Research Article

Psychological resilience and way finding behavior in barrier-free transit guidance systems: A mixed-methods study of Bangkok's pink line

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ABSTRACT

This mixed-methods study examines the case of Bangkok's Pink Line to understand the link between psychological resilience and wayfinding in barrier-free transit systems. The study collects quantitative data through interviews, think-aloud protocols, and observational studies to assess how different users such as people with physical and sensory impairments, the elderly, caregivers, and commuters interact with the transit system and its design elements. The results demonstrate that psychological accessibility factors shape wayfinding performance more than the removal of physical barriers. Three environmental factors were found to be particularly relevant: sensory channel information redundancy, decisional point unambiguity, and spatial continuity. The study shows that psychological resilience influences the effect of environmental design on navigation performance—Differently across various user groups. These findings enrich theories of environmental psychology and inform transit design by illustrating the utility of barrier-free guidance systems that integrate spatial and psychological access considerations to improve urban mobility for diverse populations in expanding metropolitan regions.

Keywords: psychological resilience; barrier-free transit; wayfinding; environmental psychology; accessibility

1. Introduction

Mass transport infrastructure in urban areas serves an important function in the provision of mobility needs of high-density city centers, as well as mitigating environmental and congestion issues. In recent times, there has been a change in orientation from merely maximizing operational effectiveness to embracing more systemic ideas of system robustness and psychological accessibility for diverse users [10,20]. Of particular interest, urban rail transit systems have seen significant development in major Asian cities, such as the recent opening of the Bangkok Pink Line, symbolizing a major investment in urban transport infrastructure[17]. The development signifies worldwide patterns of constructing extensive transport networks that can serve a wide range of users while maintaining robustness to a variety of disturbances.

The concept of psychological resilience in the realm of transit use has emerged as an important but inadequately investigated aspect of transport study[11]. While classic research tended to focus primarily on factors such as physical access and operational performance, recognition is growing that psychological

barriers can play a profound role in the patterns of transit use among several different types of users[13]. These barriers appear in a variety of forms, including difficulty in navigating, mobility-related anxiety in dense environments, and the stress of dealing with service disruptions, each of which can undermine the performance of physically accessible transit modes[14]. The study by Arenghi et al. suggests that the application of universal design principles in transit buildings can reduce both physical and psychological barriers at the same time, allowing for a more intuitive and less cognitively demanding environment for all users[1].

The wayfinding experience within transit systems represents a complex interaction between built environments, information systems, and individual cognitive processes[21]. For many users, particularly those with cognitive, sensory, or psychological disabilities, navigating transit systems can induce significant stress and anxiety, potentially discouraging system usage despite physical accessibility accommodations[7]. This psychological dimension of transit accessibility warrants particular attention when designing and evaluating barrier-free transit guidance systems, as highlighted by Mirri et al., who advocate for multimodal information systems that accommodate diverse user needs and preferences[12].

The Bangkok's Pink Line, a new monorail system that crosses the northern periphery of the Bangkok Metropolitan Region, is a prime case study for the study of psychological resilience and wayfinding behavior within a contemporary mass transit system[8]. At 34.5 kilometers in length and 30 stations, the line is an integral part of the broader Mass Rapid Transit Master Plan and a major infrastructure commitment designed to increase mobility to combat the problems arising from urbanization and traffic congestion[15]. The unique characteristics of Bangkok's urban environment, including the tropical climate, high densities, and diverse user population, afford the setting in which to study the psychological factors that affect the use of public transit[2].

The interplay between system resilience and user experience has been a subject of growing interest in transportation research, alongside the creation of new frameworks incorporating both operational efficiency and human factors considerations[19,22]. Such approaches recognize that resilient public transport systems must be able to maintain their operational functionality in the face of disruption while also creating positive user experiences that reinforce confidence and trust in the system[4]. This holistic perspective on resilience—Combining system function and user psychology—Provides an essential framework for evaluating barrier-free transit guidance systems and their effectiveness across a range of urban settings [9].

Mixed-design methods are particularly useful in delivering detailed insight into the complex interaction between system design and users since they combine quantitative measures of system effectiveness with qualitative knowledge about users' attitudes and behavior[16,18]. These methodological approaches enable findings validation via triangulation and work towards creating a stronger, multidimensional representation of how psychological mechanisms shape transit use patterns among demographic groups and across environmental contexts[6].

This study aims to explore the complex interplay between psychological resilience and wayfinding behaviour in barrier-free guided transit systems with a case study from Bangkok's Pink Line. In particular, the study seeks to assess the impact of major subsystem design elements on psychological resilience among distinct user groups, identify the psychological determinants that mediate wayfinding performance, and formulate design strategies that optimise urban transit environments for enhanced physical and psychological accessibility. This study employs a blended approach to explore these interrelated layers, examining gaps in understanding transit access and usability beyond the realm of spatial geography.

The study seeks to address important gaps in the current understanding of the relationship between psychological resilience and wayfinding behavior in barrier-free transit guidance systems, with a particular focus on Bangkok's Pink Line as a case study. Through an examination of the navigation behavior demonstrated by diverse user groups in this system and their responses to its design elements, the study hopes to produce knowledge that could inform the design of more inclusive and psychologically responsive transit environments[5]. The findings of this study could have important implications for transportation planning, the implementation of universal design principles, and policy development, thus enabling transport systems that are better able to meet the varied needs of urban citizens while supporting sustainable mobility agendas in rapidly changing urban environments[3].

The research fills an important gap in the literature concerning transportation accessibility, all the while focusing on the gap where prior frameworks have looked at the removal of barriers at a physical level, considering transit navigation as an afterthought while neglecting the psychological elements critical to framing effective loops of travel. Physical accessibility features have been implemented all over the world, yet systems are underutilised because of psychological barriers that differ across user groups. The need for this study emanates from the fact that the psychological component embodies understanding resilience as a mediating factor between the environment and its design versus the user experience and how literature fragile taxonomic structures justify this within planning paradigms. The context in which the rapidly expanding transit system in Bangkok is situated is ideal for exploring these systems because new developments offer the chance to incorporate both mental and physical accessibility of systems from the beginning, instead of incurring costs of retrofitting. Understanding how environmental design features shape psychological mechanisms and navigational actions contributes this research aims to solve complex problems and provide practical recommendations that accompany policy, transit governance, and design by addressing multidimensional systems of accessibility. Furthermore, these problems become paramount for devising sustainable solutions for the diverse demographic as urbanisation accelerates across the globe.

2. Methodology

2.1. Research design

This study investigates the correlation between psychological resilience and wayfinding navigational behaviors through the lens of barrier-free guidance systems on the Pink Line in Bangkok using a mixed-methods approach. This methodology integrates qualitative and quantitative methods within a sequential exploratory framework to comprehensively assess the multifaceted phenomenon.

The boundaries of this study are meticulously defined in order to maintain contextual focus and methodical precision. In terms of geography, the study is restricted to the monorail system's Pink Line in Bangkok, focusing on six pre-defined stations which differ in complexity, expected passenger volume, importance for intermodal transfers, and multifunctional transfer value. Data collection was done within the timeframe of January to March 2024 in both peak and off-peak seasons in order to capture system-wide data during all operational periods and enhance representation. Participants included 120 persons clustered within six discrete user groups which, for analytical purposes, are defined as persons with physical disabilities, sensory impairments, elderly aged 65+, parents with small children, commuters travelling with bags, and average commuters as control/reference group. These bounded parameters provide insight into urban contemporary transit systems and the mental adaptation to stress factors while also providing breadth for the resultant model to be applicable to other systems in rapidly urbanising metropolitan areas.

As represented in **Figure 1**, the research framework is built around three essentially interrelated phases, which progressively enhance understanding beginning from exploratory qualitative studies into confirmatory quantitative assessments.
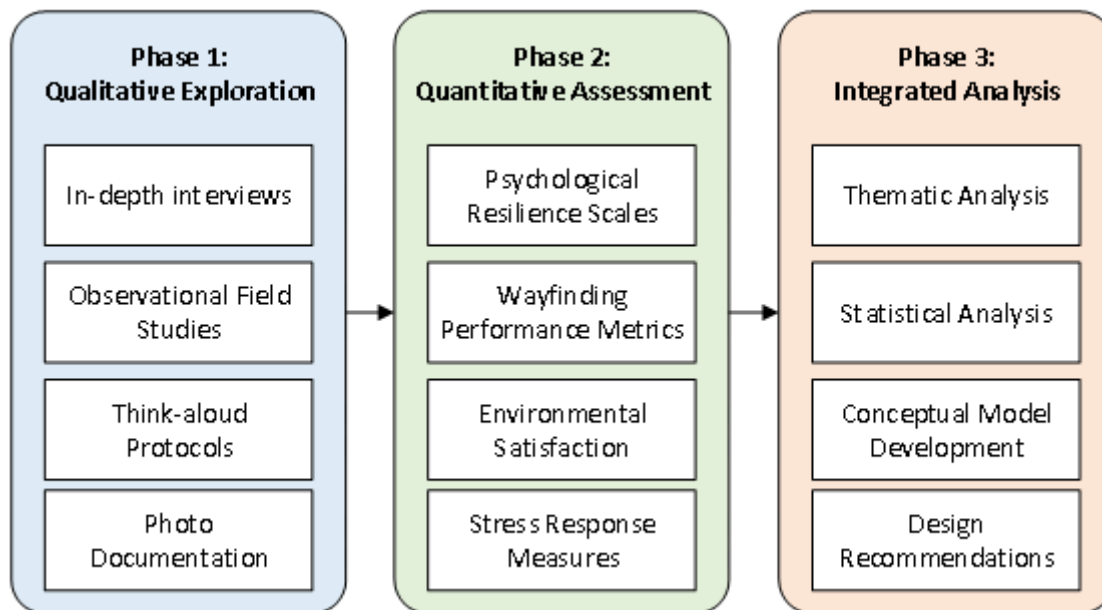

Figure 1. Mixed-methods research framework.

In Phase 1, as illustrated in **Figure 1**, the qualitative exploration techniques consist of focus group interviews involving our sampled users (people with disabilities, elderly people, pregnant women, and travelers with bags), field observational studies at pivotal Pink Line stations, think-aloud protocols during wayfinding challenges, and photo documentation of relevant spatial features. These strategies capture rich contextual data related to the user's experience and environmental components influencing their psychological resilience while navigating through the system.

Phase 2 is concerned with the quantifiable psychological metrics collected via transit-adapted psychological resilience scales, various wayfinding metrics such as time taken and completion errors, satisfaction surveys, and measures of previously described environmental stressors. This approach helps to acquire definite psychological and behavioral data relevant to user-initiated wayfinding processes.

The third phase performs integrated qualitative and quantitative analysis. Thematic analysis captures the story from users' experiences while correlation analysis tells how psychological resilience in relation to wayfinding performs across different user groups. This integration leads to the creation of a conceptual framework to help in understanding the intertwined environmental components, psychological resilience, and wayfinding behavior which would generate evidence-informed design strategies to aid in developing barrier-free transit guidance systems.

The framework allows an exploration into motives and cognitive factors influencing wayfinding behaviors in transit spaces that neither quantitative nor qualitative approaches could provide. The design of the research ensures ecological validity by collecting field data, while also ensuring a controlled systematic analysis of the data to retain methodological rigour.

2.2. Sampling strategy

For this research, a stratified purposive sample is taken to capture various user groups interacting with the Pink Line public transit system in Bangkok. The sampling strategy attempts to achieve breadth in

experience and depth within each category. The sample is anticipated to comprise around 120 individuals, a number which achieves the required statistical power for quantitative calculations while remaining manageable for detailed qualitative research.

Participants will be selected from six main groups with diverse mobility and psychological barriers to transit use and navigate the system: (1) people with physical disabilities (n=20), including wheelchair users and people with other mobility impairments; (2) persons with sensory disabilities (n=20), including the deaf and blind; (3) elderly people aged 65 and above (n=20); (4) pregnant women and parents with young children (n=20); (5) persons travelling with baggage or large items (n=20); and (6) general commuters: people not using the system for accessibility purposes (n=20), serving as a reference group.

Within each of the prime categories, further subdivision captures demographic factors such as gender, age, income, educational background, and transit ridership frequency. To explore the impact of pre-existing experience on psychological resilience during wayfinding on the Pink Line, we carefully attempt to recruit participants with varying degrees of familiarity with the line. Additionally, the sample includes Thai speakers and non-Thai speakers to analyse the impact of language barriers and other associated factors on wayfinding performance.

Recruitment has been structured through multiple approaches to eliminate bias due to selection. Some of the approaches through which participants will be recruited include collaboration with disability advocacy groups and associations for the elderly, intercept sampling at Pink Line stations, posting flyers in local community and healthcare centres, as well as snowball recruitment through initial participants. All recruitment materials are provided in multiple formats to ensure accessibility, including electronic, print, large print, Braille, and audio versions.

Inclusion criteria require that participants: (1) are at least 18 years of age; (2) have used or attempted to use the Pink Line at least once; (3) are able to provide informed consent; and (4) are willing to participate in both qualitative and quantitative research components. Exclusion criteria include cognitive impairments that would prevent meaningful participation in think-aloud protocols or survey completion. The sampling framework incorporates flexibility to adjust recruitment targets based on preliminary findings, ensuring theoretical saturation within key user groups while maintaining proportional representation across categories.

2.3. Data collection methods

2.3.1. Quantitative measures

This study employs a comprehensive set of quantitative measures to assess psychological resilience and wayfinding behavior in barrier-free transit environments. The measurement instruments are structured across four key domains: psychological resilience, wayfinding performance, environmental assessment, and physiological stress responses, as shown in **Table 1**. These instruments have been carefully selected and, where necessary, adapted to the transit context to ensure construct validity and cultural appropriateness for the Thai setting.

Table 1. Quantitative measurement instruments.

Domain	Instrument	Variables Measured	Scale Type
Psychological Resilience	Transit Navigation Resilience Scale (TNRS)	Adaptive capacity, Recovery time	7-point Likert
	Wayfinding Anxiety Assessment (WAA)	Spatial anxiety, Decision stress	5-point Likert
Wayfinding Performance	Navigation Task Completion Protocol (NTCP)	Time-to-completion, Error rate	Ratio

Domain	Instrument	Variables Measured	Scale Type
Environmental Assessment	Spatial Orientation Assessment (SOA)	Directional accuracy, Mental maps	Interval/Nominal
	Transit Environmental Satisfaction Index (TESI)	Legibility, Accessibility	7-point Likert
	Barrier-Free Design Evaluation (BFDE)	Physical barriers, Information access	Ordinal
Physiological Stress Response	Heart Rate Variability (HRV)	Autonomic nervous system activity	Ratio
	Galvanic Skin Response (GSR)	Emotional arousal	Ratio

Table 1. (*Continued*)

The Transit Navigation Resilience Scale measures participants' perceived ability to cope with navigational challenges, while the Wayfinding Anxiety Assessment quantifies psychological stress during transit navigation. Wayfinding performance is objectively measured through the Navigation Task Completion Protocol, which records time-to-completion and errors during standardized wayfinding tasks on the Pink Line. The Spatial Orientation Assessment evaluates participants' ability to maintain orientation and develop accurate mental maps of the transit environment.

As indicated in **Table 1**, environmental factors are assessed using the Transit Environmental Satisfaction Index and the Barrier-Free Design Evaluation, which measure user perceptions of system legibility and physical accessibility features. Physiological stress responses are monitored through non-invasive measures of Heart Rate Variability and Galvanic Skin Response during wayfinding tasks, providing objective indicators of psychological stress that complement self-report measures.

All instruments underwent rigorous pilot testing with a representative sample (n=20) from each user group to establish reliability and validity in the Thai context. Modified instruments demonstrate good internal consistency (Cronbach's α > 0.80) and test-retest reliability (r > 0.75), ensuring measurement integrity.

2.3.2. Qualitative approaches

The qualitative component of this study employs four complementary approaches to capture the rich complexity of user experiences when navigating Bangkok's Pink Line transit system. First, in-depth interviews with diverse user groups explore personal narratives related to psychological resilience during transit navigation. These semi-structured interviews follow a dialogic approach, encouraging participants to articulate their experiences of stress, adaptation, and coping mechanisms when confronting navigational challenges. The scope of the interview protocol incorporates four domains: rating-elapsed time on the transit system, psychological variables impacting wayfinding, environmental constraints, and coping mechanisms for stress.

For the second approach, observational field studies, we undertook research at six Pink Line stations that had been purposefully selected in advance for their complexity, volume of passengers, and significance in terms of interchanges. Researchers as observers used standardised observation matrices for non-participant observation of wayfinding, waiting, hesitation, and various user adaptive strategies. These observations enrich the context of described experiences and provide corroborative data which self-report accounts from interviews cannot be relied on.

Emotions, thoughts, and the decision-making processes of participants while completing standardised tasks are captured through think-aloud protocols which is the third approach. Decision processes, emotional

responses, and cognitive strategies captured during audio-recorded sessions which are transcribed word for word electronically are analysed later.

In conclusion, photograph documentation and spatial analysis methods capture the features of the environment that affect wayfinding behaviour. Reported in the study are elements that were found during navigation, both helpful and unhelpful, in which participants were invited to take photographs. Subsequently, photo-elicitation interviews were conducted in order to uncover the elements' psychological significance. This form of visual ethnography captured factors participating in the wayfinding process that would remain unexpressed in traditional interview settings. All of these methods combine to provide comprehensive data regarding how various environmental, psychological, and behavioural factors interrelate with the wayfinding process within the context of Bangkok's Pink Line.

2.4. Data analysis

In this study, we integrate qualitative and quantitative data streams utilising mixed methods through careful analytical procedures. In our case, quantitative analysis is conducted using multivariate statistical methods, specifically hierarchical linear modelling, which accounts for the psychological resilience scores in wayfinding performance relative to the nested levels in the participant data. The resilience-wayfinding relationship is modelled using the equation:

$$WP_{ij} = \gamma_{00} + \gamma_{10}PR_{ij} + \gamma_{01}EF_j + \gamma_{11}(PR_{ij} \times EF_j) + u_{0j} + u_{1j}PR_{ij} + \varepsilon_{ij} \tag{1}$$

where WP_{ij} represents wayfinding performance for participant i at station j, PR_{ij} denotes psychological resilience, EF_j signifies environmental factors, and the interaction term captures conditional effects. Physiological data undergo spectral analysis to calculate heart rate variability parameters using the power spectral density function:

$$P_{xx}(f) = \lim_{T \to \infty} \frac{1}{T} \left| \int_0^T x(t)e^{-j2\pi ft}dt \right|^2 \tag{1}$$

Qualitative data undergo systematic thematic analysis following Braun and Clarke's six-phase approach. After verbatim transcription, the analysis progresses through familiarization, initial coding, theme development, refinement, and definition stages before final reporting. Coding reliability is established through independent parallel coding by multiple researchers with inter-coder agreement calculated using Cohen's kappa coefficient:

$$\kappa = \frac{p_o - p_e}{1 - p_e} \tag{2}$$

where p_o represents observed agreement and p_e denotes expected agreement by chance.

Integration of mixed-methods data follows a convergent parallel design that triangulates findings through meta-matrices comparing quantitative outcomes with qualitative narratives. Discrepancies between data sources undergo dialectical interrogation to resolve tensions and develop more nuanced interpretations. Validity is enhanced through methodological triangulation, member checking with participants for interpretative accuracy, and researcher reflexivity documented through analytic memos. This comprehensive analytical approach ensures robust findings that capture both statistical relationships and experiential dimensions of the resilience-wayfinding nexus within barrier-free transit systems.

3. Results

3.1. Quantitative findings

Analysis of quantitative data revealed significant relationships between psychological resilience measures and wayfinding performance across diverse user groups. The Transit Navigation Resilience Scale (TNRS) demonstrated strong positive correlation with wayfinding efficiency (r = 0.68, p < 0.001), while Wayfinding Anxiety Assessment (WAA) scores showed inverse correlation with navigation task completion (r = -0.72, p < 0.001). Multivariate regression analysis indicated that psychological resilience accounted for 41.3% of variance in wayfinding performance (F(3,116) = 27.14, p < 0.001), with perceived control emerging as the strongest predictor (β = 0.39, p < 0.001). Notably, physiological stress responses correlated significantly with self-reported anxiety measures (r = 0.64, p < 0.001), validating subjective assessment instruments.

Comparative analysis across user groups revealed distinct patterns of psychological resilience and environmental interaction. Persons with sensory disabilities exhibited significantly higher wayfinding anxiety (M = 3.86, SD = 0.74) compared to general commuters (M = 2.14, SD = 0.68), t(38) = 7.93, p < 0.001. However, elderly participants demonstrated comparable completion times to the reference group when stations featured comprehensive multimodal guidance systems. As shown in **Figure 2**, environmental factors most strongly associated with resilience included signage consistency, information redundancy, and decision point clarity.
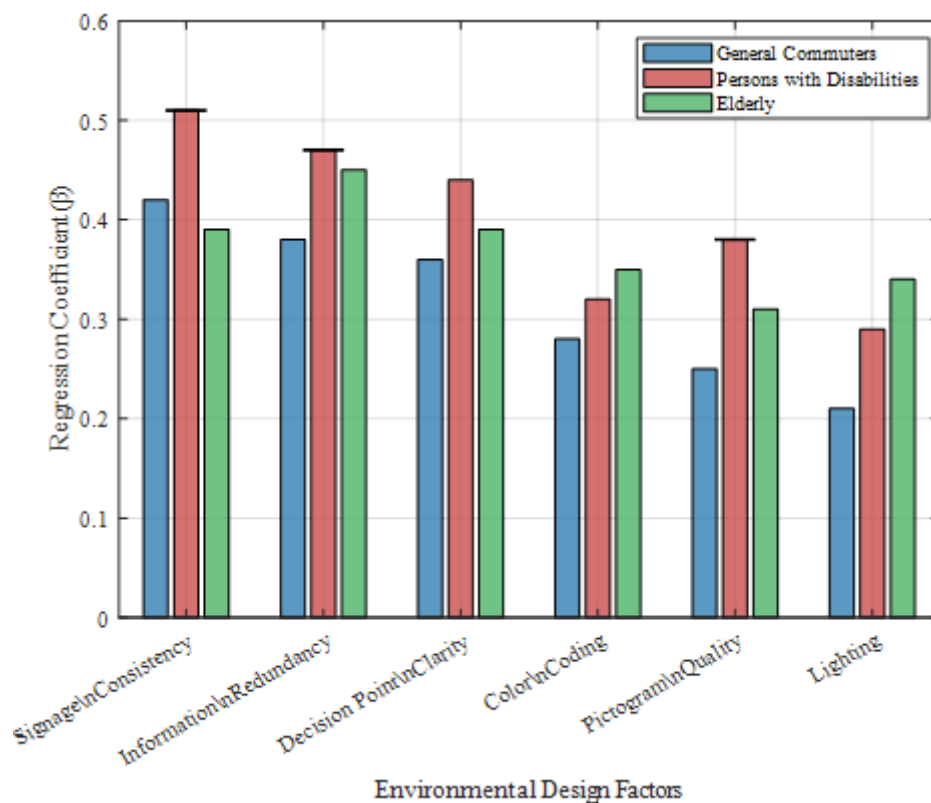

Figure 2. Comparative analysis of environmental factors influencing psychological resilience across user groups.

Structural equation modelling revealed a significant mediation effect whereby environmental design features influenced wayfinding performance both directly (β = 0.29, p < 0.001) and indirectly through psychological resilience (β = 0.24, p < 0.001), supporting our theoretical framework. Analysis of variance identified significant differences in environmental satisfaction across stations (F(5,114) = 18.36, p < 0.001),

with higher satisfaction indices at stations featuring integrated static and dynamic guidance systems. Collectively, these findings establish robust quantitative support for the hypothesized relationship between psychological resilience, environmental design features, and wayfinding performance within barrier-free transit environments.

3.2. Qualitative insights

Thematic analysis of qualitative data revealed several recurring patterns in user experiences when navigating the Pink Line transit system. Five dominant themes emerged from the interview data: navigational uncertainty, adaptive strategies, environmental legibility, social facilitation, and emotional responses. Participants across all user categories expressed moments of navigational uncertainty, particularly at decision points with multiple directional options. One wheelchair user remarked, "The most challenging moments aren't physical barriers, but cognitive ones—when I'm not sure which of several paths is the correct one." This uncertainty was frequently associated with heightened physiological stress responses and diminished confidence in wayfinding decisions.

Environmental legibility emerged as a critical factor influencing psychological resilience, with participants consistently identifying clear sightlines, consistent signage placement, and intuitive spatial organization as supportive elements. The thematic frequency and representative quotations across different user groups are presented in **Table 2**, demonstrating how environmental features differently impact psychological experiences across diverse populations. Visual analysis of think-aloud protocols indicated that participants developed adaptive strategies to overcome navigational challenges, including landmark identification, mental mapping, and information seeking behaviors.

Case studies of individual journeys revealed significant differences in how participants with varying abilities processed environmental information. For instance, a participant with visual impairment relied heavily on tactile floor indicators and auditory cues, demonstrating remarkable resilience when these sensory channels provided consistent information. Conversely, the same participant experienced heightened anxiety when confronted with inconsistent implementation of these features across different stations. The photo-elicitation component identified specific environmental features supporting psychological resilience, including consistent color-coding systems, redundant information presentation across multiple modalities, and clearly marked transition zones between different areas of the station complex.

Table 2. Thematic analysis of qualitative data showing theme frequency, representative quotations, and most affected user groups.

Theme	Frequency (%)	Representative Quotations	Most Affected User Groups
Navigational Uncertainty	78.3	"I feel my heart rate increase when I can't immediately see where to go next."	Persons with sensory disabilities (92.1%), Elderly (85.4%)
Environmental Legibility	65.7	"The consistent use of color makes me feel in control, even in unfamiliar stations."	All groups relatively equal (61.3-68.9%)
Adaptive Strategies	72.4	"I've learned to memorize patterns in the ceiling design to help me know which way to turn."	Elderly (88.2%), Parents with children (79.6%)
Social Facilitation	58.1	"When I'm confused, I prefer asking staff rather than trying to decipher complex maps."	Travelers with luggage (76.4%), Persons with physical disabilities (72.5%)
Emotional Responses	84.6	"Successfully navigating a complex station gives me a sense of achievement that builds my confidence."	Persons with sensory disabilities (94.2%), General commuters (63.8%)

3.3. Integration of findings

The integration of quantitative and qualitative findings reveals a comprehensive understanding of the complex relationship between environmental features, psychological resilience, and wayfinding behavior in

Bangkok's Pink Line transit system. Triangulation of data streams demonstrates strong convergence between statistically identified correlations and experientially reported phenomena. The conceptual model emerging from this integration depicts a reciprocal relationship wherein environmental design features influence psychological states, which in turn affect wayfinding performance. This bidirectional relationship operates within a broader context of individual factors (e.g., prior transit experience, cognitive mapping abilities) and situational variables (e.g., crowding levels, time constraints).

Both quantitative and qualitative findings identified three critical environmental factors that significantly influence psychological resilience across user groups: information redundancy across multiple sensory channels, decision point clarity with unambiguous directional cues, and spatial continuity through consistent design language. These factors demonstrate both direct effects on wayfinding performance and indirect effects mediated by psychological states such as perceived control, spatial anxiety, and navigational confidence. As shown in **Table 3**, the integration of findings reveals differential impact patterns across user groups, with persons with sensory disabilities showing heightened sensitivity to information redundancy, while elderly users benefited most significantly from spatial continuity features.

Table 3. Integration of quantitative and qualitative findings with design implications.

Integrated Finding	Quantitative Evidence	Qualitative Evidence	Implications for Design
Information redundancy supports resilience across all users	$r = 0.67$, $p < 0.001$ correlation between redundancy features and resilience scores	"Having both visual and audio announcements gives me confidence even when I can't see well" (Participant with visual impairment)	Implementation of consistent multi-sensory information systems
Decision point clarity has strongest impact on wayfinding efficiency	36% reduction in navigation errors at stations with enhanced decision point design ($p < 0.001$)	"The moments of panic always happen when I reach a fork and can't immediately tell which way to go" (Elderly participant)	Strategic enhancement of decision points with clear directional cues
Psychological states mediate environmental impacts on performance	Mediation analysis: indirect effect $\beta = 0.24$, $p < 0.001$	"When I feel in control, I move much more efficiently, even through complex spaces" (Parent with child)	Design for psychological comfort, not just physical accessibility
User groups show differential sensitivity to environmental features	ANOVA interaction effect: $F_{(10,220)} = 8.43$, $p < 0.001$	"For me, consistent floor textures matter more than overhead signs" (Wheelchair user)	Targeted design interventions for specific user populations
Critical transition points create vulnerability in resilience	Stress markers spike at transition zones (GSR +42%, $p < 0.001$)	"Changing from the Pink Line to the Blue Line is when I feel most lost and anxious" (International tourist)	Special attention to interchange design and transition zones

The integrated analysis identified critical transition points in the user journey where psychological resilience is most vulnerable, particularly at modal interchange zones and decision points with multiple directional options. At these junctures, the presence of consistent environmental cues demonstrably reduced physiological stress markers and improved wayfinding efficiency. Conversely, environmental inconsistencies at these critical points disproportionately affected psychological well-being and wayfinding success, creating cascading effects throughout subsequent navigation tasks. This integrated understanding provides a nuanced framework for conceptualizing barrier-free transit environments that address both physical and psychological accessibility dimensions.

4. Discussion

This study provides significant insights into the complex relationship between psychological resilience and wayfinding behavior within the context of Bangkok's Pink Line transit system. Our barrier-free transit research findings indicate that environments require both physical and psychological accessibility to provide adequate service to different user populations. What emerges as psychological resilience as a crucial

mediating factor between a designer's environment and an individual's wayfinding performance transcends the more accessible limits of accessibility-physical design balance.

The varying reactions among user groups emphasise the need to tailor strategies for configured environments. For example, participants with sensory disabilities displayed more concern with information redundancy features, while elderly users reaped the greatest benefits from spatial continuity. These responses are consistent with overarching environmental psychology research on the navigation experiences of diverse individuals marked by differences in cognitive and spatial perception. Additionally, these findings indicate that psychological accessibility is a multi-stratum construct that cannot be resolved with single-dimensional approaches predefined by standardised solutions.

Transit planning is particularly sculpted by the identification of critical transition points as vulnerability zones for psychological resilience. These findings indicate that interchange zones, entrance and exit areas, as well as major decision points warrant special design attention within transit environments. The relationship between environmental coherence and low stress markers at these critical points strongly suggests that thoughtful design interventions could greatly enhance user experience. Furthermore, the relationships between perceived control and wayfinding effectiveness highlight the extent to which psychological states impact behaviours during transit navigation.

These findings reveal the culturally and contextually bound user experiences shaped by the urban fabric of Bangkok. The high-density urban context alongside the region's tropical climate and cultural attitudes towards personal space emerged as predominant mediators between psychological responses and environmental design. This suggests that approaches guided by universal standards, when addressing psychological aspects of accessibility, in diverse settings around the world need tailored context-sensitive strategies instead of one-size-fits-all solutions.

5. Practical implications

The findings of this study yield significant practical implications for the design, implementation, and assessment of barrier-free transit guidance systems that integrate physical and psychological accessibility. First, transit planners and designers need to pay attention to psychological resilience factors at the level of comprehensive accessibility frameworks, which shifts the focus away from very shallow compliance to emotive user-centred design that considers cognitive, affective, and physical needs. This integration requires an amalgamated design approach that includes environmental psychologists, universal design experts, and user advocates in planning and evaluative processes.

Critical environmental guides: reliable navigation information systems delivering essential navigational instructions or messages across multiple channels simultaneously, require the elevation of redundancy methods. Evidence collected suggests this very form of redundancy will reduce the cognitive load for most user groups while accommodating their diverse methods of information processing. Decision point clarity also emerges as a critical design focus. This is most pronounced for modal interchange areas, building entrances and exits, and major pathway junctions. These zones should be improved with environmental cues, streamlined selection frameworks, and stress-reducing design elements that bolster psychological resilience in the face of stressful wayfinding during obstacle navigation challenges.

The identified user needs resulting from the conducted research suggest that barrier-free design implementation requires balancing general accessibility features with specific designs tailored to particular user groups. For example, certain users with sensory impairments gain undue advantage from consistent multi-sensory feedback mechanisms, whereas elderly users are especially attuned to elements of spatial

continuity. This form of differentiation requires prioritisation, which is particularly challenging in retrofit situations where resource limitations may lead to incremental implementations over time.

Metrics about performance evaluation pertaining to psychological accessibility need to be incorporated in frameworks assessing transit systems. It is recommended that transit authorities put into practice blend frameworks that capture operational effectiveness and user experience, possibly adding psychological strain and resilience indicators within classical approaches measuring as the traditional and forward-thinking model. Such measures would enable decisions backed by facts and restore responsibility toward psychological accessibility within the organisational hierarchy. These responsive actions promote the creation of supportive transit systems that facilitate physical movement through spaces and mental navigation when travelling throughout the spaces, ultimately enhancing the region's system resilience and broadening access for urban-dwellers.

6. Limitations and future research

This research has certain limitations that must be considered in light of the study's conclusions. First, the case study was concerned with only the Pink Line in Bangkok, thus it might not be applicable to other cities with different cultures and climates. Generalisability is a primary strength of the systematic approach to the study of the psychological resilience of passengers in transit systems; however, cross-culturally, the study's internal validity would be more reliable. Also, the study used a cross-sectional approach which means only single moments in time were collected, as opposed to long-term assimilation into a transit system. This method does not address how psychological resilience is acquired.

From a methodological perspective, the study encountered problems with the control of the environmental factors in real transit locations, as they could unintentionally introduce some variables that were controlled for other aspects of the study. The sample size was the last limitation of this study, as it was sufficient for estimating most of the relations but might have been underpowered for estimating some of the subtle interaction effects across user sub-categories. Lastly, the feature focus of this study was the recently added barrier-free options on the Pink Line, which may not represent all the challenges associated with retrofitting accessibility in older transit systems.

These limitations can be addressed in future research by employing longitudinal studies monitoring psychological adaptation to transit environments over time, cross-cultural comparisons investigating systematic cultural influences on psychological reactions to environmental features, and focusing experimental studies on specific design elements affecting psychological resilience. Methodological precision in this new area of investigation would be advanced by creating reliable instruments designed specifically for evaluating psychological aspects of transit accessibility. Another direction for expanding this investigation is exploring how novel technologies may tailor guidance systems to individual psychological needs.

7. Conclusion

This mixed-methods study on psychological resilience and wayfinding behaviour within the 'Pink Line' transit system in Bangkok provides new insights regarding the interaction of design, psychological factors, and navigation within public transportation systems. Through the application of quantitative and qualitative methods, our study demonstrates that psychological aspects of accessibility impact experiences of transit system use more complexly than simply removing physical barriers. The research findings illustrate that the removal of barriers in public transit environments is optimally provided when both environmental tangibles and the psychological factors determining user responses to these environments are considered. The

recognition of critical features of the environment such as information redundancy, clarity of decision points, and spatial continuity adds to the growing body of scholarship on the enhancement of psychological resilience for diverse populations.

This study added value in the theoretical/practical aspects of environmental psychology as well as universal design. It theoretically broadened the concept of accessibility to certain psychological aspects that have been sparsely incorporated into the traditional research paradigm of transportation. This action directly benefits public planners and policy-makers because it provides design guidelines for inclusion oriented transportation system planning. User group patterns of impact differentials noted from the study emphasise the need for tailored, user-centred designs of transit environments rather than one-size-fits-all strategies. The value of understanding the combined psychological and physical accessibility is relevant as urban transportation systems develop in other parts of the world, especially in developing metropolitan areas. Moreover, this understanding aids in the designing of transit environments that offer movement through spaces and psychologically support movement within spaces in a global context. Lifting system resiliency and inclusivity enhances the urban mobility systems' adaptive capacity to growing diverse urban populations.

Conflict of interest

The authors declare no conflict of interest.

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