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Research on Travel Preferences of Wheelchair Users in Barrier-Free Environments and Improvement Strategies for Adaptive Urban Roads

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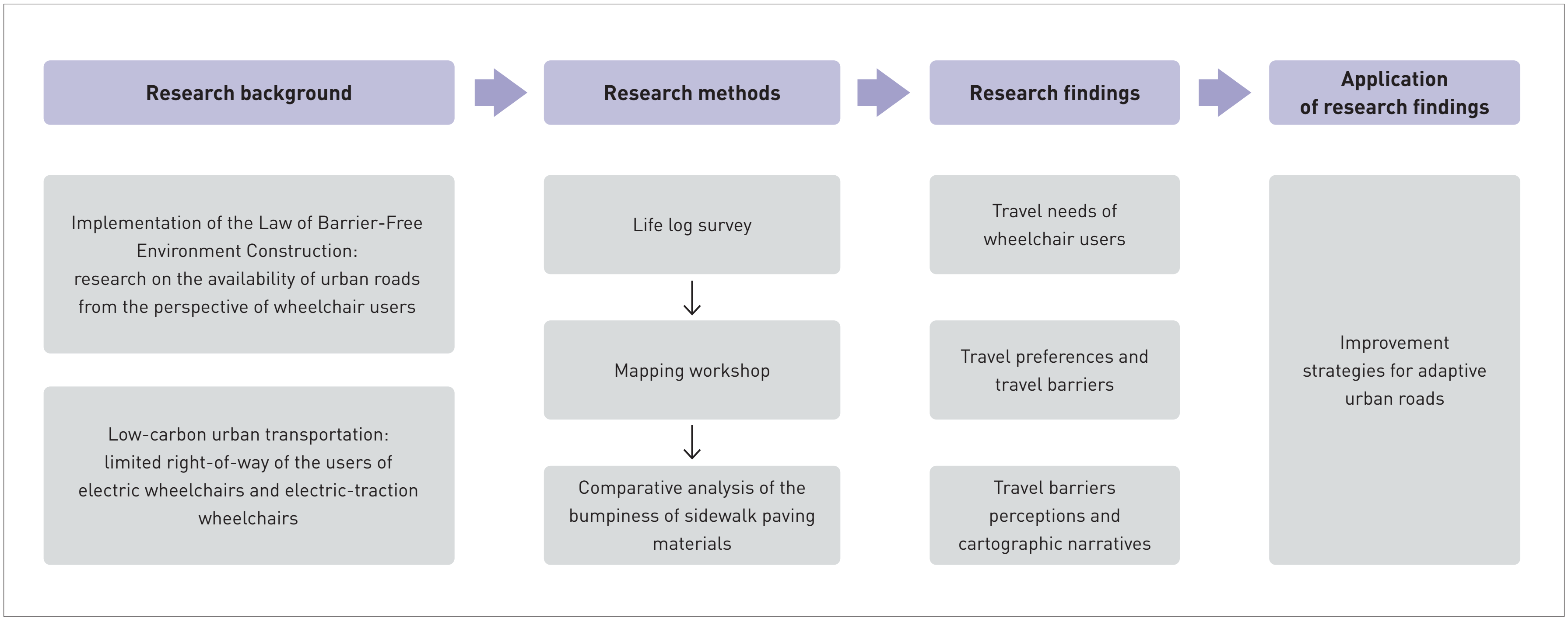
GRAPHICAL ABSTRACT



ABSTRACT

The construction of a barrier-free environment is an important measure that guarantees the safety, right-of-way, and interests of the disabled, the elderly, and other mobility disadvantaged groups. It is also an indispensable part of the low-carbon urban transportation and a necessary way to protect the rights of mobility disadvantaged groups in green travel. In this paper, the researchers conducted life log surveys on the travels of 10 wheelchair users residing in Beijing with IoT Inspector, a self-developed, wheelchair-mountable intelligent sensing device. Wheelchair users' travel preferences and reasons were then analyzed using the image and textual data from the surveys. Combined with a mapping workshop, a comparative analysis was performed on the bumpiness of sidewalk paving materials. The study found that wheelchair travelers' preferred non-motor lanes over sidewalks; substandard curb ramps, unleveled tree pools, limited access widths, and bumpy pavement were the main problems faced by wheelchair users in sidewalk accessibility. In addition, the study explores the inclusive needs and challenges of non-motorized right-of-way for new transportation means at urban planning and traffic management levels. Based on multi-sourced data, this paper discusses the

possibility of assessing urban barrier-free environment and representing a narrative of the needs of mobility disadvantaged groups, so as to provide practical experience and technical support to the improvement strategies of adaptive roads.

KEYWORDS

Inclusive Landscapes; Barrier-free Environment; Mobility Disadvantaged Group; Multi-sourced Data; Spatial Data; Wheelchair Users; Mapping; Right-of-Way

HIGHLIGHTS

- Uses self-developed intelligent sensing devices for life log surveys of mobility disadvantaged groups
- Mobility disadvantaged groups preferred non-motor lanes to sidewalks
- Travel barriers are mainly caused by improper traffic behaviors and inadequate construction of road facilities
- The bumpiness of asphalt is lower than that of permeable brick, granite, limestone, and marble; and the bumpiness of brick is lower than that of asphalt, with a smaller variation

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1 Introduction

The Law of Barrier-Free Environment Construction of the People's Republic of China came into effect on September 1, 2023[1], which designates the target group as individuals with disabilities, the elderly, and others with accessibility needs, legally guaranteeing the rights of social justice and landscape justice for mobility disadvantaged groups. It specifies the goal of universal environment construction, i.e., to facilitate safe and independent movement for people with disabilities and the elderly, enabling them to access buildings, use their facilities, utilize public transportation, communicate information, and receive social services. Scholars have noted that although handcycles, motorized wheelchairs, electric wheelchairs, and disabled-friendly vehicles assist the daily travels of mobility disadvantaged groups, current transport policies, infrastructure, and vehicle designs do not fully meet their needs[2]. For example, the Law of the People's Republic of China on Road Traffic Safety classifies wheelchairs as "assistive devices" permitted only indoors and in specific hospital areas①.

While legal scholars have focused on the rights of mobility disadvantaged groups in barrier-free access, priority, road use, and pedestrian traffic[3]~[6], their studies largely remain at discussions on statutory rights, seldom addressing the challenges and problems in reality. Among existing research on the right of barrier-free access of mobility disadvantaged groups, some studies focus on the relationship between public awareness, physical environment, and right-of-way. Deficient public and institutional awareness of universal accessibility leads to physical environment defects, which prevents the realization of priority rights for people with disabilities[5]. In terms of physical environment, researchers have examined the characteristics of barrier-free facilities using Kernel density analysis[7], travel restrictions[8], and spatial mismatches of barrier-free facilities at the community scale[9]. Some scholars also argue that the goal of universal accessibility construction urgently needs to shift its emphasis from completion degree to availability[10]. However, there is still a lack of explanation regarding the specific travel needs and travel characteristics of wheelchair users, with only a few scholars focusing on the travel characteristics of the disabled groups. For instance, from the perspective of social equity and inclusion, the proliferation of shared bicycles has solved the "last kilometer" travel issue for most people, but has not responded to the needs of those with lower limb disabilities[11]. Furthermore, inadequate performance evaluation, lack of coordinated standards, and insufficient collaboration among implementing agencies have caused many

① The Law of the People's Republic of China on Road Traffic Safety stipulates that motorized wheelchair-cars for the disabled are non-motor vehicles that are allowed to be driven on roads after getting registered and licensed by the traffic administration department of public security agency; conveyances like electric wheelchairs and elderly scooters are not legally identified as non-motor vehicles and are not allowed to be driven on roads.

traffic accidents[12] and failed to resolve the issue of "barrier-free islands"②[13].

The emergence of electric wheelchairs, electric-traction wheelchair③, and other electric micro-mobility devices has stirred discussions on the barrier-free environment for mobility disadvantaged groups in aspects of industry standards, transportation regulations, and travel safety. Additionally, new devices such as IoT Inspector and portable panoramic cameras offer new methods for data collection on barrier-free environments. This study thus aims to focus on wheelchair users among mobility disadvantaged groups, utilizing smart sensing devices to record their travel data. By combining life logs and mapping workshops, this research seeks to create profiles of wheelchair users, analyze their travel preferences and travel barriers, and compare the bumpiness of different paving materials for sidewalks; then the study proposes strategies for creating a barrier-free urban environment, to further guarantee the rights of mobility disadvantaged groups.

2 Research Methods and Data Collection

This study focuses on wheelchair users with lower limb disabilities residing in Beijing ("volunteers" hereafter). Their mobility devices include manual wheelchairs, electric wheelchairs, and electric-traction wheelchairs (collectively "wheelchairs" hereafter). Combining quantitative and qualitative research methods, this study investigated volunteers' travel modes, routes, and barrier-free accessibility needs.

The researchers recorded volunteers' daily travel data on both weekdays and weekends through life log surveys, including movement routes, types of spatial environments, and subjective experiences. Spatial data analysis was conducted on the types of destinations, travel preferences, and travel obstacles encountered. Additionally, through a mapping workshop, researchers and volunteers collaboratively created cartographic narratives to discuss the details of travel barriers. Given that the bumpiness of sidewalks significantly impacted volunteers' travel preference, the researchers further conducted a comparative analysis on the bumpiness of different paving materials for sidewalks. Based on quantitative and qualitative findings, improvement strategies for adaptive roads were proposed.

2.1 Volunteer Profile

In mid-August 2023, ten volunteers were recruited online, with five female and five male participants and 80% of them under the age of 35. All of the volunteers used wheelchairs due to limb or spinal cord injuries. Their mobility devices included five electric-traction wheelchairs, three manual wheelchairs, and two electric wheelchairs. Volunteers' professions included landscape architects, architects, e-commerce professionals, and software engineers (Table 1).

2.2 Life Log Surveys

Volunteers were asked to do a life log survey on a weekday and a weekend day between August 26 and October 2, 2023 to record their

Table 1: Overview of the volunteers in this research

Volunteer No.	Gender	Age	Reason for using wheelchair	Wheelchair type	Occupation
A	Female	28	Spinal cord injury	Electric-traction	New media practitioner
B	Male	32	Spinal cord injury	Electric-traction	Medical practitioner
C	Male	52	Limb injury	Electric-traction	E-commerce practitioner
D	Female	36	Limb injury	Manual	Landscape architect
E	Female	26	Spinal cord injury	Electric-traction	E-commerce practitioner
F	Female	28	Spinal cord injury	Manual	Telemarketer
G	Male	24	Limb injury	Electric	Business agent
H	Male	53	Limb injury	Electric	Architect
I	Female	34	Spinal cord injury	Electric-traction	Foundation staff
J	Male	23	Limb injury	Manual	Software engineer

② Barrier-free islands refer to the challenging reality of inadequate and unbalanced barrier-free environment construction caused by insufficient resource allocation, coordination, and mechanism guarantees (source: Ref. [13]).

③ At present there is no clear definition for electric-traction wheelchairs. Media and e-commerce platforms often use terms like "electric leading" or "electric traction" to describe the manual wheelchairs with added electric devices. The China Rehabilitation Assistive Devices Directory (2023 Edition) refers to such devices as manual wheelchairs with additional small electric tractions that can be used for low-speed travels indoors and outdoors, including on-road travels.

daily travels. The sensing device used in the survey was the IoT Inspector, developed by UrbanXYZ (Patent No. 202322990046.X), which consists of panoramic photography and road surface sensing devices (Fig. 1). The panoramic photography device, mounted at the rear of the wheelchair, includes sensors and a panoramic camera that can record the spatial environment from volunteers' perspective while protecting their privacy. The sensors trigger the camera to take a photo every 10 seconds, simultaneously recording the wheelchair's geological location. The road surface sensing device includes incline and vibration detectors that measure road incline and bumpiness along the travel routes; this device is easily attachable and detachable from the wheelchair using clamping and positioning components.

The life log data comprise panoramic photos, timestamps, geological coordinates, and textual data of volunteers' audio transcripts. The IoT Inspector collected 9,261 panoramic photos, among which 6,443 valid photos were retained after removing redundant and indoor images. The valid photos, along with the audio transcripts, were manually audited and tagged with categories of spatial type, road type, description of travel barriers, and barrier type (Table 2). Bases on spatial coordinates, QGIS software was employed to statistically analyze and visualize the destination types, travel distances, road types, and barrier types.

The researchers developed the UrbanXYZ–Panoramic Space data visualization platform, which automatically identifies features in the uploaded photos and links them with spatio-temporal information, supporting street view representation (Fig. 2). This,

Table 2: Label categories in the travel log survey

Label category	Interpretation
Spatial type	Road/path Indoor environment Outdoor environment Traffic conveyance
Road type	Sidewalk Non-motor lane Motor lane (including mixed traffic lane)
Description of travel barriers	● (red) Shared bikes parking, blocking wheelchair access ● (red) Pedestrian occupying non-motor lane ● (red) Motor vehicles parking, occupying non-motor lane ● (red) Non-motor vehicle is parking, occupying non-motor lane ● (red) Non-motor vehicles reversely running ● (red) Barrier-free compartment or wheelchair parking lot occupied ● (green) Disordered mixed traffic of motor and non-motor vehicles ● (green) No crosswalk or traffic lights ● (green) Entrance/exit bollards obstructing wheelchair access ● (blue) Entrance/exit without wheelchair ramps, or constructed with substandard gradient or materials ● (blue) Entrance/exit difficult to open ● (blue) Elevation differences at sidewalk junctions ● (blue) Pedestrian overcrossing without accessible elevators/ramps

NOTE

Barrier types: ● (red) indicates barriers caused by improper traffic behaviors; ● (green) indicates barriers caused by inadequate construction of traffic facilities; ● (blue) indicates barriers caused by inadequate construction of barrier-free facilities.

1. IoT inspection device.
2. Interface of UrbanXYZ–Panoramic Space data visualization platform.

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combined with the records of volunteers' subjective experiences, can help identify details of travel obstacles.

2.3 Mapping Workshop

In collaboration with Diversability Lab, a mapping workshop was held on October 15, 2023. Professionals or students of expertise in built environment design were invited as mappers, and public participants were recruited openly. Each mapping group included at least one volunteer, one mapper, and one public participant. Such a grouping was to increase the awareness of built environment professionals and the general public about travel barriers to the mobility disadvantaged group.

Before the workshop, the researchers demonstrated the route mapping by taking Volunteer E as an example. The visualization method of this mapping, referring to previous research[14], was realized through group discussions upon panoramic photos, audio transcripts, and volunteers' narratives, and each volunteer's travel route was represented with photo collages (Fig. 3). Descriptions of travel obstacles included details of spatial environment, public behaviors, and feedback on problem-solving experiences. The mapping approach was considered an interactive, dialogic, and reflective dynamic process to generate "situated knowledge"[15] based on spatial cognitive narratives.

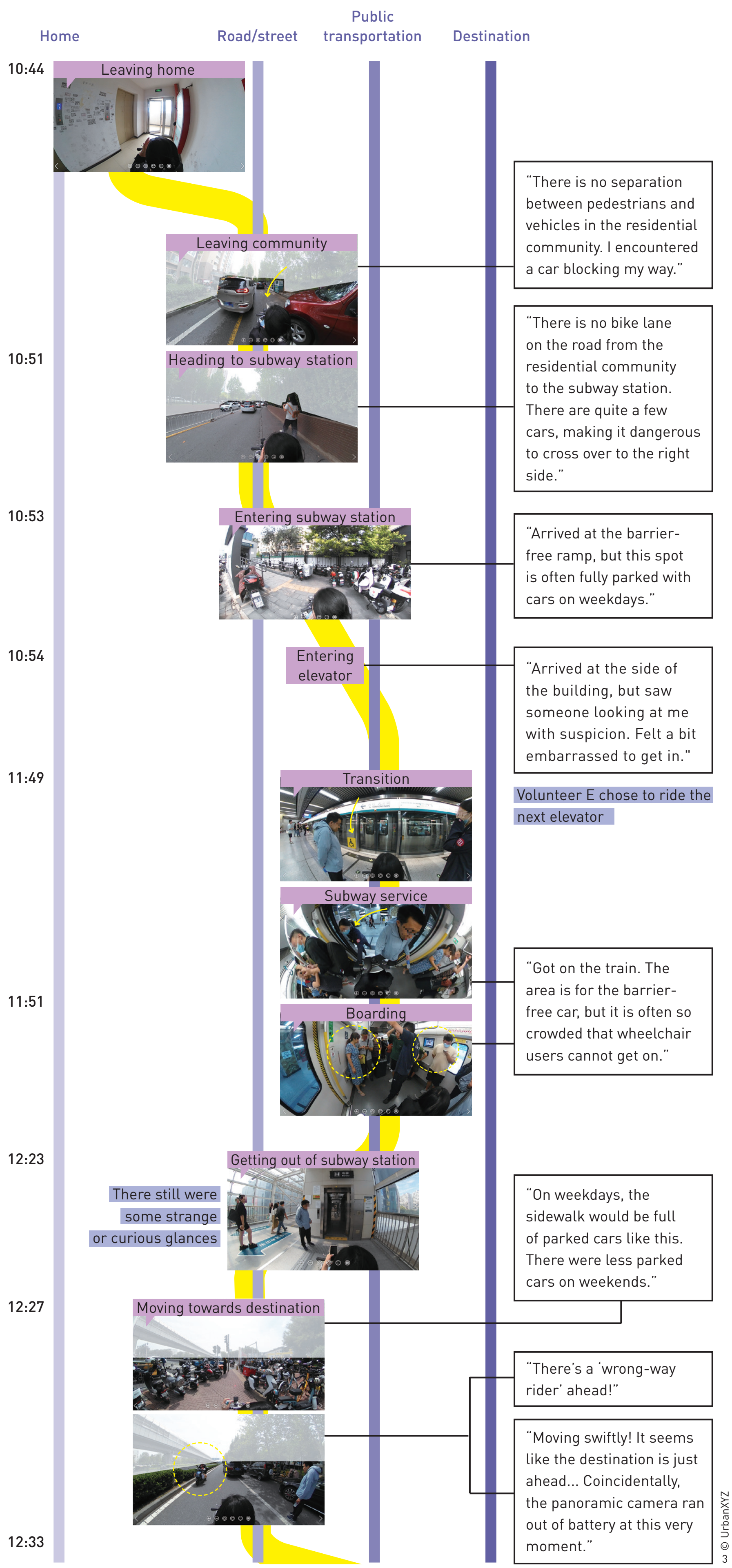
2.4 Comparative Analysis on Bumpiness of Different Paving Materials for Sidewalks

Based on insights from the life logs and mapping workshop regarding sidewalk obstacles, it was found that the bumpiness significantly affected volunteers' preference for using non-motor lanes. To further probe to wheelchair users' right-of-way on non-motor lanes, a comparative analysis on the bumpiness of different paving materials for sidewalks was conducted.

After classifying the sidewalk paving materials recorded from the life logs, the researchers planned a survey route that covered all the paving materials types. Using the IoT Inspector, data of the acceleration and angular velocity in the x, y, and z axes were collected, and the bumpiness of each material was calculated as:

$$result = \sqrt{acc_X{}^2 + acc_Y{}^2 + acc_Z{}^2} \times \sqrt{gyro_X{}^2 + gyro_Y{}^2 + gyro_Z{}^2}\ , \quad (1)$$

where acc_X, acc_Y, and acc_Z represent the acceleration in the x, y, and z axes, respectively; $gyro_X$, $gyro_Y$, and $gyro_Z$ represent the angular



3. Mapping visualization: example of Volunteer E's travel route.

velocity in the x, y, and z axes, respectively; and *result* indicates the product of the vector magnitudes of acceleration and angular velocity, i.e., bumpiness.

A total of 622 photos of sidewalk paving materials and 234,111 pieces of bumpiness results were collected from 20 road segments. The photos were matched with the bumpiness results. Given that the bumpiness recording frequency (every 0.025 ~ 0.033 seconds) was higher than that of the photography (every 10 seconds), the researchers manually audited and associated the data of paving materials with bumpiness results. The final dataset of 234,111 bumpiness results, associated with paving material types, was used for the comparative analysis of the bumpiness across different paving materials.

3 Research Findings

3.1 Types of Travel Destinations

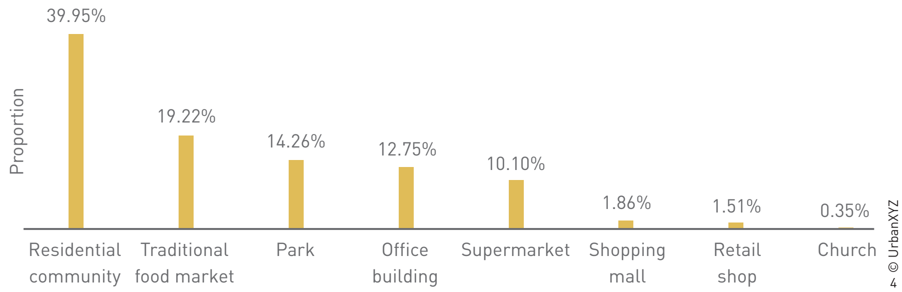
The results of life log surveys showed that volunteers' travel routes covered most districts in Beijing, including Dongcheng, Xicheng, Chaoyang, Fengtai, Haidian, Changping, Tongzhou, and Daxing. The types of travel destinations included traditional food markets, supermarkets, retail shops (e.g., restaurants, convenience stores, beverage shops), shopping malls, parks, office buildings, churches, and residential communities, encompassing nearly all types of urban public spaces (Fig. 4). Apart from daily commuting destinations (i.e., residential communities and office buildings, accounting for 39.95% and 12.75%, respectively), markets (19.22%), parks (14.26%), and supermarkets (10.10%) were also frequently visited destinations.

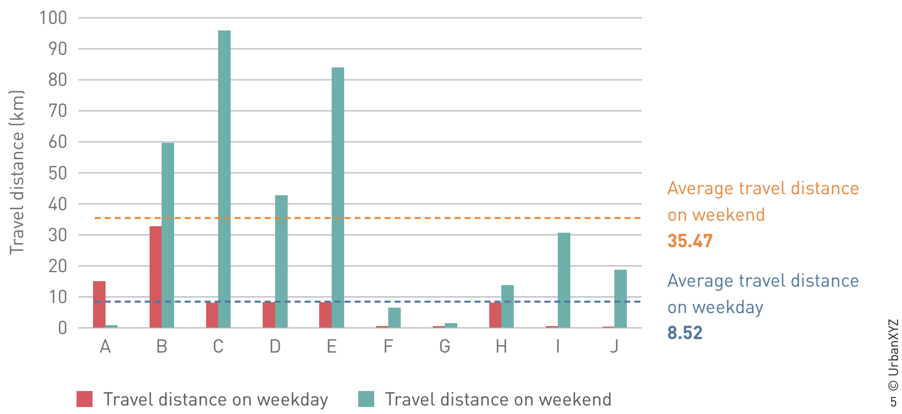
On weekdays, volunteers primarily traveled for commuting purposes, with an average travel distance of 8.52 km (minimum of 0.48 km, maximum of 32.80 km); 80% of travel distances were within 10 km, and 40% within 0.7 km. On weekends, the average travel distance was 35.47 km (minimum of 0.97 km, maximum of 95.78 km), generally exceeding weekday travel distances (Fig. 5).

The volunteers were young and middle-aged wheelchair users with varied professions and diverse travel needs. Their primary mode of travel was wheelchair use, often combined with subway travel, making them representative of young and middle-aged mobility disadvantaged groups with ordinary work and daily travel demands.

3.2 Travel Preferences and Obstacles Types

The results of life log surveys showed that 62% of volunteers preferred to take non-motor lanes for travel, while 24% chose





4. Analysis of travel destination types.
5. Analysis of travel distances on weekday and weekend.

sidewalks and 14% chose motor lanes.

The main problems encountered on non-motor lanes included improper parking of motor vehicles (58.12%) and reverse running of non-motor vehicles (35.90%). Volunteers using sidewalks mainly faced improper parking of non-motor vehicles (31.46%) and elevation differences at sidewalk junctions (30.34%). Those using motor lanes largely encountered mixed traffic with non-motorized vehicles (62.31%) and parking obstructions (33.17%). The improper parking of vehicles and disordered mixed traffic made most volunteers take motor vehicle lanes, which led to more danger for wheelchair users who would be in vehicle blind spots (Table 3).

The most common obstacle type encountered was improper traffic behaviors (47.97%), followed by problems caused by inadequate construction of traffic facilities (42.50%) and barrier-free facility construction (9.53%). Improper traffic behaviors primarily involved improper occupancy, for example, non-motor vehicles parking on sidewalks or pedestrians walking on the non-motor lanes. Road facility issues were primarily due to mixed traffic on some minor lanes, making wheelchair users have to share lanes with motor vehicles, increasing safety risks. Issues caused by inadequate construction of barrier-free facilities included elevation differences, which were often caused by the staged access of residential buildings, missing or non-compliant wheelchair ramps, or substandard ramp materials (Table 4).

However, panoramic photos and statistical analyses see limitations and could not fully capture travel obstacles and volunteers' real perceptions. For instance, researchers could not determine from photos alone what specific sidewalk obstacles led to volunteers choosing non-motor lanes. During the mapping

Table 3: Main travel barriers influencing volunteers' preference to different road types

Description of travel barriers	For volunteers taking non-motor lane	For volunteers taking sidewalk	For volunteers taking motor lane
● Shared bikes parking, blocking wheelchair access	—	31.46%	—
● Motor vehicles parking, occupying non-motor lane	58.12%	16.85%	33.17%
● Non-motor vehicles parking, occupying non-motor lane	—	—	1.76%
● Non-motor vehicles reversely running	35.90%	2.25%	2.76%
● Disordered mixed traffic of motor and non-motor vehicles	—	8.99%	62.31%
● No crosswalk or traffic lights	2.56%	—	—
● Entrance/exit without wheelchair ramps, or constructed with substandard gradient or materials	1.71%	8.99%	—
● Entrance/exit difficult to open	—	1.12%	—
● Elevation differences at sidewalk junctions	1.71%	30.34%	—

NOTE

Barrier types: ● (red) indicates barriers caused by improper traffic behaviors; ● (green) indicates barriers caused by inadequate construction of traffic facilities; ● (blue) indicates barriers caused by inadequate construction of barrier-free facilities.

Table 4: Statistics of types of travel barriers

Barrier type	Description of travel barriers	Proportion
Improper traffic behaviors	Motor vehicles parking, occupying non-motor lane	33.75%
	Non-motor vehicles parking, occupying non-motor lane	8.59%
	Non-motor vehicles reversely running	3.75%
	Shared bikes parking, blocking wheelchair access	1.09%
	Pedestrian occupying non-motor lane	0.47%
	Barrier-free compartment or wheelchair parking lot occupied	0.31%
Inadequate construction of traffic facilities	Disordered mixed traffic of motor and non-motor vehicles	40.47%
	No crosswalk or traffic lights	1.88%
	Entrance/exit bollards obstructing wheelchair access	0.16%
Inadequate construction of barrier-free facilities	Entrance/exit without wheelchair ramps, or constructed with substandard gradient or materials	4.69%
	Elevation differences at sidewalk junctions	2.03%
	Pedestrian overcrossing without accessible elevators/ramps	2.03%
	Entrance/exit difficult to open	0.78%

workshop, volunteers provided researchers with more situated knowledge, explaining the details of travel obstacles (Table 5, Fig. 6).

The findings reveal that the road facilities and barrier-free issues on sidewalks made most volunteers have to choose non-motor lanes. Specially, barriers caused by inadequate construction of traffic facilities included disordered mixed traffic of motor and non-motor vehicles, improper parking of shared bikes and other non-motor vehicles, occupancy by tree pools and road ancillary facilities, unleveled tree pools or rolling pavement by tree roots, elevation differences, barriers at non-motor lane ends, anti-slip features with over/little resistance, blind tracks, etc., would all impact road evenness and accessibility. One significant reason influencing volunteers' travel preference was that sidewalks had a higher bumpiness for wheelchair users, which could harm individuals with limb disabilities, especially those with spinal cord injuries. Barrier-free facility problems were mainly due to non-compliant or missing curb ramps or wheelchair ramps.

Table 5: Detailed description of travel barriers from some volunteers

Volunteer	Detailed description of travel barriers
A	"The front entrance of the office building I work in, which is a 5A-grade office building in Fengtai District, has no access for wheelchair users. So every day I have to walk against the road through the basement and motor vehicle lane to get into the office building."
C	"The potholes in the road are particularly obstacles for me. I don't like the bumps because they hurt my body."
D	"When entering the office park, an iron fence stands at one of the intersections. Normally this is fine for pedestrians, but for our wheelchairs, the access is too narrow to pass." "The reason for not taking sidewalks is that most of them are bumpy and poor in maintenance... and the turnings of the sidewalks don't have curb ramps that is difficult for us to pass. So basically I would like to choose non-motor lanes when I travel."
I	"The path is even challenging for pedestrians, let alone wheelchair users like us. For example, electric line poles and road blockings stand right in the middle of the curb slopes, making it too narrow to pass."

3.3 Comparative Analysis on the Bumpiness of Different Paving Materials for Sidewalks

Given that sidewalk bumpiness is a primary reason for volunteers opting to use non-motor lanes, the researchers conducted a comparative analysis on the bumpiness between five common paving materials for sidewalks (limestone, brick, marble, permeable brick, and granite) with asphalt, the most common paving materials for non-motor lanes. The study found that asphalt-paving non-motor lanes had lower bumpiness than sidewalks paved with permeable bricks, corroborating volunteers' preference for non-motor lanes.

The analysis revealed that the median bumpiness of asphalt paving was generally lower than that of limestone, marble, permeable brick, and granite (Tables 6 and 7, Fig. 7). Notably, the bumpiness of brick was close to that of asphalt, with lower values of both the median and the upper and lower quartile, as well as the lowest variance, indicating its overall superiority in bumpiness over asphalt. The variance analysis of bumpiness data for different paving materials showed a *p*-value of less than 0.05, indicating a significant disparity.

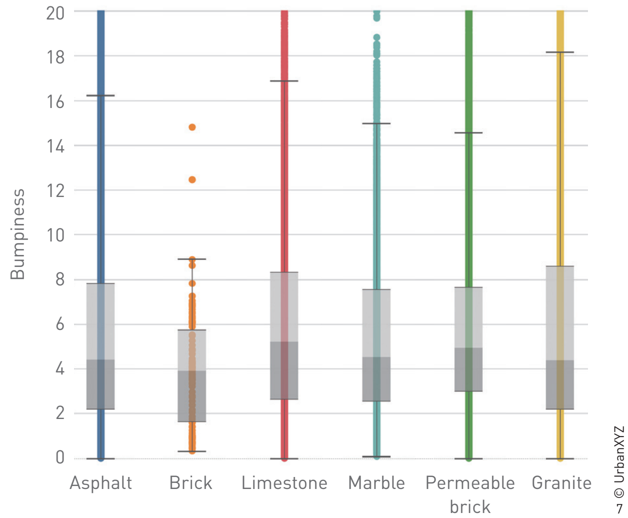
Further comparative analysis was conducted between brick and granite, which had the closer medians of bumpiness to asphalt and with various paving patterns. The findings showed that though natural-cleft granite provided a more natural and rustic visual effect compared with flamed and bush-hammered finishes, it has a significantly higher bumpiness: the variance (114.85)

6. © UrbanXYZ

6. Examples of specific travel barriers encountered by volunteers.

Table 6: ANOVA for the bumpiness of different paving materials

Group	Sample size	Mean	Variance	Median
Brick	32,498	4.42	23.59	3.46
Asphalt	82,011	5.64	52.25	3.79
Limestone	206	3.97	7.25	3.91
Granite	55,978	6.42	58.17	4.11
Marble	3,946	5.57	23.72	4.54
Permeable brick	59,472	6.03	30.29	4.89



7. Box plots of bumpiness for different paving materials.

Table 7: ANOVA results for bumpiness of different paving materials

Source	*SS*	*df*	*MS*	*F*	*p*-value	*F*-critical
Between group	88 673.9225	5	17734.7845	406.875476	0	2.2141377

and mean (12.10) of bumpiness indicated that generally natural-cleft granite has a high bumpiness and a large variability among samples (Table 8, Fig. 8). Generally, bricks had a low bumpiness, but different paving patterns exhibited varied bumpiness, where stretcher-bond paving performed better than herringbone 45° and basket-weave patterns (Table 9, Fig. 9).

4 Conclusions and Discussion

By utilizing a self-developed IoT Inspector, combined with life log surveys, mapping workshops, and a comparative analysis on the bumpiness of varied paving materials, this study refined the accessibility needs of wheelchair users in urban environments. The main findings are as follows.

1) Mobility disadvantaged groups have diverse daily travel needs, with traditional food markets, supermarkets, and parks being the most frequently visited destinations except for commuting; their weekend travel distances significantly exceeding weekday distances.

2) Mobility disadvantaged groups prefer non-motor lanes over sidewalks.

3) Travel obstacles are mainly caused by improper traffic behaviors and inadequate construction of traffic facilities, such as improper parking of vehicles and disordered mixed traffic.

4) Asphalt, commonly paving material used for non-motor lanes, has a better performance in bumpiness than the paving materials commonly used for sidewalks like permeable brick, granite, limestone, and marble; however, brick has an overall best performance in bumpiness than asphalt, and exhibits smaller variations in bumpiness.

5) For paving materials like granite and brick, different paving patterns also result in varied bumpiness.

4.1 Wheelchair Users’ Preference for Non-Motor Lanes and their Right-of-Way

The preference for non-motor lanes by mobility disadvantaged groups highlights the gap between wheelchair users’ actual needs and the lagging construction of barrier-free environment in cities, particularly sidewalks. Current urban spatial construction and traffic management regulations are primarily designed for pedestrians, often overlooking the right-of-way and environmental needs of mobility disadvantaged groups. In addition, there is a general lack of understanding of the travel needs of such groups, and a poor awareness of their assistive devices like electric or electric-traction wheelchairs. The study found that mobility disadvantaged groups have the need to independently and safely use both sidewalks and

Table 8: Comparative analysis results of the bumpiness of different paving patterns of granite

Paving pattern	Maximum	Minimum	Mean	Variance
Bush-hammered	98.04	0	5.15	32.83
Naturally-cleft	106.94	0	12.10	114.85
Flamed	177.49	0	5.44	42.95

Table 9: Comparative analysis results of the bumpiness of different paving patterns of brick

Paving pattern	Maximum	Minimum	Mean	Variance
Herringbone 45°	38.04	0	4.49	21.98
Stretcher-bond	34.2	0	7	17.29
Basket-weave	55.57	0	3.36	26.81

8. Photos of different paving patterns of granite: naturally-cleft, flamed, and bush-hammered, from left to right.

9. Photos of different paving patterns of brick: herringbone 45°, basket-weave, and stretcher-bond, from left to right.

non-motor lanes, as well as access public transportation and public spaces. For urban planning and traffic management, this poses a challenge to the inclusiveness of non-motors' right-of-way for new travel devices, which requires a broader societal consensus and public participation to jointly create an inclusive and adaptive travel environment.

In the discussion of public right-of-way, the travel rights of mobility disadvantaged groups need to be prioritized. The Law of Barrier-Free Environment Construction will promote the definition of right-of-way in the fields of transportation and planning to achieve a societal consensus of prioritizing mobility disadvantaged groups' rights on non-motor lanes, ensuring social justice in the current transition towards low-carbon transportation. According to current regulations, wheelchairs are excluded from non-motor vehicles and thus do not have the right-of-way of non-motor lanes. However, it is critical to take into consideration of the reality that wheelchair users have the demand to use non-motor lanes. This paper aims to promote a more in-depth discussion and definition of mobility disadvantaged groups' right-of-way through thorough argumentation and broad public participation.

This paper suggests that the construction experiences from other countries can be drawn for a reference. For example, UK classifies (powered) wheelchairs and mobility scooters into three categories: the first, manual wheelchairs can be used on sidewalks or pedestrian areas at speeds not exceeding 6 km/h; the second, powered wheelchairs and scooters can be used on sidewalks at speeds not exceeding 6 km/h; and the third, powered wheelchairs and scooters can be used on both sidewalks and roads at speeds not exceeding 12 km/h[16]. This hierarchical regulation on wheelchair types and speeds helps maximize the inclusion of the accessibility of transportation means with different mobility abilities while safeguarding the safety of travelers. With the updating of transportation means for mobility disadvantaged groups and the diversification of travel needs, this kind of refined management of right-of-way can help improve China's construction of barrier-free environment.

4.2 Improvement Strategies for Adaptive Roads in Urban Barrier-Free Environment

For landscape design of urban pedestrian environment, it is necessary to enhance the adaptability and equity of mobility disadvantaged groups. The study results reveal that current problems found in sidewalks mainly include substandard curb ramps, unleveled tree pools, bollards blocking, and bumpiness of paving materials. These issues not only force wheelchair users to choose non-motor lanes but also increase safety risks for cyclists and pedestrians.

Standards for barrier-free facility construction and related spatial environment construction should comprehensively consider the needs of wheelchair users, pedestrians, and cyclists. This paper recommends academic or professional standards-setting institutions to launch funding studies on new barrier-free infrastructure construction, and to demonstrate the feasibility of relevant standardization and promotion of pilot projects.

1) Compared with the commonly used permeable bricks and granite, asphalt and bricks would cause less bumpiness. Considering permeability, future urban renewals can use permeable asphalt concrete, cement concrete or bricks for sidewalk pavement. Moreover, the use of these materials can improve surface smoothness and reduce costs. Standardized design and construction processes of sidewalk paving can also help improve surface smoothness.

2) Raised crosswalk facilities can avoid the elevation differences caused by substandard curb ramps in existing urban areas while enhancing sidewalk continuity. This can also guide motor and non-motor vehicles to slow down and ensure the visibility and safety of wheelchair users and pedestrians (Fig. 10). In addition, refined assessments can be conducted to identify road segments with low non-motor traffic flows, where traffic calming strategies[17] can be adopted and raised crosswalk pilot projects can be taken place. Then, evaluations on the safety and friendliness for mobility disadvantaged groups are required, while considering the convenience for visually disadvantaged individuals and possible drainage problems.

3) Current urban road spatial planning and design standards generally consider leveling tree pools as a suggestion. It is recommended to revise relevant specifications to make it a mandatory requirement and to propose maintenance requirements for tree grates, so as to improve the travel experience of mobility disadvantaged groups.

4) Bollard facilities are often installed to restrict the entry of electric vehicles into pedestrian areas, for management reasons. However, current bollards and turning pedestrian entrances lack standard design requirements, obstructing wheelchair passage. It is suggested to conduct research to establish scientific and procedural standards at local and national scales for bollard facility settings, ensuring the legal rights of mobility disadvantaged groups in public spaces. Additionally, it is recommended to test bollard facilities in different sizes, inviting organizations and individual volunteers into performance evaluations, so as to ensure the independent use by all types of users with different disabilities.

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10

10. Elevated crosswalk.

4.3 An Innovative Approach Combining Multi-Sourced Data Perception and Workshops

By employing a multi-dimensional research approach that integrates life log survey, mapping workshops, and comparative analysis, this study investigated wheelchair users' travel needs and barriers from their own perspectives. This approach enables researchers to become translators between travelers' needs and the existing spatial environment, and the visualized translation results can be presented to the public and government decision-makers, helping effectively increase public awareness of travel barriers and promote social actions to address real-world travel issues.

The researchers conducted detailed empirical studies and life log surveys on the needs of wheelchair users, providing more accurate demand descriptions and data support for inclusive landscape design. The incorporation of public participation through mapping activities helped represent travel scenarios and form situated knowledge, deepening the public's understanding of localized travel needs, preferences, and barriers faced by mobility disadvantaged groups. By constructing situated knowledge, this study hopes to foster a consensus on inclusive landscapes among researchers, designers, and users, offering a new research paradigm for future travel demand studies.

It is worth noting that the sample size of life log surveys in this study is relatively small, which may lead to certain limitations to the research results. Future efforts can expand the sample size, using the travel data collection and analysis methods from this study, to enrich the understanding and evidence of the travel needs of mobility disadvantaged groups.

Competing interests | The authors declare that they have no competing interests.

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城市道路无障碍环境轮椅使用者出行偏好与适应性道路改善策略研究

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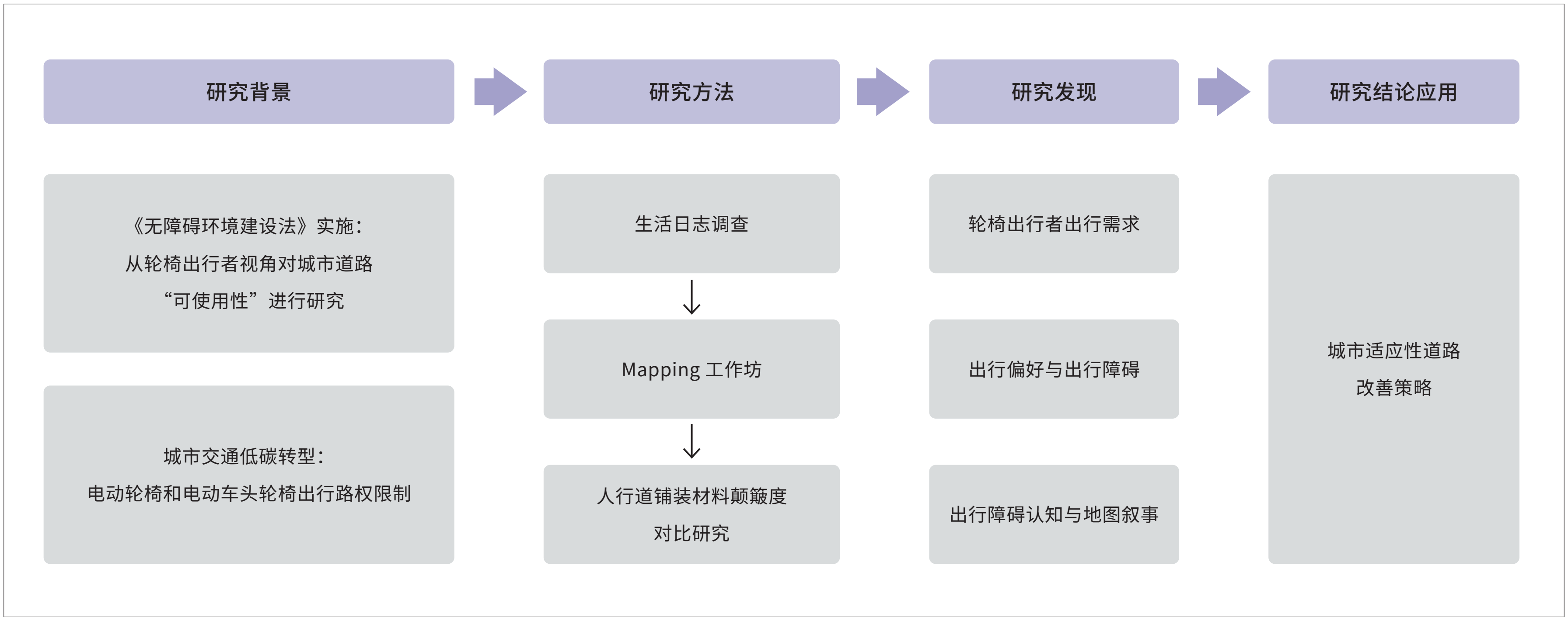
图文摘要



摘要

无障碍环境建设是保障残疾人、老年人等交通弱势群体自主、安全通行道路的重要措施，也是城市交通低碳转型的重要组成部分，更是保障残障群体绿色出行权利的必要途径。研究团队利用自主研发的、可安装在轮椅上的智能感知设备——IoT一体巡检机，以居住在北京的10位轮椅出行者为研究对象，通过与生活日志调查的图像标签和文本数据进行交叉分析，并采用Mapping（图绘）活动工作坊与人行道铺装材料颠簸度实证研究来分析轮椅出行者道路选择偏好及原因。研究发现，相较于人行道，轮椅出行者更偏好选择非机动车道作为通行道路。研究结果指出，不合规的路缘坡道、缺乏平整化的树池、通行宽度受限、路面铺装颠簸等是轮椅出行者在人行道无障碍环境中面临的主要问题。此外，研究从城市规划和交通管理层面探讨了新型出行工具的非机动车道路权的包容性需求与挑战。通过多源数据的研究方法，本文探索了对城市道路无障碍环境进行评估与构建交通弱势群体需求叙事的可能性，为支持适应性道路改善策略提供了实践经验与技术支撑。

关键词

包容性景观；无障碍环境；交通弱势群体；多源数据；空间数据；轮椅使用者；图绘；路权

文章亮点

- 利用自主研发的智能感知设备对交通弱势群体进行生活日志调查
- 发现相较于人行道，交通弱势群体偏好选择非机动车道通行
- 出行障碍主要由不规范交通行为与道路设施建设缺陷所导致
- 沥青的颠簸度低于人行道常用的透水砖、花岗岩、青石、大理石；青砖的颠簸度整体低于沥青，且变化相对小

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编辑 田乐，王胤瑜
翻译 田乐

1 引言

《中华人民共和国无障碍环境建设法》自2023年9月1日起施行[1]，该法案明确规定，受益群体包括“残疾人、老年人”，以及“有无障碍需求的其他人”，这为交通弱势群体享有社会公正和景观正义提供了法律层面的保障。该法案明确了无障碍建设的目的，即“为残疾人、老年人自主安全地通行道路、出入建筑物以及使用其附属设施、搭乘公共交通运输工具，获取、使用和交流信息，获得社会服务等提供便利”。相关研究指出，尽管手摇车、残疾人机动轮椅车、电动轮椅、残疾人汽车等交通工具为交通弱势群体的出行提供了便利，但目前的交通政策、交通基础设施、交通工具设计等仍未能充分考虑此类群体的实际需求[2]。例如，《中华人民共和国道路交通安全法》将轮椅定义为“辅具”，且只能在室内和部分医院附近空间使用①。

虽然法学领域已关注到交通弱势群体的无障碍通行权、优先权、上路权，以及慢行路权[3]–[6]，但相关讨论仍主要停留在法定权利层面，较少涉及真实路权现状问题。在针对交通弱势群体无障碍通行权困境的现有研究中，部分学者关注公众认知、物质环境与路权的关系，即由于公众认知及制度层面无障碍意识的薄弱导致物理环境缺陷，进而阻碍了残疾人先行权的实现[5]。物理空间环境视角下，有学者研究了无障碍设施聚集度特征[7]、出行限制因素[8]、社区无障碍设施空间错配[9]等问题；也有学者提出，当前无障碍设施建设的目标迫切需要从“建成度”向“可使用性”转换[10]。但目前仍缺乏对轮椅使用者的具体出行需求和特征的阐释，仅有少数研究关注残障群体的出行特征——例如，有学者从社会公平与包容的视角指出，共享单车的普及解决了大多数普通人出行的“最后一公里”问题，但并未覆盖到下肢残障群体[11]。此外，由于对无障碍环境“性能”检验不足、不同标准之间缺乏衔接、各执行机构之间缺乏协同机制，导致出现了诸多交通事故[12]，“无障碍孤岛”②问题未能有效解决[13]。

电动轮椅、电动车头轮椅③及类似电动微型交通工具的出现，已从行业标准、交通法规和出行安全等角度引发对交通弱势群体无障碍出行环境的讨论。同时，物联传感器、便携式全景相机等新型设备的出现，也为研究无障碍出行环境提供了新的数据获取途径。因此，本文希望聚焦交通弱势群体中的轮椅使用者，利用智能感知设备记录他们出行过程，并结合生活日志和Mapping（图绘）工作坊结果，形成轮椅使用者的群体画像；然后分析他们的通行道路偏好和出行障碍认知情况，并对人行道路面铺装材料颠簸度进行对比研究，从而提出城市无障碍出行环境营建策略，进一步保障轮椅使用者等交通弱势群体的出行权利。

2 研究方法与数据采集

本文选择居住在北京的下肢障碍轮椅使用者（以下简称“志愿者”）作为研究对象，其出行辅具包括普通轮椅、电动轮椅、电动车头轮椅等（以下均简称“轮椅”）。本文采用定量、定性相结合的研究方法，对志愿者的出行方式、出行路线及无障碍环境需求展开调查。

① 《中华人民共和国道路交通安全法》规定，残疾人机动轮椅车属非机动车，经公安机关交通管理部门登记并领取牌证后，方可上道路行驶；电动轮椅、老年代步车等各类交通工具不属于《中华人民共和国道路交通安全法》规定的非机动车范畴，即不属于道路车辆，不能上路行驶。

② “无障碍孤岛”指由于资源配置、统筹衔接、协同行动、机制保障的不足所导致的无障碍环境建设不充分、不平衡等难题（来源：参考文献[13]）。

③ “电动车头轮椅”暂无明确定义，新闻媒体与电商平台多使用“电动车头”“电动牵引头”等表述来描述增加了电动功能的手动轮椅装置。《中国康复辅助器具目录（2023版）》中将此类装置称为“手动轮椅附加小型电动牵引装置”，并将其预期用途描述为“进行室内、室外及道路的低速通行活动”。

首先，研究者以生活日志的调查方法对志愿者日常与周末出行的路线轨迹、空间环境类型与主观感受等数据进行记录。通过空间数据分析志愿者的出行目的地类型、通行道路选择偏好与障碍类型；研究者与出行者通过Mapping工作坊共同完成地图叙事，以分析具体的出行障碍问题。鉴于路面颠簸度是影响志愿者通行道路选择的主要因素，研究团队补充设计了关于人行道路面铺装材料颠簸度的对比研究。最终，基于定量和定性研究结果，提出城市道路无障碍环境的适应性提升策略。

2.1 志愿者概况

研究于2023年8月中旬以线上方式招募了10位志愿者，男、女各5位，35岁以下者占比为80%。志愿者均由于肢体损伤或脊髓损伤而需要使用轮椅出行，其中5位使用电动车头轮椅，3位使用普通轮椅，2位使用电动轮椅。志愿者的职业包括景观设计师、建筑师、电商平台客服、软件工程师等（表1）。

2.2 生活日志调查

志愿者被要求于2023年8月26日~10月2日之间进行为期2天（工作日与周末各一天）的生活日志调查，以记录他们的出行情况。本次调查过程使用的感知设备是由北京城市象限科技有限公司自主研发的IoT一体巡检机（专利号：202322990046.X），包含轮椅及全景拍摄设备和路面感知设备（图1）。全景拍摄设备包括传感器和全景相机，安装在轮椅后部，能够在以志愿者视角记录出行过程中空间环境情况的同时，充分保护志愿者的隐私；传感器控制全景相机每隔10秒拍一张照片，同时记录轮椅所在的空间地理位置。路面感知设备包括坡度和震动检测设备，通过记录轮椅的倾斜姿态，可自动测量路面坡度和颠簸度；通过夹持组件与定位组件固定于轮椅安装管上，可实现便捷装卸。

表 1：志愿者信息概况

志愿者编号	性别	年龄	使用轮椅原因	使用轮椅类型	职业
A	女	28	脊髓损伤	电动车头轮椅	新媒体从业者
B	男	32	脊髓损伤	电动车头轮椅	医疗行业从业者
C	男	52	肢体损伤	电动车头轮椅	电商平台从业者
D	女	36	肢体损伤	手动轮椅	景观设计师
E	女	26	脊髓损伤	电动车头轮椅	电商平台从业者
F	女	28	脊髓损伤	手动轮椅	电话销售员
G	男	24	肢体损伤	电动轮椅	商务专员
H	男	53	肢体损伤	电动轮椅	建筑设计师
I	女	34	脊髓损伤	电动车头轮椅	基金会从业者
J	男	23	肢体损伤	手动轮椅	软件工程师

生活日志数据包括全景照片、拍摄时间及拍摄时的空间坐标信息等，以及由志愿者录音转录而成的文本数据。IoT一体巡检机共收集了9 261张全景照片，剔除长时间画面无明显变化的连续照片和室内空间照片后，获得6 443张有效照片。随后，基于全景照片内容与录音文本数据，对这些照片中的空间类型、通行道路类型、障碍问题描述及障碍类型等进行人工分类，并分别赋予标签（表2）。最终，依据空间坐标信息，借助QGIS空间地理信息软件对出行目的地类型、出行距离、通行道路类型和障碍类型进行数据统计与可视化分析。

笔者团队开发了“城市象限—全景空间”数据可视化平台，可自动识别所上传照片的要素信息并与时间、空间信息进行关联，实现街景的可视化还原（图2）。同时，结合志愿者的录音文本数据，本研究还原了志愿者的主观感受，以细化障碍问题描述。

2.3 Mapping工作坊

研究团队与残障融合实验室联合发起Mapping工作坊，于2023年10月15日进行。研究团队以邀约的方式招募具有建成环境专业背景的从业者或学生作为画图者，同时公开招募公众参与者。每个Mapping小组中至少包含一位志愿者、一位画图者和一位普通公众。这种分组方式旨在深化建成环境专业人士和普通公众对于交通弱势群体出行障碍的理解。

在Mapping工作坊正式开展之前，研究团队首先以志愿者E为例，进行了出行路线的Mapping可视化示范。可视化方法参考了既有研究[14]，根据全景照片、录音文本数据，以及志愿者的回忆讲述，分小组讨论，并以拼贴照片的形式呈现每一位志愿者的出行线路（图3）。每位志愿者的障碍问题描述包括空间环境细节、公众行为和反馈解决经验等。这种方式将Mapping作为互动、对话和思考的动态时间过程，以形成基于空间认知叙事的“情境性知识”[15]。

2.4 人行道路面铺装材料颠簸度对比研究

基于生活日志和Mapping工作坊所获取的关于人行道障碍的认知，本研究发现，人行道路面颠簸度是影响志愿者选择非机动车道通行的主要原因，而这也进一步引发了轮椅在非机动车道上的路权争议。因此，研究团队进行了人行道路面铺装材料颠簸度对比实证研究。

研究对生活日志中涉及的人行道路面铺装材料进行了分类，并依照

表 2：出行生活日志调查标签分类

类别	内容
空间类型	通行道路 室内空间 室外空间 交通工具
通行道路类型	人行道 非机动车道 机动车道（含混行道路）
障碍问题描述	● 共享单车路侧停放，限制轮椅通行 ● 行人占用非机动车道 ● 机动车路侧停放，占用非机动车道 ● 非机动车停放，占用非机动车道 ● 非机动车逆行 ● 占用无障碍车厢、轮椅停放位置 ● 部分支路机非混行 ● 无过街斑马线与红绿灯设施 ● 出入口阻车桩阻碍轮椅进出 ● 出入口台阶无轮椅坡道；坡道坡度和材质不达标 ● 出入口大门难以打开 ● 人行道接驳处有高差 ● 人行天桥无无障碍电梯／坡道

注
障碍类型：● 表示交通行为不规范障碍；● 表示道路设施建设障碍；● 无障碍设施建设障碍。

铺装类型设计了调研路线；随后利用IoT一体巡检设备实地采集了x、y、z轴方向的加速度和角速度数据，从而计算出各种材料的颠簸度。计算公式为：

$$result=\sqrt{acc_X{}^2+acc_Y{}^2+acc_Z{}^2}\times\sqrt{gyro_X{}^2+gyro_Y{}^2+gyro_Z{}^2},\quad(1)$$

式中，acc_X、acc_Y、acc_Z分别表示x、y、z轴方向的加速度；$gyro_X$、$gyro_Y$、$gyro_Z$分别表示x、y、z轴方向的角速度；$result$表示加速度和角速度矢量模长的乘积，即颠簸度。

研究调研了20条路段，共采集人行道路面铺装材料照片622张，颠簸度数据234 111条。研究团队将照片和颠簸度记录点位数据进行拟合。由于颠簸度点位记录频率（0.025~0.033秒记录1次）高于照片（10秒记录1次），研究团队根据位置信息，对不同地点颠簸度所对应的铺装材料标签进行补充，并将照片的铺装材料类型数据与颠簸度数据进行关联。最终，以关联铺装材料类型后的234 111条颠簸度数据作为原始数据，对不同铺装材料类型的颠簸度进行了对比研究。

3 研究结果

3.1 出行目的地类型

生活日志调查结果显示，志愿者出行路线覆盖北京市东城区、西城区、朝阳区、丰台区、海淀区、昌平区、通州区、大兴区部分路段。出行目的地类型包含菜市场、超市、底商店铺（餐馆、便利店、奶茶店等）、商场等购物场所，以及公园、园区写字楼、教堂、居住小区等，涵盖了几乎各类城市公共空间（图4）。其中，除了与通勤目的地较为相关的居住小区、园区写字楼占比较高（分别为39.95%、12.75%），菜市场（19.22%）、公园（14.26%）、超市（10.10%）也是占比相对较高的目的地类型。

志愿者工作日出行目的以通勤为主，平均出行距离为8.52km（最长32.80km，最短0.48km）；80%出行距离在10km以内，40%在0.7m以内。志愿者周末平均出行距离为35.47km（最长95.78km，最短0.97km），出行距离普遍高于工作日（图5）。

本研究中的志愿者主要为中青年轮椅使用者，职业涉及多个领域，具有通勤及多样化的休闲出行需求；出行方式主要为轮椅，或者地铁与轮椅组合出行。因此，本文的研究对象可以代表有固定工作与日常出行需求的中青年交通弱势群体。

3.2 通行道路选择偏好与障碍类型

生活日志调查结果显示，62%的志愿者选择非机动车道通行，选择人行道和机动车道通行的比例分别为24%和14%。

使用非机动车道通行主要面临的问题包括机动车路侧停车占道（58.12%），以及非机动车违规逆行（35.90%）。选择人行道通行的志愿者面临非机动车所带来的路权挤压（31.46%）和人行道接驳处高差（30.34%）所带来的出行障碍。机动车道通行面临的障碍主要为机非混行（62.31%）和机动车路侧占道停车（33.17%）。由于机动车路侧停车和机非混行等空间限制，被迫选择机动车道通行的志愿者面临更多由于高度较低而易处于机动车视线盲区的安全风险（表3）。

志愿者在出行中遇到的最常见障碍是交通行为不规范（47.97%），其次是道路设施建设障碍（占比42.50%），无障碍设施建设障碍较少（9.53%）。交通行为不规范障碍主要为出行空间挤压，即机动车道、非机动车道和人行道的通行空间中均出现本不应使用该道路的交通出行工具或行人。交通设施建设障碍问题主要为部分支路机非混行，导致轮椅使用者被迫与机动车混行，面临更高的安全风险。无障碍设施建设障碍

表 3：影响志愿者道路选择偏好的主要障碍问题

障碍问题描述	选择非机动车道通行	选择人行道通行	选择机动车道通行
● 共享单车路侧停放，限制轮椅通行	—	31.46%	—
● 机动车路侧停放，占用非机动车道	58.12%	16.85%	33.17%
● 非机动车停放，占用非机动车道	—	—	1.76%
● 非机动车逆行	35.90%	2.25%	2.76%
● 部分支路机非混行	—	8.99%	62.31%
● 无过街斑马线与红绿灯设施	2.56%	—	—
● 出入口台阶无轮椅坡道；坡道坡度和材质不达标	1.71%	8.99%	—
● 出入口大门难以打开	—	1.12%	—
● 人行道接驳处有高差	1.71%	30.34%	—

注
障碍类型：● 表示交通行为不规范障碍；● 表示道路设施建设障碍；● 无障碍设施建设障碍。

主要为出入口高差，具体表现为居住小区内建筑出入口不合规、无障碍轮椅坡道缺失或坡度不合规，以及坡道的坡面减速带材质不达标（表4）。

然而，全景照片数据和统计分析仍然存在叙事限制，无法完全反映志愿者的出行障碍与真实感知。例如，研究者难以仅仅通过照片识别或感知是什么样的人行道障碍导致了志愿者当下选择非机动车道通行。在Mapping工作坊中，志愿者为研究团队提供了更多情境性知识，解释了出行障碍问题的具体细节（表5，图6）。

调查发现，志愿者选择非机动车道作为主要通行道路是出于人行道道路设施建设和无障碍设施建设两方面的考虑。在道路设施建设层面，机非混行、共享单车等非机动车的占道停放、树池与道路附属设施占道、树池铺装不平整或树根造成铺装凸起、台阶高差、非机动车道出入口的阻车设施、防滑设施阻力过大／过小、盲道等因素都会影响路面平整度和可通行性。其中，一个影响通行道路选择的重要原因是人行道路面更容易造成轮椅颠簸，而这种颠簸会对肢体残障群体（尤其是脊髓损伤群体）造成进一步的身体伤害。无障碍设施建设层面的问题则主要在于人行道缘石坡道、轮椅坡道的不合规和缺失，致使志愿者无法选择人行道通行。

3.3 人行道铺装材料颠簸度对比研究

鉴于人行道路面颠簸问题是志愿者选择非机动车道通行的主要原因之一，研究团队对人行道5种常见的铺装材料（青石、青砖、大理石、透水砖、花岗岩）与非机动车道常见的铺装材料沥青对路面颠簸度的影响

表 4：出行障碍问题类型占比统计

障碍类型	障碍问题描述	占比
交通行为不规范	机动车路侧停放，占用非机动车道	33.75%
	非机动车停放，占用非机动车道	8.59%
	非机动车逆行	3.75%
	共享单车路侧停放，限制轮椅通行	1.09%
	行人占用非机动车道	0.47%
	占用无障碍车厢、轮椅停放位置	0.31%
道路设施建设	部分支路机非混行	40.47%
	无过街斑马线与红绿灯设施	1.88%
	出入口阻车桩阻碍轮椅进出	0.16%
无障碍设施建设	出入口台阶无轮椅坡道；坡道坡度和材质不达标	4.69%
	人行道接驳处有高差	2.03%
	人行天桥无无障碍电梯／坡道	2.03%
	出入口大门难以打开	0.78%

表 5：部分志愿者出行障碍细节描述

志愿者	出行障碍细节描述
A	“我工作的办公楼，它是属于丰台区 5A 级的办公楼，但是它的正门是完全没有地方能进去的。所以我每一天上班都要逆行一段马路过去——我要通过地库，然后跟汽车挤道过去，才能进到办公楼里面。”
C	“还有道路上的坑坑洼洼特别难受，因为我本身身体抗颠簸能力差，所以我就特别不喜欢这种。”
D	“进入园区的时候，一个路口上有一个铁栅栏。一般行人走铁栅栏是没有什么问题的，但是像我们常规轮椅的话尺寸都比较大，基本上是无法通行。” “不选择走人行道的原因就是它大部分的路面都比较颠簸，路面上的破损的情况也比较多……就是我到转弯的时候它是没有缘石坡道的，我上去以后就下不来了，所以基本上出行的话都会选择非机动车道。”
I	“这条路对于行人来说也是比较有挑战、比较困难的，会有一些电线杆和路挡等等，就树立在路缘坡的中间，所以说它整体的宽度是不够的。”

表 6：不同铺装材料颠簸度分析

组	观测数（条）	平均值	方差	中位数
青砖	32 498	4.42	23.59	3.46
沥青	82 011	5.64	52.25	3.79
青石	206	3.97	7.25	3.91
花岗岩	55 978	6.42	58.17	4.11
大理石	3 946	5.57	23.72	4.54
透水砖	59 472	6.03	30.29	4.89

进行了对比研究。研究发现，用沥青铺装的非机动车道颠簸度小于用透水砖的人行道，这进一步证明了志愿者所代表的交通弱势群体选择非机动车道通行的原因。

分析结果显示，沥青铺装材料的颠簸度中位数小于青石、大理石、透水砖、花岗岩（表6，7；图7）。值得注意的是，青砖的颠簸度接近于沥青，其中位数和上下四分位数均低于沥青，且方差最低，说明其颠簸度情况甚至优于沥青路面。不同铺装材料颠簸度数据的方差分析结果p值小于0.05，说明差异具有显著性。

研究选取颠簸度中位数相对接近沥青且铺面形式多样的青砖与花岗岩，就铺面形式对颠簸度的影响进行了进一步对比研究。分析结果表明，相较于烧面和荔枝面，自然面的花岗岩铺面形式虽然更具自然、质朴的景观效果，但也极大地增加了路面颠簸度：花岗岩自然面颠簸度的方差（114.85）和平均值（12.10）均说明，这种铺面形式普遍颠簸度较大且样本间颠簸度差异较大（表8，图8）。青砖虽然整体颠簸度较低，但不同铺面形式的颠簸度仍呈现出一定差异，工字铺形式的颠簸度较人字铺和田字铺更高（表9，图9）。

4 结论与讨论

本研究利用自主研发的IoT一体巡检设备，结合生活日志调查、Mapping工作坊和路面铺装材料颠簸度对比研究等方式，得出了轮椅出行者对城市无障碍环境需求的准确描述。研究主要发现包括以下几点。

1）交通弱势群体有着丰富多样的出行需求，菜市场、超市和公园是除通勤外占比较高的出行目的地类型，且周末出行距离远高于工作日通勤出行距离。

2）相较于人行道，交通弱势群体偏好选择非机动车道通行。

3）出行障碍主要由不规范交通行为与道路设施建设缺陷所导致，例如机动车路侧停车、机非混行等问题。

4）非机动车道常用的沥青铺装材料颠簸度低于人行道常用的透水砖、花岗岩、青石、大理石铺装材料；青砖铺装材料颠簸度整体低于沥青，且颠簸度变化相对小。

5）对于花岗岩和青砖两种铺装材料，不同铺面形式的颠簸度也存在差异。

表 7：不同铺装材料颠簸度方差分析结果

差异源	*SS*	*df*	*MS*	*F*	*p*-value	*F*-critical
组间	88 673.9225	5	17 734.7845	406.875476	0	2.2141377

表 8：花岗岩不同铺面形式颠簸度对比分析结果

铺面形式	最大值	最小值	平均值	方差
荔枝面	98.04	0	5.15	32.83
自然面	106.94	0	12.10	114.85
烧面	177.49	0	5.44	42.95

表 9：青砖不同铺面形式颠簸度对比分析结果

铺面形式	最大值	最小值	平均值	方差
人字铺	38.04	0	4.49	21.98
工字铺	34.2	0	7	17.29
田字铺	55.57	0	3.36	26.81

4.1 非机动车道通行偏好与轮椅出行路权讨论

交通弱势群体的通行道路选择偏好体现了城市无障碍环境，尤其是人行道无障碍环境与出行者实际需求之间的差距。目前，城市物理空间建设及交通管理规范主要以行人为对象来制定出行环境与无障碍设施标准，在一定程度上忽略了交通弱势群体对非机动车道路权与环境的需求，且公众普遍缺乏对交通弱势群体出行需求，以及电动轮椅、电动车头轮椅等出行工具的有效认识。研究发现，在出行过程中，交通弱势群体需要自主、安全地通行人行道和非机动车道，以及进出公共交通工具和公共空间。这向城市规划和交通管理中非机动车道路权对新型出行工具的包容性提出了挑战，也需要广泛的社会共识和其他出行者的参与，从而共同构建包容性、适应性出行环境。

在公共路权的讨论中，交通弱势群体的出行路权需要被置于更高优先级，以《无障碍环境建设法》推动交通和规划领域路权界定，形成“交通弱势群体可享有非机动车道优先路权”的社会共识，以保障当前交通低碳转型过程中的社会公正。虽然依照现行法律规定，轮椅不属于非机动车，不享有非机动车的路权，但非常有必要以弹性动态的视角来看待轮椅出行者偏好使用非机动车道通行的事实。本文希望以充分论证及公众广泛参与的方式，推动法律和社会对交通弱势群体的路权问题进行更深入的探讨和界定。

针对上述问题，本文建议充分借鉴其他国家的建设经验。例如，英国的交通法律将轮椅、动力轮椅和代步车分为三类，第一类手动轮椅可在人行道或行人区域行驶，速度不得超过6km/h；第二类动力轮椅和代步车可在人行道行驶，速度也不得超过6km/h；第三类动力轮椅和代步车均可在人行道和道路中行驶，速度不得超过12km/h[16]。英国对轮椅类型和速度的分级管理有助于在保障出行者安全的同时，最大限度地包容不同出行能力的交通工具。随着交通弱势群体出行工具的更新与出行需求的多样化，这种精细化的路权管理有助于中国无障碍环境建设水平的提升。

4.2 城市无障碍环境的适应性道路改善策略

在城市步行环境的景观设计中，需要增加对交通弱势群体适应性与权益公正性的考量。研究结果表明，针对轮椅出行需求，当前人行道无障碍环境问题主要体现在路缘坡道不合规、树池不平整、阻车桩导致通行宽度受限，以及地面铺装造成颠簸。这些问题不仅导致轮椅出行者不得不选择非机动车道通行，同样也增加了骑行者和行人的安全风险。

无障碍设施建设相关标准及相关空间环境建设应综合考虑轮椅出行者、行人和骑行者的通行需求，同时建议相关研究机构或标准制定机构以申报研究课题与经费支持的形式，从以下方向开展对无障碍新型基础设施建设开展试点研究，并论证试点标准化和推广的可行性。

1）相对于目前人行道普遍使用的透水砖和花岗岩，沥青、青砖铺装材料的路面颠簸度更低，同时考虑到透水性，建议城市更新过程中人行道铺装采用透水沥青混凝土、水泥混凝土路面或青砖路面；使用这些铺装材料也可以提高路面平整度并减少成本。同时，人行道铺装材料的设计把关、施工过程中的找平工艺等严格要求也有助于提高路面平整度。

2）抬升式人行横道设施有助于改善城市中已建成但不合规的缘石坡道与车行道的高差，同时提高人行道连续性，这既能引导通行机动车与非机动车减速，又能保障轮椅及行人过街的高度可视性与安全性（图10）。同时，建议通过精细化评估来识别非机动车通行流量较低且需要采用静稳化交通策略[17]的路段，并将这些路段作为抬升式人行横道试点，评估其对交通弱势群体的安全性与友好性，并考虑到对视障人士的便利引导性及排水问题。

3）当前，城市道路空间规划设计标准中普遍将树池平整化仅仅作为建议性条文。建议在设计规范修订中将树池平整化处理作为强制性要求，并提出对树池篦子的维护要求，从而提升交通弱势群体的出行体验。

4）在出入口设置阻车设施多是由于管理方意图限制电动车进入步行区域，但是当前阻车桩、回字型出入口等阻车设施缺乏设计标准，导致轮椅通行受阻。建议针对出入口阻车设施的设置标准进行研究论证，并形成基于科学依据、具有流程规范性的国际及地方标准，以保障交通弱势群体出入公共空间的合法权益。同时，建议对不同尺寸要求的阻车设施进行测试，广泛邀请交通弱势群体组织与个体志愿者参与，以确保各类使用者均可自主通行。

4.3 多源数据感知与工作坊结合的创新方法

本研究采用了生活日志调查、Mapping工作坊、对比研究等多维度的研究方法，从轮椅出行者的视角来探知交通弱势群体的出行障碍与需求。这种综合研究方法在一定程度上使研究者成为出行者需求与空间环境现状的转译者，并将可视化的转译成果向公众与政府管理决策部门展示，有助于更准确且有效地帮助公众建立出行障碍认知并推动社会行动，从而解决现实中的在地出行问题。

研究团队对轮椅出行者这一交通弱势群体的需求进行了较为细致的实证研究与生活日志探索，为包容性景观设计提供了更加准确的需求描述与数据支持。研究结合公众参与的Mapping活动，有助于再现出行场景，并形成情境性知识，深化公众对交通弱势群体在地化出行需求、出行偏好与出行障碍的认知。通过构建情境性知识，本研究旨在促使研究者、设计者与研究对象之间形成包容性景观的共识，为未来出行需求研究提供了一种研究方法范式。

值得指出的是，本研究中的生活日志调查样本量相对较小，导致研究结果存在一定的局限性。未来相关研究可扩大样本量，参考利用本研究的出行数据采集与分析方法，形成更具普适性的交通弱势群体出行需求认知。

图 1. IoT 一体巡检设备
图 2. 城市象限 – 全景空间数据可视化平台界面
图 3. Mapping 可视化示范：以志愿者 E 出行路线为例。
图 4. 出行目的地类型统计
图 5. 工作日和周末出行路线与距离分析
图 6. 志愿者出行遇到的具体障碍示例
图 7. 不同铺装材料类型的颠簸度箱形图
图 8. 花岗岩不同铺面形式照片：从左到右为自然面、烧面和荔枝面。
图 9. 青砖不同铺面形式照片：从左到右为人字铺、田字铺和工字铺。
图 10. 抬升式人行横道