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Enhancing Spatial Cognition in Online Virtual Museum Environments: Integrating Game-Based Navigation Strategies for Improved User Experience

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Abstract: Online Virtual Museums (OVM) serve as vital conduits for the global propagation of cultural heritage but grapple with the challenge of user disorientation due to the absence of physical references. Leveraging the successful paradigm of game-based virtual navigation, this study investigates the potential integration of game mini-map navigation design elements into OVM to enhance spatial cognition. Through empirical investigation, a conceptual model was developed to probe the role of core mini-map design elements (interactivity, visual guidance, and information content) in augmenting spatial cognition. Results indicate that optimizing these elements significantly enhances user immersion and presence, thereby improving spatial cognition. Specifically, information content and visual guidance exerted stronger effects on immersion and presence, respectively. This research contributes a novel perspective on incorporating game design strategies into non-game virtual experiences, offering practical guidance for enhancing navigation in OVM and similar virtual environments. This bridges the gap between virtual museum navigation and game design, propelling the evolution of more dynamic, interactive, and user-centric virtual environments, thus fostering the preservation and dissemination of digital cultural heritage.

Keywords: online virtual museums; spatial cognition; mini-map; navigation design; game design elements

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1. Introduction and Background

Online Virtual Museums (OVM), serving as vital complements to physical museums, have emerged as significant channels for cultural dissemination [1,2]. OVM transcends spatial, temporal, and geographical limitations, allowing global visitors to access, explore, and learn about cultural heritage at any time and from anywhere [3]. However, the intangibility of virtual environments introduces novel challenges; the absence of physical reference points and spatial boundaries can lead to user disorientation, complicating self-localization and subsequently diminishing their immersion and presence, thereby adversely affecting the user experience in virtual museums [4,5]. Spatial disorientation among visitors in virtual museums is partly attributed to spatial orientation challenges and navigational design issues within the virtual environment [6]. Scholarly testing and analysis of virtual museum navigation have demonstrated a significant impact on user experience, with visitors often experiencing poor location awareness and a lack of clarity in direction during their visits [7]. This issue is particularly pronounced when navigational aids and informational displays are inadequate for effective spatial positioning [8–10]. To enhance user experience, it is crucial to identify and implement improvements in navigation that can mitigate spatial disorientation and enhance spatial cognition within the virtual domain.

Spatial cognition represents a multidisciplinary research nexus spanning cognitive psychology and geographic information science, among others, focusing on how humans understand, recall, and navigate spatial information. This domain extensively engages with cognitive maps [11–13], navigation systems [14–16], and information visualization [17–19], uncovering the profound interplay between spatial cognition and the mechanisms of navigation and information processing within complex settings.

In the real world, navigation is often associated with tools such as compasses or maps [20]. Maps are indispensable for facilitating navigation and enhancing spatial cognition, offering visitors increased security on unfamiliar paths, improved focus [21], and efficient exploration [22]. Similarly, within virtual environments, maps depict fictional geospatial constructs [23], often materializing as mini-maps [22]. Mini-maps offer a top view of the virtual landscape, either in entirety or partially [24], acting as a critical tool in games to convey essential information, allowing users to obtain a comprehensive overview and make informed decisions [25,26].

Effective game design elements significantly enhance user engagement and interactivity, particularly in virtual environments devoid of physical spatial references [23]. Given the longstanding success of games in facilitating spatial navigation and cognition in intricate virtual environments. McGregor, G.L., and Akira, B. [27] focused on spatial usage patterns in video games, exploring how players interact within virtual spaces and the connections between architecture and gaming. Their research highlights the context-specific significance of game spaces, guiding players to integrate game environments with the real world. Peacocke, M. et al. [24] discussed how game design elements could be transformed into the concept of "gamification", proposing that displaying paths in space is optimal for navigation and that mini-maps can enhance player performance. Blackman, T. [25] examined the intersection of virtual reality (VR) and video games, focusing on the concepts of immersion, presence, and spatiality in virtual environments. His study underscores that virtual worlds transcend mere technological constructs, serving as socially and culturally constructed spaces that enable specific interactions and performances. Similar to video games, virtual museums employ first-person interaction modalities, incorporating a variety of interactive design and user experience strategies [26]. Consequently, this study turns to game design to enhance user experience and engagement by integrating gaming elements into virtual museum navigation.

According to a Wikipedia list of the world's most visited museums [28], among the top 30 museums that have virtual online exhibition hall, only four (the National Art Center, the Museum of Modern Art, the Moscow Kremlin Museums, and the Victoria and Albert Museum) lack virtual exhibitions. This highlights the rapid growth of OVM as primary channels for accessing cultural heritage. The need to optimize navigation design in OVM is becoming increasingly urgent. Mini-maps, as an effective navigational aid, have been demonstrated to be crucial in games for enhancing spatial cognition and navigational efficiency [22]. Thus, this study explores the potential application of mini-maps in virtual museums and their possible impact on user experience, further deducing which elements of navigation affect spatial cognition in virtual museums. Additionally, the present work addresses whether game mini-map navigational design elements can be directly translated to this context and how these elements' impact on spatial cognition can be evidenced, forming the core focus of this investigation.

This study aims to address the following three issues. Firstly, validated gaming mini-map navigation design elements are integrated into virtual museum environments in this study, aiming to utilize game design elements to enhance non-gaming virtual environments. Secondly, this study aims to determine which gaming navigation design elements are applicable to virtual museums. Upon identifying essential design elements, their potential to enhance user immersion and presence is assessed. Immersion and presence, crucial to the user experience in virtual museums, significantly contribute to sustaining and increasing user engagement [29,30]. Thirdly, considering spatial cognition's critical role in virtual environment navigation, impacting how users interpret, understand, and remember information [31,32], this study seeks design elements that positively affect spatial cognition, addressing issues of user disorientation and enhancing the virtual museum experience.

The remainder of the article is structured as follows: Section 2 provides a literature review on spatial cognition theory, immersion and presence in virtual environments, and research on gaming mini-maps, enabling us to formulate nine hypotheses to construct our research model. Section 3 elaborates on the research design and implementation methods, including data collection and analysis procedures. Section 4 presents the empirical findings of the study. Section 5 discusses the implications of the research findings. Finally, Section 6 summarizes the main conclusions of the study, highlights its limitations, and suggests directions for future research.

2. Literature Review and Hypotheses Development

2.1. Virtual Museum Navigation Experience

There exist numerous categories of virtual museums, distinguished by their common feature of exhibition spaces devoid of physical barriers or obstructions [33]. In this study, an OVM is defined as a virtual space created using 360° panoramic technology to closely replicate the physical environment of offline museums [34]. Its hallmark feature lies in the authentic representation of physical museum spaces in the digital sphere [35], accomplished through the digitization of architectural or exhibition components from real-world museums, subsequently disseminated and showcased via online museum platforms [7]. Currently, there continues to be sustained interest from diverse audiences and the existence of numerous well-known OVM cases, highlighting the significance and practicality of researching this domain [36,37].

Within the OVM environment, users face a critical challenge marked by a dearth of adequate vestibular and proprioceptive cues [38], hindering their interaction quality and impeding spatial cognition within the virtual realm. As users engage solely through screens, mice, and keyboards, they struggle to discern real-world pathways and obstacles, easily succumbing to distractions from other interfaces, thus disrupting their viewing experience at any given moment. To surmount these constraints and enrich user immersion and engagement, researchers and developers have explored diverse technologies and methodologies, including recommendation systems [39,40], personalized navigation [41–43], virtual assistants [44–46], and navigation devices [47].

Furthermore, with the continuous advancement of technology and application platforms, a plethora of design guidelines for virtual museums have emerged, covering various platforms such as Augmented Reality (AR) [44,48], Virtual Reality(VR) [49,50], Mixed Reality (MR) [51,52], and Extended Reality (XR) [53]. Within the domain of OVM, Lin et al. identified four critical design features (usability, aesthetics, sensory appeal, personalization) and five guidelines (interactivity, content relevance, ease of use, emotional engagement, discovery) [54]. These are crafted to enhance both user engagement and learning effectiveness in online museum experiences. Tavčar et al. explored the architecture of a virtual museum guide system that employs a recommender system and a virtual assistant to personalize visitor interactions [45]. This approach highlights the growing use of intelligent personalization in cultural heritage settings to improve educational and immersive experiences. More recently, Trichopoulos et al. investigated the development of museum guides utilizing ChatGPT4, suggesting that AI will facilitate the introduction of novel functionalities and substantially reduce operational costs [55]; nevertheless, further scrutiny regarding the accuracy of the information imparted is warranted.

While research on design guidelines for virtual museums is expanding, there is a relative scarcity of studies specifically dedicated to design guidelines for OVM. Moreover, empirical research examining the impact of virtual navigation design on users is insufficient. These observations underscore the ample research opportunities within the realm of OVM, particularly concerning the formulation of design guidelines for virtual navigation and the enhancement of user experience.

2.2. Spatial Cognition

The study of spatial cognition dates back to TroWBriDgE's 1913 proposition of "imaginary maps" [56], which delved into the reasons behind individuals' tendency to lose their way in unfamiliar territories, introducing concepts like "sense of direction", "sense of locality", and the "Ego-centric Method of Orientation". Subsequently, psychologist Edward C. Tolman introduced the concept of "cognitive maps" in 1948 [57], laying the groundwork for understanding intricate cognitive behaviors. Moreover, Downs and Stea delved into the practical application of cognitive maps in daily navigation [58], discussing how individuals acquire, retain, and utilize spatial information, stressing the influence of structured environmental knowledge on spatial behavior, later evolving into "Landmark Knowledge, Route Knowledge, and Survey Knowledge" [59–62]. This theoretical framework also lends support to our investigation into the utilization of "mini-map". O'Keefe and Nadel contributed to spatial cognition theory by elucidating how the hippocampus in the brain supports spatial navigation, providing a neuroscientific foundation and illuminating how design can impact visitors' spatial comprehension and memory [63].

In virtual environments, research on spatial cognition is particularly important because these environments lack direct sensory inputs from the physical world (such as touch or vestibular sensation) to perceive spatial information, directly affecting their spatial orientation and navigation abilities. Smith and Marsh found in their study, that the lack of physical reference points significantly reduces participants' navigation efficiency in virtual environments, thus increasing the likelihood of spatial disorientation [64]. Recently, LaValle reiterated the importance of virtual environments providing adequate visual guidance to assist users in developing spatial awareness; the absence of these cues can severely affect users' spatial cognition and experience quality [5]. The assessment of user experience quality in academia commonly relies on immersion and presence as key metrics of measurement [65–67]. Next, we will discuss in detail how immersion and presence influence spatial cognition.

2.3. Immersion and Presence

Regarding immersion and presence, although frequently mentioned in virtual environments, they are still prone to confusion, often considered to convey the same meaning or used interchangeably. While some scholars classify both as psychological states [65,68,69], others define immersion either as a systemic objective attribute [70] or as a technological quality of the medium [71]. Presence, on the other hand, is delineated as a subjective psychological response to the system [66], occasionally characterized by illusions or hallucinations [30]. Ultimately, we summarize the concepts, immersion is typically associated with the technical attributes of virtual environments, reflecting the system's technical characteristics and quantified descriptions of technology, such as visual stimulation, interaction fluency, and richness of information feedback; presence is the subjective and dynamic result of immersion, describing users' subjective experiences in virtual environments, such as enjoyment and fulfillment.

In various virtual environments, the interplay between immersion and presence has been substantiated to positively correlate with user engagement, enjoyment, satisfaction, memory retention, and spatial cognition. Mochocki et al. delved into the realm of virtual gaming, elucidating the pivotal role of immersion in augmenting the perception of realism and thereby influencing players' spatial cognition [72]. Rasheed et al. in the context of virtual classrooms, posited immersion as a fundamental aspect for enriching spatial awareness, encompassing facets like color perception, directional acuity, and size comprehension [73]. Sylaiou et al. through experimental research in virtual museums, demonstrated that participants experiencing a "sense of presence" derived greater enjoyment and exhibited higher user satisfaction during interactions with specific interfaces, corresponding to what is commonly referred to as presence [74]. Maneuvrier et al. further corroborated this assertion by elucidating the correlation between presence and performance in spatial cognition tasks within VR environments, underscoring the facilitative role of presence in spatial cognition assessment performance [75].

Despite the established correlations between immersion, presence, and various user metrics across different virtual environments, there remains limited research attempting to measure these factors within the context of OVM and their associations with potential influencing factors. Our objective is to empirically examine the relationships between immersion, presence, and spatial cognition within the OVM environment, thereby contributing to a deeper understanding of user experiences in virtual museum settings. Therefore, the following hypotheses are proposed:

H1: *Immersion (IM) has a positive effect on spatial cognition (SC);*

H2: *Presence (PR) has a positive effect on spatial cognition (SC);*

H3: *Immersion (IM) has a positive effect on presence (PR).*

2.4. Mini-Map and Online Virtual Museums

In the current landscape of OVM, the utilization of mini-map displays notable disparities. Some renowned museums such as Musei Vaticani [76], Tokyo National Museum [77], National Gallery Singapore [78], and The Metropolitan Museum of Art [79] have not integrated mini-map functionality. Conversely, a few museums like Palace Museum [80], Hermitage Museum [81], and National Palace Museum [82] have adopted mini-map, but their functionality primarily remains limited to providing basic navigation by displaying an overview of the museum from a top-down perspective. They have not fully utilized the potential of mini-map in aspects such as displaying key exhibit information, guiding visitors in the correct direction, providing relative position cues for items, and offering timely interactive feedback.

Considering that games, as digital content on the Internet, exhibit the pivotal at-tribute of replicability [83], OVM share a spectrum of analogous visual presentation traits with video games, notably including first-person perspective interaction [84]. Extensive research has underscored the efficacy of mini-map in games for enhancing user experience and proficiently guiding users through virtual environments, thereby augmenting their spatial cognition capacities [9,85]. Our objective is to explore the transfer of design elements from game mini-maps to facilitate user navigation in virtual museums. However, a direct adaptation of game mini-map designs may not seamlessly align with the nuanced context of OVM. Guided by the definition of museums outlined by the International Council of Museums (ICOM) [86], virtual museums are characterized by their seriousness, educational value, and instructional potential. Thus, our emphasis rests on precision in refining mini-map features tailored explicitly to the context of OVM.

Drawing on the synthesis of eight key design features of mini-map in 100 games by Krzysztof Zagata et al., namely shape, position, orientation, centering, projection, base layers, proportions, and additional navigational elements [87], we found a breakthrough in understanding how mini-map facilitates user navigation and spatial cognition in virtual environments. These eight features have been adapted for implementation within OVM and reconceptualized into three fundamental elements: Interactivity, Visual Guidance, and Information Content. This conceptual refinement process was informed by an extensive literature review, revealing that visual, interactive, and content elements are not only essential components of game mini-map [87–89], but are also repeatedly mentioned in user interactions with virtual environments. Marty's research underscored the impact of visual effects, interactivity, and virtual exhibition content and technology on visitor engagement [90]. Studies by Falk, John H et al. demonstrated the influence of interactivity on museum visitors' learning abilities [91]. Burceva's work emphasized the critical role of visual aids and information acquisition in museum settings [92].

It is noteworthy that within the multitude of factors contributing to the formation of immersion and presence, visual, interactive, and informational factors stand out as crucial [30,65,93]. Hence, we propose the following hypotheses to explore the impact of these fundamental elements on immersion and presence within user experiences, both of which are pivotal for comprehending users' spatial cognition.

H4: *Interactivity (IE) has a positive effect on Immersion (IM);*

H5: *Interactivity (IE) has a positive effect on Presence (PR);*

H6: *Visual Guidance (VG) has a positive effect on Immersion (IM);*

H7: *Visual Guidance (VG) has a positive effect on Presence (PR);*

H8: *Information Content (IC) has a positive effect on Immersion (IM);*

H9: *Information Content (IC) has a positive effect on Presence (PR).*

2.5. Research Model

Based on the above discussion, this study proposes the research model in Figure 1. The model aims to empirically explore the relationship between the key elements extracted from game mini-map (interactivity, visual guidance, information content) and user immersion and presence, further verifying the impact of these three variables on spatial cognition. Figure 1 illustrates the hypothesized relationships among the variables.

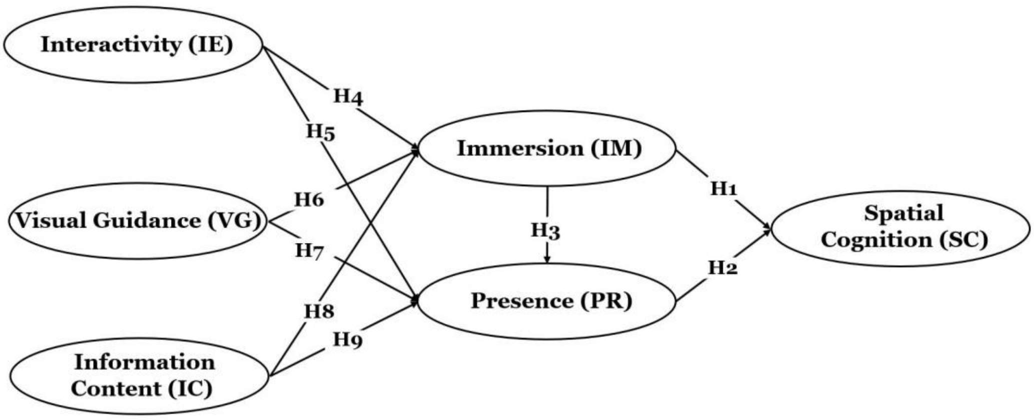

Figure 1. The conceptual model in this study.

3. Methods

3.1. Research Design

Before answering the questionnaire, each participant engaged in a between-subjects experiment. The experimental design included two virtual museum map experience conditions: Condition A (as shown in the top left of Figure 2) did not utilize mini-map navigation, and participants navigated through designated links [94]. Condition B (as shown in the top right of Figure 2) featured mini-map guidance, with participants experiencing it through an outsourced experimental test package. Both conditions utilized the Anhui Museum's online virtual exhibition hall, which predominantly features ancient artifacts, with Condition B adding a mini-map to the setup of Condition A.

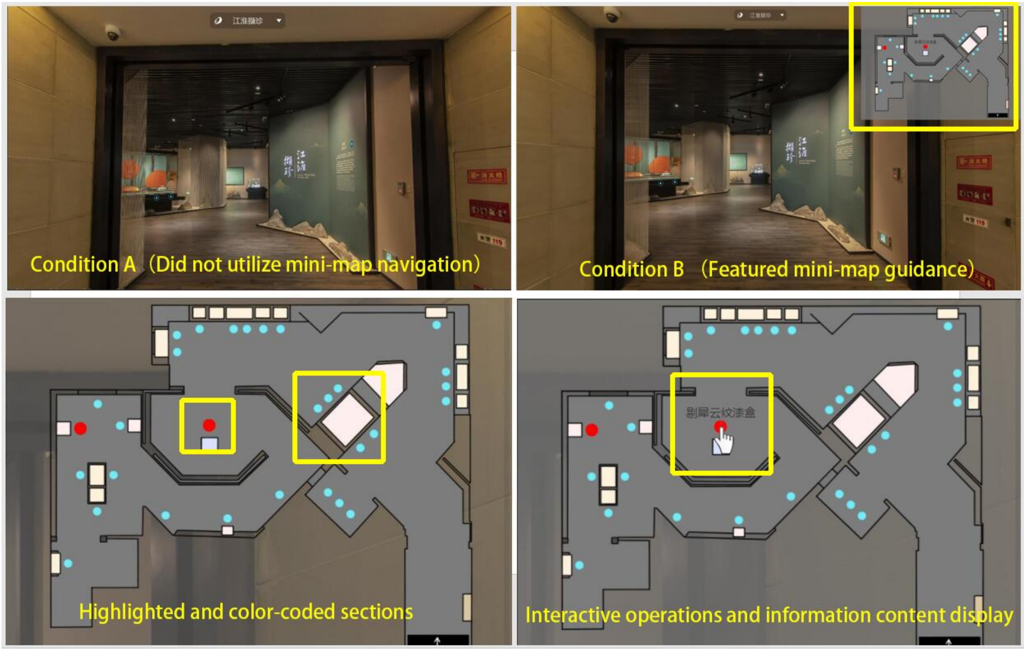

Figure 2. Design experiment of museum mini-map. (The red dot indicates the location of the museum's most treasured item. The blue dot indicates the relative positions of the exhibited items).

The experimental design was a one-way control experiment, comprising two conditions of virtual museum map experiences: one without mini-map navigation and the other with mini-map navigation. The mini-map, based on the eight different game mini-map features summarized by Krzysztof Zagata et al. [87], integrated three types of stimuli: visual, interactive, and informational. Specifically, visual stimuli included shape (rectangular mini-map shape), position (mini-map positioned in the upper right corner of the user interface), centering (centered around the world), projection (top-down view), base layers (transparent base layer), and proportions (3.1–4% of the entire display screen); interactive stimuli included orientation (no rotation of the mini-map relative to the museum environment); informational stimuli included additional navigation elements (names or other artifact information), as shown in the top right, bottom left, and bottom right of Figure 2.

Additionally, we incorporated further design details based on the factors outlined by Lombard and Witmer that influence immersion and presence. These include visual stimuli (e.g., user location display, color differentiation, highlighted cues), interactive stimuli (e.g., click-to-jump, hover-over display, pop-up functions), and informational stimuli (e.g., consistency with real-world information) [30,65], as depicted in Figure 2. These elements serve as crucial precursory components of our model variables.

The measurement metrics utilized in this study are derived from the existing literature and adapted based on the specific focus and objectives of this research. Specifically, the evaluation criteria for interactivity (Questions 6–10), visual guidance (Questions 11–15), and information content (Questions 16–20), and spatial cognition (questions 31–35) were adapted from the " Evaluation scale for virtual tours of online museums" developed by Li, Jia et al. [7] and Meng, Lei's "Digital Museum Website User Assessment Scale" [95], with further refinements. The metrics for immersion (Questions 21–25) and presence (Questions 26–30) are adapted from Bob G. Witmer's "Presence Questionnaire Item Stems (Version 2.0)" [65]. In total, the measurement instrument consisted of 30 items, all of which were measured on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). All items used in the questionnaire were adapted from validated questionnaires and translated into Chinese. The list of question items and reference sources of the questionnaire are shown in Table 1.

Table 1. Results of exploratory factor analysis of the questionnaire.

	EFA Results for Questionnaire Items	Factor Loading
Interactivity (IE) $\alpha = 0.850$	IE1 Interacting with the mini-map is easy.	0.726
	IE2 Interacting with the mini-map is effective.	0.742
	IE3 My interaction process feels very natural, without any restrictions.	0.794
	IE4 I know what I can and cannot do when interacting with the mini-map.	0.764
	IE5 Feedback is timely when I interact with the mini-map.	0.778
Visual Guidance (VG) $\alpha = 0.864$	VG1 The mini-map helps me easily locate my position in the virtual museum.	0.765
	VG2 The mini-map guides me to important exhibits.	0.786
	VG3 I can quickly find the locations I want to visit through the mini-map.	0.702
	VG4 The colors and symbols on the mini-map are clear and easy to understand.	0.787
	VG5 The mini-map clearly directs me to where I should go.	0.791
Information Content (IC) $\alpha = 0.876$	IC1 The information provided on the mini-map is accurate.	0.739
	IC2 The information on the mini-map is clear and understandable.	0.791
	IC3 Text descriptions on the mini-map are helpful for navigation.	0.806
	IC4 The information provided by the mini-map meets my needs.	0.782
	IC5 The information provided by the mini-map helps me better understand the exhibits.	0.768
Immersion (IM) $\alpha = 0.888$	IM1 I spend more time exploring the virtual museum than I expected when using the mini-map.	0.766
	IM2 When using the mini-map to explore the virtual museum, my awareness of the surrounding environment decreases.	0.748
	IM3 I am not influenced by the surrounding real environment when exploring the virtual museum.	0.728
	IM4 I lose track of time when exploring the virtual museum.	0.765
	IM5 I prefer visiting virtual museums with mini-map assistance.	0.790
Presence (PR) $\alpha = 0.878$	PR1 My experience in the virtual museum feels like being in a real space.	0.723
	PR2 I easily adapt to navigating the virtual museum with mini-map assistance.	0.751
	PR3 I can predict what will happen next based on the actions I perform.	0.663
	PR4 The information provided by the mini-map in the virtual museum is consistent with that in real museums.	0.774
	PR5 By the end of the experience, I am proficient in using the mini-map to navigate the virtual museum.	0.731
Spatial Cognition (SC) $\alpha = 0.879$	SC1 I always know the direction to explore through the mini-map.	0.717
	SC2 I always know where I am through the mini-map.	0.756
	SC3 I can easily find previously visited exhibits or areas through the mini-map.	0.703
	SC4 The mini-map helps me better understand the spatial layout of the museum.	0.753
	SC5 The mini-map helps me form a clear understanding of the pathways in the virtual museum.	0.689

3.2. Participants

Data were collected using the online survey platform QuestionStar, a professional online survey platform in China. All responses were completed online immediately after participants had finished the virtual museum experience. Throughout the entire process, participants volunteered their involvement, and no conflicts of interest were present. This study received approval from the Institutional Review Board (IRB) of Kookmin University (IRB NO. KMU 202312-HR-386). A total of 380 questionnaires were distributed online, of which 352 were returned. After excluding 28 questionnaires due to insufficient response time, the response rate was calculated to be 92.63%. Ultimately, 304 questionnaires were deemed valid, yielding an effective rate of 86.36%. Descriptive analysis of demographic information revealed nearly equal gender participation, with 73.33% of respondents aged between 18 and 35 years. The high proportion of participants aged between 18 and 35 is justified by their advanced digital literacy, cognitive flexibility, and active participation in social and cultural activities. As Mitchell highlighted [96], this demographic exhibits a receptive attitude towards emerging technologies and cultural products, demonstrating higher levels of engagement and learning efficiency in virtual environments. Including this group in the sample allows us to gain valuable insights into optimizing the design of virtual museums to align with future trends [97]. Among the participants, 98.68% reported prior experience with online virtual museums, with over half (64.47%) stating frequent engagement with mini-map navigation games, indicating familiarity with such games. Table 2 presents the demographic characteristics of the respondents.

Table 2. The demographic information of participants (n = 304).

Variable		*N*	%
Gender	Male	155	50.99
	Female	149	49.01
Age	<18	20	6.58
	18~25	126	41.45
	26~35	103	33.88
	36~60	44	14.47
	>60	11	3.62
Education	Below High School	35	11.51
	High School Diploma or Equivalent	66	21.71
	Associate Degree	78	25.66
	Undergraduate Degree	115	37.83
	Graduate Degree	10	3.29
Experience with Mini-map Games	Absolutely Unfamiliar: Never played	6	1.97
	Slightly Unfamiliar: Rarely play	50	16.45
	Moderate: Some experience	52	17.11
	Familiar: Often play	112	36.84
	Highly Familiar: Regularly play	84	27.63
Frequency of Using Online Virtual Museums	Never: Never visited	4	1.32%
	Rarely: A few annual visits	43	14.14%
	Occasionally: Monthly visits	138	45.39%
	Often: Weekly visits	81	26.64%
	Very Often: Multiple visits per week	38	12.50%

3.3. Data Analysis Methods

To ensure the reliability of our research hypotheses, we comprehensively tested the reliability and validity of our questionnaire. Given that the items were derived from multiple validated sources, we first assessed internal consistency using Exploratory Factor Analysis (EFA) and Cronbach's alpha. After collecting the data, we processed it using SPSS V.26. Structural Equation Modeling (SEM) was then performed using AMOS V.23, to analyze the significance and effect sizes of the path coefficients and test the research hypotheses [98]. The composite reliability (CR), average variance extracted (AVE), and Kaiser–Meyer–Olkin (KMO) were calculated. The model's fit was assessed using the Chi-square/degrees of freedom ratio, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI), and Normed Fit Index (NFI). Hypotheses were confirmed based on the significance of the path coefficients ($p < 0.05$).

4. Results

4.1. Measurement Tool Assessment

4.1.1. Results of the Reliability and Validity Tests

Results indicated that all variables exhibited Cronbach's alpha values greater than 0.8, confirming the high reliability of the questionnaire. Subsequent EFA with maximum variance rotation in SPSS revealed that the component matrix aligned with the predefined six dimensions, with each dimension's measurement variables showing high factor loadings (greater than 0.7), and only a few items exhibiting slightly lower loadings (between 0.65 and 0.7). As confirmed in Table 1, all variables were identified as independent. Detailed factor loadings and Cronbach's alpha coefficients for the two sections of the questionnaire are provided in Table 1. The KMO measure was 0.928, demonstrating the questionnaire's internal consistency and validity. CR values for all variables exceeded 0.8, indicating sufficient convergent validity [99]. Additionally, as shown in Table 3, factor loadings exceeded 0.703 and all variables' Average Variance Extracted (AVE) values were above the recommended threshold of 0.5, suggesting good convergent validity [99]. Individual item loadings greater than 0.7 indicated that the variance explained by the constructs was greater than the variance due to measurement error [100], thereby supporting the structural measurement's validity.

Table 3. The results of the construct assessment.

Variable	M	SD	Loading	AVE	CR	CA
IE1	3.980	1.024	0.703	0.532	0.850	0.850
IE2	3.997	1.104	0.703			
IE3	4.013	1.099	0.755			
IE4	3.911	1.085	0.718			
IE5	3.931	1.104	0.767			
VG1	3.908	1.196	0.759	0.561	0.865	0.864
VG2	3.905	1.227	0.763			
VG3	3.951	1.090	0.706			
VG4	3.891	1.229	0.760			
VG5	3.924	1.171	0.757			
IC1	3.711	1.195	0.743	0.586	0.876	0.876
IC2	3.763	1.223	0.771			
IC3	3.786	1.168	0.738			
IC4	3.770	1.253	0.810			
IC5	3.730	1.229	0.762			
IM1	3.566	1.308	0.793	0.614	0.888	0.888
IM2	3.628	1.260	0.781			
IM3	3.536	1.224	0.776			
IM4	3.474	1.364	0.773			
IM5	3.569	1.367	0.793			
PR1	3.704	1.245	0.764	0.591	0.878	0.878
PR2	3.638	1.251	0.761			
PR3	3.579	1.235	0.722			
PR4	3.582	1.279	0.749			
PR5	3.622	1.322	0.842			
SC1	3.691	1.281	0.746	0.595	0.880	0.879
SC2	3.668	1.247	0.761			
SC3	3.628	1.201	0.752			
SC4	3.671	1.268	0.817			
SC5	3.609	1.295	0.777			

Note: SD = standard deviation; CR = construct reliability; CA = Cronbach's alpha; AVE = average variance extracted.

4.1.2. The Results of the Discriminant Validity Test

Table 4 shows the results of the discriminant validity test. The square root values of AVEs for all constructs are higher than the inter-construct correlations, proving sufficient discriminant validity [99].

Table 4. The results of discriminant validity test.

	IE	VG	IC	IM	PR	SC
IE	**0.729**					
VG	0.242	**0.749**				
IC	0.224	0.278	**0.765**			
IM	0.334	0.375	0.416	**0.783**		

Table 4. *Cont.*

	IE	VG	IC	IM	PR	SC
PR	0.383	0.431	0.411	0.491	**0.769**	
SC	0.384	0.407	0.418	0.545	0.600	**0.771**

Note: Figures on the diagonal line (in bold) are the square roots of the average variance extracted (AVE). Off-diagonal figures show inter-construct correlations.

4.2. Assessment of the Structural Model and the Hypotheses

4.2.1. Model Fit Index

Upon analyzing the fit indices of the variables, it is evident that the model in this study exhibits good fit in terms of Chi-square/df, RMSEA, and CFI, indicating that the model accurately reflects the observed data. Furthermore, the GFI, AGFI, NFI, and RFI values reside within acceptable thresholds, indicative of a robust fit. Both PNFI and PGFI affirm the model's commendable parsimony, suggesting that the model strikes a balance between complexity and data fidelity. As shown in Table 5.

Table 5. Model Fit Index.

Fit Indices	Criteria for Evaluation	Results	Model Fit
Absolute Fit			
χ^2/df	1–3 indicates a good fit, <5 acceptable	1.316	Good
GFI	$\geq$0.9 is good, $\geq$0.8 acceptable	0.899	Acceptable
AGFI	$\geq$0.9 is good, $\geq$0.8 acceptable	0.882	Acceptable
RMSEA	$\leq$0.05 is good, $\leq$0.08 acceptable	0.032	Good
Incremental Fit			
NFI	$\geq$0.9 is good, $\geq$0.8 acceptable	0.898	Acceptable
RFI	$\geq$0.9 is good, $\geq$0.8 acceptable	0.888	Acceptable
CFI	$\geq$0.9 is good, $\geq$0.8 acceptable	0.973	Good
Parsimonious Fit			
PNFI	>0.5	0.818	Good
PGFI	>0.5	0.766	Good

Note. χ^2/df: Chi-Square/Degrees of Freedom; GFI: Goodness of Fit Index; AGFI: Adjusted Goodness of Fit Index; RMSEA: Root Mean Square Error of Approximation; NFI: Normed Fit Index; RFI: Relative Fit Index; CFI: Comparative Fit Index; PNFI: Parsimonious Normed Fit Index; PGFI: Parsimonious Goodness of Fit Index.

4.2.2. Hypothesis Testing

This study computed path coefficients and *p*-values based on a sample of 304 participants. As illustrated in Table 6 and Figure 3, all hypotheses received support at a significant level of $p < 0.001$.

Table 6. Standardized Structural Estimates and Hypothesis Tests. *** $p < 0.001$.

Hypothesis/Path	Estimate	S.E.	C.R.	Results
H1: IM→SC	0.341 ***	0.061	5.230	Supported
H2: PR→SC	0.491 ***	0.061	7.106	Supported
H3: IM→PR	0.252 ***	0.074	3.613	Supported
H4: IE→IM	0.260 ***	0.071	4.253	Supported
H5: IE→PR	0.257 ***	0.074	4.234	Supported
H6: VG→IM	0.288 ***	0.068	4.693	Supported
H7: VG→PR	0.291 ***	0.072	4.721	Supported
H8: IC→IM	0.374 ***	0.066	5.935	Supported
H9: IC→PR	0.255 ***	0.070	4.044	Supported

This study supports Hypotheses 1 and 2, demonstrating that both immersion (IM) and presence (PR) significantly positively influence spatial cognition (SC), with the effect of presence being more pronounced. Hypothesis 3 is also supported, although the impact of immersion on presence is relatively weaker, suggesting that additional factors may need to be considered. For the other hypotheses (H4, H5, H6, H7, H8, H9), the analysis indicates that information content, interactivity, and visual guidance all significantly affect both immersion and presence, highlighting their importance in enhancing the user experience. Specifically, information content has the most substantial influence on immersion, while visual guidance plays a critical role in enhancing presence.

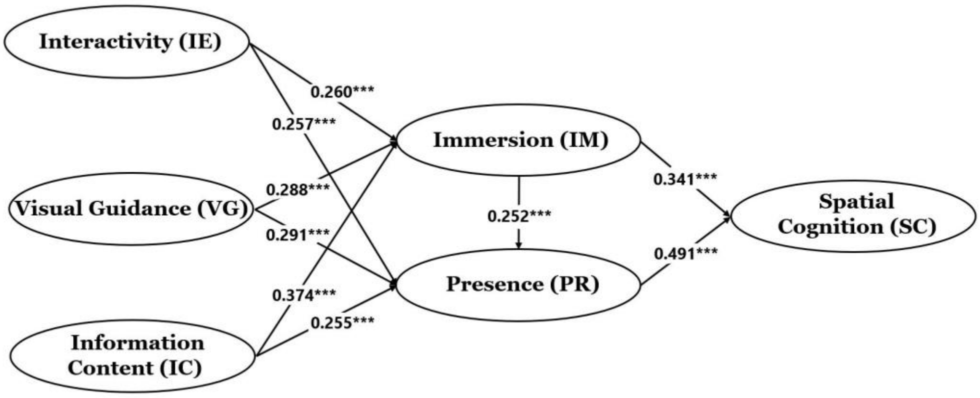

Figure 3. Standardized Structural Estimates and Hypotheses Tests. *** $p < 0.001$.

5. Discussion

This study delves into the potential impact of game mini-map navigation design elements utilized in an online virtual museum to enhance users' spatial awareness. We conceptualize the characteristics of game mini-map navigation design into three key elements: interactivity, visual guidance, and information content. This conceptualization not only provides us with a framework for analysis, but also a basis for understanding how these design features work in combination to enhance user experience and cognition. The findings support our initial hypothesis that enhanced interactivity (e.g., click-to-jump, hover display, pop-up functionality), clear visual guidance (e.g., highlighting, color zoning), and rich information content (e.g., information content that is consistent with the objective world) through the optimization of design elements can significantly enhance the user's sense of immersion and presence, and thus effectively improve their spatial cognitive abilities. In this section, we will review and analyze the key elements of game mini-map navigation design and discuss in depth how these elements work together to enhance spatial cognition. Next, we will discuss the theoretical contributions of this research and the importance of practical applications. We will also point out the limitations encountered during the research process and suggest directions for future research in this area based on our current findings.

5.1. Mini-Maps' Key Elements and Spatial Cognition

The first key element is interactivity. Interactivity, identified as a fundamental component within game mini-map navigation design, plays an indispensable role in augmenting spatial cognition, as evidenced in this investigation. This study elucidates the nuanced mechanisms through which interactivity influences spatial cognition, offering novel insights into its pivotal function. The implementation of interactive features in online virtual museums, such as click-to-navigate, hover-to-reveal, and pop-up functionalities, markedly bolsters cognitive engagement and enriches the user experience. These enhancements are consistent with the findings of Cyr [101] and Sundar et al. [102], underscoring the integral role of interactivity in cognitive facilitation. Focusing on the user interface, our analysis delves into the significance of design elements that catalyze interaction between users and dynamic media within virtual contexts, thereby intensifying immersion and presence, a synergy corroborated by Sutcliffe [103]. Notably, this research reveals that interactive mini-map designs not only exert a positive influence on immersion and presence but also substantially advance spatial cognition among users. This insight extends the discourse beyond the realms explored by Maneuvrier et al. [75], who affirmed the efficacy of immersion and presence in augmenting virtual spatial cognition without delineating their causative factors. Additionally, this study supplements the views of Marty et al. [8], who concentrated on interactions with artifacts in online museums but did not explore interactions with interface navigation.

The second key element is visual guidance. Visual guidance has been identified as a key visual element for virtual space navigation. According to Seok et al. [104], visual guidance significantly enhances navigation efficiency and spatial layout comprehension in virtual environments by directing users' gaze movements. Our study further validates that visual guidance markedly enhances users' immersion and presence, thereby rendering the virtual experience more authentic. This finding aligns with Witmer and Singer's [65] assertion regarding the pivotal role of visual stimuli in heightening immersion and presence and is corroborated by Ruddle et al. [105] and LaValle [5] regarding the significance of visual guidance in facilitating spatial orientation and mitigating disorientation. It is noteworthy that our study found visual guidance to have a more significant effect on enhancing presence compared to interactivity. This underscores the importance of visual elements in virtual environment design, possibly because visual information serves as the primary source of sensory input, providing a direct, intense, and focused experience in virtual space. This immediacy and focus may be the reason why visual guidance is particularly effective in influencing presence, aligning with Pękowska's [106] description of the importance of visual experience in digital museum experiences. Our findings underscore the imperative of leveraging visual elements, such as color differentiation and highlighting cues, in crafting virtual museum mini-map navigation designs to elevate users' virtual experience and spatial cognition prowess.

The third key element is information content. We conducted an in-depth exploration into the impact of information content on the immersive and presence experiences within the design framework of online virtual museum mini-maps. Our findings illuminate that the seamless integration of information content into mini-map designs not only enhances user experiences but also significantly augments spatial cognition, thus emphasizing the indispensable value of information in the domain of virtual navigation. These conclusions resonate with the assertions posited by Witmer and Singer [65]. Furthermore, our analytical endeavors divulged that the richness of information content, denoted by the inclusion of additional navigational elements, and its accuracy, characterized by the consistency between conveyed information and the objective world, collectively contribute to amplifying users' recall of traversed paths and catalyzing exploration and engagement, thereby fostering higher-order cognitive processing. This aligns harmoniously with Thorndyke's [107] taxonomy of spatial knowledge (including landmarks, routes, or survey knowledge), alongside the empirical observations delineated by Chen [17] and Liu and Stasko [18]. It is important to highlight that our study suggests that providing rich information content significantly enhances user immersion. This effect is likely due to the internet's primary function as a text-based information medium [106], combined with the essential demands of museums for accurate and comprehensible information [108].

5.2. Immersion, Presence, and Spatial Cognition

This study has identified the potential of employing game mini-map design elements in online virtual museums to enhance both user experience and spatial cognition. This observation resonates with the findings of Juul and Norton [109], who emphasized the benefits of replicating established effective game design patterns across different projects. Immersion and presence play pivotal roles in user experience within virtual environments, particularly in facilitating spatial cognition [75]. By exploring how the design elements of game mini-maps trigger immersion and presence, this study reveals that three key elements (interactivity, visual guidance, and informational content) not only independently influence user experience but also have a combined effect on immersion and presence. This dual impact enhances spatial cognition and creates a positive synergistic model. This finding transcends the limitations of prior research, which tended to consider factors affecting user experience independently [102], proposing a more flexible and synergistic model. Initially, it was unclear whether such a model would hold when these elements coexist at the interface. However, this study precisely demonstrates the effectiveness of their synergistic effect. Furthermore, our research finds that immersion significantly promotes the formation of presence, aligning with the findings of Fan et al. [110] regarding the key driving factors of immersion and presence enhancement in the user experience.

5.3. Implications

The present study offers both theoretical and practical implications. From a theoretical standpoint, the study establishes a novel paradigm by recognizing the expansive potential of integrating game-inspired navigational design elements into diverse virtual environments. This study showcases how such elements, particularly exemplified by mini-map-based navigation, transcend the conventional confines of digital domains, profoundly enhancing user experiences within online virtual museums. This involves enhancing the interactivity, visual stimulation, and content accuracy of online museum virtual navigation, thereby fostering amplified user immersion, heightened presence, heightened engagement, augmented spatial cognition, and alleviated directional disorientation. Moreover, this investigation advances fresh perspectives on contemporary guidelines pertaining to virtual museum design, thereby fostering constructive contributions towards the educational and knowledge dissemination facets of online virtual museums. Leveraging the replicable nature of digital content, this research proffers optimized navigational design trajectories applicable to a spectrum of virtual spaces, encompassing VR, AR and MR. The study advocates for a gamified approach entailing the integration of multisensory feedback mechanisms, inclusive of interactive, visual, and informational modalities, alongside the deployment of adaptive narrative frameworks tailored to diverse virtual settings, thereby propelling immersive and presence-amplifying navigational experiences to new heights.

Although each virtual environment has its own narrative design methods, essential navigational elements are required for each approach. Our research provides universal design guidelines that can be customized through the integration of environmental and user data. This customization enhances Adaptive Narrative Frameworks (a highly adaptable and responsive narrative technology), ensuring that it meets the varied navigational requirements of different virtual environments. For instance, with mini-maps, while satisfying basic requirements for interactivity, visual guidance, and information content, customizable settings allow for accommodating specific user preferences. Users may add multiple mini-maps, choose highlight colors, and adjust map scaling within the virtual environment. This approach promotes the development of more inclusive products by catering to the individualized needs of a broad user base.

The theoretical innovation of this study also encompasses the creation of a novel conceptual model for virtual museum navigation design by integrating game design elements, immersion and presence experiences, and spatial cognition theories. This model explores the supportive role of mini-map design elements, including interactivity, visual guidance, and informational content, in enhancing users' navigational capabilities within virtual environments lacking physical spatial references. Currently, game design elements have not been widely used in non-game virtual environments. By re-evaluating and integrating these elements, the study minimizes conceptual overlap and affirms the independence of interactivity, visual guidance, and information content in research. Findings reveal that the impact on user experience depends not only on current technological innovations but also on how these technologically based designs psychologically engage users. The study highlights the necessity of targeted research in user experience (UX) design aims. The insights derived from this study are poised to inform designers on crafting more engaging and efficient navigational methods for virtual environments, thereby contributing to the expansion of the theoretical base for future research into virtual engagement and cognitive processes.

From a practical point of view, this study provides actionable guidance for the design and enhancement of online virtual museums and analogous virtual environments. The study furnishes empirically supported strategies for optimizing virtual museum navigation design, with a particular emphasis on the effective utilization of interactivity, visual cues, and informational content to enrich user experiences. Our research presents practical design directives tailored to alleviate users' spatial disorientation and bolster their engagement, catering specifically to virtual museum designers. For example, augmenting the interactivity features of the mini-map, via interactive exhibit information pop-ups and click-to-navigate functionalities, can significantly elevate user motivation and engagement in exploration. Thoughtful design of visual guidance elements, such as color coding and symbolic markers, facilitates users' comprehension of spatial layouts and mitigates disorientation. Additionally, the provision of comprehensive and accurate exhibit information addresses users' knowledge retention and spatial recall requirements, while also enhancing immersive learning opportunities, thereby markedly improving the overall visiting experience. Our findings offer practical strategies for adaptively integrating principles from game design to optimize navigation and spatial cognition in non-gaming virtual environments. By underscoring the significance of virtual navigation design, this study also offers specific guidance for mitigating users' susceptibility to disorientation during virtual tours, stemming from the absence of physical reference points.

The study's scope and depth still carry certain limitations. In this study, experiments were conducted via desktop interfaces to access virtual museums. Whether the optimized mini-map design is suitable for mobile or other virtual device interfaces remains to be validated. Further exploration is warranted to delineate the specific design elements underpinning interactivity, visual guidance, and informational content across diverse virtual environments. Additionally, investigating the differential impact of these design elements on spatial cognition among various user demographics, considering variables such as age, cultural background, and spatial proficiency, will be crucial. This endeavor aims to foster the development of more universally applicable and tailored virtual navigation design strategies to cater to the multifaceted needs of different virtual settings. Subsequent research endeavors could explore the impact of virtual navigation design on user experiences and spatial cognition within intellectually stimulating virtual environments similar to virtual museums, as well as investigate the effects of virtual navigation design on learning outcomes within virtual museums. As we advance into the future with technological platforms like the metaverse and AI-generated content (AIGC), there is a growing necessity for comprehensive research on virtual navigation. Our aim is to deeply analyze how virtual navigation design influences user behavior, thereby enriching the user experience in virtual museums and other virtual environments with enhanced richness, efficiency, and educational value. These "other virtual environments" may include virtual educational platforms, virtual tourist attractions, virtual art spaces, and virtual shopping centers, among other prospective platforms. These efforts aim to provide a theoretical framework with practical implications for the design, development, and application of virtual environments, thereby unlocking novel avenues for enhancing user experiences.

6. Conclusions

As one of the few empirical studies addressing user disorientation in online virtual museums from the perspective of virtual navigation design, this research explores the potential application of mini-map navigation design elements from gaming to virtual museums. It provides a comprehensive analysis of the impact of virtual navigation design on spatial cognition, contributing a new theoretical perspective to the field. It offers practical guidance for the navigation design and enhancement of online virtual museums and similar virtual environments. Additionally, this study builds a bridge between game design and online virtual museum design, introducing a user experience optimization methodology that focuses on enhancing spatial cognition. We anticipate that the insights and methods proposed in this study will inspire future research to contribute to the development of more flexible, interactive, and user-friendly virtual environments, as well as to the preservation and dissemination of digital cultural heritage.

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