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Original Research

The Effect of Infinity on Immersion in Virtual Exhibitions

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Abstract: This study delves into the concept of "infinity" within head-mounted display (HMD) virtual reality (VR) exhibitions. In this study, "infinity" is defined as an endless space and a boundless scope of virtual experience and interactions. We investigate how this expansive interpretation creates a unique and special exhibition experience that distinguishes virtual exhibitions from physical exhibitions. To this end, the study examines the effects of the spatial and participatory characteristics of virtual exhibitions on immersion, cybersickness, completion time, and interaction time. The experiment was conducted through surveys, behavioral observations, and interviews. The results showed that infinity of spatial characteristics increased participants' immersion. While participatory characteristics had no direct effect on immersion, there was a significant interaction between spatial and participatory characteristics. The 3D (space) surrounded by walls and create (participation), which allows participants to create their own exhibits, was the only combination that decreased immersion and increased cybersickness. The combination with the highest immersion was "3D infinite (space)" and "change (participation)," indicating that a design that allows users to interact with the exhibition in an infinite space is useful for promoting immersion in virtual exhibitions. Adjusting the proportion of spatial and participatory characteristics according to the purpose of the exhibition is recommended since infinity of spatial characteristics increases interaction time and infinity of participatory characteristics significantly increases completion time. The results of this study have practical implications for organizations developing virtual exhibitions and shed light on the value of infinity-based virtual exhibitions and the specific elements that make them possible.

Keywords: *Virtual Exhibition, Infinity, Immersion, Cybersickness, Spatial Characteristics, Participatory Characteristics*

Introduction

Exhibitions that create a sense of immersion for visitors are a long-standing aspiration and goal of artists, curators, and researchers (Bartlem 2005). In response to visitor demand for engaging and heartwarming content, virtual exhibitions employ various digital technologies such as videos, projection, augmented reality (AR), and virtual reality (VR) to provide high levels of immersion. Interactions with users and participatory elements that allow users to engage deeply with the narrative of the virtual exhibition have become an integral part of modern exhibition design (Park and Seong 2018).

Virtual exhibitions are particularly emphasized as an important means of bridging educational and cultural gaps by overcoming the spatial constraints of physical exhibitions (Marty 2011). For example, virtual exhibitions combine AR and VR experiences utilizing mobile devices and head-mounted display (HMD) devices in traditional offline exhibitions, providing visitors with expanded information and sensory experiences that are not typically accessible. For instance, the Smithsonian National Museum of Natural History in Washington, D.C. introduced AR technology in their "Skin & Bones" exhibition experience (Billock 2017). Visitors could closely explore additional information and normally invisible details through their smartphone or tablet. Furthermore, the Louvre, in Paris, France, partnered with HTC Vive Arts to create a VR experience of the Mona Lisa. The program, called "Mona Lisa: Beyond the Glass," provides an experience that uses HMDs to provide details not visible to the naked eye (Antunes 2021). HMDs provide a multi-sensory experience due to complete isolation from the outside world, resulting in high immersion and engagement. These technologies can complement the existing exhibition space without additional devices or replace existing exhibitions using the web or VR applications. The "Immersive Van Gogh Exhibit" by Lighthouse Immersive projected Vincent Van Gogh's artworks onto a large screen, extending the viewer's experience without the need for a mobile device or VR headset. Visitors could enjoy a 360-degree view of Van Gogh's work as it moved in response to piano music (Chen 2023). Similarly, other approaches that only utilize digital platforms are increasing. The British Museum, in London, England, digitized its collection for easy online access, and the Guggenheim Museum in New York, United States, used Google's street view to digitize its artwork, thereby establishing an online virtual museum that anyone can access without restrictions of time and space (Romano 2022).

Virtual exhibitions can offer rich content and a freedom that physical exhibitions alone cannot provide, and interactive technology can encourage visitors to engage proactively with the exhibition (Seok 2019). Therefore, the type of work displayed in a virtual space has more freedom of space and content than virtual exhibitions based on a real space. However, various virtual exhibitions are currently limited in that they provide an experience similar to that of traditional physical exhibitions (Park and Kim 2020) as they replicate the physical space and are presented through traditional curation methods. Although usability issues in virtual environments have been emphasized, attempts to explore the possibilities of VR and build free-form content to provide a distinct experience have been found to be insufficient (Barbieri, Bruno, and Muzzupappa 2017). Given that virtual exhibitions can create unique environments that maximize the possibilities of the medium rather than replicating physical spaces, further research is needed to develop and implement design elements to enhance the quality of the virtual exhibition experience and provide a memorable experience for visitors.

In the design of virtual exhibitions, factors such as spatial design, interactive elements, interface and navigation tools, content, and technical quality are crucial, as noted by Schweibenz (1998), Mortara et al. (2014), and Wojciechowski et al. (2004). Unlike physical

exhibitions, virtual ones are not confined by physical space constraints and typically offer greater interactivity, enhancing visitors' connection with the exhibition. Our study delves into the concept of "infinity" as a distinguishing feature of virtual over physical exhibitions, emphasizing the unique possibilities for showcasing works in a virtual space. This concept challenges the traditional notion of infinite physical space. In the domain of HMD VR, "infinity" is redefined as endless opportunities for the creation and immersive exploration of virtual environments. Moreover, Benyon (2022) notes that VR, as a digital space, is intangible but infinitely transmittable and transformable, covering unlimited spatial dimensions and the vast potential for user interaction and engagement within these spaces, a perspective deeply rooted in VR's fundamental elements of virtual space and interaction.

Furthermore, the concept of infinity transcends the boundaries of physical reality and stimulates visitors' imagination, which in turn enhances immersion in virtual exhibitions, as suggested by Ahn (2015). This study explores the broader interpretation of infinity within the context of HMD VR and its impact on immersion in virtual exhibitions. We conduct an empirical analysis to better understand the application of this concept. Specifically, we examine the effects of applying infinity to the "spatial" and "participatory" elements of virtual exhibitions, aiming to propose a new paradigm for virtual participatory exhibitions.

The research methodology comprised three phases. First, the unique characteristics of virtual exhibitions were derived, and a research hypothesis was formulated through a theoretical review of VR, virtual exhibitions, and immersion. Second, an experimental framework and stimuli were created to analyze the effects of spatial and participatory characteristics on immersion and cybersickness. Finally, the impact of these characteristics on immersion was analyzed through surveys, behavioral observations, and interviews.

Theoretical Background

Virtual Reality

VR is a technological innovation that allows users to experience immersion while interacting with a virtual environment. The characteristics of VR can be described as follows: First, the environment is completely three-dimensional, and users can enjoy a high degree of autonomy in their interactions (Martinet, Casiez, and Grisoni 2010). Second, the information provided in VR allows users to access and process a variety of data through all sensory input (Steuer 1992). Finally, VR blocks external stimuli and provides a fully immersive experience for the user (Lindeman, Sibert, and Hahn 1999). Therefore, immersion and interaction are among the defining characteristics of VR (Sherman and Craig 2018; Jeon 2017).

Burdea and Coiffet (2003) also emphasized "imagination" as a third "I" of the "VR triangle: interaction, immersion, and imagination," defining imagination as the ability to perceive things that do not exist, and it is an artistic and creative realm that implies endless possibilities for VR. Furthermore, in VR, one can create worlds where physical laws no longer

exist and go beyond the scope of physical reality through imagination (Huo and Zhang 2021). As Xu and Xiao (2020) argue, the ability to construct a nonexistent virtual situation expands the user's cognitive range, a feature that is markedly absent in physical settings. Similarly, Jha, Singh, and Sharma (2019) note that VR generates an imaginative environment for exploring the places we have never been to in the real life. In terms of offering the freedom to explore new possibilities, imagination is connected deeply to "infinity." Infinity symbolizes virtual environments with infinite possibilities beyond human recognition, established solely through imagination (Ahn 2015). As differentiation of virtual exhibitions, infinity through imagination plays a determinative role in providing visitors with deeper immersion. In this context, this study focuses on the concept of infinity to explore how it can be applied effectively to virtual exhibition design and what value it can create. Moreover, infinity is expected to offer a new experience that goes beyond physical reality and contribute to creating an environment where virtual exhibitions create a rich and engaging experience.

Virtual Exhibitions

The virtual exhibition area can be categorized into two main types: the representation of a specific time and place of a physical exhibition and the creation of distinct situations and experiences (Gilbert 2002). The former prioritizes the reproduction of physical exhibits and is currently the focus of research and development efforts, while the latter emphasizes the realm of imagination. One of the main challenges of virtual exhibitions that focus on reproducing physical exhibits is that it is difficult to differentiate them from physical exhibitions. Over-reliance on representation can confine VR within the shadows of the physical world, limiting its transformative potential. Unlike physical exhibits that are constrained by the laws of physics and material limitations, VR can present environments that defy these bounds-enabling designers to craft experiences that extend far beyond the mere replication of reality. As highlighted by Li (2021), VR itself has unique capabilities to create new art types that are impossible in the real world, thereby offering new forms of engagement. The spatial flexibility, multidimensional storytelling capabilities, and sensory experiences offered by VR constitute key differentiators from traditional exhibit design (Myrivili 2007; Tzortzi 2016). These elements highlight the potential of VR to transcend mere replication of physical exhibits, offering a value proposition that extends well beyond conventional exhibition paradigms.

Furthermore, despite advances in technology, it is almost impossible to reproduce the synergy created by the atmosphere and spatial harmony of a physical exhibition, which plays an important role in the overall appreciation of an exhibit in a physical space (Gu, Kim, and Shin 2014). In this context, recognizing that the distinguishing factor that makes a virtual exhibition useful is not its physical representation but its intangible values, such as imagination, is important.

Immersion

Immersion is a widely used concept in VR and digital gaming. However, immersion is not limited to technology-mediated experiences; it is a human state that can also occur naturally in nontechnology-mediated environments (Ghani 1995), representing a state of intimate engagement and optimal involvement with the environment (Bartlem 2005). Immersion can be viewed as a psychological state of being enveloped and included while interacting with an environment providing a continuous stream of stimuli and experiences (Witmer and Singer 1998).

Immersion is sometimes described as a gradual psychological process. Brown and Cairns (2004) conceptualized immersion as a staged psychological process, proposing a model with three stages, namely, participation, immersion, and full immersion. Moreover, Jennett et al. (2008) argued that immersion in a gaming environment can be conceptualized as engagement, immersion, and full immersion and that immersion is a gradual psychological process that triggers an optimal state of "flow" (Csikszentmihalyi 1988) and a sense of presence described as "being there" (Heeter 1992). The MIT Enterprise Forum suggests that immersion can be increased through mental focus, multi-sensory interactions, and immersion configurations (Lee et al. 2016).

Immersion is also explained through its multidimensional nature. Csikszentmihalyi (1988) cited the following as the characteristics of immersion, namely, mental focus on a limited set of stimuli, complete immersion resulting in the disappearance of self-consciousness, dispersion of constraints, the absence of space–time concepts, enhanced cognition, and pleasure. Witmer and Singer (1998) divided the characteristics of presence into involvement and immersion. Furthermore, Chung and Yang (2012) conducted a study on measurement tools to evaluate 3D videos, which they refined into spatial and temporal engagement, dynamic immersion, and realistic immersion. The reliability and validity of these measures have since been further developed in subsequent studies (Baek and Chung 2016; Lee and Chung 2019; Nam, Yu, and Shin 2017).

As this study investigates the impact of infinity on immersion, it focuses on multidimensional characteristics rather than stages. Therefore, various criteria were used to measure immersion, such as spatial, temporal, dynamic, and realistic immersion and pleasure.

Characteristics That Affect Immersion

Immersion in a virtual exhibit is affected by numerous factors, including the size of the exhibit and the level of interactivity. In VR, however, the spatial nature of the environment affects visual immersion rather than the size of the exhibit as the digital environment allows for arbitrary scale changes and shifts in viewing position. Therefore, this study categorized spatial characteristics along with participatory characteristics presented in participatory exhibitions by proxying the degree of infinity.

Spatial Characteristics

Spatial characteristics are a crucial factor that influences a visitor's immersion experience in an exhibit, representing how the space in which exhibits are provided is used. Studies have shown that large screen sizes and viewing angles play an important role in increasing the perceived realism and presence of content, which affects immersion (Grabe et al. 1999). In addition, studies have found that the size and space utilization of an exhibition directly influence the temporal persistence of visitors (Bitgood, Patterson, and Benefield 1988).

Virtual spaces increase the degree of freedom to design the spatial characteristics of exhibits, allowing for infinite size, distance, and viewing perspectives to give visitors more ways to experience the exhibits. However, the impact of a broad field of view (FOV) and varied perspectives on visitor experience is not completely understood, as highlighted by Tan (2004) and Patrick et al. (2000), indicating the need for further research to clarify their roles in enhancing visitor engagement and satisfaction. This study uses infinity as a defining element of spatial characteristics. First, spatial characteristics can be categorized into finiteness and infinity depending on whether the (FOV) is infinite. Second, depending on whether the viewing perspective is infinite, the finiteness can be divided into "two-dimensional space (2D)," which provides only a single perspective, and "three-dimensional space (3D)," which provides four perspectives, namely, front, left, right, and bottom. 3D space provides more adjustability on the viewing perspective than 2D space. "3D Infinite (space)" is a space with no restrictions on viewing perspective and distance (Figure 1).

Based on research showing that larger exhibits lead to longer viewing times and a higher level of immersion (Bitgood, Patterson, and Benefield 1988; Grabe et al. 1999), this study formulated two hypotheses for virtual exhibitions. These hypotheses will be tested using completion time or the total amount of time participants voluntarily spend exploring the exhibits.

- H1-1: Infinity of spatial characteristics will have a positive (+) impact on immersion.
- H1-2: Infinity of spatial characteristics will have a positive (+) impact on the exhibit completion time.

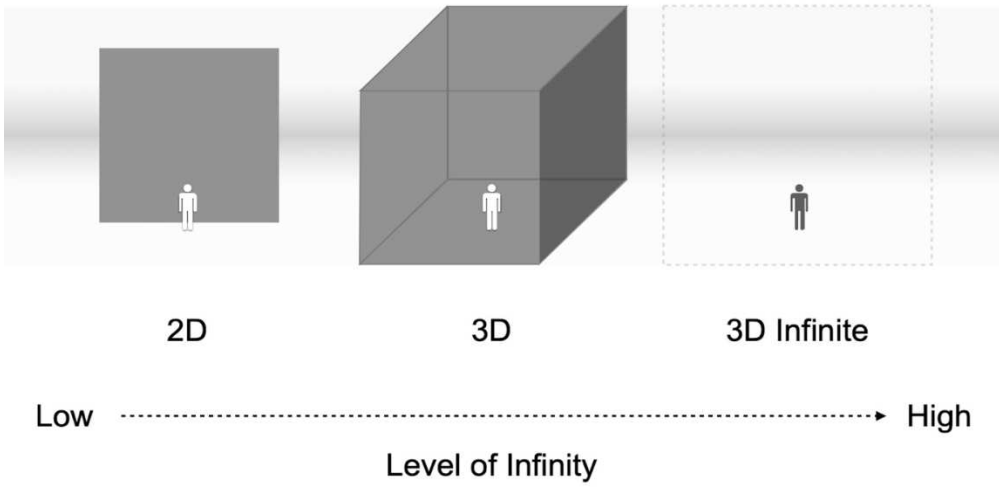

Figure 1: Spatial Characteristics according to Infinity

Participatory Characteristics

In virtual exhibitions, the interaction of visitors with the exhibit is important along with the exhibition space and the exhibits (Park and Seong 2018). Participatory exhibitions focus on interaction during the exhibition, where the exhibit is completed through the active participation of visitors, and are broadly divided into those in which the artist invites participation and those in which the visitors participate in the production (Lee 2019).

Considering the degree of participation, it can be said that exhibitions where visitors participate in the production have a higher degree of participation than exhibitions that invite participation, which can be understood as the level of interaction between the system and the user in virtual exhibitions.

In this study, the level of engagement was defined in three ways. Exhibits "View" and "Change," where the user interacts with the exhibit to affect the exhibit itself, and "Create," where the user plays an important role in the creation of the exhibit. Based on the participatory characteristics, the following hypotheses were formulated (Figure 2). Interaction time is a measure of the amount of time participants spend interacting with the exhibit.

- H2-1: Infinity of participatory characteristics will have a positive (+) impact on immersion.
- H2-2: Infinity of participatory characteristics will have a positive (+) impact on interaction time.

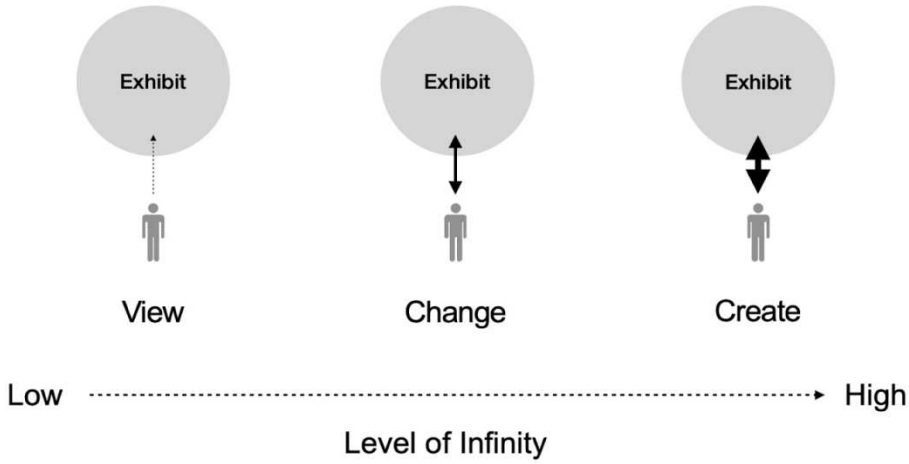

Figure 2: Participatory Characteristics according to Infinity

Cybersickness

Cybersickness is a common problem that occurs during or after VR participation, where users may experience symptoms such as nausea, dizziness, headaches, and fatigue (Caserman et al. 2021). This can sometimes be caused by a mismatch between movement and visual stimuli (Kim and Park 2013; Han and Kim 2011), and despite advances in hardware such as HMDs, it remains a problem in VR (Kim and Park 2013; Caserman et al. 2021). According to Chang, Kim, and Yoo (2020), a variety of factors such as hardware, contents, and individual differences can cause cybersickness. Previous research has shown that content elements such as visual flow, graphical realism, frame of reference, duration, content viewing angle, and controllability have a significant impact on the immersion experience in VR.

This study investigates the impact of content factors on immersion in VR environments, with a particular focus on the viewing angle and participatory nature of the content. The viewing angle of the content refers to the spatial characteristics, which refer to the range of the observable world in the VR environment and is closely related to the visual perception of space. Previous studies have shown that limiting the FOV can reduce cybersickness; however, excessively reducing the FOV can disrupt immersion (Chang, Kim, and Yoo 2020). Conversely, a wider viewing angle increases cybersickness but simultaneously enhances immersion (Kim and Park 2013; Han and Kim 2011). The participatory characteristics of the exhibit are an important factor in the immersion experience. Users tend to experience more cybersickness when VR content provides passive observations rather than active participation, suggesting that the participatory nature of the content may mitigate cybersickness (Chang, Kim, and Yoo 2020). Furthermore, studies have also shown that deeper immersion in VR environments can reduce cybersickness (Lee 2019; Weech, Kenny, and Barnett-Cowan 2019; Rowland et al. 2022; Jonson et al. 2021; Martingano et al. 2022).

Therefore, this study hypothesizes that increasing the infinity of spatial and participatory characteristics can provide users with a more immersive experience that reduces cybersickness, which, in turn, increases users' pleasure.

H3: Increasing the infinity of the spatial and participatory characteristics will enhance the immersion experience and reduce cybersickness by providing pleasure to the user.

Experiments

Participant Recruitment and Experimental Methods

A total of sixty participants (twenty-four men and thirty-six women) participated in the study, with the following age distribution: 53.33 percent (n = 32), 36.67 percent (n = 22), and 10 percent (n = 6) of the participants were in their 20s, 30s, and 40s, respectively, with a mean age of 31.48 years and a standard deviation of 5.81. While 88.33 percent (n = 53) of the participants had previously used a VR device, only 11.67 percent (n = 7) considered themselves comfortable with VR. Thus, most participants are novice users with limited VR experience. All the participants had normal or corrected-to-normal vision. The participants were informed about the purpose and procedures of the study through a prior survey, and their consent was obtained.

This study selected a 3 × 3 mixed factorial design, with participatory characteristics as a between-subjects factor and spatial characteristics as a within-subjects factor, where the order of exposure across conditions was expected to influence outcomes. The experiment lasted approximately forty minutes, during which the participants were randomly assigned to one of three different spatial characteristics to control for order effects. The experimental process included pre- and post-surveys on cybersickness and immersion, as well as individual interviews regarding the overall experience. The main purpose of the experiment was an exploratory investigation of how spatial and participant characteristics affect cybersickness and immersion.

Stimuli Production

The virtual exhibit environment was designed to display abstract content with ascending spheres forming a column. The degree of infinity was divided based on spatial and participatory characteristics, and the exhibition was defined into three parts—"two-dimensional space (2D)," "three-dimensional space (3D)," and an open "3D infinite space" that extended up to 100 meters from the user. The 2D space provided only one side, while the 3D space provided four sides, namely, front, left, right, and bottom. Figure 3 shows how the space in the exhibition is organized.

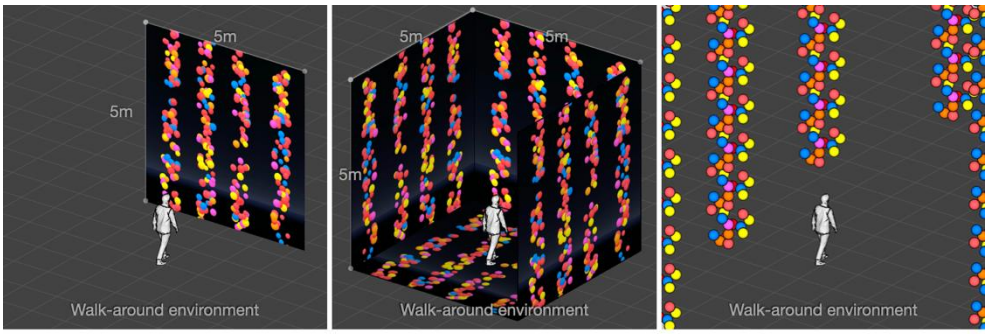

Figure 3: Design of Spatial Characteristics

Participatory characteristics comprise three levels—view (participation), change (participation), and create (participation). View (participation) is a noninteractive stage, and change (participation) has an interaction where the sphere explodes when the user touches it. Create (participation) allows the user to create a sphere by flipping their left hand; throwing the sphere with their right hand creates a column of spheres that fall away (Figure 4).

The experimental environment was developed with Unity3D and experienced with Oculus Quest 2. The space for the experiment was developed in such a manner that participants could walk around freely.

Figure 4: Design of Participatory Characteristics

Data Collection

The study used a variety of methods to collect data, including quantitative measures such as completion time and interaction time, as well as qualitative assessments of immersion and cybersickness. Furthermore, cybersickness was measured using the cybersickness questionnaire

developed by Kennedy et al. (1993). In addition, in-depth interviews were conducted based on behavioral analysis and questionnaire responses. The immersion questionnaire was based on Chung and Yang's (2012) measurement tool and used the following criteria: spatial immersion, temporal immersion, dynamic immersion, and pleasure, which have been refined in subsequent studies (Lee and Chung 2019). Immersion was evaluated on a five-point scale; a higher score indicated a higher degree of immersion.

Table 1: Immersion Questionnaire

Category	*Questions*
Spatial Immersion	I felt like I was in the exhibition space
	It felt like I was watching the exhibition in person
	I felt like a visitor to the exhibition
	I felt as if I had experienced a different world while appreciating the exhibition
Temporal Immersion	I did not notice the passing of time while viewing the exhibition
	I was completely immersed while watching the exhibition
	Time seemed to pass quickly while viewing the exhibition
	I could not think of anything else while watching the exhibition
Dynamic Immersion	I felt like I had to move my body while watching the exhibition
	The collision or movement between objects was felt strongly
	I felt like I was going to hit something
	I felt a big change in emotions due to the exhibits
Pleasure	It was interesting to see the exhibition itself
	I think the virtual exhibition is worth appreciating
	It was fun to see the exhibition

Discussion

Immersion Survey

Following the analysis of immersion survey data based on spatial characteristics, a significant difference emerged in the overall immersion ($F = 22.24$, $p < .001$). The results reveal that immersion increases as the infinity of the space increases, from 2D (space) to 3D (space) to 3D Infinite (space). Paired comparisons for the main effect of spatial characteristics using Bonferroni corrections indicate a main effect reflecting a significant difference ($p < .01$) between all types. Therefore, Hypothesis H1, which stated that spatial characteristics with infinity would have a positive effect on immersion, is supported.

In terms of participatory characteristics, immersion increased in each category as infinity increased from view (participation) to change (participation), to change (participation), however, no significant difference was found ($F = 1.6$, $p > .05$). Therefore, Hypothesis H2, which stated that participatory characteristics with infinity would have a positive effect on immersion, was not supported.

When spatial and participatory characteristics were analyzed together, there was a significant interaction between spatial characteristics and participatory characteristics ($F = 3.92$, $p < .01$), indicating that infinity had a different effect on immersion for the three spatial characteristics compared to the three participatory characteristics. Figure 5 demonstrates that 3D infinite space increased immersion for all participatory characteristics. Furthermore, create (participation) maintained a high immersion for all spatial characteristics, meaning that the level of creation increases immersion regardless of spatial characteristics.

However, it is interesting that 3D Infinite (space) in change (participation) has the highest immersion of all cases and not "3D Infinite (space)" in "create (participation)." According to the interviews, the 3D Infinite (space) with all the exhibits was already immersive, and interacting with it further increased immersion. Conversely, the 3D Infinite space in create (participation) had an impact because it was empty when participants began viewing the exhibit.

In Figure 5, the create (participation) and 3D space (3D) had one downside. The score was high, but it was the only dip in the graph to show a different trend. In Figure 6, which shows cybersickness, create (participation) was the highest when it met 3D (space). In Figure 7, which shows completion time, the completion time was significantly higher for create (participation) compared to view (participation) and change (participation). The highest level of participatory characteristics, create (participation), increased participants' completion time, which appeared to have a negative effect on 3D (space), and had a higher level of cybersickness than other spaces, and similarly for immersion. In the in-depth interviews, the responses suggested that, for the 3D (space), it was "hard to be in immersion because it was claustrophobic and dizzying."

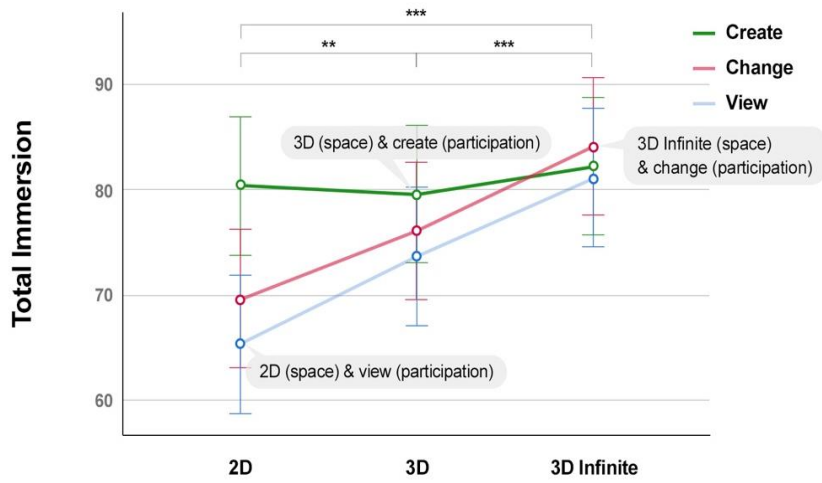

Figure 5: Total Immersion according to Spatial and Participatory Characteristics

Cybersickness Survey

Cybersickness was analyzed by subtracting the post-experiment values from the pre-experiment values in the cybersickness questionnaire. Therefore, data greater and less than 0 indicate an increase and decrease in cybersickness after the experiment, respectively.

In Figure 6, most of the data is below 0, indicating that cybersickness was mostly reduced after the experiment. In particular, cybersickness decreased sharply in 3D (space) and view (participation), and all data was negative in 2D (space) and 3D Infinite (space). In the interviews, participants reported that they usually felt cybersickness in virtual experiences but rarely felt cybersickness in this experiment. However, in the 3D (space), data was shown to be positive in the order of create (participation) and change (participation), indicating that cybersickness increased slightly. When examining spatial characteristics and participatory characteristics separately, as the infinity of spatial characteristics increased, there was an upward and downward pattern, with cybersickness increasing in 3D (space) compared to 2D (space) and decreasing in 3D infinite (space); meanwhile, cybersickness increased as the infinity of participatory characteristics increased.

However, with respect to the cybersickness item, there was no significant difference in cybersickness as infinity increased in terms of spatial characteristics ($F = .23$, $p < .05$) and participatory characteristics ($F = .64$, $p < .05$). Furthermore, no significant interaction between spatial characteristics and participatory characteristics ($F = .83$, $p < .05$) was observed. This indicates that infinity does not have a different effect on immersion for the three spatial characteristics than for the three participatory characteristics. Therefore, Hypothesis H3, which stated that infinity reduces cybersickness by providing users with the pleasure of immersion, was not supported. However, most of the cybersickness decreased after the experiment, especially in 3D infinity, which can be considered a positive result.

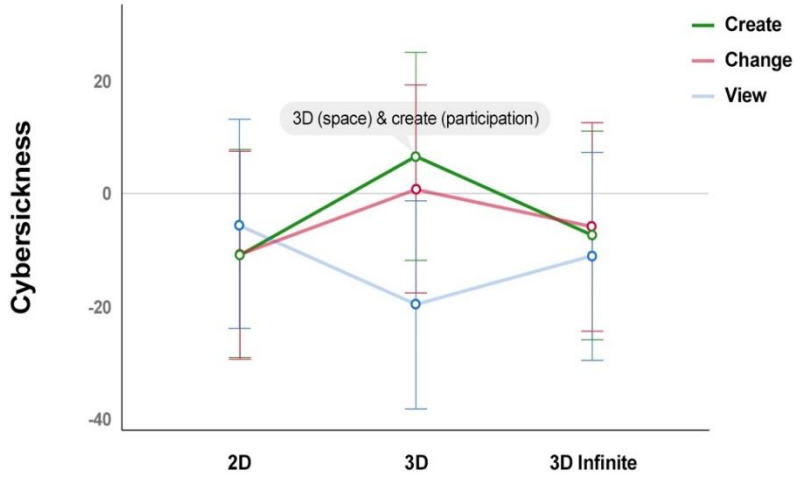

Figure 6: Total Cybersickness Score (Subtracting Pre-Cybersickness Scores from Post-Cybersickness Scores)

Completion and Interaction Time

In this study, completion time measures the time between the participant's viewing of the exhibit and their voluntary termination of viewing, whereas interaction time is the total amount of time a participant spent interacting directly with the exhibit or interacting to create it.

Completion time remained extremely high in create (participation) across all spatial characteristics (Figure 7). There was a significant main effect of participatory characteristics on completion time ($F\,[2, 57] = 263.85$, $p < .01$), which was driven primarily by the difference between create (participation) and the other groups (Tukey HSD, $p < .01$). However, there was no significant effect of completion time on spatial characteristics. In other words, regardless of the spatial characteristics, user-generated exhibits significantly increase completion time. Therefore, Hypothesis H2, which claimed a positive effect of spatial characteristics with infinity on completion time, was not supported. However, create (participation) was found to have a significant effect on completion time ($F = 9.68$, $p < .001$).

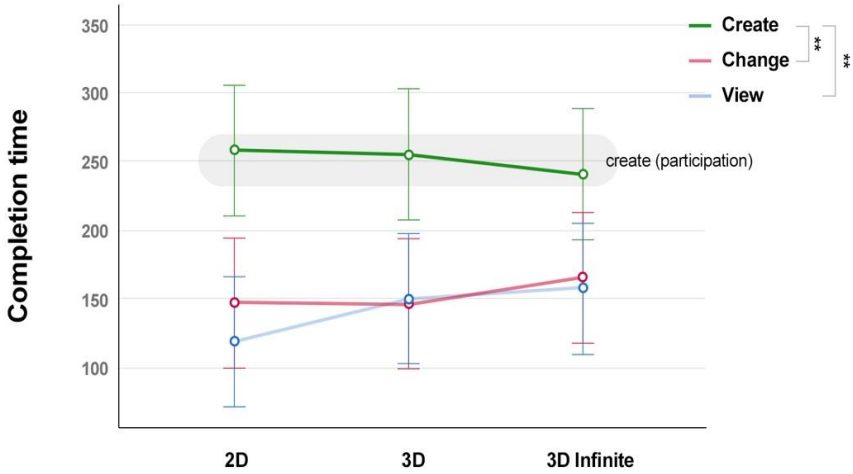

Figure 7: Completion Time according to Spatial and Participatory Characteristics

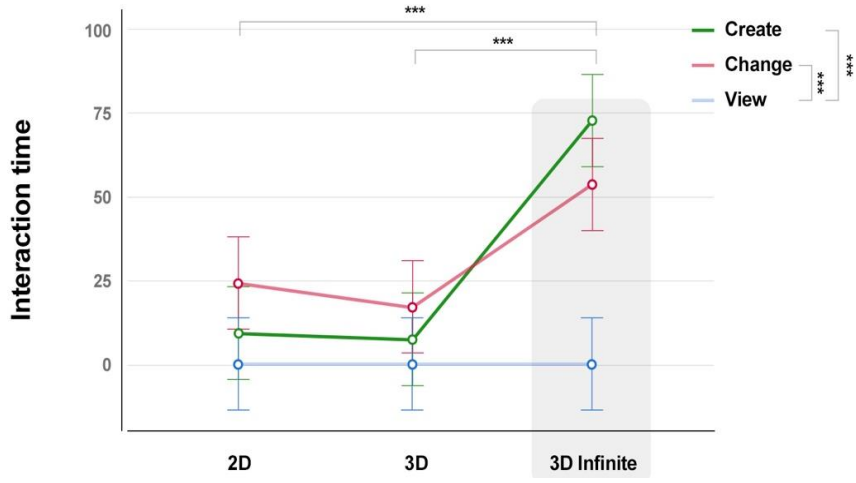

Figure 8: Interaction Time according to Spatial and Participatory Characteristics

Interaction time dramatically increased in 3D infinite (space) for change (participation) and create (participation; Figure 8). Participants were more interactive in 3D infinite space. There were significant effects of spatial characteristics and participatory characteristics on interaction time ($p < .001$). This was mainly due to the difference between the 3D Infinite (space) and the other two groups by spatial characteristics (Bonferroni, $p < .01$) and the difference between the view (participation) and the other two groups by participatory characteristics (Tukey HSD, $p < .001$). Therefore, Hypothesis H4, which claimed a positive effect of participatory characteristics with infinity on interaction time, was not supported. However, 3D infinite (space) showed a significant increase in interaction time for all interaction types. In fact, participants said in interviews that they wanted to "explore more" and "try more and keep going."

In summary, contrary to this study's hypotheses, interaction time, and not completion time, increased with increasing spatial infinity. Moreover, completion time, and not interaction time, increased with increasing participation infinity.

Interviews

The participants reported that experiencing an open, infinite space (3D infinite) gave them a sense of space and depth, making them feel included in the space. "In 2D and 3D (space), it was like looking at an aquarium; however, in infinite space, it was like stepping into the aquarium and touching it," one participant said. Many respondents also mentioned that the infinite space made the artwork stand out more, increased their focus, made them feel like they were experiencing a lot, and that the infinite space itself was a lot of fun.

On an emotional level, participants reported feeling "mesmerized" and "healed," "like I was imagining a faraway place," and "happy to have a space to think endlessly because of its infinity." These answers reveal the connection between infinity and imagination.

In terms of interactive characteristics, in 2D, participants said they felt like they were watching and appreciating the exhibit, and in 3D, they felt it was similar to an actual interactive exhibit. Notably, 2D and 3D (space) lacked an experiential feel. In 3D infinity, participants wanted more movement, felt like they could do more, and felt more in control. Many participants wanted more interaction, especially in the view phase, when they experienced 3D infinity.

Regarding the advantages of virtual exhibitions, one of the participants mentioned that "physical exhibitions can be a bit distracting, but virtual exhibitions can be fully appreciated by yourself" and expressed that "it would be interesting to open an infinite space as an exhibition," and "I wish it could be more interactive and develop in different ways." However, other participants said, "It's better to go to a museum and see the actual painting."

Conclusion

In recent years, VR has become increasingly popular (Park and Kim 2020), and various presentation methods for exhibition spaces using VR are being implemented (Yang and Lee 2017). This study analyzes how infinity affects user immersion through its spatial and participatory characteristics, with the goal of proposing a unique form of virtual exhibitions. The results of this study have practical and theoretical implications for the design and implementation of virtual exhibitions.

Practical Implications

This study demonstrated that the infinity of spatial characteristics is quantitatively related to visitors' immersion. In particular, the combined analysis of spatial and participatory characteristics showed that infinite space led to the highest immersion across all participatory forms, underscoring the significance of spatial "infinity" in enhancing visitor engagement, regardless of the form of participation in the exhibition.

However, for create (participation), despite some differences in spatial characteristics, a high level of immersion was consistently observed. This finding indicates that in creative participatory forms where users actively construct the exhibit, the role of spatial characteristics may be less pronounced. Conversely, in view (participation) and change (participation), immersion was notably higher in environments with infinite spatial characteristics, suggesting the importance of spatial "infinity" in both noninteractive and interactive exhibit designs.

In a 3D space surrounded by walls, some decreases in immersion and increases in cybersickness symptoms were observed during create (participation). Based on these results, it can be suggested that an open, infinite space is more appropriate for participatory exhibitions, where users create the exhibits themselves, than a closed, walled space. This

recommendation is supported by participant feedback and quantitative data showing that the infinite space stimulated the users' desire to interact and made them more engaged. Conversely, it can be concluded that when designing a walled exhibition space, it is necessary to consider a larger scale than the 5m cube space used in this study and assess the possibility of cybersickness in advance.

Considering these findings, we posit that an open, infinite space is more conducive to participatory exhibitions, especially in a context where users are creators themselves, as opposed to closed and walled environments. This approach could better stimulate user interaction and engagement, which is supported by participant feedback and quantitative data. For walled exhibition spaces, considering a larger scale than the 5m cube space used in this study is advisable to minimize cybersickness and enhance the immersive experience.

Considering the results of completion time and interaction time based on participation type and spatial characteristics, create (participation) had a significantly longer completion time, while 3D infinite (space) had a significantly longer interaction time. Based on these results, it could be confirmed that in virtual exhibitions, user-centered, creative, and participatory exhibits retain visitors for longer times in the exhibition space, and an infinite space encourages user interaction.

Finally, the results of experiments on cybersickness showed that an expansive environment that allows visitors to walk freely plays a crucial role in reducing cybersickness. As the range of movement in a virtual exhibition space may be physically limited, introducing a secondary movement feature such as teleportation may be considered to compensate for this limitation. In addition, the suddenness of the safety boundary that emerged with the change in spatial scale was confusing for some participants. As a solution, introducing a user interface that displays the estimated location of the safety protection boundary may be considered, which is suggested to improve visitor experience and reduce anxiety.

The study concludes that infinite space is suitable for virtual exhibitions across all participation types and is particularly useful for highly interactive exhibitions. In particular, user-created participatory exhibits are best implemented in infinite space, which creates an environment that retains visitors in the exhibition for longer periods and enhances interaction. However, for optimal immersion, a design that interacts with the exhibit that is already created is required. These results will provide deeper insights into the understanding of exhibit design, especially the design of virtual exhibitions.

Reflecting on the implications of "infinity" and "immersion" in VR exhibitions, one practical scenario for a better-designed VR museum experience would involve a harmonious blend of specific, realistic settings and the expansive nature of virtual spaces. For instance, a VR museum could start with a detailed recreation of a historical site or an art gallery, offering users a tangible connection to a specific time and place. This initial realistic setting could serve as a gateway to more expansive, "infinite" virtual experiences, where visitors can then engage in immersive and interactive journeys that extend beyond the physical replication.

Theoretical Implications

Numerous studies attempted to enhance the immersion of virtual exhibitions and therefore provide a differentiated experience through the possibilities of VR technology (Park and Kim 2020; Lee 2018; Kim and Yong 2021). However, few studies have empirically validated the specific factors for their implementation. While previous studies have separately examined immersion based on size and interactivity, this study analyzed the mixed effects of spatial and participatory characteristics, yielding results that can be helpful to the design of virtual exhibitions.

Moreover, infinity was introduced as a concept that should be applied to spatial and participatory characteristics to realize a unique sense of immersion in virtual exhibitions. Infinity is a concept that expresses the imagination as a VR element, an awareness of scale beyond our perception. Infinity should be treated as a distinguishing factor between physical and virtual exhibitions, and its usefulness is verified in this study. The results were particularly clear numerically depending on the infinity of the space. Further, an interview response mentioned: "[I]f the virtual exhibition was an infinite space, I would want to participate."

Limitations

This study has several limitations. First, the experiment was conducted with a specific abstract exhibit, making it challenging to generalize the results of the experiment. Second, due to the lack of existing research, only two factors that affect immersion were studied. In addition to vision and interactivity, sensory experiences such as hearing and touch are important immersion factors in VR and should be considered in future research. Third, the study was based on single-user experiences; hence, future research could explore multiuser experiences. Despite these limitations, this study provides a guideline for utilizing spatial and participatory characteristics to enhance immersion in virtual exhibitions, and it can contribute to expanding possibilities for future virtual exhibitions.

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The authors declare that generative AI or AI-assisted technologies were not used in any way to prepare, write, or complete essential authoring tasks in this manuscript.

Informed Consent

The authors have obtained informed consent from all participants.

Conflict of Interest

The authors declare that there is no conflict of interest.

REFERENCES

Ahn, Seongmo. 2015. "Architectural Manifestation of Hiroshi Sugimoto's Photographic Infinity." *Korean Institute of Interior Design Journal* 24 (5): 31–41. https://doi.org/10.14774/JKIID.2015.24.5.031.

Antunes, Jose. 2021. "Mona Lisa: Beyond the Glass, a VR First for the Musée du Louvre." *Provideo Coalition*, April 2, 2021. https://www.provideocoalition.com/mona-lisa-beyond-the-glass-a-first-for-the-musee-du-louvre/.

Baek, Seungjin, and Donghun Chung. 2016. "Gamers' Psychological Responses to Depth Levels in 3D Stereoscopic Gaming." *International Telecommunications Policy Review* 23 (2): 81–117. https://ssrn.com/abstract=2804936.

Barbieri, Loris, Fabio Bruno, and Maurizio Muzzupappa. 2017. "Virtual Museum System Evaluation through User Studies." *Journal of Cultural Heritage* 26:101–108. https://doi.org/10.1016/j.culher.2017.02.005.

Bartlem, Edwina. 2005. "Reshaping Spectatorship: Immersive and Distributed Aesthetics." *Fibreculture Journal: Distributed Aesthetics* 7. http://www.immersence.com/publications/2005/2005-EBartlem.html.

Benyon, David. 2022. *Spaces of Interaction, Places for Experiences*. Cham, Switzerland: Springer Nature.

Billock, Jennifer. 2017. "Five Augmented Reality Experiences That Bring Museum Exhibits to Life." *Smithsonian Magazine*, June 29, 2017. https://www.smithsonianmag.com/travel/expanding-exhibits-augmented-reality-180963810/.

Bitgood, Stephen, Donald Patterson, and Arlene Benefield. 1988. "Exhibit Design and Visitor Behavior: Empirical Relationships." *Environment and Behavior* 20 (4): 474–491. https://doi.org/10.1177/0013916588204006.

Brown, Emily, and Paul Cairns. 2004. "A Grounded Investigation of Game Immersion." In *CHI2004 Extended Abstracts on Human Factors in Computing Systems*, Vienna, Austria, April 24–29, 2004:1297–1300. https://doi.org/10.1145/985921.986048.

Burdea, Grigore C., and Philippe Coiffet. 2003. *Virtual Reality Technology*. Hoboken, NJ: John Wiley & Sons.

Caserman, Polona, Augusto Garcia-Agundez, Alvar Gámez Zerban, and Stefan Göbel. 2021. "Cybersickness in Current-Generation Virtual Reality Head-Mounted Displays: Systematic Review and Outlook." *Virtual Reality* 25 (4): 1153–1170. https://doi.org/10.1007/s10055-021-00513-6.

Chang, Eunhee, Hyun Taek Kim, and Byounghyun Yoo. 2020. "Virtual Reality Sickness: A Review of Causes and Measurements." *International Journal of Human–Computer Interaction* 36 (17): 1658–1682. https://doi.org/10.1080/10447318.2020.1778351.

Chen, Dalson. 2023. "Immersive Van Gogh Exhibition Coming to Windsor This Summer." *Windsor Star*, March 30, 2023. https://windsorstar.com/news/local-news/immersive-van-gogh-exhibition-coming-to-windsor-this-summer.

Chung, Dong-Hun, and Ho-Cheol Yang. 2012. "Reliability and Validity Assessment in 3D Video Measurement." *Journal of Broadcast Engineering* 17 (1): 49–59. https://doi.org/10.5909/JEB.2012.17.1.49.

Csikszentmihalyi, Mihaly. 1988. *Optimal Experience Psychological Studies of Flow in Conscious*. New York: Cambridge University Press.

Ghani, Abdul J. 1995. "Flow in Human-Computer Interactions: Test of a Model." In *Human Factors in Information Systems: Emerging Theoretical Bases*, edited by J. Carey, 291–311. Hoboken, NJ: Ablex Publishing.

Gilbert, Hallie. 2002. "Immersive Exhibitions: What's the Big Deal." *Visitor Studies Today* 5 (3): 10–13. http://kora.matrix.msu.edu/files/31/173/1F-AD-297-8-VSA-a0a6e0-a_5730.pdf.

Grabe, Maria E., Matthew Lombard, Robert D. Reich, Cheryl C. Bracken, and Theresa B. Ditton. 1999. "The Role of Screen Size in Viewer Experiences of Media Content." *Visual Communication Quarterly* 6 (2): 4–9. https://doi.org/10.1080/15551399909363403.

Gu, Jihyang, Taeyang Kim, and Donghee Shin. 2014. "Study on the Factor of Affordance to Improve Flow in On-Line Exhibition." *Journal of Korea Design Knowledge* 31:239–250. https://doi.org/10.17246/jkdk.2014..31.023.

Han, Kyung Hun, and Hyun Taek Kim. 2011. "The Cause and Solution of Cybersickness in 3D Virtual Environments." *Korean Journal of Cognitive and Biological Psychology* 23 (2): 287–299. https://doi.org/10.22172/cogbio.2011.23.2.007.

Heeter, Carrie. 1992. "Being There: The Subjective Experience of Presence." *Presence: Teleoperators & Virtual Environments* 1:262–271.

Huo, Jiaofei, and Guangpeng Zhang. 2021. "High-Temperature Environmental Protection Metal Material 3D Printing Equipment Development and Process Research." *Advances in Materials Science and Engineering* 1–9.

Jennett, Charlene, Anna L. Cox, Paul Cairns, Samira Dhoparee, Andrew Epps, Tim Tijs, and Alison Walton. 2008. "Measuring and Defining the Experience of Immersion in Games." *International Journal of Human-Computer Studies* 66 (9): 641–661. https://doi.org/10.1016/j.ijhcs.2008.04.004.

Jeon, Gyong Ran. 2017. "A Study on the Visual Characteristics of HMD-Based Virtual Reality Images." *Korean Animation Society* 13 (1): 66–83. http://www.dbpia.co.kr/journal/articleDetail?nodeId=NODE07239951.

Jha, Gauri, Pawan Singh, and Lavanya Sharma. 2019. "Recent Advancements of Augmented Reality in Real Time Applications." *International Journal of Recent Technology and Engineering* 8 (2S7): 538–542. https://doi.org/10.35940/ijrte.B1100.0782S719.

Jonson, Miles, Sinziana Avramescu, Derek Chen, and Fahad Alam. 2021. "The Role of Virtual Reality in Screening, Diagnosing, and Rehabilitating Spatial Memory Deficits." *Frontiers in Human Neuroscience* 15:628818. https://doi.org/10.3389/fnhum.2021.628818.

Kennedy, Robert S., Norman E. Lane, Kevin S. Berbaum, and Michael G. Lilienthal. 1993. "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness." *International Journal of Aviation Psychology* 3 (3): 203–220. https://doi.org/10.1207/s15327108ijap0303_3.

Kim, Boreum, and Hoseong Yong. 2021. "A Study on the Types and Implications of Virtual Exhibition Spaces." *Journal of Digital Contents Society* 22 (8): 1303–1314. https://doi.org/10.9728/dcs.2021.22.8.1303.

Kim, Deog Young, and Jong Bum Park. 2013. "Virtual Reality Based Stroke Rehabilitation." *Journal of the Korean Medical Association* 56 (1): 16–22. https://doi.org/10.5124/jkma.2013.56.1.16.

Lee, Hyejin, and Donghun Chung. 2019. "Influence of Virtual Reality Image Depth on User's Perceived Characteristics, Presence, and Fatigue." *Korean Association for Broadcasting and Telecommunication Studies* 33 (2): 184–216. https://doi.org/10.22876/kab.2019.33.2.006.

Lee, Ji Hye. 2018. "VR System Environment Technologies and User Input Elements." *Journal of the Korean Society of Design Culture* 24 (2): 586–596. https://doi.org/10.18208/ksdc.2018.24.2.585.

Lee, Joong-Ho. 2019. "Research Issues and Major Design Considerations on Video See-through HMDs." *Journal of the Convergence on Culture Technology* 5 (2): 345–353. https://doi.org/10.17703/JCCT.2019.5.2.345.

Lee, Minhwa, Yeongjoon Kim, Changbae Kim, Jongwon Park, Yeongho Lee, Hanjin Park, Yoseong Seo, and Sangok Lee. 2016. *Talking about Virtual Reality*. Seoul: Cloud Books.

Li, Yunpeng. 2021. "Research Based on Visual Sensors and VR in the Field of Visual Culture." *Journal of Sensors* 2021: 1–11. https://doi.org/10.1155/2021/2013303.

Lindeman, Robert W., John L. Sibert, and James K. Hahn. 1999. "Towards Usable VR: An Empirical Study of User Interfaces for Immersive Virtual Environments." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Pittsburgh, PA, May 15–20, 1999:64–71. https://doi.org/10.1145/302979.302995.

Martinet, Anthony, Géry Casiez, and Laurent Grisoni. 2010. "The Effect of DOF Separation in 3D Manipulation Tasks with Multi-Touch Displays." In *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology*, New York, November 22, 2010:111–118. https://doi.org/10.1145/1889863.1889888.

Martingano, Alison Jane, Ellenor Brown, Sydney H. Telaak, Alexander P. Dolwick, and Susan Persky. 2022. "Cybersickness Variability by Race: Findings from 6 Studies and a Mini Meta-Analysis." *Journal of Medical Internet Research* 24 (6): e36843. https://doi.org/10.2196/36843.

Marty, Paul F. 2011. "My Lost Museum: User Expectations and Motivations for Creating Personal Digital Collections on Museum Websites." *Library and Information Science Research* 33 (3): 211–219. https://doi.org/10.1016/j.lisr.2010.11.003.

Mortara, Michela, Chiara Eva Catalano, Francesco Bellotti, Giusy Fiucci, Minica Houry-Panchetti, and Panagiotis Petridis. 2014. "Learning Cultural Heritage by Serious Games." *Journal of Cultural Heritage* 15 (3): 318–325. https://doi.org/10.1016/j.culher.2013.04.004.

Myrivili, Eleni. 2007. "Performativity, Interactivity, Virtuality and the Museum." *Museology e-Journal* 4.

Nam, Sunsook, Hongsik Yu, and Donghee Shin. 2017. "User Experience in Virtual Reality Games: The Effect of Presence on Enjoyment." *International Telecommunications Policy Review* 24 (3). https://ssrn.com/abstract=3050290.

Park, Sieun, and Junghwan Seong. 2018. "Analysis of Digital Exhibitions Reflecting Participation Experience of Visitors in Digital Exhibition Space." *Journal of the Korea Contents Association* 18 (1): 336–344. https://doi.org/10.5392/JKCA.2018.18.01.336.

Park, Sieun, and Jusub Kim. 2020. "Converting 2-D Artworks into 2.5-D Content for More Immersive HMD VR Exhibition Experience." *Digital Contents Society* 4:653–661. https://doi.org/10.9728/dcs.2020.21.4.653.

Patrick, Emilee, Dennis Cosgrove, Aleksandra Slavkovic, Jennifer A. Rode, Thom Verratti, and Greg Chiselko. 2000. "Using a Large Projection Screen as an Alternative to Head-Mounted Displays for Virtual Environments." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (ACM)*, The Hague, The Netherlands, April 1, 2000:478–485. https://doi.org/10.1145/332040.332479.

Romano, Andrea. 2022. "These 12 Famous Museums Offer Virtual Tours You Can Take on Your Couch." *Travel + Leisure*, April 27, 2022. https://www.travelandleisure.com/attractions/museums-galleries/museums-with-virtual-tours.

Rowland, Dale P., Leanne M. Casey, Aarthi Ganapathy, Mandy Cassimatis, and Bonnie A. C lough. 2022. "A Decade in Review: A Systematic Review of Virtual Reality Interven tions for Emotional Disorders." *Psychosocial Intervention* 31 (1): 1–20. https://doi.org /10.5093/pi2021a8.

Schweibenz, Werner. 1998. "The 'Virtual Museum': New Perspectives for Museums to Present Objects and Information Using the Internet as a Knowledge Base and Communication System." In *Proceedings des 6. Internationalen Symposiums für Informationswissenschaft (ISI '98)*, Prague, November 1998:185–200.

Seo, Eui Seok. 2019. "A Study on Interactivity of Fusion Contents Based on VR-Technology: Focusing on Image Expansion Change." *Korean Cinema Association* 79:183–216. https://doi.org/10.17947/FS.2019.3.79.183.

Sherman, William R., and Alan B. Craig. 2018. *Understanding Virtual Reality: Interface Application, and Design*. Burlington, MA: Morgan Kaufmann.

Steuer, Jonathan. 1992. "Defining Virtual Reality: Dimensions Determining Telepresence." *Journal of Communication* 42 (4): 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x.

Tan, Desney S. 2004. "Exploiting the Cognitive and Social Benefits of Physically Large Displays." PhD diss., Carnegie Mellon University.

Tzortzi, Kali. 2016. *Museum Space: Where Architecture Meets Museology*. New York: Routledge.

Weech, Séamas, Sophie Kenny, and Michael Barnett-Cowan. 2019. "Presence and Cybersickness in Virtual Reality Are Negatively Related: A Review." *Frontiers in Psychology* 10:158. https://doi.org/10.3389/fpsyg.2019.00158.

Witmer, Bob G., and Michael J. Singer. 1998. "Measuring Presence in Virtual Environments: A Presence Questionnaire." *Presence: Teleoperators and Virtual Environments* 7 (3): 225–240. https://doi.org/10.1162/105474698565686.

Wojciechowski, Rafal, Krzysztof Walczak, Martin White, and Wojciech Cellary. 2004. "Building Virtual and Augmented Reality Museum Exhibitions." In *Proceedings of the 9th International Conference on 3D Web Technology*, Monterey, CA, April 5–8, 2004:135–144. https://doi.org/10.1145/985040.985060.

Xu, Dazhi, and Xiaoyong Xiao. 2020. "Influence of the Development of VR Technology on Enterprise Human Resource Management in the Era of Artificial Intelligence." *IEEE Access*. https://doi.org/10.1109/ACCESS.2020.3020622.

Yang, Ahyoung, and Jaekyu Lee. 2017. "A Study on Experience Characteristics Utilizing HMD in Virtual Exhibition Space." *Journal of Korea Institute of Spatial Design* 12 (5): 275–287. https://doi.org/10.35216/kisd.2017.12.5.275.

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