015). Overall, there are problems such as systematic deficiencies, low levels of intelligence, and limited social participation. This difference reveals the uneven development of barrier free environments in county-level cities in China: Southeast coastal counties and cities shape modern urban competitiveness and cultural warmth through barrier free construction, while North China counties and cities focus more on completing basic compliance tasks. The two are in stark contrast in terms of construction motivation, technological application, and system integrity.

In addition, owing to the lack of effective higher-level planning and guidance, refined evaluation and optimization, and insufficient integration with the actual situation in the region, lax management mechanisms and outdated design concepts in county-level cities have been exacerbated (Sun et al., 2023). County-level cities face problems such as mismatched planning and demand for accessible facilities, loose regulatory systems, and weak public participation awareness (Deng and Zhou, 2022). Little research has been conducted on the adaptability of barrier-free systems to their own development levels, population structures, and spatial characteristics, and there is still insufficient consideration of the feedback needs of residents, resulting in many county-level cities’ construction of BFEs lagging behind real conditions and people’s needs.

Regarding the latest research findings, existing achievements are primarily grounded in an analysis and evaluation of the activity-related characteristics of disabled people in prefecture-level cities or large and super-large cities (Chen et al., 2020; Hua et al., 2025). Urban spatial features have a significant impact on the travel intentions of disabled and elderly people (Cheng et al., 2019; Chidiac et al., 2024; Wen et al., 2023). Some studies have shown a significant correlation between the activity-related characteristics of people with disabilities and the distribution of urban public service facilities (PSFs) (Shen et al., 2023; Jiang et al., 2025; Zhou et al., 2022). However, in research on county-level cities or cities of a similar scale, qualitative survey methods or static facility statistics rely mainly on basic data (such as people’s life perceptions and activity-related characteristics) through traditional means (such as key person interviews and questionnaire collection) to evaluation the matching relationship between people’s daily travel and various PSFs, public spaces, and other environmental elements (Ravi et al., 2021; Zhang et al., 2021; Chen et al., 2024; Fan et al., 2024). There has been insufficient research on optimization strategy for building accessible environments and clarifying the focus of design elements (Xiang and Wang, 2025). Owing to issues such as information accuracy and sample size, it is difficult to support precise decision-making, and a systematic practical path has not yet been formed.

Through a review of relevant studies on the evaluation and optimization strategy experience and present situation in different countries, we can deduce that research on accessible environments for county-level cities has begun to establish a foundation, and emerging technologies have provided possibilities

for building new research paths. However, limitations remain in the governing and building of accessible environments in county-level cities in China—including a lack of effective macro-guidance, inadequate evaluation of spatial adaptability, and an unclear focus on the optimization strategy of accessible environments in urban areas—which hinder the goal of refined construction. The research data and methods at the county level are relatively single, and a correlation analysis of pertinent dimensions (such as urban structure, facility configuration, population travel demand, and activity space in the region) has not yet been established. The spatial coupling mechanism between population activities and environmental factors has not been quantified and cannot effectively guide the development of barrier-free designs and governing. Insufficient social attention and a lack of humanistic care from citizens and governments in county-level cities have reduced the driving force and quality of BFE construction.

Compared with prefecture-level cities or large or super-large cities, county-level cities have their own features with a moderate urban scale, clear urban and population structures, and a fairly clear allocation of relevant PSFs (Xiang and Wang, 2025). This provides a solid foundation for refining the evaluation and optimization of building an accessible environment. However, there are gaps in existing research on county-level cities, such as small data volumes and insufficient coupling between facilities, paths, and regions. We relied on multi-source spatiotemporal data and a facility weight model to compensate for this circumstance. Learning and simulating data features can provide new research perspectives and methods to address the difficulties in obtaining data on disabled populations and insufficient sample data in county-level cities. Thus, based on the urban structural aspects of county-level cities, combined with the evaluation of people’s spatio-temporal data and facility needs, this study conducted research on an accessible public activity system (PAS) to refine the key points, goals, and requirements for building accessible environments in county-level cities, and to develop an evaluation and optimization path for developing accessible environments in county-level cities with reference values.

3 Investigation and methodology

3.1 Investigation in Xinle City

We selected Xinle, Hebei Province, as the research object. The urban construction land in Xinle covers 2779.44 ha, with moderate transportation distances from Beijing, Tianjin, and Xiong’an. It is surrounded by Shijiazhuang Airport and the Zhengding High-Speed Railway Station, and two highways pass through the city. Location and transportation conditions are favorable. As of the start of 2023, the permanent population of Xinle is approximately 480,000 inhabitants, and the residential population in the central urban hub numbers approximately 280,000 (SJZ Gov.cn, 2023).

From the characteristics of county-level cities, the economic scale of Xinle is much lower than that of developed county-level cities in the Yangtze River Delta and Pearl River Delta (e.g., Kunshan and Yiwu). However, due to the influence of cities such as Beijing and Tianjin, some infrastructure is better than that of remote county-level cities. Through discussions with government departments, we learned that public service resources (such as healthcare and

education) in Xinle are relatively weak, with low coverage of barrier-free facilities and limited employment opportunities for people with disabilities. When implementing policies such as national disability protections and the construction of BFEs, Xinle faces similar problems of insufficient funding and lagging implementation compared to most county-level cities. Hence, Xinle can serve as a reference for conducting research on ordinary county-level cities in Central and Western China.

In terms of data selection, the study takes into account the difficulty of collecting data on vulnerable groups in county-level cities, and select two groups of people: the elderly and disabled, based on the travel characteristics, travel abilities, and travel desires of relevant vulnerable groups. At the same time, to further ensure the operability of the research, based on the data from the Seventh National Population Census and the Second National Disability Sampling Survey, the team ultimately focused on the sub groups with the highest proportion in the target population, namely, the 60–65 age group (accounting for about 50% of the elderly population over 60 years old) and the two types of disabilities, physical and visual disabilities (totaling over 40%), to ensure that the research results can meet the needs of the widest range of people. After preliminary discussions and research with the Disabled Persons' Federation of Xinle, we found that, as of 2023, the main types of vulnerable groups in Xinle who can independently carry out daily activities are the elderly (aged 60 years and older, with normal physical conditions, accounting for approximately 18% of the permanent population), the physically disabled (1.91%), and the visually impaired (0.26%). As such, from October to November 2024, we collaborated with the city's Natural Resources and Planning Bureau as well as the Disabled Persons' Federation to hold talks with 94 volunteers from the three groups (aged 60–65) and tracked their spatio-temporal activity data for 10 days. Simultaneously, we collected the points-of-interest (POI) data of relevant PSFs in Xinle and investigated the urban road network, tactile paving, and other pertinent features of the built environment.

3.2 Design of the research

Based on the literature covering accessible PAS, we first constructed a technical route to evaluation the characteristics of people's facility needs, predict potential activity areas, and design PAS optimization strategies.

1. Evaluation the characteristics of people's facility needs: Using spatio-temporal data, we examined and statistically analyzed various PSFs within the activity areas of the three groups. Based on facility weights, we built a dataset regarding common and non-common needs PSFs, with a high correlation to the three groups of people studied.
2. Predicting potential activity areas: Based on the spatial layout of common and non-common public services and PSFs, we identified the main activity areas and importance levels of the three groups of people. In combination with existing roads, tactile paving and other systems, we distinguished the structural characteristics and existing problems of the barrier-free PAS in Xinle's central hub from the node-path-area perspective.

3. Designing PAS optimization strategies: Based on the urban spatial layout of the central urban hub, we formulated a optimization strategy for the accessible PAS in Xinle's urban center, including accessible facility nodes, travel paths, activity areas, and public service networks. Next, we constructed a governing practical framework.

3.3 Analysis methods

We used the stop point weighting method based on spatio-temporal data, combined with the length of stay, to calculate the weight of facilities (Formula 1), quantify their importance, identify the common and non-common activity areas of the three groups through kernel density analysis, and evaluate the matching degree of the service facilities and tactile paving (Formula 2) to build an accessible PAS.

The time-weighted weight formula is:

$$Wk\ Time = \frac{\sum (stay\ time \times quantity\ of\ certain\ types\ of\ facilities)}{\sum (stay\ time \times total\ number\ of\ facilities)} \times 100\% \quad (1)$$

The calculating the matching degree between service facilities and tactile paving formula is:

$$Matching\ degree = \frac{number\ of\ service\ facilities \times (covered\ by\ tactile\ paving)}{total\ number\ of\ facilities} \times 100\% \quad (2)$$

4 Results

4.1 Characteristics of people's activities and the need for PSFs

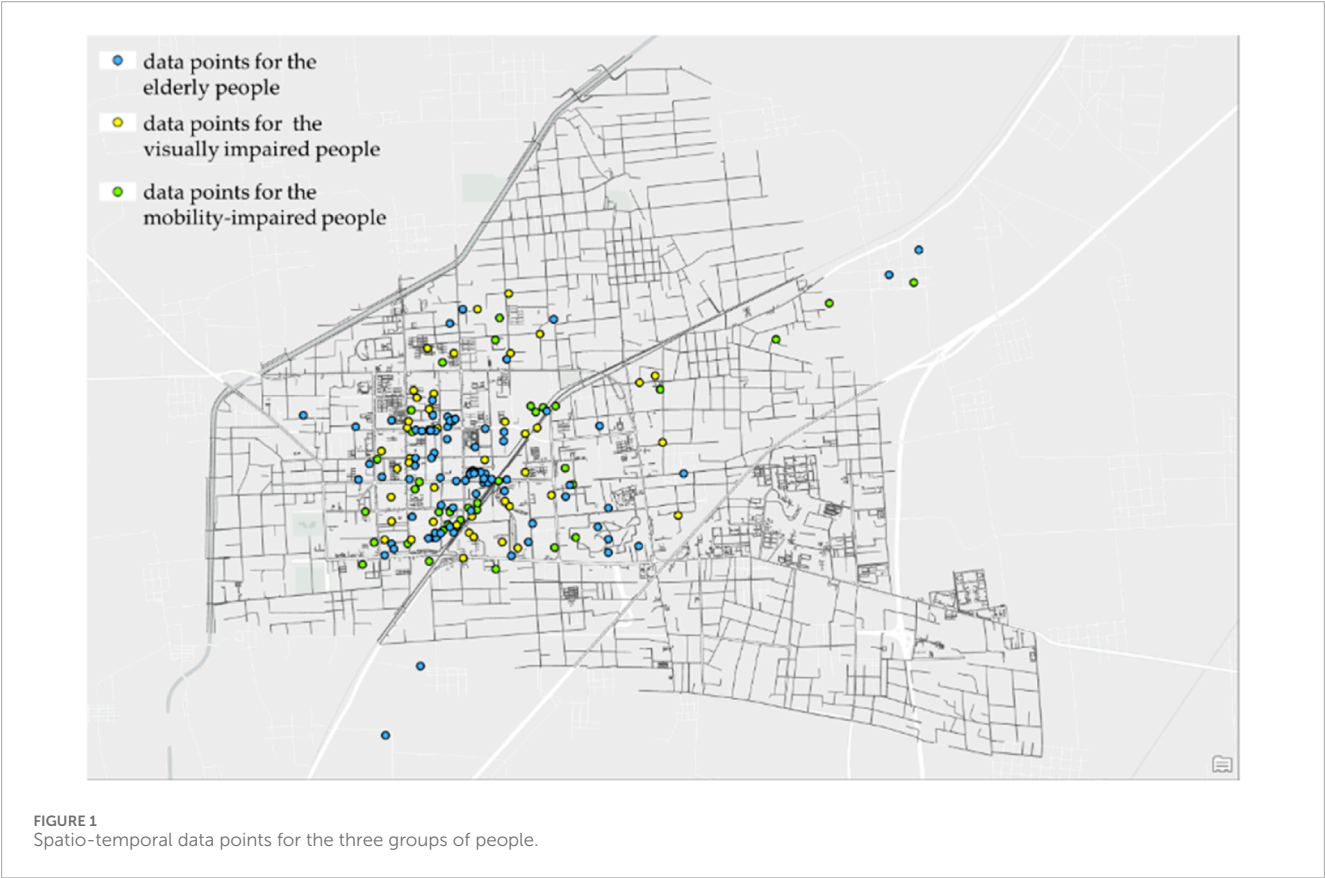
From the basic characteristics of the 94 volunteers (Table 1), we can see that although the participants ranged in age from 60 to 65 years old, the visually impaired people engaged in a higher proportion of work, reaching 41.4%. After the interviews, we learned that they mainly engage in blind massage to earn a living. However, this group displayed a lower ability to perform activities independently. People with lower-limb disabilities use wheelchairs as tools and have greater mobility. Most of the participants, including the visually impaired, became disabled after birth and have daily life experiences. All participants engage in independent activities.

Figure 1 shows the spatial stopping point information for the three groups after filtering their residential areas. The main activity areas of the elderly are concentrated in Xinle's old urban center, with a high share of shopping malls, restaurants, and other facilities, whereas the activity areas of the visually impaired and physically disabled are somewhat scattered.

We set up a buffer zone 10 m around the stopping point; we then counted the stay time of the volunteers in the PSFs within the buffer zone to identify the weight of the facilities. Table 2 presents the results.

TABLE 1 Basic characteristics of the volunteers.

Information	Elderly people	Visually impaired people	People with motor impairments
Number	38	29	27
Sex (Male/Female)	20/18	11/18	12/15
Proportion in employment	26.3%	41.4%	25.9%
Proportion of independent activities	100%	34.5%	74.1%
Share of disabilities caused by acquired disabilities	-	72.4%	81.5%



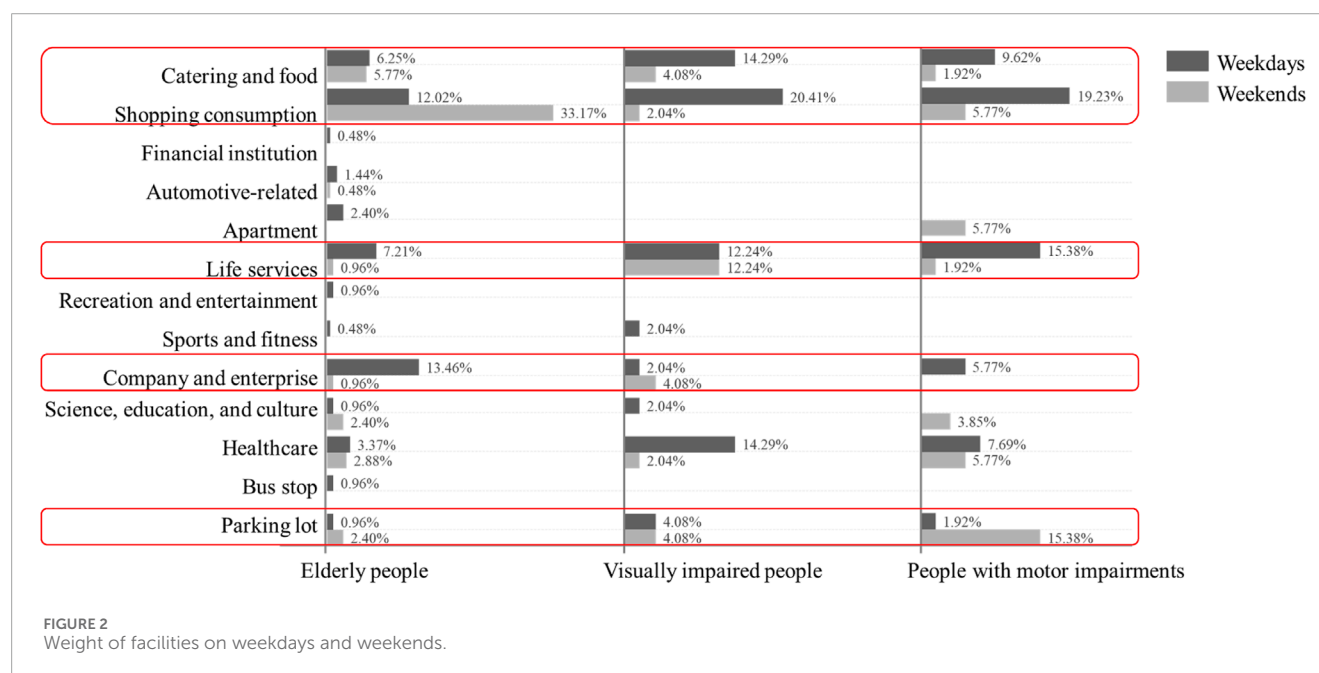
From the analysis of facility weight characteristics, we can see that the main types of facilities that elderly people use for daily activities are shopping and consumption facilities, companies and enterprises, and catering and food facilities, accounting for 71.63% of total importance. The main facilities for daily activities of visually impaired people are life services, shopping and consumption, and healthcare, accounting for 65.31% of total importance. The main facilities for the daily activities of the physically disabled are shopping and consumption, parking lots, and healthcare, accounting for 58.77% of total importance. At the same time, we also divided the crowd facilities into weekdays and weekends (Figure 2), and further discussed the activity characteristics and facility demand characteristics of the three types of people in Xinle City.

From the statistical results of facility weights on weekdays and weekends, it can be seen that the elderly population in Xinle City

has richer facility needs compared to the other two groups. For Catering and food facilities, the needs of the elderly on weekends and weekdays are relatively close, but the two groups of disabled people show a much lower demand on weekends than on weekdays (with a difference of about 7%–10%); But for shopping consumption facilities, the demand of the elderly on weekends is higher than that on weekdays, showing completely opposite demand characteristics to the two groups of people. This may be highly correlated with the ability of the elderly to independently carry out daily activities; For Life services facilities, the daily and weekend needs of visually impaired people are almost the same, while the elderly and physically disabled people show more characteristics of daily needs. Through follow-up visits, we also learned that this is somewhat related to the organization of activities for visually impaired people; At Company and Enterprise facilities, elderly people have certain activity needs

TABLE 2 Characteristics of the facility weights.

PSFs	Elderly people	Visually impaired people	People with motor impairments
Catering and food	12.02%	16.33%	6.54%
Shopping consumption	45.19%	22.45%	25.00%
Financial institution	0.48%	0.00%	0.00%
Automotive-related	1.92%	0.00%	0.00%
Apartment	2.40%	0.00%	5.77%
Life services	8.17%	24.49%	17.31%
Recreation and entertainment	0.96%	0.00%	0.00%
Sports and fitness	0.48%	2.04%	0.00%
Company and enterprise	14.42%	6.12%	5.77%
Science, education, and culture	3.37%	2.04%	3.85%
Healthcare	6.25%	18.37%	13.46%
Bus stop	0.96%	0.00%	0.00%
Parking lot	3.37%	8.16%	20.31%



on weekdays, and some elderly people have expressed that they are still in positions of rehiring or management. At the same time, we have noticed that visually impaired people also have certain facility needs on weekends, which is highly correlated with some of their work (such as blind massage); For the Parking lot facilities, it can be seen that the demand for elderly and physically disabled people is higher on weekends than on weekdays, while the visually impaired

are more evenly distributed, which may be related to their inability to engage in more activities.

Based on this, we built an important facility set consisting of six categories of facilities with high weight rates: catering and food, shopping and consumption, life services, companies and enterprises, healthcare, and parking lots. Through one-way analysis of variance (ANOVA), we identified the differential

TABLE 3 Characteristics of differences in importance of facilities.

PSFs	Statistical comparison	SS	df	MS	F-value	P-value
Catering and food	Between-group	17.49	2	8.745	13.059	<0.001**
	Within-group	58.928	88	0.67		
	Total	76.418	90			
Shopping consumption	Between-group	0.541	2	0.271	0.047	0.954
	Within-group	562.219	97	5.796		
	Total	562.76	99			
Life services	Between-group	18.361	2	9.181	28.221	<0.001**
	Within-group	30.904	95	0.325		
	Total	49.265	97			
Company and enterprise	Between-group	1.178	2	0.589	0.303	0.739
	Within-group	163.098	84	1.942		
	Total	164.276	86			
Healthcare	Between-group	14.098	2	7.049	29.544	<0.001**
	Within-group	21.472	90	0.239		
	Total	35.57	92			
Parking lot	Between-group	14.375	2	7.187	56.722	<0.001**
	Within-group	11.277	89	0.127		
	Total	25.652	91			

*Significance levels of 0.05, 0.01, and 0.001.

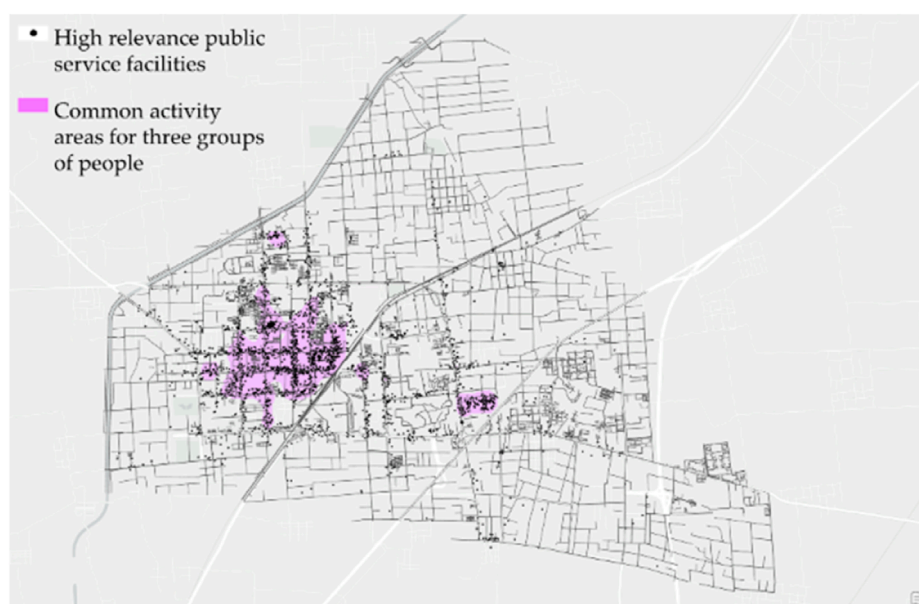
TABLE 4 Classification characteristics of activities and places for the three types of people.

PSFs	Characteristics of people' activities	Classification of activity areas
Catering and food Company and enterprise	Three groups of people engage in daily shopping, work, and other activities.	Common activity area
Shopping consumption Life services Healthcare Parking lot	Visually impaired and physically disabled individuals have a low demand for dining activities outside. The life service category includes telephone and telecommunications services as well as home appliance maintenance, which are the main activity areas for visually impaired people. Healthcare and parking lots are primarily activity areas for people with physical disabilities.	Non-common activity area

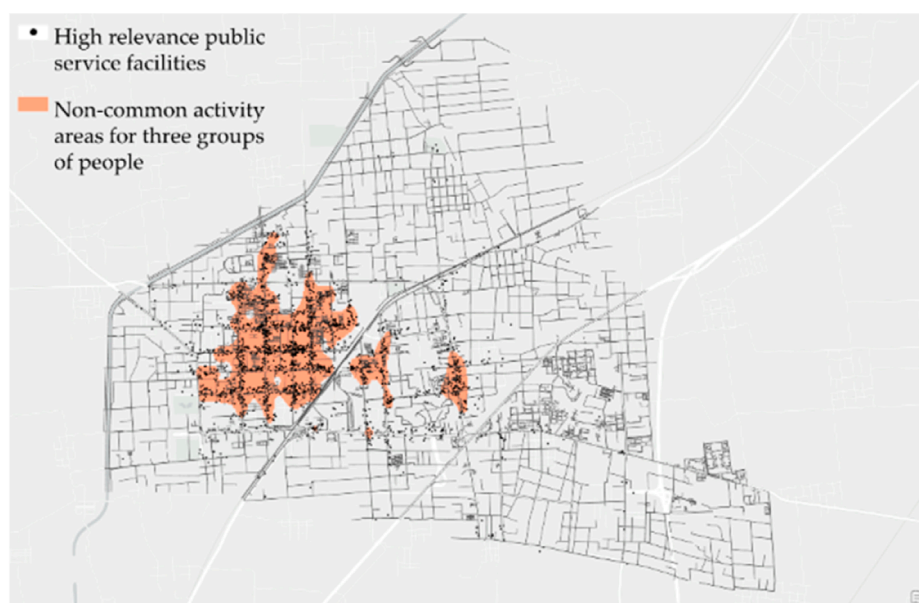
characteristics of facility importance among the three groups (Table 3).

We found statistically significant differences in the dependence of the three groups on catering and food, lifestyle services, healthcare, and parking lots. However, the intergroup differences in shopping consumption ($F = 0.047$, $p = 0.954$) and company and enterprise ($F = 0.303$, $p = 0.739$) are not statistically significant. Hence, we inferred

that the two types of PSFs for shopping consumption and company enterprises that do not have significant differences are the three types of high-frequency stay facilities for the people and have highly common characteristics regarding needs. The four kinds of PSFs—catering and food, lifestyle services, healthcare, and parking lots—reflect significant weight differences and represent the needs of different types of people, thus possessing non-common characteristics surrounding needs. As



a



b

FIGURE 3

Layout characteristics of PSFs with a high correlation to the three groups of people. (a) Spatial distribution of common activity areas (b) Spatial distribution of non-common activity areas.

such, we further sorted the features regarding the activity and venue classification of the three groups of people in Xinle's urban center from the perspective of the common and non-common needs of facilities (Table 4).

Among non-common facilities, the need for medical facilities for visually impaired people is significantly higher than that for

other people, and attention should be paid to the connection between tactile paving and life services, shopping and consumption, and healthcare. Simultaneously, the need for parking lots among people with motor impairments is significant, and attention should be paid to barrier-free links between shopping, parking lots, and healthcare.



FIGURE 4
Accessibility public activity system in Xinle's urban center.

4.2 Spatial distribution characteristics of PSFs and their compatibility with the tactile paving system

4.2.1 Identifying areas of people's activities

Based on the features of the three types of activities and place-based classification, we analyzed the spatial kernel density of facilities and distinguished different density areas with unified colors to simulate and predict the main public activity areas for the three types of people (Figure 3). Figure 3a shows the spatial density distribution of common facilities for shopping consumption and corporate enterprises. The facility concentration areas are mostly located in the old urban part of Xinle and around the government buildings, with some distribution near the Hebei Academy of Fine Arts on the east side. Figure 3b shows the core density distribution of non-common facilities such as those related to catering, food, lifestyle services, healthcare, and parking lots. The overall concentration of facilities still revolves around the old city center, but there are also multiple potential activity areas near the Hebei Academy of Fine Arts and Xinhua Factory, with more obvious spatial differentiation characteristics than common activity areas.

4.2.2 Construction of an accessible PAS in Xinle's urban center

Based on the characteristics of these areas, we investigated the distribution of tactile paving in the center of Xinle. We expanded the tactile paving by 5 m on both sides to form coverage of tactile paving. Coupled with the coverage of tactile paving and related

facilities, we studied and constructed a model of Xinle's current barrier-free PAS (Figure 4).

The six types of facilities that are of great relevance to the three groups of people are catering and food, shopping and consumption, life services, companies and enterprises, healthcare, and parking lots. They constitute the core of an accessible PAS. As the most common type of barrier-free facility, the tactile paving system plays an important role in guiding the visually impaired and other vulnerable groups when they travel. Hence, it is an important path for support in a barrier-free PAS. At the same time, the common and non-common activity areas of people can provide a reference for the precise construction of BFEs, among which common areas can be considered key zones for BFE design and are visited by vulnerable groups. Non-common areas, owing to their targeting of specific people, are not universal and therefore general areas for BFE design.

The barrier-free PAS built in this study by coupling facilities, tactile paving, and regions can serve as a crucial guarantee for the disabled and other vulnerable groups who need to carry out daily life activities.

4.2.3 Current problems

In combination with the barrier-free PAS in Xinle's urban center, we conducted field research on urban facilities, tactile paving, and activity areas, and summarized the existing problems in governing and design.

1. Lack of barrier-free construction of highly relevant facilities

Diverse types of highly relevant facilities are arranged primarily along the street; however, some shops and places have step

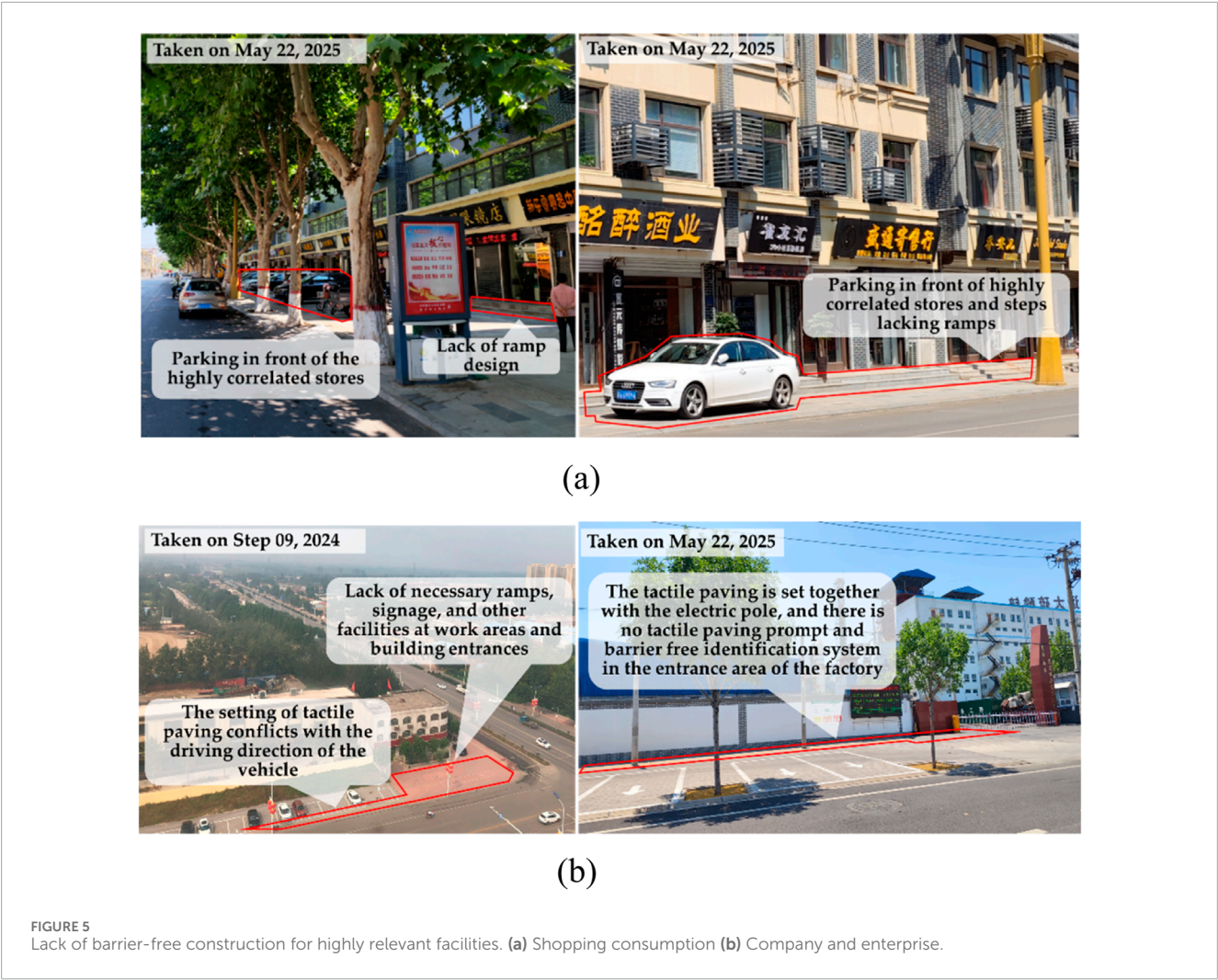


TABLE 5 Matching degree of tactile paving and highly relevant facilities.

Facility	PSFs	Total	Covered facilities	Degree of matching
Common needs facility	Shopping consumption	2128	1277	60.0%
	Company and enterprise	519	145	27.9%
Non-common needs facility	Life service	868	634	73.0%
	Catering and food	966	531	55.0%
	Parking lot	141	65	46.1%
	Healthcare	358	132	36.9%

height differences and lack access to ramps. At the same time, some area markings have difficulty distinguishing colors, and some signs are obscured by plants or have inappropriate heights. The high occupancy of cars and bicycles at the entrances of most shops has caused difficulties for various vulnerable groups in accessing these facilities (Figure 5). In addition, although the Fuxi Terrace Scenic Area is not the main activity area of the crowd, as the core scenic spot of the city, the overall barrier-free design is insufficient; the tactile paving, ramp, and voice prompt system are missing, and the guide map lacks Braille prompts, which cannot meet the needs of vulnerable groups.



FIGURE 6
The construction of tactile paving is not standardized.

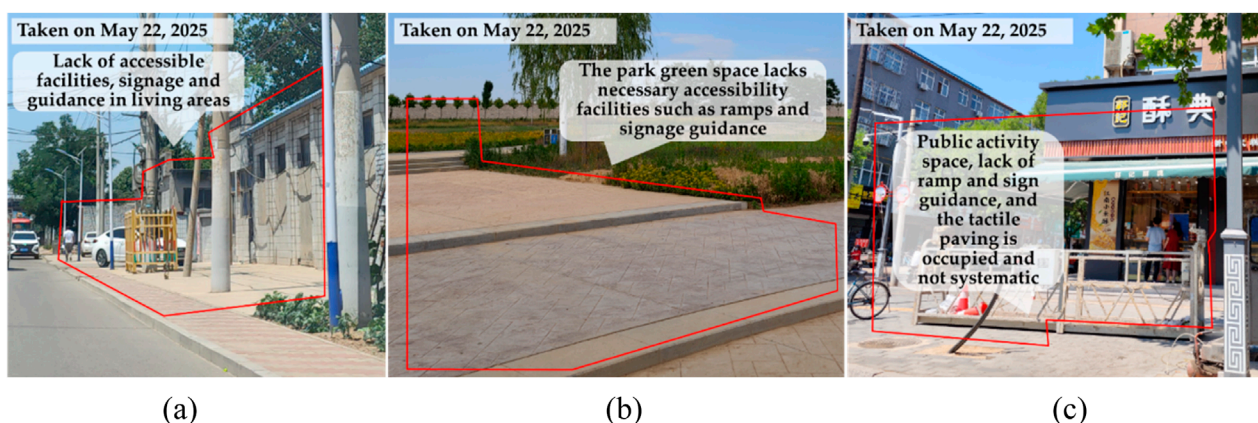


FIGURE 7
The construction of tactile paving is not standardized. (a) Apartment (b) Recreation and entertainment (c) Catering and food.

- The tactile paving has low compatibility with highly relevant facilities, and its construction is not standardized

We studied the spatial superposition of the current tactile paving system and the six types of facilities in Xinle. We took 5 m around the tactile paving as its service scope, and calculated the fit between the PSFs and the tactile paving (Table 5). In common activity areas, tactile paving has a high degree of coincidence with shopping and consumer facilities (60%) but a low degree of coincidence with company and enterprise facilities (27.9%). In non-common activity areas, tactile paving has a high degree of fit with life service facilities, reaching 73%; however, the fit with catering and food, parking lot, and healthcare is insufficient, at only 55%, 46%, and 37%, respectively.

Through a comparison between facilities and tactile paving, we found some problems in the construction of tactile paving in Xinle's center. The precise design of key areas and facilities is insufficient,

which cannot effectively meet people's daily travel needs. This difference in spatial fit reflects the structural weakness of current tactile paving systems in serving specific types of PSFs. For example, a convenient connection with a tactile paving system was not fully considered when designing the entrances and exits of catering and healthcare facilities. At the same time, existing tactile paving has problems of interruption (Figure 6) and detours or unreasonable designs at critical paths to pertinent facilities (such as crosswalks and entrance ramps).

- Poor quality of the accessible environment in activity areas

A survey of main activity areas revealed that apartments and rural self-built houses are the main living areas. Due to the recent construction period, the BFE around apartments is fairly good, but there is almost no barrier-free design around rural self-built houses, which lack necessary barrier-free facilities and

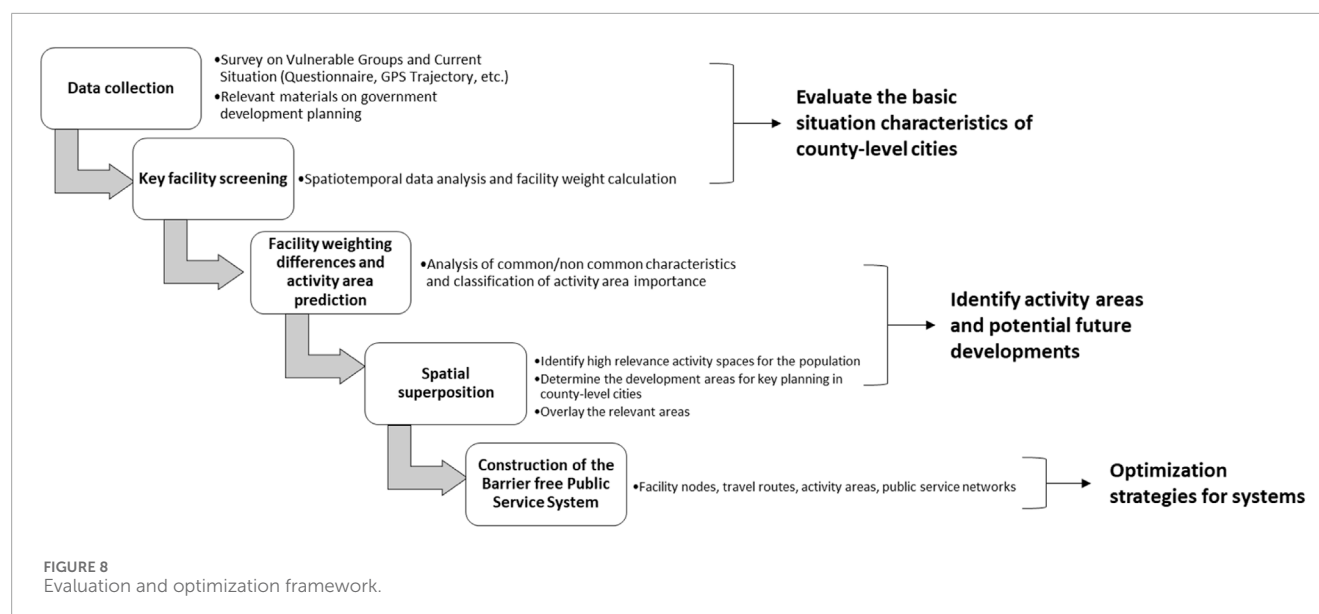


TABLE 6 Optimization strategy of barrier-free public activity systems.

Dimension	Optimization strategy
Accessible facility nodes	Ensure that the key facilities along the street in the important BFE area are related to the urban tactile paving. The entrances and exits of buildings in important accessible environmental areas should ensure the installation of ramps and accessible guidance signs. Bus stops and public parking lots in important and general barrier-free areas shall be accessible to sidewalks and tactile paving. Suggest installing electronic bus stop signs in areas such as bus stops and parking lots. Public parking lots should be equipped with accessible parking spaces and low-level payment terminals.
Accessible travel path	Pedestrian and 3D transportation systems within important accessible environmental areas should achieve seamless connectivity throughout the entire journey. The roads in important accessible environmental areas should be flat and equipped with necessary rest seats and signage. In important and generally accessible areas, the width for wheelchair and pedestrian crossing should be ensured. Trees, structures, parking spaces, and directional signs on both sides of the road should not protrude into the pedestrian area to obstruct traffic, and manhole covers and drainage grates should not have a height difference with the pavement of the sidewalk. In important and generally accessible areas, road parking is prohibited to ensure road accessibility. Given the demand for cycling in county-level cities, it is necessary to ensure the barrier-free transfer and interchange of bicycles, electric vehicles, and other transportation vehicles at bus stops and important public activity areas. In slow-moving systems such as greenways and waterfront boardwalks, continuous traffic requirements should be met to avoid interruptions or steep slopes.
Accessible activity areas	Strengthen barrier-free connectivity between facilities in important BFE areas through signage guidance, lighting, and tactile paving system connections to ensure the quality of BFE construction in the area and meet the usage needs of all kinds of people. Street-level green spaces within important and general accessible environments, as well as accessible tourist routes within county squares, should be wide enough for wheelchairs to pass through and able to connect seamlessly with rest areas, children's play areas, fitness facilities, and waterfront platforms (boardwalks). For special terrains such as sunken plazas, barrier-free lifting facilities should be combined to ensure convenient access for the entire population.
Accessible public service networks	Strengthen the accessibility coordination and systematicity among facilities, facility areas, and regions within important and general accessible environmental areas. Ensure the accessibility connectivity of "facility paths areas" within important and general accessible environmental areas, forming a network system of points, lines, and surfaces. Accessible facility distribution points and route maps can be set up at major intersections as well as public activity areas within important accessible environmental zones to facilitate crowd use. Establish a group of elderly and disabled people to participate in program evaluation, improve implementation quality through public supervision, and form an efficient, accurate, and implementable accessible planning and design scheme.

signage guidance. In the green space related to people activities, most places lack ramps, necessary tactile paving, identification systems, and other relevant barrier-free facilities. In commercial

activity spaces, some areas still have poor overall accessibility due to issues such as parking occupying lanes, stairs, and bicycles (Figure 7).

5 An evaluation and optimization framework for building a barrier-free public service system in Xinle

Based on an analysis of the current situation and existing problems in Xinle's urban center, we first built an evaluation and optimization framework for a barrier-free public service system (Figure 8).

First, we could researched people with disabilities and other vulnerable groups in the city, and obtained data on their activities using questionnaires and GPS. Second, we should identified relevant facilities through spatio-temporal data and selected key facilities by calculating the weight value. We performed differential detection on the weight of the third pair of facilities, clarified the common and non-common characteristics of people needing such facilities, predicted and simulated the main activity areas through the spatial distribution of facilities, and classified the importance of barrier-free design in these areas. Fourth, combine different types of activity areas with key public spaces for future urban development, and construct accessible public activity areas. Finally, based on the importance classification of barrier-free design, we refined barrier-free facility nodes, travel paths, activity areas, and public service networks into barrier-free governing and design strategies (Table 6), and a barrier-free public service system to provide a reference for the precise construction of BFEs can be established in cities.

6 Conclusion

According to warnings about the population's structure, approximately 40% of county-level cities in China have experienced deep aging. Historical infrastructure arrears, narrow roads, and high building density are common in the urban centers of county-level cities, and accessibility renovations face spatial limitations. In addition, county-level cities are prone to facing difficulties in implementing national policies accurately due to insufficient financial, technological, and regulatory resources. Meanwhile, due to the involvement of multiple entities (such as housing and construction, civil affairs, and the Disabled Persons' Federation) in the construction of accessible environments, county-level governments in China often face coordination difficulties due to institutional issues, which have a profound impact on the development of accessible environments in county-level cities.

In research on accessibility evaluation and optimization strategy, county-level cities do not simply apply the big city model but need to establish precise and practical solutions, which are of great significance for realizing the concept of "people's cities" and improving the quality and fairness of urban life. The evaluation and optimization path of an accessible PAS proposed in this study can provide a basis and guidance for county-level cities or cities of the same type in the world to implement special designs and governing for accessibility and advance the construction of accessible environments. Priority can be given to ensuring the building of key areas to meet the activity needs of the vast majority of the population, even if it is not possible to meet the BFE construction requirements of the entire urban area. In addition, county-level cities should simultaneously explore the mechanism of combining accessible design with overall urban and detailed

design, making accessible design a vital part of the planning system, forming a higher-level foundation and guidance, and ensuring the transmission of accessible design goals and final implementation.

This study has certain shortcomings and areas that need to be optimized and improved. In terms of data, the 93 population samples cannot represent the activity characteristics and facility demand characteristics of the elderly and disabled in Xinle City. However, we have added 10 days of spatiotemporal data collection, hoping to make up for the shortcomings brought by the sample data in terms of depth and richness. At the same time, comprehensive analysis of interview results and spatiotemporal data characteristics of the population can further improve the accuracy of activity area identification, evaluation, and the construction of accessible public activity systems. We hope that this method and approach can also provide guidance and reference for future larger scale confirmatory research. At the same time, we are also working closely with relevant departments in Xinle City to strengthen the collection of data on vulnerable groups and provide more support for future research work. In addition, the plan is to examine more county-level cities in different regions to explore practical strategies and paths for building BFEs in county-level cities in different areas, the goal being to further improve the theoretical composition and methods of barrier-free design.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SZ: Conceptualization, Funding acquisition, Project administration, Writing – original draft, Writing – review and editing. KZ: Software, Writing – original draft, Conceptualization, Data curation, Investigation, Methodology. HZ: Validation, Writing – original draft, Formal Analysis, Software. JZ: Investigation, Validation, Writing – original draft. JC: Data curation, Project administration, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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