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Simulating the Mild Visually Impaired Commuters in Rail Transit: An Inclusive Design Study Using Able-Bodies' Role-Playing and Immersive Experience

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ABSTRACT

Considering the critical importance of public transportation, especially rail transit, in shaping urban landscapes and its alignment with the United Nations Sustainable Development Goals, this investigation delves into the architectural intricacies of rail transit environments through the lens of inclusivity. This scholarly inquiry adopts a multifaceted qualitative research methodology that synergizes empirical case studies, the formulation of strategic frameworks, and the application of design methodologies to elucidate and operationalize the principles of inclusive design within the context of rail transit systems.The study embarked on an initial empirical exploration through an in-depth case study of Singapore's Thomson-East Coast Line, where able-bodied participants role-played and engaged in an immersive experience by wearing glasses that simulate mild visual impairment. By coding the data from these on-site experiences, a robust inclusive design framework was distilled, characterized by a tripartite structural hierarchy and four thematic pillars. Building on this foundational framework, the study proposed a quintet of innovative inclusive design prototypes tailored to enhance the tactile interaction points within rail transit environments. These prototypes were further evaluated through the reconstruction of subway navigation scenarios experienced by visually impaired commuters, employing storyboards as a tool for situational analysis. The comprehensive inclusive design framework and the ensuing design prototypes unveiled through this study hold profound implications for the strategic planning and architectural design of urban rail transit systems, particularly within the ambit of nascent urban centers poised to embark on or currently engaged in the development of rail transit infrastructures. This research significantly contributes to the discourse on sustainable urban development and the promotion of social inclusiveness, presenting actionable insights for policymakers, urban planners, and designers engaged in the creation of more accessible and inclusive urban transit ecosystems.

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1. Introduction

Driven by the United Nations' Sustainable Development Goals, public transport, led by rail transit, is playing an increasingly significant role in the acceleration and deepening of urban construction. Many cities have preliminarily established extensive rail transit networks, leading to a surge in the number of subway riders and diversifying travel demands. Consequently, there is a growing dependency on the inclusivity of rail transit. However, current design and planning for rail transit spaces are solely focused on accessibility, failing to meet the nuances of its conceptual design and implementation motives in the face of evolving societal forms.

The concept of "inclusive design," as mentioned in this paper, was proposed in the 1990s. Its core tenet is to respect human diversity and uniqueness, committed to designing products and services for a broader population to meet diverse needs, opposing design exclusion (Dong, 2020), with a focus on fairness and sustainable development. Similar concepts include "universal design" and "Design for all". These philosophies have influenced each other throughout their evolution and can even be interchangeable (Ormerod and Newton,2005; Clarkson and Coleman, 2015; Persson et al., 2015; Yuan et al., 2020). In this article, the term "inclusive design" was used to represent the aforementioned human-centered design advocacies.

The goal of inclusive design is to accommodate as many people as possible, addressing the diverse commuting needs of groups such as the elderly, the disabled, and children (Martens, 2018; Levine and Karner, 2023; Kim and Sohn, 2020). Based on this, scholars have proposed the concept of equity in public transportation (Tribby and Zandbergen, 2012), often discussed alongside the issues of accessibility, and the equity of medical and educational resources (Lei et al., 2012; Anjomshoaa et al., 2017). The public transportation system must offer and serve everyone in a non-discriminatory manner (Kose, 2018). This stance aligns with the philosophy of inclusive design. Therefore, design concepts such as inclusive design and universal design have been applied to various dimensions of rail transit to address the challenges faced in public transportation development.

This study refers to MVI as a condition where visual function is below the normal level but does not reach the severity of moderate or severe visual impairment. Here, the target population primarily experiences symptoms such as the loss of fine detail recognition, including difficulties in achieving proper focus, decreased sensitivity of retinal cells, and lens opacity. These symptoms are caused by conditions such as myopia, age-related macular degeneration, diabetic retinopathy, cataracts, and retinitis pigmentosa. Except for retinitis pigmentosa, the other mentioned eye diseases are very common in the global population and show a high incidence trend (We et al., 2023;Fleckenstein et al., 2024; Teo et al., 2021). Therefore, the group of mild visually impaired individuals among rail transit passengers should not be overlooked.

From a spatial perspective, rail transportation combines user behavioral characteristics with universally equipped environment devices at subway entrances and exits, focusing on the needs of individuals with mobility impairments and informational disabilities. Zhang et al. (2011) argue, from the perspective of inclusive design, that audio-oriented message conversion is a beneficial supplement to visual recognition systems. The physical environment can influence the form of travel (Mahdzar et al., 2016), some scholars have researched the inclusive design of rail transit facilities, suggesting that combining physical design changes with reasonable adjustment measures can enhance the user experience (Seriani, 2022; Xu et al., 2018; Shi and Zhao, 2022). In terms of time, it's worth attempting to treat inclusive design as a process in subway development. By allowing pilot users to become stakeholders or even decision-makers in the design scheme, profoundly impactful solutions can be generated (Strickfaden and Devlieger, 2011).

The value of these studies lies primarily in their ability to go beyond the principles of accessibility design and embrace the diversity and ability differences of users in a more humane and inclusive design approach, thereby avoiding discrimination against certain groups. However, the limitation of these studies is that they often overlook the importance of examining and understanding the perspectives of both pilot users and designers. Inclusivity in the environment is a complex and multi-dimensional concept (Heylighen and Dong, 2019). However, for urban rail transit spaces, which elements are inclusive to a certain group of people, how they are reflected in the design of urban rail transit spaces, and what kind of use scenarios can be obtained, have not been widely discussed. Therefore, systematic qualitative research is essential.

The core objective of this study is to explore the elements of inclusive design in the context of rail transit spaces for individuals with visual impairments and to uncover the underlying logic of spatial inclusivity in design. The research attempt to establish a qualitative research process for in-depth exploration of spatial inclusivity design, consisting of three key steps: on-site case studies, strategic framework development, and design practice application. The study initially adopts design research methods by simulating the experience of visually impaired commuters through the use of simulated glasses and conducting case studies on the Thomson-East Coast Line (TEL) in Singapore. Subsequently, the grounded theory approach is employed to code and extract themes from the raw data collected through mobile recordings, leading to the development of an inclusive design framework. Furthermore, the framework is utilized to present four inclusive design prototypes for spatial touchpoints. Finally, a storyboard is employed to reconstruct scenarios of visually impaired commuters using the subway system, followed by a situational analysis. The study's significance lies in the integration of design research methods and sociological approaches to systematically examine inclusive design in rail transit spaces, thereby providing valuable insights for planning and constructing rail transit systems in emerging cities.

2. Methodology

2.1 Overview of Research Subject

In Singapore, the trifecta of limited land resources, high population density, and an aging demographic structure pose considerable challenges to its development. Prioritizing public transport development not only addresses the issue of commute congestion but, with the support of universal design, it can also become a key mechanism for providing environmental support for an aging society. The TEL commenced operations in January, 2020, initially launching with 20 stations. The whole line plans to span 43 kilometers and include a total of 32 stations, connecting well-established residential areas. The design of TEL strictly follows accessibility guidelines, ensuring wheelchair accessibility across all stations, thereby promoting inclusivity in the public transport system. Therefore, TEL was selected the as the case for this research, using it as a spatial instance to explore the specific composition of spatial inclusiveness from the perspective of the visually impaired, thereby refining the design strategies of inclusive design.

2.2 Research Method

This study employs a mixed qualitative approach that combines design and sociology. The former includes role-play, immersive experience, high-fidelity prototypes, and storyboards (Hu and Mi, 2022), while the latter pertains to coding derived from grounded theory. Role-play and immersive experiences are regarded as methods of cultivating empathy in design, matching the user's mindset with the designer's imagination (Yadav, 2020). This approach yields empathetic, immersive, and vicarious insights suitable for deriving inclusive design insights in urban rail transit spaces. High-fidelity prototypes serve to test and evaluate design concepts in the early stages, playing a crucial role in the development process. They assist the research team in better understanding how optimized inclusive design in space operates in practice. Storyboards effectively recreate the context of the user, reflecting the entire process of visually impaired commuters riding the subway in a holistic and concrete manner. The latter coding, originating from grounded theory, is a bottom-up qualitative research method that is widely used. The underlying logic of inclusive design in transportation spaces is discerned through the refinement, tagging, and conceptualization of research data, leading to the construction of a strategic framework for inclusive design.

2.3 Research Process

The research process includes three steps: case study, framework development, and design practice. Among them, role-playing, immersive experiences, and coding are mixed used to construct the inclusive design strategy framework. Design prototypes and storyboards are used to deduce the application of the framework in rail transit spaces. See figure 1 for the steps.

2.3.1 Case Study

In February 2023, the research group rode the MRT TEL in Singapore. A single journey was made from Marina Bay to Orchard Station (a total of 6 stops). The specific method involved wearing simulation glasses to role-play a commuter with mild visual impairment (MVI). An earphone-equipped smartphone was used to record spoken thoughts, typically comprising statements describing and evaluating aspects such as "listing difficulties", "proposing improvement ideas", "describing experiences", and "post-use evaluation". At the same time, photos were taken for on-site documentation, as shown in figures 2 and 3.

The simulation glasses used were developed by the Engineering Design Center at the University of Cambridge. These glasses simulate the loss of detailed capture capability of the human eye, resulting in effects such as unfocused vision, reduced retinal cell sensitivity, and blurred vision. The specific visual effects are shown in figures 4 and 5. Prior to this, the number of glasses to wear was determined through specialized vision tests.

According to research by the Cambridge University Engineering Design Centre on visual acuity and its normal distribution among the population, only a small proportion of people with very poor vision use visual assistive technologies for help, while most young designers possess above-average visual acuity. As a result, their design outputs tend to cater to those with normal or above-average vision, leaving individuals with mild visual impairments-who fall between these extremes-easily overlooked (Inclusive Design Toolkit, n.d.). See figure 6. Simulation glasses can be beneficial for this group through methods that involve collaboration between researchers, designers, and users with visual impairments to perceive characteristics (Chivaran et al., 2021).

Figure 1. Research steps

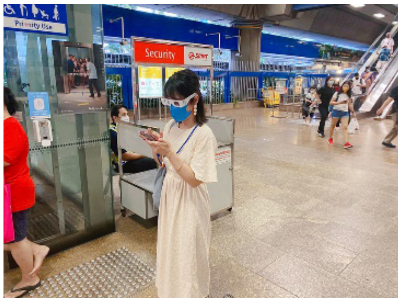

Figure 2. Researcher wearing simulation glasses searching for a route

Figure 3. Researcher observe the service notification screen while wearing glasses

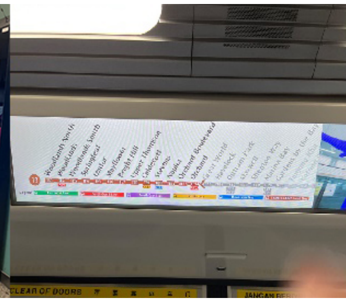

Figure 4. Visual effects under normal vision

Figure 5. Visual effects after wearing glasses

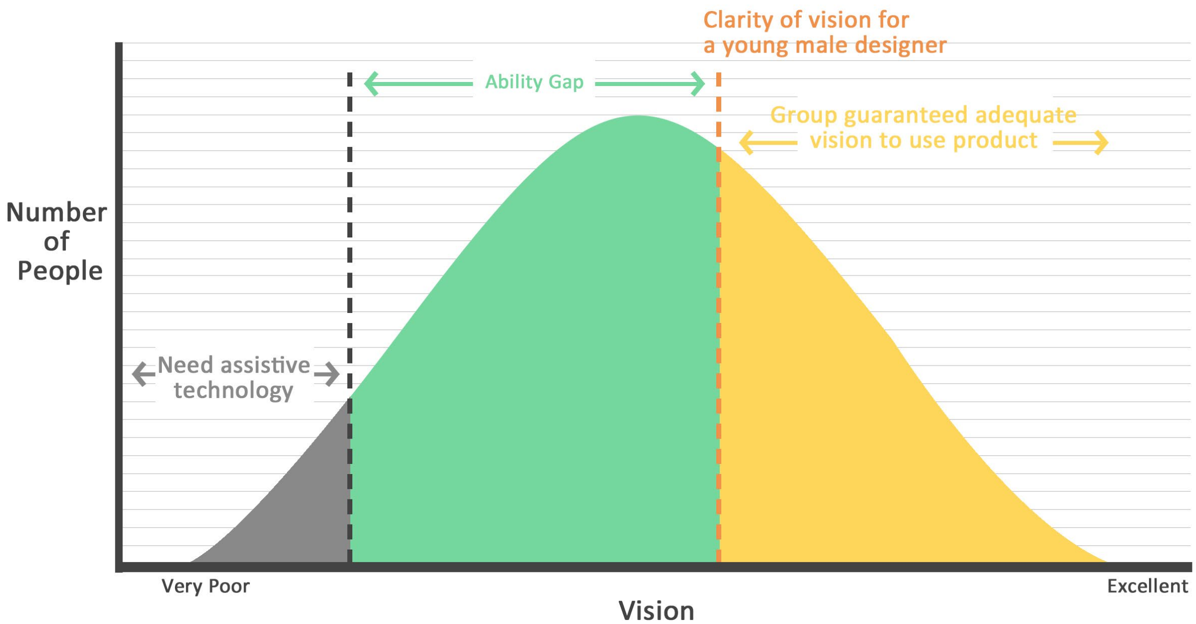

Figure 6. Visual acuity distribution among the population

It is important to note that the objective of the TEL case study is to assist designers in conceptualizing commuter usage of space from the perspective of individuals with MVIs. This is achieved through the construction of inclusive design codes for urban rail transit spaces based on commuting experiences. However, this case study cannot guarantee complete inclusivity for visually impaired individuals in TEL, and negative experiences may still occur. The encoding of such adverse emotions nonetheless contributes to the formulation of an inclusive design framework. It can potentially facilitate reflective contemplation among researchers, as well as provide insights for design strategies.

2.3.2 Framework Development

Coding and theme exploration are employed in the construction of the inclusive design strategy framework for rail transit. Initially, atlas.ti qualitative analysis software was used to transcribe raw data, which included audio, video, and photos. Following this, open coding was performed on the transcribed files, generating 210 open codes. Next, through categorization, filtering, deletion, merging, and linking of codes, 39 axial codes (underlying logic) were identified. Finally, 16 selective codes (design strategy) related to subway inclusive design were established, from which four themes were extracted. This process helped to construct a systematic framework for inclusive spatial design.

2.3.3 Design Practise

Based on the established framework for inclusive spatial design, four optimized standard spatial touchpoint prototypes were proposed and elaborately explained. These touchpoints involve ticketing and passage areas, location and waiting areas. Specific standardized settings and detailed explanatory were provided from various aspects of the inclusive spatial design strategy. To verify the applicability and universality of the optimized design, a storyboard was created to depict a scenario of a visually impaired commuter taking the subway. This allowed for situational analysis, displaying the ideal experience and design details. Then, following the order of a visually impaired person's subway journey, eight subway scenario storyboards were constructed to provide in-depth explanations of the specific use cases of these inclusive design prototypes.

3. Result and Discussion

3.1 Framework for Inclusive Design Strategy in Rail Transit Spaces

Through detailed coding of ride experience records, including voice-to-text transcription and photo analysis, a total of 210 open codes were obtained . These open codes, although based on the TEL experience, do not assure that all experiences are positive; negative feedback also persists. This feedback does not hinder the extraction of codes but instead serves as a catalyst for designer reflection. After meticulous screening, integration, and categorization, these open codes were refined into 39 axial codes. These axial codes reveal the strategic implications of inclusive design in subway spaces, offering substantial practical value and real-world significance. Further integration and classification culminated in the reduction of these axial codes to 16 selective codes. These selective codes represent the design logic of inclusive design for urban rail transit spaces. Their breadth and depth are dictated by the complexity of the space and the diversity of passenger experiences.

Upon in-depth analysis, this research ultimately defined four themes: minimize sensory ability burden, minimize cognitive ability burden, minimize motor ability burden, and services. In the theme of minimize sensory ability burden, five selective codes - acoustic environment, light environment, perceptual threshold, perspective, and sensory compensation - played key roles. In the theme of reducing cognitive load, the integrality of the guidance system, the logic of the guidance system, and the systematicity of guidance exerted decisive influence. In the theme of reducing action load, effort-saving for horizontal movement, effort-saving for vertical movement, body accessibility, and specialized facilities played crucial roles. In the theme of services, continuous infrastructure optimization, open-ended interaction, and specialized services were deemed essential. Figure 6 shows a bottom-up Sankey diagram, reflecting the relationships among axial codes, selective codes, and themes. The numbers in the diagram represent the quantity of codes, and the different colored lines indicate the themes to which the codes belong.

Additionally, during the coding process, an attempt was made to cluster codes from the perspective of spatial touchpoints, primarily due to the significant spatiotemporal sequence inherent to the process of riding the subway(Harding, 2019; Li and Dai, 2019). The single journey subway ride pathway was divided into five stages according to different experience locations: entering the station hall, accessing the platform, riding the subway, leaving the platform, and exiting the station hall. Key touchpoints for each stage were identified based on the interaction between individual abilities and external factors, with touchpoint judgement based on whether interaction occurred between people, machines, and the environment. These were referred to as spatial touchpoints. The setting of spatial touchpoints enabled researchers to simplify spatial demands, focus on critical aspects of inclusive design, and enhance the operability of data coding classification. These touchpoints, following the sequence of event occurrence, include ground location, entrance, using vertical transport, passages, ticket purchase, tap in, use of vertical transport, location, waiting, boarding, in the carriage, location, alighting, location, use of vertical transport, location, tap out, passages, use of vertical transport, exiting, and ground location. It is worth noting that some touchpoints might vary depending on the actual conditions of the space and the users. In Figure 7, the rightmost column represents these spatial touchpoints. By analyzing the flow of thematic coding and spatial touchpoint cluster coding, the result found that almost all spatial touchpoints involve the use of perceptual, cognitive, and action abilities, intuitively validating the notion that individuals utilize multi-abilities in space.

Therefore, a strategic framework for the inclusive design of rail transit space has constructed using a coding approach. The first three themes of this framework respond to the capability and demand model proposed by Persad et al. (2007), while the fourth theme underscores the characteristics of public transportation. As a public service product (Chu and Shen, 2021), the public transportation system requires continuous operation and maintenance, which further enhances its inclusiveness and sustainability. The innovation of our research framework lies in adopting a user-oriented perspective, an experience-based process, and a mixed research method combining role-playing and grounded theory. By investigating successful groups in an aging society and subway lines in countries with similar cultural backgrounds, this inclusive design strategy framework has been built from the ground up.

3.2 Design Prototypes

Under this inclusive design strategy framework, this study have presented optimized prototypes for inclusive design, taking specific spatial touchpoints as examples, including self-service ticket purchasing and passage, locating and waiting, and toilets - a total of five spatial touchpoints. These optimized prototypes are built on the foundation of the inclusive design framework; thus, themes, elements, design strategies, and specific design points can be identified from the table. Specifically, themes correspond to the themes in the coding, elements correspond to the selective codes in the coding, design strategies correspond to the axial codes, and design points provide explanatory details about specific designs. Furthermore, the design prototypes have been graphically demonstrated .

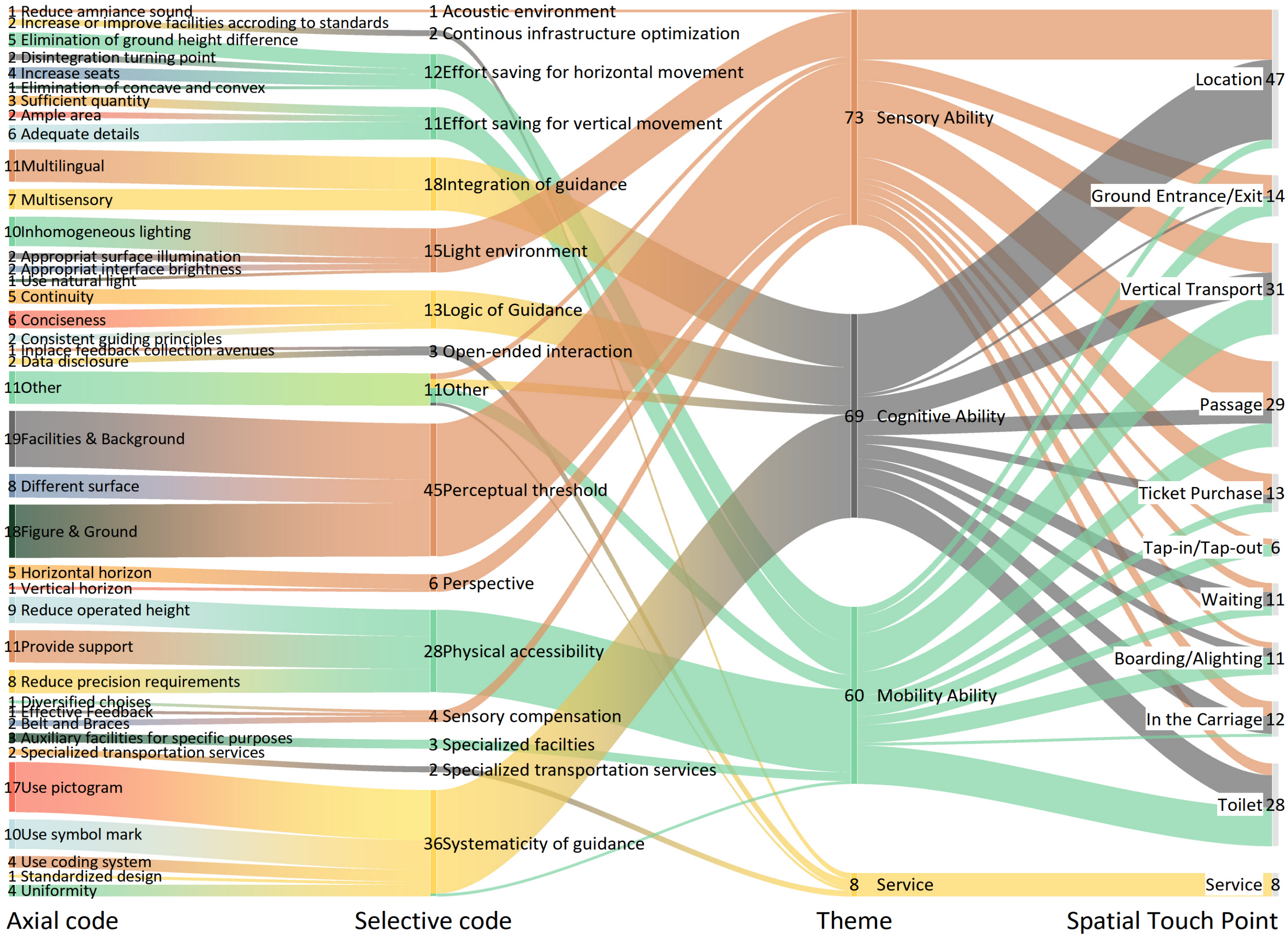

Figure 7. The refinement process of the inclusive design framework

3.2.1 Passage Touchpoint

The optimized design prototype for urban rail transit space passages specifically focuses on five inclusive design elements across three themes, considering how to enhance inclusive design from the perspectives of mobility, perception, and cognition, thereby ensuring an effortless, accessible, comfortable light environment, and easy perception throughout the commuting process. Details can be seen in table 1, where the first three columns represent the inclusive design strategy framework, and the column on the right includes specific details to be noted. For specific dimensions, forms, and colors, please refer to figure 8.

Table 1. Design considerations for passage

Theme	Elements	Design strategy	Concrete
Minimize mobility burden	Effort-saving for horizontal movement	Eliminate ground height difference	Minimize the differences in ground elevation as much as possible to prevent missteps and falls
		Disintegrate corner	Reduce spatial turns and the depth and complexity of buildings to prevent difficulties in locating, and to increase visibility
		Eliminate protrusions	An integrated design of the wall and reducing protruding elements can effectively prevent passengers with impaired vision from getting hurt Treat the corners of buildings with guiding angles to avoid sharp architectural components causing harm to passengers
	Physical accessibility	Provide support where needed	Install handrails wherever possible to provide the support needed for commuters with mobility issues
	Other	Other	Make the ground slip-resistant to prevent slipping accidents
Minimize sensory burden	Light environment	Appropriate surface illumination	Anti-glare characteristics of the floor surface should be ensured to reduce visual interference
	Perceptual threshold	Different surface	Different materials and colors for walls and floors can clearly identify the boundaries of the space
Minimize cognitive burden	Other	Other	Eliminate unnecessary advertisement spots on the walls to highlight guide signs

3.2.2 Ticket purchase touchpoint

The design prototype for the automatic ticket vending area specifically focuses on ten inclusive design elements across three themes. It contemplates how to enhance the inclusiveness of the ticket purchasing process from the perspectives of mobility, perception, and cognition, thereby ensuring an effortless, accessible, comfortable light environment, easy perception, and understanding throughout the ticket purchasing process. Details can be seen in table 2, where the first three columns represent the inclusive design strategy framework, and the column on the right includes specific details to be noted. For specific dimensions, forms, and colors, please refer to figure 8 (Shi and Zhao, 2022).

Table 2 Design considerations for ticket purchase

Theme	Elements	Design strategy	Concrete
Minimize mobility burden	Effort-saving for horizontal movement	Eliminate protrusions	Devices such as ticket vending machines should be designed to be embedded in the wall to reduce space occupation
	Other	Other	Enough open space should be reserved in front of the ticket machines to ensure a safe and effective shared space between the ticket buyers and those passing by
	Specialized facilities	Auxiliary facilities for specific purposes	Sufficient space should be provided under the ticket vending machines and ATMs to accommodate knees, making them accessible to people with mobility impairments, such as wheelchair users
	Physical accessibility	Reduce precision requirements	Devices such as cash and coin outlets should be enlarged appropriately to reduce the precision required for users' actions
Minimize sensory burden	Light environment	Appropriate surface illumination	Anti-glare characteristics of the floor surface should be ensured to reduce visual interference
	Perceptual threshold	Facilities& background	In order to highlight the ticket machines, the color of their decorative surface should be distinctly different from the surrounding environment The shape and color of devices like cash outlets and coin slots should be distinct from the background

Theme	Elements	Design strategy	Concrete
	Light environment	Appropriate interface brightness	The brightness of the machine screen should be controlled within a reasonable range that matches the brightness of the surrounding environment to avoid glare that may impact vision
	Sensory compensation	Effective feedback	Set audio prompts for touching the touch screen
Minimize cognition burden	Integration of guidance	Multilingual	Multilingual
	Systematicity of visual guidance	Use symbol mark	Use symbol mark

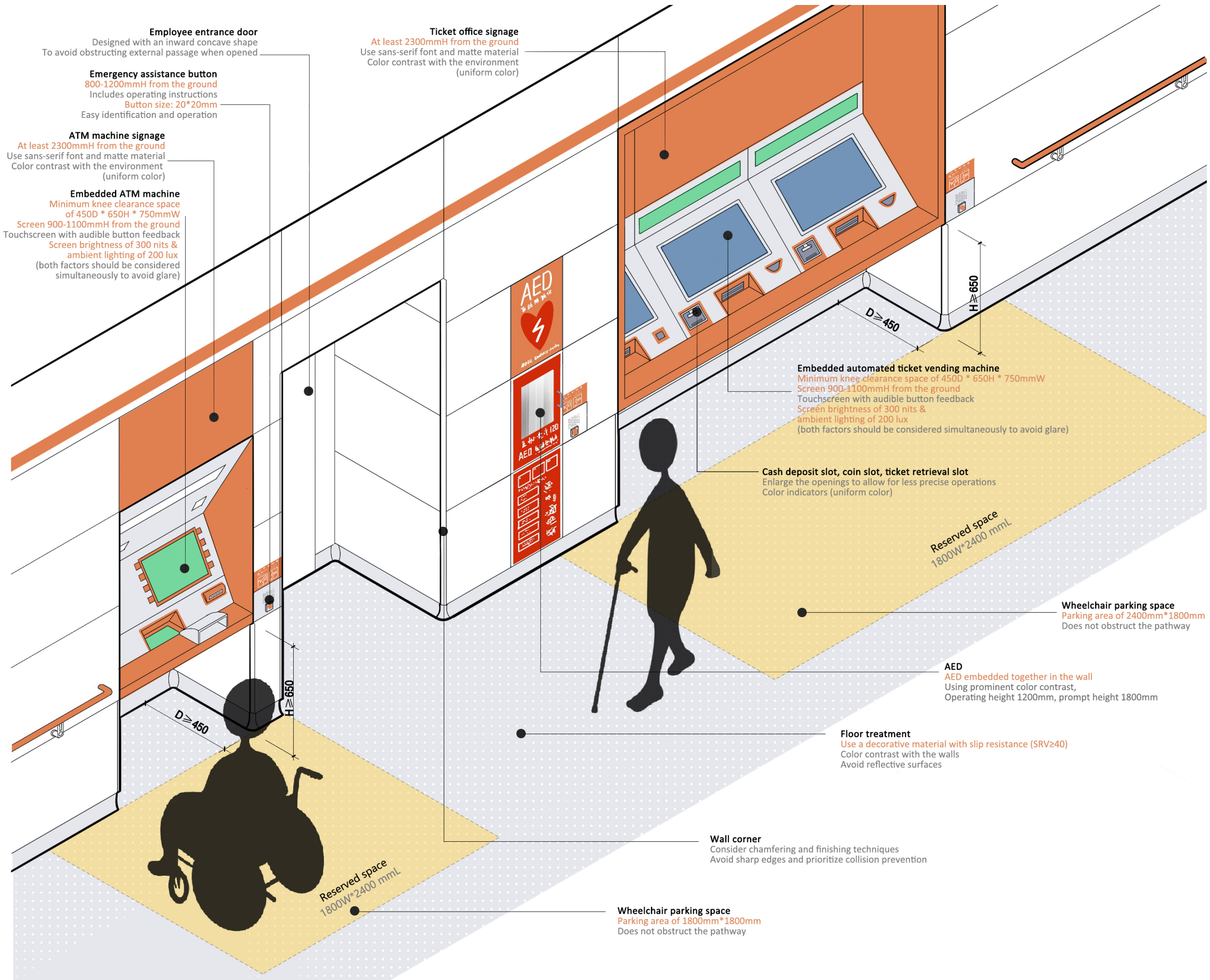

Figure 8. Design prototype for passage and ticket purchase area

3.2.3 Location Touchpoint

The design prototype for the location touchpoint specifically focuses on five inclusive design elements across three themes. It contemplates how to enhance the inclusiveness of location and way finding from the perspectives of physical accessibility, perceptibility, sensory compensation, and cognitive logic. Details can be seen in table 3, where the first three columns represent the inclusive design strategy framework, and the column on the right includes specific details to be noted. For specific dimensions, forms, and colors, please refer to figure 9.

Table 3. Design considerations for location

Theme	Elements	Design Strategy	Concrete
Minimize mobility burden	Physical accessibility	Reduce precision requirements	The guidance system should be designed to facilitate information acquisition for people with different viewing height and visual acuity, such as the use of low viewing position designs
Minimize sensory burden	Perceptual threshold	Different surface	To assist visually impaired individuals in better recognition and use, the material and texture of the tactile paving should significantly contrast with the ground paving around it
		Facilities& background	The color of the guide map should contrast significantly with the surrounding environment for quick discovery by commuters
	Sensory compensation	Belt and braces	The guidance system should use multi-sensory compensatory designs as much as possible, conveying information in parallel through visual, auditory, and tactile means to meet the needs of users with different abilities
	Light environment	Appropriate surface illumination	It should use a matte material to prevent light reflection affecting information reading
Minimize cognition burden	Logic of guidance	Continuity	When setting up tactile maps, they should be connected to the tactile paving as much as possible to enable visually impaired commuters to navigate independently The placement of the guide map should be set reasonably according to the environment and the distribution of pedestrian traffic so that commuters can easily discover and read it at key locations or paths
		Conciseness	The design of tactile paving should be simple and intuitive, and its layout should be effective and comply with the navigation logic of the visually impaired. For example, unnecessary turns and sudden endpoints should be avoided
		Consistent guiding principles	When arranging tactile paving, consideration can be given to setting up some breakpoints or transition areas to facilitate crossing by wheelchair users, baby stroller pushers, and users of personal mobility aids. These breakpoints should be clearly marked and ensure they do not mislead the visually impaired away from the predefined safe path

3.2.4 Waiting Touchpoint

The design prototype for the waiting touchpoint specifically focuses on three inclusive design elements across two themes. It contemplates how to enhance the inclusiveness of the seating design from the perspectives of mobility and perception, thereby ensuring the physical accessibility, effort-saving, and easy perceptibility of resting seats for commuters. Details can be seen in table 4, where the first three columns represent the inclusive design strategy framework, and the column on the right includes specific details to be noted. For specific dimensions, forms, and colors, please refer to figure 9 (Shi and Zhao, 2022).

Table 4. Design considerations for waiting

Theme	Elements	Design strategy	Concrete
Minimize mobility burden	Physical accessibility	Provide support where needed	The form of the seat should have armrests and backs for better support and comfort for passengers Sufficient space should be reserved as a wheelchair parking spot for convenience for wheelchair users
		Reduces operate height	It is recommended to set seats at different heights to meet the needs of passengers of different ages, heights, and physical conditions The sides of the seat should be widened appropriately to accommodate passengers of different body sizes
	Effort-saving for horizontal movement	Increase seats	It is recommended to set up a resting seat every 50 meters, which is in line with the average walking distance limit for users with a walking cane
		Disintegrate corner	The edges of the seats should be designed to be rounded to prevent potential injuries
Minimize sensory burden	Perceptual threshold	Facilities& background	The color of the seat should form a significant contrast with the surrounding environment to enhance its visual recognizability

Figure 9. Design prototype for location and waiting area

3.3 Discussion

To validate the widespread applicability and value of inclusive design optimization, storyboarding was used to portray the optimized scenarios. Mildly visually impaired commuter A riding a certain subway line was used as an example, recreating a series of specific commuting scenarios. The six scenarios included departure from home, entering the station, tap in, taking the elevator, location, and exit by escalator, with a detailed depiction of the specific details that might be encountered in these steps. The visual storyboards help researchers and designers to explain and validate the effectiveness of optimized design in practical application, as shown in figure 10.

- Scene 1: Departure from Home. The scenario is portrayed where the mildly visually impaired commuter, referred to as Commuter A, embarks on the journey from the residence to the workplace. In Detail 1, commuter A moves along the tactile paving, using a smartphone navigation to help with orientation.

- Scene 2: Entering the Station. The situation is depicted in which commuter A successfully arrives at the subway station entrance via tactile paving. Subsequently, commuter A then chooses to use the stairs to enter the hall level. In Detail 1, A accesses the steps through an accessible ramp (in cases where there are fewer accessible elevators). In Detail 2, A proceeds along the tactile paving and hears a voice prompt from the escalator, 'The escalator is going down, please hold onto the handrail, mind your steps!' In Detail 3, the tactile paving continuously guides to the stairs, and round dots are used to alert commuter A to be cautious.

- Scene 3: Ticket tap in. The scenario is depicted where commuter A, after passing through the security check, successfully navigates through the accessible ticket checking gate under the guidance of tactile paving. In Detail 1, the accessible ticket checking gate is marked with conspicuous orange color, and there is an accessible ticket checking prompt at the top of the gate with the voice 'Entrance, tap your card here'. In Detail 2, the passage of the accessible ticket gate is designed with a generous width of 1000mm and stands 150mm lower than a standard gate. In Detail 3, considering the slower movement speed, the gate employs a sensor glass swing gate to prevent sudden incidents. In Detail 4, more than one accessible ticket gates have been set up. In Detail 5, the tactile paving directly guides commuter A to the elevator.

- Scene 4: Taking the Elevator. The scenario is depicted where commuter A uses the elevator and successfully arrives at the platform level. In Detail 1, the elevator features low-positioned, prominent buttons, each adorned with Braille indications. In Detail 2, the entrance to the accessible elevator is highlighted with the signature orange color for accessibility and equipped with a transparent observation window in the door. Detail 3 highlights the presence of audio prompts in the elevator, such as, 'Ding! The elevator is ascending to the platform level.' In Detail 4, Adequate seating with armrests and backrests.

- Scene 5: Location. The scenario is described where commuter A uses a large touchscreen to obtain information such as current location, transit route network, and exit locations. A tactile guide map is provided on the right side of the touchscreen. In Detail 1, the large-size guide map uses larger fonts. In Detail 2, the tactile guide map is made of a transparent acrylic custom overlay featuring Braille and raised line indicators, allowing visually impaired individuals to understand the general layout of the hall and the location of the entrances and exits through touch.

- Scene 6: Exit. Commuter A exits through the escalator. In Detail 1, standalone guide posts are placed both sides in front of the escalator, with more prominent indications for both ascending and descending directions, and includes explanatory icons. In Detail 2, the standalone post has a voice prompt 'Escalator ascending, watch your step.' In Detail 3, More than one ascending escalator is provided.

Storyboards are utilized to demonstrate the purpose, feasibility, and implementation results of inclusive design strategies through specific scenarios. By analyzing the entire commuting process of visually impaired individuals, the validity, logic, reasonableness, and reliability of the derived inclusive design strategy framework can be confirmed.

The significance of this storyboard lies in three aspects. Firstly, it demonstrates the specific plan after the optimization of inclusive design, which is innovative and practical. Secondly, it reemphasizes the importance of human-centered design. By considering the needs and behaviors of visually impaired commuters in conjunction with specific scenarios, it aims to provide a convenient and comfortable experience. Thirdly, it validates and illustrates whether inclusive design can effectively support vulnerable groups in specific contexts, enabling their equal participation in public services and social activities, which is the ultimate goal of inclusive design.

4. Conclusions

This study delves into the realm of inclusive design within rail transit spaces, employing a qualitative research methodology that encompasses three pivotal stages: conducting a case study, constructing a strategic framework, and engaging in design practice. A notable innovation of this research is the development of a comprehensive, current, and practically viable framework for inclusive design strategy, which is achieved by amalgamating qualitative research techniques from both design and sociology for inductive and deductive analysis. TEL in Singapore serves as the empirical focus, where extensive field research and data analysis were undertaken. The application of grounded theory coding refined the strategic framework for inclusive design in rail transit environments. This methodology not only uncovers the foundational design principles of inclusive design from a grassroots perspective but also enhances the understanding of equity and inclusivity in rail transit spaces. Building upon the inclusive design framework, the study introduces prototype recommendations aimed at enhancing five key spatial touchpoints. The optimized experience effects in specific scenarios are elucidated and validated through the use of storyboarding, providing a tangible demonstration of the framework's application and effectiveness.

In the context of rapid changes in current social demographics, social forms, and development trends, this qualitative research method will provide strong methodological support for the inclusive design and practice of subway spaces in emerging cities. It will help enhance the user attraction and stickiness of public rail transit, promote positive revenue and profit, drive the city to gradually form a public transport system dominated by rail transit, and achieve energy-saving, low-carbon, and sustainable transportation development goals.

A significant limitation of this study is the inability to capture a comprehensive understanding of inclusive design from the perspective of all subway users. The role-playing conducted was limited to commuters with MVIs, overlooking the diverse spectrum of subway passengers, each with unique needs. A more inclusive approach, incorporating a broader range of roles, would yield a more holistic understanding of inclusive design in rail transit spaces. Despite these constraints, the research has provided valuable insights into the inclusive design of rail transit environments, paving the way for further investigation and offering practical references for achieving a more encompassing and inclusive design of these spaces.

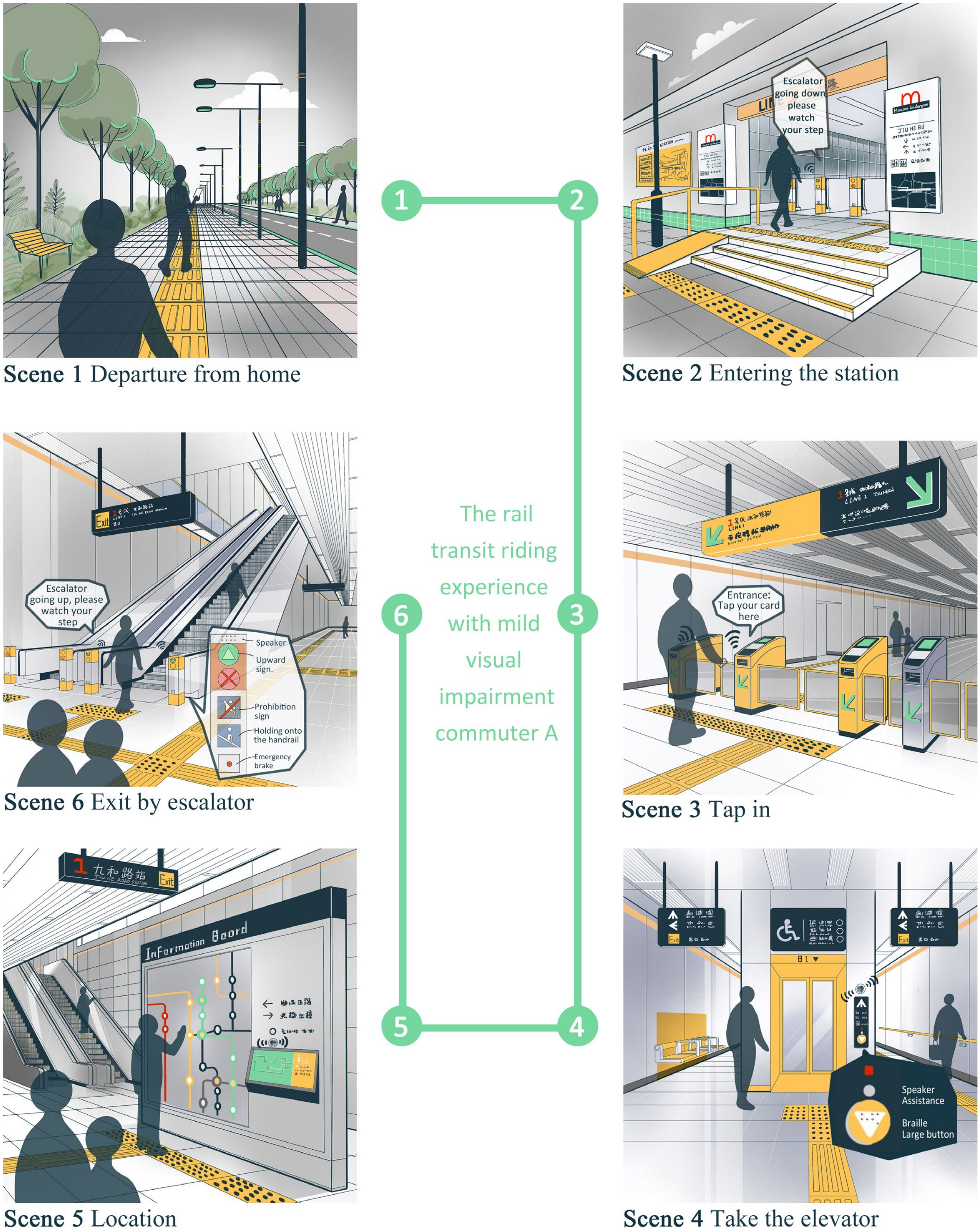

Figure10. Storyboard of Visually Impaired Commuter A Riding the Subway

Another limitation is the limited applicability of role-playing and immersive experiences. These methods can only serve as tools to help designers enhance empathy, understand the mental models of users with mild visual impairments, and assess whether the design outcomes are inclusive for such users. However, they lack empirical research. Future studies could focus on the effectiveness of inclusive design optimization in rail transit spaces, conducting comparative experiments on subjects using virtual simulation technology to determine whether the optimized designs are truly inclusive.

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