

Article

Quantifying the Impact of Adaptive Space and Inclusive Design on User Experience in Exhibition Halls: A Mixed-Methods Study in Wuhan, China

Yong Zhang ¹, Salmiah bt Abdul Hamid ^{1,*} and Leilei Shi ²

¹ Faculty of Applied and Creative Arts, Universiti Malaysia Sarawak, Kota Samarahan 94300, Sarawak, Malaysia; 23010161@siswa.unimas.my

² School of Fashion Design, Wuhan Institute of Design and Sciences, Wuhan 430205, China; shileilei@wids.edu.cn

* Correspondence: ahsalmiah@unimas.my; Tel.: +60-11-23029710

Abstract

As exhibition halls become highly adaptable and technology-driven, they risk excluding aging demographics due to cognitive barriers. Addressing the empirical gap regarding this tension, this study validates a quantitative evaluation model based on the User-Space Interaction Framework. Using an explanatory sequential mixed-methods design, survey data from two contrasting cultural venues in Wuhan, China (N = 312) were analyzed via ANOVA and Structural Equation Modeling (SEM). Findings reveal a “technological adaptability paradox.” Visitors over 60 experience significantly higher cognitive load in highly adaptive spaces ($F = 35.42, p < 0.001$). SEM confirms that while technological adaptability increases cognitive load ($\beta = 0.56, p < 0.01$), robust inclusive spatial cues act as a psychological buffer. These cues significantly enhance perceived control ($\beta = 0.62, p < 0.001$), which emerges as the strongest predictor of overall user satisfaction ($\beta = 0.71, p < 0.001$). Ultimately, this research shifts the evaluative focus from static physical compliance to measurable psychological outcomes, providing an empirically validated framework for architects and policymakers to balance cutting-edge spatial flexibility with multi-generational inclusivity.

Keywords: adaptive space; inclusive design; structural equation modeling (SEM); environmental psychology; user experience; Wuhan



Academic Editors: Szu-Cheng Chien, Aung Myat, Tzen-Ying Ling and Chew Beng Soh

Received: 19 August 2026

Revised: 11 September 2026

Accepted: 15 September 2026

Published: 16 September 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

In the contemporary evolution of cultural infrastructure, exhibition halls are undergoing a profound paradigm shift: transitioning from static, artifact-centric repositories into highly flexible, technology-driven, and visitor-centric experiential environments. This transition is particularly evident in Wuhan, China, a rapidly urbanizing megacity that serves as a microcosm for the nation’s massive, state-led expansion of cultural infrastructure. This rapid urban transformation is deeply intertwined with broader socio-economic and neoliberal urbanism trends, in which cultural mega-structures are increasingly utilized as strategic catalysts for urban regeneration and city branding [1,2]. However, this accelerated architectural development exposes a fundamental, yet frequently overlooked, tension. The technological complexity required to achieve high spatial adaptability—manifesting through dynamic digital interfaces, reconfigurable modular partitions, and multi-sensory participatory layouts [3,4]—often inadvertently contradicts the intuitive simplicity and environmental predictability required for

universal inclusivity. Consequently, spaces designed to be infinitely adaptable can unintentionally generate high cognitive friction for non-digital-native demographics, thereby creating exclusionary barriers.

Despite the implementation of stringent national policies, such as the Code for Accessibility Design (GB 50763-2012) [5], a significant and widening gap persists between static regulatory compliance and the dynamic, lived experiences of diverse visitors [6]. Current statutory frameworks remain overwhelmingly anchored in physical barrier removal—prioritizing dimensions for wheelchair turning radii or the installation of tactile paving. While essential, these physical mandates entirely fail to address the cognitive and sensory disorientation induced by highly fluid, digitally augmented environments. Furthermore, current academic discourse predominantly treats inclusive design and adaptive space as isolated, if not competing, entities [7]. Recent scholarship increasingly highlights the critical necessity of balancing technological responsiveness with cognitive accessibility in smart built environments [8–10]. However, this fragmented approach obscures the critical interdependence of these principles, leaving a theoretical void regarding how spatial flexibility impacts psychological accessibility.

To directly address this methodological and empirical deficit, our previous qualitative investigations established the “User-Space Interaction Framework.” This framework identified key environmental psychology constructs—namely perceived control, environmental comfort, cognitive load, and wayfinding efficiency—as the critical psychological mediators that bridge physical architectural design and subjective user experience. Building upon that qualitative foundation, the primary objective of the current study is to empirically operationalize and quantify these relationships. By transforming qualitative insights and visitor narratives into a standardized, statistically testable measurement scale, this research transitions from theoretical exploration to rigorous empirical validation. Ultimately, this study asks: How do varying intensities of inclusive and adaptive design strategies quantitatively affect the psychological mediators and ultimate experiential satisfaction of diverse audiences in Wuhan’s exhibition halls, as typified by the architectural venues illustrated in Figure 1?



Figure 1. Interior views and architectural layouts of the selected case study venues: Hubei Science and Technology Museum and Wuhan Qintai Art Museum. (Image sources: Official websites of the respective museums).

2. Theoretical Framework and Hypotheses

2.1. *The Intersection of Inclusive and Adaptive Design*

Inclusive design has evolved significantly from basic architectural accessibility (e.g., wheelchair ramps and elevators) to a holistic paradigm that advocates for creating mainstream environments universally accessible across physical, sensory, and cognitive dimensions [11,12]. Concurrently, adaptive space theory reconceptualizes the built environment not as a static container, but as a highly dynamic, technologically responsive system capable of continuous reconfiguration to meet shifting curatorial and functional needs. In the context of contemporary cultural institutions, these two theoretical trajectories increasingly intersect, presenting a profound architectural paradox. While adaptability—characterized by modular layouts, interactive digital displays, and participatory installations—offers unprecedented operational efficiency and aesthetic novelty, its inherent technological complexity can inadvertently introduce severe cognitive and sensory barriers. This friction generates “invisible exclusions,” particularly for elderly demographics, neurodivergent visitors, or individuals lacking digital fluency [13,14]. Consequently, the uncritical pursuit of spatial flexibility risks alienating the very public it intends to serve, creating environments that are technically physically accessible, yet cognitively hostile.

2.2. *Environmental Psychology as an Analytical Lens*

To rigorously evaluate this architectural paradox, environmental psychology provides a vital analytical lens, elucidating the complex cognitive and emotional responses elicited by specific spatial stimuli [15,16]. Traditional post-occupancy evaluations often prioritize functional efficiency or aesthetic appeal; however, capturing the nuanced realities of visitors’ spatial behaviors [17] and the true efficacy of accessibility implementations requires examining the psychological mediators between humans and their built environment. Therefore, this study operationalizes five interconnected constructs drawn from environmental psychology literature to form the User-Space Interaction Framework:

Perceived Control: Moving beyond mere physical access, this construct measures the extent to which users feel they have the autonomy to navigate, predict, and influence their spatial experience without constant reliance on external assistance.

Comfort: Encompassing both physical ergonomics and psychological ease, this reflects a state of freedom from environmental stress, ensuring that the visitor feels a sense of spatial safety and institutional welcome.

Cognitive Load: Defined as the mental effort required to process complex environmental stimuli, interpret fluid layouts, and decode multifaceted interactive exhibitions without suffering from sensory saturation.

Wayfinding Efficiency: The cognitive and behavioural ability to orient oneself and successfully navigate a complex interior using both static architectural cues and dynamic digital signage.

Satisfaction: The holistic, ultimate evaluation of the user experience, determined by the successful mitigation of spatial stressors and the fulfilment of visitor expectations.

2.3. *Hypotheses Development*

Grounded in the theoretical integration of the User-Space Interaction Framework, we construct a predictive structural model to quantify how specific spatial design strategies impact user experience. Drawing on visual cognition and cognitive load theories, we argue that highly adaptable environments, saturated with dynamic and reconfigurable stimuli, demand excessive cognitive processing from non-digital natives. Thus, we propose:

H1. *The perceived intensity of adaptive spatial features is positively correlated with elevated cognitive load, particularly among elderly and vulnerable visitor demographic groups. When visitors exhaust their mental resources attempting to navigate these complex spaces, their capacity for aesthetic and educational engagement diminishes.*

H2. *Cognitive load has a significant negative impact on overall user satisfaction. To counteract this cognitive depletion, the environment must provide stable, highly legible spatial anchors. We argue that robust inclusive design elements serve as these necessary anchors, reducing spatial anxiety and restoring user autonomy.*

H3. *Comprehensive inclusive spatial cues significantly enhance visitors' perceived control. We posit that the physical environment does not influence user satisfaction in a vacuum; rather, its structural effects are entirely filtered through psychological experiences.*

H4. *Perceived control and environmental comfort act as critical mediators, positively bridging the relationship between inclusive spatial design and overall visitor satisfaction.*

3. Materials and Methods

3.1. Study Sites and Sample

This study utilized a multi-case research design [18] embedded within an explanatory sequential mixed-methods framework, bridging an interpretivist epistemology for initial theory building with a post-positivist approach for quantitative validation [19]. The empirical investigation was conducted in two architecturally and functionally contrasting cultural institutions in Wuhan, China, purposefully selected to represent typological extremes in contemporary exhibition design. The Hubei Science and Technology Museum was selected as the archetype of high-tech, highly adaptive interactive spaces, characterized by dynamic digital interfaces and reconfigurable modular exhibits. Conversely, the Qintai Art Museum was chosen to represent contemplative, contemporary spatial configurations, relying heavily on static spatial fluidity, sculptural forms, and natural lighting. During the initial qualitative phase of the sequential design, semi-structured interviews were conducted with 24 participants, comprising 14 general visitors of varying ages and 10 design practitioners, to empirically identify core socio-spatial barriers before quantitative scale development. Subsequently, for the quantitative phase, to capture a highly representative cross-section of attendees, a stratified purposive sampling strategy was employed, guided by the principle of information power to ensure rigorous sample adequacy across diverse demographic strata [20]. Trained research assistants intercepted visitors aged 18 and above at the primary exit zones of both venues, ensuring data collection spanned both weekdays and weekends to capture varying crowd densities. Out of 350 systematically distributed questionnaires, 312 fully completed and valid responses were retained after rigorous data cleaning to remove incomplete or unengaged responses (yielding a high effective response rate of 89.1%), comprising an exactly balanced cohort of 156 participants from each museum.

3.2. Instrument Development

The quantitative survey instrument was meticulously developed through a transformative mixed-methods process, directly converting the qualitative coding nodes and visitor narratives from our previous ethnographic fieldwork into measurable psychometric variables. By deriving scale items from prior in-depth interviews [21] and rigorous thematic analysis [22], the questionnaire maintained high ecological validity and cultural resonance. Responses were recorded using a standardized 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The finalized instrument comprised three distinct analytical sections: Section A captured detailed demographic profiles, including age, gender,

and the presence of any self-reported mobility or sensory constraints. Section B assessed visitors' subjective perceptions of the physical environment, specifically measuring the intensity of Adaptive Features (e.g., modularity, digital interactivity) and Inclusive Cues (e.g., wayfinding clarity, tactile accessibility). Section C evaluated the core environmental psychology mediators and experiential outcomes, comprising validated subscales for Perceived Control, Cognitive Load (reverse coded), Environmental Comfort, Wayfinding Efficiency, and Overall Satisfaction. A preliminary pilot study ($N = 30$) was conducted to refine item wording and confirm internal consistency (Cronbach's Alpha > 0.80), ensuring robust construct reliability prior to full-scale deployment. The instrument comprised three sections:

1. Demographics: Age, gender, presence of mobility/sensory constraints.
2. Spatial Perceptions: Items measuring the perceptions of Adaptive Features (e.g., "The space uses highly flexible/modular displays") and Inclusive Cues (e.g., "The signage and pathways are universally accessible").
3. Psychological Mediators & Outcomes: Items assessing Perceived Control (4 items), Cognitive Load (4 items, reverse-coded), Environmental Comfort (4 items), Wayfinding Efficiency (3 items), and Overall Satisfaction (3 items).

A pilot study ($N = 30$) confirmed the instrument's initial internal consistency (Cronbach's Alpha > 0.80 for all constructs), though it is acknowledged that the relatively small pilot sample size limits the statistical robustness of these early reliability estimations.

3.3. Data Analysis

All quantitative data were systematically processed and analyzed using IBM SPSS Statistics 27.0 and IBM SPSS AMOS 24.0. Prior to hypothesis testing, the dataset underwent strict screening for missing values, multivariate outliers, and normality to ensure parametric assumptions were met. To comprehensively assess building performance from the localized user's perspective [23], a one-way Analysis of Variance (ANOVA) paired with Tukey's HSD post hoc tests was conducted. This approach allowed us to pinpoint statistically significant disparities in spatial experiences across different demographic cohorts, particularly highlighting age-related vulnerabilities. Subsequently, Pearson correlation analysis was executed to evaluate the preliminary bivariate relationships between architectural features and psychological responses, while simultaneously screening for multicollinearity. Finally, Structural Equation Modeling (SEM) utilizing Maximum Likelihood estimation was performed to rigorously test the hypothesized directional and mediating path relationships defined by the User-Space Interaction Framework. The overall structural validity of the proposed model was evaluated against stringent goodness-of-fit indices, including the Comparative Fit Index (CFI), Tucker–Lewis Index (TLI), and the Root Mean Square Error of Approximation (RMSEA), ensuring the empirical conclusions were both statistically robust and theoretically sound.

4. Results

4.1. Demographic Differences in Spatial Experience (ANOVA)

To rigorously test the impact of age on visitors' spatial experiences and psychometric responses, a one-way Analysis of Variance (ANOVA) was conducted (Table 1). Age was treated as the primary independent categorical variable to ascertain whether highly adaptable, technology-driven exhibition environments disproportionately affect specific demographic segments. The results revealed statistically significant disparities across the diverse age groups, particularly concerning the dependent variables of Cognitive Load and Perceived Control. This foundational analysis was critical in identifying the specific demographic vulnerabilities within complex spatial layouts, confirming that chronologi-

cal age heavily influences how architectural adaptability is subjectively experienced and cognitively processed.

Table 1. One-way ANOVA comparing age groups on Environmental Psychology Constructs.

Age Group	N	Cognitive Load M (SD)	Perceived Control M (SD)	Satisfaction M (SD)
18–25 years	85	2.15 (0.81)	4.32 (0.64)	4.45 (0.52)
26–40 years	102	2.30 (0.92)	4.15 (0.71)	4.20 (0.61)
41–60 years	75	3.10 (1.12)	3.50 (0.92)	3.80 (0.83)
>60 years	50	4.25 (0.75)	2.45 (1.15)	3.15 (1.02)
F-value		35.42 *	41.18 *	22.56 *

* Note: $p < 0.001$. Post hoc comparisons indicated that visitors over 60 years old reported significantly higher Cognitive Load ($M = 4.25$) compared to all younger demographics ($p < 0.001$), while their Perceived Control was the lowest. This validates the premise that highly adaptable, tech-heavy environments inadvertently create cognitive barriers for older populations, as shown in Figure 2.

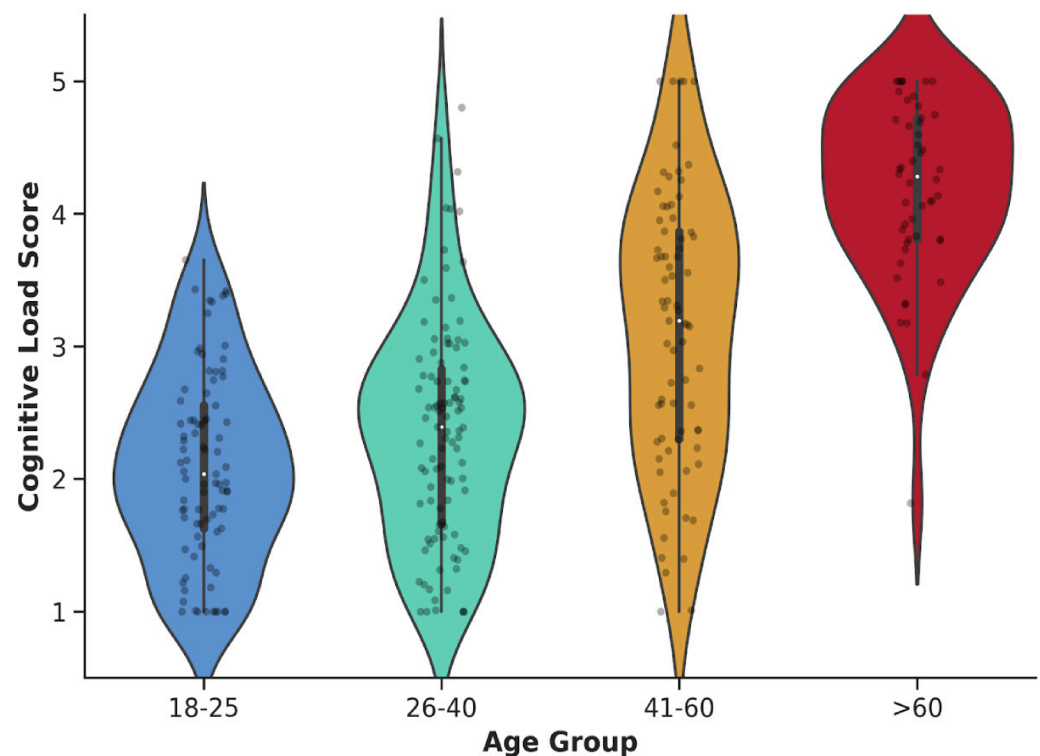


Figure 2. Distribution of Cognitive Load Across Age Groups. To more granularly illustrate the distribution of cognitive load across different age cohorts, a Violin Plot was generated based on the collected survey data ($N = 312$). Unlike traditional mean-based tables, the violin plot reveals that, for the over 60 demographic, the data is heavily skewed toward high values (4.0–5.0), with a dense distribution around the upper quartile, indicating a pervasive and consistent experience of cognitive overload compared to the more varied and lower-load profiles of younger participants.

4.2. Pearson Correlation Analysis

Prior to constructing the complex structural models, a Pearson correlation matrix (Table 2) was generated to systematically explore the initial bivariate relationships between the physical spatial features (Adaptive Features and Inclusive Cues) and the resulting user psychological outcomes. This analytical step served a crucial dual purpose: first, to establish baseline empirical associations that confirmed the theoretical directions proposed

in our framework; and second, to rigorously screen the quantitative dataset for potential multicollinearity issues that could distort subsequent regression analyses. The correlation matrix successfully illuminated the foundational patterns of the spatial experience, setting the stage for deeper causal modeling.

Table 2. Pearson Correlation Matrix.

Variables	1. Adaptive Features	2. Inclusive Cues	3. Comfort	4. Cognitive Load	5. Satisfaction
1. Adaptive Features	1				
2. Inclusive Cues	0.24 **	1			
3. Comfort	0.35 ***	0.52 ***	1		
4. Cognitive Load	0.48 ***	−0.61 ***	−0.45 ***	1	
5. Satisfaction	0.38 ***	0.58 ***	0.65 ***	−0.55 ***	1

Note: ** $p < 0.01$, *** $p < 0.001$. The matrix reveals a crucial paradox. While the perception of “Adaptive Features” is positively correlated with overall satisfaction ($r = 0.38$, $p < 0.001$), it is also strongly correlated with increased “Cognitive Load” ($r = 0.48$, $p < 0.001$). Conversely, “Inclusive Cues” strongly reduce cognitive load ($r = -0.61$) and enhance satisfaction.

4.3. Structural Equation Modeling (SEM) Path Analysis

To comprehensively test the directional hypotheses (H1–H4) and evaluate the mediating roles of the environmental psychology constructs, a Structural Equation Modeling (SEM) path analysis was constructed utilizing AMOS 24.0. SEM was selected as the optimal analytical technique due to its robust capacity to simultaneously estimate multiple interrelated dependence relationships while rigorously accounting for measurement error. The proposed structural model demonstrated excellent goodness-of-fit indices, strongly indicating that the theoretical model adequately captured the empirical data structure. Specifically, the relative chi-square ratio ($\chi^2/\text{df} = 1.85$) fell well below the conservative threshold of 3.0; the Root Mean Square Error of Approximation (RMSEA = 0.045) indicated a close fit (typically < 0.08); and the baseline comparison indices, including the Comparative Fit Index (CFI = 0.94) and Tucker–Lewis Index (TLI = 0.95), both comfortably exceeded the recommended rigorous > 0.90 benchmarks. (Please refer to Figure 3 for the visual mapping of the standardized path coefficients).

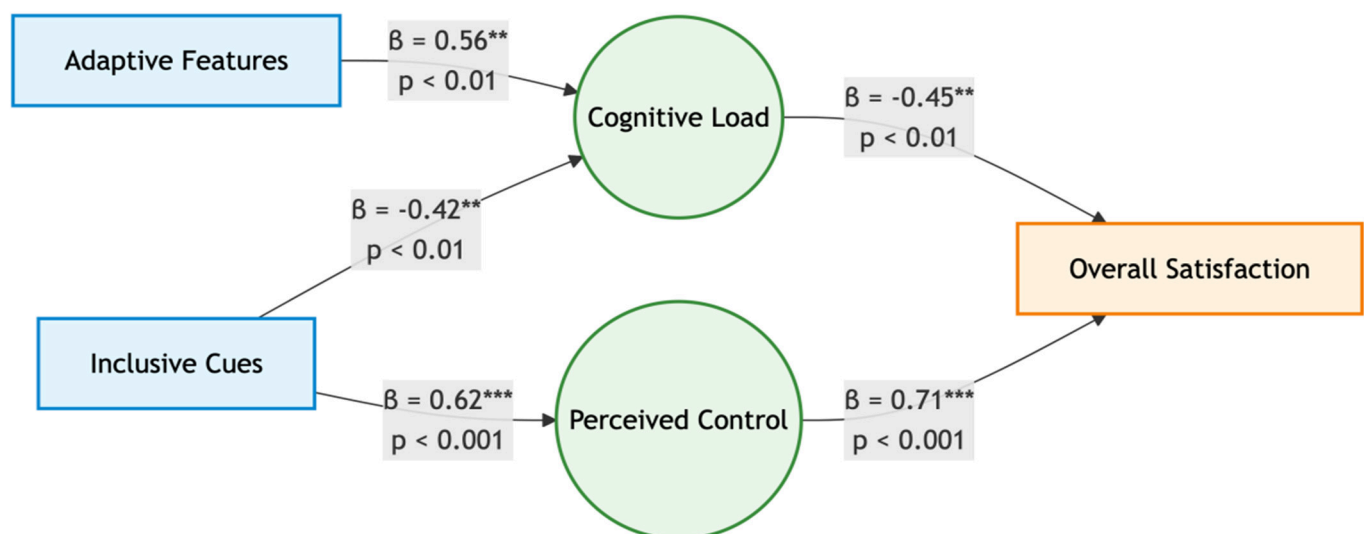


Figure 3. Structural Equation Modeling (SEM) path analysis illustrating the direct and mediating relationships among adaptive features, inclusive cues, psychological mediators (cognitive load and perceived control), and overall satisfaction. (** $p < 0.01$, *** $p < 0.001$).

Path Analysis Findings:

H1 Supported: “Adaptive Features” directly and significantly increase “Cognitive Load” ($\beta = 0.56, p < 0.01$).

H2 Supported: “Cognitive Load” has a significant negative impact on “Overall Satisfaction” ($\beta = -0.45, p < 0.01$).

H3 Supported: “Inclusive Cues” significantly enhance “Perceived Control” ($\beta = 0.62, p < 0.001$) while significantly mitigating Cognitive Load ($\beta = -0.42, p < 0.01$).

H4 Supported: “Perceived Control” emerges as the strongest positive predictor of “Overall Satisfaction” ($\beta = 0.71, p < 0.001$).

4.4. Integrated Mixed-Methods Analysis: Connecting Survey Data to Lived Experience

Adhering strictly to the explanatory sequential mixed-methods design, the purely quantitative statistical findings were subsequently contextualized using rich qualitative data. To fundamentally enhance the empirical depth and explanatory power of the study, a Joint Display Table (Table 3) was constructed. This advanced methodological technique systematically triangulates the abstract SEM path results with authentic firsthand qualitative narratives retrieved from participants during the initial ethnographic interview phase. This rigorous integration bridges the gap between positivist measurement and interpretivist meaning, vividly demonstrating how abstract mathematical correlations (β coefficients) manifest in reality as tangible, specific socio-spatial barriers or affordances for visitors navigating the exhibition environment.

Table 3. Joint Display of Quantitative Findings and Qualitative Evidence.

Quantitative Finding (SEM Path)	Associated β Coefficient	Qualitative Evidence (Visitor Quotes)	Integrated Insight
Adaptive Features → Cognitive Load	$\beta = 0.56, p < 0.01$	“The flashing interactive wall made me dizzy. there were too many things jumping around and I gave up trying to find the path.” (Participant A-V01, 68 year; fieldwork transcript data)	High-tech adaptability acts as a “sensory stressor” for non-digital natives.
Inclusive Cues → Perceived Control	$\beta = 0.62, p < 0.001$	“Once I found the large-format tactile map, I felt like I could finally breathe. It gave me the confidence to walk alone.” (Participant B-V05, 72 year; fieldwork transcript data)	Clear wayfinding cues are psychological “stabilizers” that counteract spatial complexity.
Perceived Control → Satisfaction	$\beta = 0.71, p < 0.001$	“It wasn’t just about the art; it was about the fact that I didn’t need to ask for help every five minutes. That made the visit meaningful.” (Participant B-V12, 60 year)	Autonomy in navigation is the primary driver of institutional belonging and satisfaction.

5. Discussion

The empirical findings of this quantitative study robustly validate the core premise of the User-Space Interaction Framework: spatial adaptability does not automatically equate to human inclusivity. Consistent with our first hypothesis (H1), the triangulated ANOVA and SEM data revealed a statistically significant, disproportionate increase in

cognitive load among vulnerable demographics—most notably visitors over the age of 60—when they were exposed to highly reconfigurable, tech-heavy environments. This phenomenon strongly aligns with established paradigms in visual cognition and environmental psychology, particularly theories concerning cognitive aging and environmental stress. It demonstrates that the disrupted spatial coherence inherent in rapidly changing digital layouts severely overloads visitors who lack preexisting institutional familiarity or digital fluency. In the broader context of rapid urban regeneration, newly built cultural mega-structures often prioritize futuristic aesthetics, ephemeral spatial configurations, and immersive technologies to project an image of civic modernization. However, our data suggest this dynamic inadvertently creates an invisible architectural barrier. Instead of fostering the intended interactive and participatory engagement, the sensory saturation produced by dynamic lighting, modular screens, kinetic installations, and non-linear routing frequently induces profound disorientation and spatial anxiety. By demanding continuous cognitive processing simply to decode the physical environment, these highly adaptable spaces risk systematically marginalizing non-digital-native populations, effectively transforming publicly funded cultural hubs into exclusionary environments where elderly visitors feel overwhelmed rather than welcomed.

Furthermore, the Pearson correlation and SEM path analysis explicitly exposed what we conceptualize as the “technological adaptability paradox.” While highly adaptive spaces successfully increase curatorial flexibility, operational efficiency, and overall spatial utilization rates for the institution, they paradoxically degrade the individual user experience if these flexible elements are not strictly anchored by robust, user-centric inclusive design principles. As vividly demonstrated in the SEM model, inclusive spatial cues—such as highly legible, static wayfinding systems, intuitive tactile guidance, acoustically balanced zones, and strategically placed ergonomic seating—do not merely serve as passive physical amenities or regulatory afterthoughts. Rather, they act as a vital, active psychological buffer against environmental stress. These environmental affordances significantly reduce cognitive load ($\beta = -0.42$) by providing essential “spatial anchors” in an otherwise fluid, unpredictable, and overwhelmingly complex environment. By offering consistent and predictable points of reference, these static inclusive cues mitigate sensory overload, eliminating the need for continuous spatial recalculation. This crucial reduction in environmental friction thereby frees up visitors’ limited cognitive resources, allowing them to redirect their attention toward meaningful educational and aesthetic engagement with the exhibits themselves.

It is crucial to acknowledge, however, that these highly adaptive technologies are not inherently detrimental. Digitally fluent demographics—particularly younger cohorts—frequently derive significant aesthetic pleasure, heightened engagement and educational benefits from dynamic, interactive spaces. Therefore, the objective of the proposed framework is not to unconditionally eliminate technological adaptability. Rather, it advocates for a ‘layered inclusivity’ where advanced interactive features are firmly anchored by intuitive, static physical cues, successfully accommodating both digital natives and cognitively vulnerable demographics.

More importantly, the structural model reveals that the presence of these inclusive spatial anchors massively boosts the visitors’ perceived control ($\beta = 0.62$). Within a multifaceted and highly stimulating exhibition setting, this restoration of autonomy—defined as the subjective feeling of being able to navigate, explore, and rest independently without requiring constant staff assistance or peer guidance—emerges as the ultimate and most potent driver of overall user satisfaction. When visitors perceive a high internal locus of control over their spatial journey, their psychological state transitions from mere environmental tolerance to an active sense of institutional belonging and comfort. Ultimately, this

research empirically confirms the necessity for a critical theoretical paradigm shift within architectural practice. True inclusive design in contemporary cultural institutions must radically transcend the baseline of static physical compliance—such as basic wheelchair ramps, elevator dimensions, and tactile paving mandated by standard building codes. To genuinely democratize these cultural spaces, architectural frameworks must systematically encompass cognitive, sensory, and psychological accessibility. This ensures that the relentless pursuit of technological innovation and spatial flexibility never outpaces the fundamental human necessity for spatial legibility, emotional security, and cognitive equity.

6. Policy and Practical Implications

The empirical findings of this study extend far beyond the realm of architectural aesthetics or interior layout optimization. Instead, they provide critical, evidence-based parameters for cultural governance, public infrastructure investment, and urban regeneration policies, particularly within the context of China's rapidly aging demographic landscape. As megacities like Wuhan aggressively pursue "smart city" initiatives and digital modernization, public exhibition halls are increasingly transformed into showcases of technological prowess. However, true urban cultural sustainability demands spatial justice. If these publicly funded institutions are to fulfill their mandate as democratized spaces for lifelong learning, policy frameworks must urgently recalibrate to prevent the technological alienation of vulnerable demographics.

6.1. *Shifting from Physical Compliance to Cognitive Equity*

Current national regulatory codes, such as the Code for Accessibility Design (GB 50763-2012) [5], remain deeply entrenched in a paradigm of physical compliance. They focus heavily on measurable spatial parameters—such as wheelchair ramp gradients, corridor clearances, and elevator dimensions—while largely neglecting the cognitive, psychological, and sensory dimensions of accessibility. However, our SEM results unequivocally prove that excessive Cognitive Load acts as a profound, albeit invisible, barrier to overall visitor satisfaction ($\beta = -0.45$) and institutional engagement. To bridge this regulatory gap, policy-makers and architectural review boards must expand the legal definition of accessibility to encompass "cognitive equity." We strongly recommend the institutionalization of mandatory "Cognitive Impact Assessments" (CIA) for all state-funded cultural infrastructure projects prior to their approval. Similar to environmental impact studies, a CIA would proactively evaluate the sensory thresholds, digital interface complexity, and baseline spatial coherence of proposed adaptive spaces. Implementing such policy tools will ensure that the unbridled integration of adaptive technologies does not inadvertently disenfranchise elderly populations, transforming a public good into a cognitively hostile environment.

6.2. *Strategies for Urban Cultural Sustainability*

For museum curators, urban planners, and exhibition designers operating in Wuhan and similar hyper-modernizing megacities, the practice of spatial design must critically re-evaluate its priorities. The pursuit of curatorial novelty and technological spectacle must never supersede intuitive user orientation. To reconcile the tension between flexibility and accessibility, we advocate for the adoption of a "Layered Inclusivity" approach in architectural practice. This strategy proposes bifurcating the spatial environment into distinct cognitive layers. The "dynamic layer" can retain high adaptability—allowing curatorial partitions, digital installations, and interactive nodes to remain fluid and technologically advanced. Conversely, the "static layer"—comprising core wayfinding corridors, high-contrast tactile guidance systems, acoustic resting zones, and primary environmental comfort features—must remain absolutely fixed, highly legible, and universally intuitive.

By grounding fluid technological experiences within a stable and predictable spatial scaffold, architects can significantly mitigate visitors' spatial anxiety. This layered methodology guarantees that cultural institutions fulfill their civic duty, serving as genuine, multi-generational platforms for social integration rather than evolving into exclusionary digital enclaves that cater solely to digitally fluent youth.

7. Conclusions

In conclusion, this study significantly advances the theoretical discourse on contemporary exhibition design by providing robust empirical and quantitative evidence regarding the complex, and often contradictory, interplay between adaptive spatial strategies and inclusive design principles. By successfully operationalizing the User-Space Interaction Framework within a rigorous mixed-methods paradigm, we have empirically demystified the often-overlooked "technological adaptability paradox." Specifically, our findings reveal that while dynamic environments effectively serve institutional flexibility, they inadvertently erect severe cognitive barriers for the aging population if not anchored by stable spatial cues. By fundamentally shifting the evaluative focus from mere architectural intent and static physical compliance (such as traditional building codes) to measurable environmental psychology outcomes—specifically focusing on the crucial mediating roles of perceived control and cognitive load—this research successfully transcends the limitations of traditional post-occupancy evaluations. Furthermore, the methodological integration of structural equation modeling with authentic visitor narratives proves that mitigating cognitive load is not merely an ergonomic optimization; rather, it is essential for restoring visitor dignity and spatial autonomy. Consequently, this study equips architects, curators, and urban policymakers operating in rapidly urbanizing contexts with actionable, data-driven parameters. These parameters are absolutely essential to orchestrate public spaces that deeply respect both the relentless pace of technological innovation and the inherent biological limits of human cognitive processing.

Despite these substantive contributions, the present study acknowledges certain methodological boundaries that present fertile ground for future inquiry. Primarily, its cross-sectional design and strict geographic restriction to two specific cultural venues in Wuhan, China, imply that the observed socio-spatial dynamics may be partially influenced by localized cultural behaviors, specific institutional typologies, and regional demographic profiles. Specifically, three methodological limitations must be noted. First, grouping all participants over 60 into a single category obscures important cognitive differences between the "young-old" and "old-old" demographics. Second, measuring spatial perception relied solely on subjective self-reporting, which should be cross-validated with objective architectural field mapping (e.g., spatial syntax metrics or luminosity sensors) in the future. Third, due to the relatively small sample size of the elderly cohort ($N = 50$), a formal multi-group SEM moderation analysis for age was not conducted on the structural paths, restricting our ability to statistically formalize the moderating mechanism of age. Future research must systematically transcend these boundaries through longitudinal studies to track spatial cognition over time, as well as through cross-cultural comparisons to rigorously validate the User-Space Interaction Framework's global applicability across diverse international urban contexts. Furthermore, subsequent interdisciplinary studies should actively leverage the quantitative indicators established in this research to conceptualize, develop, and refine automated "Cognitive Impact Assessments" (CIA). Looking forward, these quantitative assessments could be seamlessly integrated directly into early architectural planning phases—potentially utilizing Building Information Modeling (BIM) or Virtual Reality (VR) simulations to digitally predict sensory saturation and spatial friction before any physical construction begins. Ultimately, embracing this cognitive-centric, profoundly humanistic

approach to architectural design will ensure that the public cultural infrastructures of the future fulfill their true civic mandate. By doing so, we can guarantee that these critical urban spaces are not only technologically resilient and operationally adaptable, but also genuinely, equitably, and measurably inclusive for all generations, thereby fostering a truly democratized built environment.

Author Contributions: Y.Z.: Conceptualization, Methodology, Software, Formal analysis, Investigation, Data curation, Writing—Original draft preparation. S.b.A.H.: Conceptualization, Supervision, Project administration, Writing—Reviewing and Editing. L.S.: Investigation, Validation, Writing—Reviewing and Editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study because it involved strictly low-risk, non-medical survey and observation procedures in public exhibition spaces. No sensitive personal, medical, or identifying data were collected. The study was assessed according to the guidelines of the Human Research Ethics (Non-Medical) Committee of Universiti Malaysia Sarawak, which indicates that formal ethics clearance is not required for such low-risk research intended for public disclosure where the loss of confidentiality has no adverse effect.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. All participants were fully informed prior to the survey regarding the assurance of their anonymity, the purpose of the research, and the voluntary nature of their participation. Written informed consent was obtained from the participants to publish this paper.

Data Availability Statement: The de-identified quantitative dataset, survey instrument, codebook, and statistical analysis materials supporting the reported results are available within the article.

Acknowledgments: We extend our gratitude to the management authorities of the Hubei Science and Technology Museum and the Wuhan Qintai Art Museum for their administrative support and site permissions during the data collection phase. During the preparation of this manuscript, the authors used Gemini for the purposes of English-language editing, formatting structural equation modeling outputs, and statistical data processing assistance. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. He, S.; Wu, F. China's Emerging Neoliberal Urbanism: Perspectives from Urban Redevelopment. *Antipode* **2009**, *41*, 282–304. [\[CrossRef\]](#)
2. Wu, F. How neoliberal is China's reform? The origins of change during transition. *Eurasian Geogr. Econ.* **2010**, *51*, 619–631. [\[CrossRef\]](#)
3. Simon, N. *The Participatory Museum*; Museum 2.0: Santa Cruz, CA, USA, 2010.
4. Bitgood, S. *Attention and Value: Keys to Understanding Museum Visitors*; Left Coast Press: Walnut Creek, CA, USA, 2013.
5. GB 50763-2012; Code for Accessibility Design. China Architecture & Building Press: Beijing, China, 2012.
6. Imrie, R. Universalism, universal design and equitable access to the built environment. *Disabil. Rehabil.* **2012**, *34*, 873–882. [\[CrossRef\]](#) [\[PubMed\]](#)
7. Schmidt, R., III; Austin, S. *Adaptable Architecture: Theory and Practice*; Routledge: Abingdon, UK, 2016.
8. Shi, W.; Zhou, M.; Ono, K. Cognitive Style and Visual Attention in Multimodal Museum Exhibitions: An Eye-Tracking Study on Visitor Experience. *Buildings* **2025**, *15*, 2968. [\[CrossRef\]](#)
9. Denecke, K.; Cvijic, L.; Petersen, C. Toward inclusive design heuristics for digital health interventions for the aging population: Scoping review. *J. Med. Internet Res.* **2025**, *27*, e79449. [\[CrossRef\]](#) [\[PubMed\]](#)
10. Gaiani, M.; Martini, B.; Apollonio, F.I. A framework for a smart cultural city. In *New Activities for Cultural Heritage, HeritageBot 2017*; Ceccarelli, M., Cigola, M., Recinto, G., Eds.; Springer: Berlin/Heidelberg, Germany, 2017; pp. 217–227.
11. BS 7000-6:2005; Design Management Systems—Managing Inclusive Design. British Standards Institution: London, UK, 2005.
12. Steinfeld, E.; Maisel, J. *Universal Design: Creating Inclusive Environments*; John Wiley & Sons: Hoboken, NJ, USA, 2012.

13. Dodd, J.; Sandell, R. (Eds.) *Including Museums: Perspectives on Museums, Galleries and Social Inclusion*; Research Centre for Museums and Galleries, University of Leicester: Leicester, UK, 2001.
14. Waller, S.; Bradley, M.; Hosking, I.; Clarkson, P.J. Making the case for inclusive design. *Appl. Ergon.* **2015**, *46*, 297–303. [[CrossRef](#)] [[PubMed](#)]
15. Gifford, R. *Environmental Psychology: Principles and Practice*; Optimal Books: Adelaide, Australia, 2014.
16. Pallasmaa, J. *The Eyes of the Skin: Architecture and the Senses*; John Wiley & Sons: Hoboken, NJ, USA, 2012.
17. Hillier, B.; Tzortzi, K. Space syntax: The language of museum space. In *A Companion to Museum Studies*; Macdonald, S., Ed.; Blackwell Publishing: Oxford, UK, 2006; pp. 282–301.
18. Yin, R.K. *Case Study Research and Applications: Design and Methods*; Sage Publications: Los Angeles, CA, USA, 2018.
19. Schwandt, T.A. Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics, and social constructionism. In *Handbook of Qualitative Research*; Denzin, N.K., Lincoln, Y.S., Eds.; Sage: Los Angeles, CA, USA, 2000; pp. 189–213.
20. Malterud, K.; Siersma, V.D.; Guassora, A.D. Sample size in qualitative interview studies: Guided by information power. *Qual. Health Res.* **2016**, *26*, 1753–1760. [[PubMed](#)]
21. Kvale, S.; Brinkmann, S. *InterViews: Learning the Craft of Qualitative Research Interviewing*; Sage: Los Angeles, CA, USA, 2015.
22. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [[CrossRef](#)]
23. Preiser, W.F.E.; Nasar, J.L. Assessing building performance: Its evolution from post-occupancy evaluation. *Archnet-IJAR Int. J. Archit. Res.* **2008**, *2*, 84–99.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.