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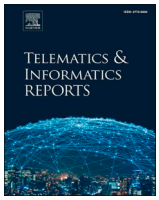

Dwells in museum: The restorative potential of augmented reality

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ABSTRACT

Augmented Reality (AR) is increasingly recognized as a transformative tool for creating restorative environments within museums. It has the potential to provide psychological benefits for visitors, including attention restoration, stress reduction, and anxiety alleviation. This study explores how AR can foster these benefits within museum spaces. By adopting AR technology, museums can go beyond their traditional roles of knowledge dissemination. The immersive, adaptive, and interactive features of AR can enhance the museum experience, transforming it into an innovative therapeutic space. By combining real exhibits with virtual elements, AR can restore visitors' psychological energy within museum settings. This integration of digital innovation into restorative contexts surpasses the traditional functions of visual service. Through empirical investigation of multiple dimensions of restorative environments, AR museum experiences offer comprehensive attention restoration. In this study, a survey was conducted with 279 participants to assess the impact of AR museum experiences on visitors' psychology. The results revealed that such experiences contribute to heightened attention restoration levels, stress reduction, and anxiety relief. With the latest advancements in generative artificial intelligence, AR technology is empowered to integrate within museums. This integration will merge individuals with customized technology, expanding human perceptual experiences and highlighting AR's significant influence within the museum environment.

Introduction

Emerging onto the scene with the turn of the 21st century, Augmented Reality (AR) has woven its spell over users' visual experiences across diverse settings, fostering collaborative creation and plunging them into the realms of the digital [1]. AR empowers users to engage with emerging media technologies, thereby forging a symbiotic relationship between the two. The exploration of AR within social sciences has engendered multifaceted discourse concerning human-machine dynamics. Particularly within commercial contexts, scholars have centered their attention on user interactions with AR applications due to their relevance in diverse business opportunities, such as digital services, e-commerce, and online shopping [2]. In tandem with the resurging fervor for Generative Artificial Intelligence on a global scale, AR technologies have once again been reinvigorated, as they intersect seamlessly with generative AI to yield tailored content. However, extant literature concerning AR's interactive experiences predominantly scrutinizes users' perceptions and sensations in particular locales, encompassing online classes [3], human resources management [4], and healthcare domains [5], with the majority entrenched within educational settings. The prevalence of AR in educational environments primarily emanates from the remarkably authentic situations AR technologies engender, rendering it an indispensable arena for informal learning. Meanwhile, other studies in the social sciences predominantly revolve around the influence of AR on individuals, often traced back to the perspective that media constitutes an extension of the human body, encompassing humanists' contemplation of novel technologies' relationship with humanity. This discourse encompasses AR's role in shaping novel forms of physical aesthetics and information media.

Museum display has a special language of expression, whether it is static physical objects, or video, photo and AR displays, it creates a display of information and conveys a psychological feeling. AR technology seamlessly amalgamates virtual and physical display spaces

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alongside related exhibits, enhancing user experiences and immersive sensations through deep interactivity, thereby amplifying audience perceptions of the exhibition venue. Consequently, this technology becomes an instrumental tool in liberating museum exhibits from institutional spaces [6]. In this natural progression, AR naturally finds its application within museum environments. For instance, the manifestation of AR information in museums predominantly materializes through visual forms. Drawing on AR technologies, panoramic videos, images, and live broadcasts offer comprehensive displays of scenes or exhibits. In the era of Web 2.0 and 3.0, numerous museums have embraced immersive AR as a medium, providing users with customized and online content that showcases exhibits in a vivid, dynamic, and intuitive manner. Several studies indicate that this novel experience heightens users' sensory perceptions [7], aligning with the concept of "flow" expounded by psychologist Csikszentmihalyi and Larson [8], wherein AR-generated scenarios induce a state of mind conducive to immersion and optimal experience. This sense of immersion is notably augmented within 3D spaces, enveloping users in simulated reality.

The coherence and compatibility inherent in many museums' exhibit content and venue designs foster an environment conducive to immersion, thereby significantly impacting visitors' experiences. Amid urban dwellers' mounting stress, museums, as public spaces, are increasingly becoming venues for relaxation and leisure activities. Some studies have explored the applications of Virtual Reality (VR) and AR technologies in museum education and other learning spaces, affirming their potential benefits in stress relief, heightened concentration, and improved language learning abilities. In the context of various museum applications, astronomy museum exhibits a high degree of integration and synergy between VR and AR technologies due to the demanding visual requirements of presenting astronomical knowledge. For instance, within astronomy museums, AR can be employed to facilitate teaching concepts like black holes. The AR experience immerses visitors to the extent that they feel as if their shadows are being stretched into the depths of a black hole, aiding in the comprehension of these complex astronomical phenomena. Furthermore, challenging topics such as gravity, which are often difficult to explain through conventional means, can be effectively elucidated within the context of an AR-equipped astronomy museum. Spectators might witness gravity manifesting as waves, responding to their interactive gestures, thereby enhancing their understanding. Contrasting with traditional static museum displays, AR-enhanced astronomy museums underscore the importance of interactivity and visual aids in educating their audience. Complex two-dimensional textual information is transformed into vivid three-dimensional animations. Hence, it becomes imperative to investigate the physical and mental impact of virtual technology applications within the context of astronomy museums, where the emphasis lies on enhancing the educational experience of the audience through interactivity and visually engaging content.

Traditional museums mainly display static objects. However, AR display utilizes digital media technology to achieve dynamic display, which can provide more forms of interactive images and create interactive experiences for visitors such as virtual live space and somatosensory games. Especially natural science museums can let visitors learn a lot of scientific knowledge. At this time, public spaces such as museums have not only become places where visitors can look at exhibits but also gradually become places where visitors can change their environment and relax.

In contrast to VR, AR technology can be integrated into mobile devices, and the cost of generating realistic special effects is comparatively lower, hence its widespread usage in commercial settings. Past research has investigated the correlation between immersive experiences and online consumer behavior [8], asserting that a sense of immersion can stimulate purchasing intent among consumers [9]. However, scant attention has been given to the relationship between attention restoration, anxiety, and AR technology within museum environments, despite AR's substantial augmentation of visitors' immersive sensations. The motivation of this study is to explore how to effectively leverage AR technology, particularly within the museum environment, to enhance visitor immersion, attention restoration, and alleviate anxiety.

Typically, people attain mental and physical restoration by engaging with natural environments, often located far from urban centers. In contrast, museums are mostly situated in proximity to urban areas, serving as expansive public facilities accommodating educational, entertainment, and exhibition functions. While some research highlights the potential of public spaces for facilitating restorative design, prior studies on museums have inadequately explored the interplay of factors such as distance, richness, attractiveness, and compatibility that empower visitors' restorative experiences in AR-enabled digital museums. Consequently, there is a call to investigate visitors' immersive experiences within digital museums, discern the mechanisms underlying visitors' restorative encounters, and harness the advantages of natural environmental restoration within the realm of emerging AR technologies. The aim of this study is to identify the impact of AR technology on visitor attention restoration by investigating the correlation between them, thereby enhancing the understanding of the mechanisms in this domain. Additionally, we seek to investigate the impact of AR technology on visitor anxiety, thereby offering guidance for the development of more effective anxiety-mitigating museum experiences. Finally, this research also holds the potential to provide practical recommendations for the design and exhibition strategies of digital museums, with insights into how to maximize visitor immersion and attention restoration. Such endeavors promise to not only enhance visitors' museum experiences but also foster human-centric technological development while aiding stakeholders in evaluating and optimizing factors shaping virtual experiences.

Literature review

Today, the application of Augmented Reality (AR) technology has garnered considerable attention, and an increasing number of museums have embraced AR technology as part of their exhibition strategies. Consequently, researchers have begun to focus on examining the experiential aspects that AR technology offers to museum visitors. This study delves into two interconnected domains. Firstly, it explores the utilization of Augmented Reality technology in various cultural institutions, including museums, exhibitions, and planetariums. Secondly, it delves into the concept of restorative environments, encompassing both theoretical investigations and practical applications associated with restorative and stress reduction theories.

Augmented reality technology and museum augmented reality display research

Augmented reality technology

AR technology, originally conceptualized by Ivan Sutherland in 1966, gained formal nomenclature as "Augmented Reality" through the work of Caudell in 1992 [10]. This innovative technology stands as a catalyst for enhancing individuals' perceptual encounters, emotional responses, and cognitive faculties within the tangible world. Its core functionality revolves around the real-time computation of positional coordinates and angles for each informational component captured by the camera, enabling the seamless integration of computer-generated virtual data into the actual environment [11]. Through this seamless amalgamation, the perceptual, emotional, and cognitive dimensions of people's real-world experiences are enriched [12].

The formulation of AR by Azuma et al. [13], widely acknowledged and accepted, not only underscores the coexistence of virtual and real elements within the same spatial realm but also underscores the interactive alignment and reciprocal registration of digitally produced content with the physical reality. Among the manifold approaches for the augmentation of reality through the overlay of computer-generated elements aimed at enriching, intensifying, or expanding one's perceptual

comprehension of the authentic world, AR emerges as the predominant choice [14,15]. Notably, the domain of AR has undergone transformative advancements, marking a paradigm shift. This has engendered its pervasive integration across diverse sectors, encompassing but not limited to the realms of gaming [16], education [17], entertainment [18], and healthcare [19], thus underscoring its ubiquity and profound impact. In this way, AR is uniquely positioned to improve knowledge outcomes and address persistent scientific misconceptions by enhancing participatory experiences and personalized interactions with science [20,21]. Thus, it occurred to us that AR displays in museums might have a similar effect.

Current research on AR displays in museums

The technological characteristics of AR's combination of reality and real-time interaction are suitable for combining with museum display design to form a new development direction. Since the beginning of the 21st century, many museums around the world have introduced it to combine with their exhibitions and exhibits. Museums have limited space and cannot exhibit all the collections at the same time, and the application of AR technology can build a virtual reality environment and use 3D means to build projections, thus fully displaying the collections in the museum. There is AR used with mobile devices to superimpose virtual images over the physical environment, allowing the viewer to see a cohesive image [22]. This pairing of virtual and physical content can deepen the level of interaction between visitors and exhibition content due to increased contextualization [23]. This supports museum-guided activities and enhances visitors' presence within a given space by allowing them to observe the location over time [23]. In interviews, visitors also reported that using AR to enjoy the exhibition made the whole experience more personalized, engaging, and interesting. Visitors who use AR spend more time enjoying the exhibition [18].

Despite the high expectations of the technology in museum environments, its use in these spaces still requires further exploration and reflection, mainly on what exactly visitors can expect from AR displays in museums. Many studies have explored the use of AR in museums from a user experience design perspective [24–26]. The results of these studies show similar aspects of using AR in museums, such as increased interest in visualizing artifacts, greater immersion, and interactivity between visitors and the artifacts on display, self-gathering of information from exhibits, generating curiosity and engaging visitors, and maintaining the public by providing a new look at the artifacts. There have also been studies of AR technology in museum environments that have examined its role in increasing visitor interest, engagement, and accessibility. For example, Damara and colleagues [27] found that a mobile museum guide containing AR was associated with increased visitor enjoyment when viewing AR-enhanced paintings at the Musée des Beaux-Arts in Rennes, France. It has also been suggested that visitors using AR also noted increased engagement and higher satisfaction with the exhibition [28]. Other studies have focused on more technical aspects of AR [28,29].

There is a body of literature focusing on museum visitor satisfaction and experience. AR enables visitors to co-create and shape digital experiences like never before [30]. Some scholars have examined the impact of AR on visitor behavior in digital services [31] e-retail [32], and the online travel space [33]. However, the current AR interactive experience literature only explores consumers' unidirectional perceptions and feelings about environmental conditions during the experience, such as perceived value [30,34,35] and satisfaction [36,37]. Other studies focus on AR outcomes such as aesthetics [34], information quality [38,39], and enjoyment (Tom Dieck et al. [40]; Pantano et al. [41]). However, we found that many AR studies have neglected the impact of AR on the co-creation of experiences by consumers, especially the impact of consistency and compatibility between consumers and AR digital environments [43]. To the best of our knowledge, visitor immersion when experiencing AR displays in museums is the result of many aspects of elements, such as the consistency and compatibility experiences that visitors feel, which are known as restorative experiences, and restorative experiences deeply affect consumers [42].

At the same time, it has been shown that online interfaces trigger immersion [43] limited to the passive experience of web browsing and ignoring proactive consumer co-creation of experiences (e.g., restorative experiences). More importantly, restorative experiences shaped by congruence and compatibility between online consumers and digital environments can have a significant impact on inspiring immersion (e.g., by prolonging their time on a website) [44]. Furthermore, Ross [45] showed that the introduction of AR technology facilitates the promotion of new services or products in museums, which is beneficial for their long-term development. However, few researchers have examined the relationship between restorative experiences, immersion, and willingness to visit [44].

Through this literature, we only know that AR displays in museums can contribute to visitor satisfaction and immersion, leading to better dissemination of exhibition content, but it is not clear how visitor immersion is created. While some scholars have noted the potential of AR displays in museums to create a restorative experience for visitors, there is no empirical evidence yet to prove whether users get a restorative experience from AR displays in museums. Existing research rarely mentions exactly how it works on visitors' restorative experiences. Therefore, a more in-depth investigation into how AR displays in museums have an impact on visitors' psychology has practical implications for the dissemination of museums' exhibition content. To structure our study to investigate how AR displays in museums work on visitors' immersion, restorative experience, etc., we draw from theories of conceptual change.

Related theoretical research

To explore the impact of AR display on visitors in museum environments and whether visitors have truly experienced restorative experiences, this article cites the concepts of restorative environment theory and stress reduction theory to explain visitors' psychology.

Restorative environment

The foundational concept of a restorative environment was originally formulated by Kaplan [46], a prominent environmental psychologist hailing from the University of Michigan. A restorative environment pertains to a specific environmental milieu with the capacity to partially replenish, restore, or rejuvenate depleted or squandered psychological reserves. In essence, it embodies an environmental setting capable of effectuating restoration and enhancement of persistently drained attentiveness and self-vitality [45]. Ulrich further contends that the attributes of a restorative environment encompass four key facets: being away, extent, fascination, and compatibility [47]. Being away necessitates environmental contexts that facilitate a sense of disengagement from daily surroundings and distractions, thereby obviating the demand for focused cognitive effort. Extent alludes to the multifaceted richness and uninterrupted coherence of the landscape, which engenders a gratifying mental experience and fosters exploration. Fascination entails the effortless absorption of contextual stimuli, promoting an unstrained appreciation of the environment. Moreover, environmental congruence aligns with individual objectives and inclinations. The pivotal constituents of restorative environments encompass visual allure, natural elements, and the absence of human intervention, each exerting a discernible impact [48].

This concept helps us to understand the elements of restorative environments, but it is not yet clear the mechanisms of psychological changes in visitors, are more specifically explained by the Attention Restoration Theory (ART) proposed by Kaplan and the Stress Reduction Theory (SRT) proposed by environmental psychologist Ulrich.

Attention restoration theory (ART)

Attention is the pointing and focusing of an individual's mental

activity on a certain object, and it is a common psychological characteristic that accompanies perception, memory, thinking, imagination, and other mental processes. When people are awake, they always pay attention to something at every moment, especially in the urban environment, where a variety of complicated information sources not only tend to make people lose the habit of long-term concentration but also make it difficult to relax. In response to this trend, Kaplan suggests that natural environments can help with the restoration of attention resources [46].

ART states that a task that requires mental resources will elicit directional attention. If the duration and intensity of the task reach a certain level, it can lead to mental exhaustion even if the goal is pleasant. Natural scenes can provide active involuntary attention to stimuli, leading to the restoration of the attentional system. The theory explains how nonconscious attention to natural environments can be attracted and how cognitive abilities can be restored. The theory describes a basic psychological mechanism by which observing natural environments produces beneficial effects.

Stress reduction theory (SRT)

Stress levels can be a complementary way of examining restorative experiences when studying the experiences of visitors because people's psychological stress has a profound effect on their physical and mental health. Roger Ulrich delves into the relationship between restorative environments and relieving personal stress [49]. The "Stress Reduction Theory" put forth by Ulrich emanates from a psychological evolutionary standpoint, positing that the human experience is punctuated by diverse social and environmental stimuli, each inciting varying degrees of psychological and physiological stress responses. Prolonged exposure to such stimuli culminates in the emergence of negative emotions, including stress, anxiety, and tension, consequently inducing mental fatigue. Ulrich emphasizes that when individuals encounter seemingly intractable stressors, environments with moderate complexity and focal visual attributes captivate attention [48].

Attention Restoration Theory and Stress Reduction Theory have different conceptual and mechanistic focuses. The former focuses on fatigue to explain the recovery of an individual's attentional resources and changes in cognitive abilities during nature experiences, while the latter focuses on an individual's emotional response to nature. In recent years, these two theories have shown a trend away from opposing integration [50]. Restorative environmental perceptions include physical, emotional, and attentional aspects. Observable restorative processes include positive mood changes, decreased levels of autonomic arousal, and improved completion of directed attention tasks [51].

AR environment embedding can effectively integrate each element in the virtual environment (such as scenery, characters, or scenes) with the consumer's body image, and establish a deep interactive connection between them, resulting in a strong sense of presence and realism. According to ART, this simultaneous and intense presence shapes the recovery experience in virtual environments [54]. For example, AR environment embedding can embed landscapes and cultural customs directly behind consumers' body images, creating the effect of consumers visiting tourist destinations in person [55,52]. However, the relation of the museum's AR display to the restorative environment was not indicated.

ART explains the recovery of individual attention resources and changes in cognitive ability during nature experience, and SRT explains the individual's emotional response to nature. According to two theories, restorative environments can improve cognitive acuity, emotional well-being, stress reduction, and various other beneficial outcomes that favor recovery. Restorative environmental perception includes physical, emotional, and attentional aspects. Observable recovery processes included positive mood changes, reduced levels of autonomic arousal, and improved completion of directed attention tasks. However, whether AR displays in museums can lead to restoration of attentional resources, cognitive changes, and emotional changes is unclear.

In summary, the above theories are helpful for us to understand the elements of a restorative environment and the psychological mechanisms of visitors. According to the above theory, AR displays in museums can be seen as a restorative environment, but current research has not yet proven whether visitors experience restorative effects during AR displays in museums. The existing research on restorative and stress-relieving experiences has limitations, with most of them referring to the natural environment [53,54]. Although some scholars have proposed the potential for non-natural environments to generate restorative experiences [55], they have not specifically pointed out the role of restorative experiences in museum environments on tourist psychology. Therefore, based on the above theories, it remains to be verified whether museums can truly provide restorative experiences and reduce stress for visitors, and how they affect their experiences.

Research questions

According to existing research, some scholars have paid attention to the potential of AR displays in museums to bring restorative experiences to visitors, but have not conducted in-depth research on the performance of visitors' restorative experiences. As mentioned earlier, AR displays have demonstrated their ability to provide viewers with immersive experiences, and there is a connection between museum AR displays and visitors' immersion, restorative experiences, and stress. Although some studies have pointed out that AR can enhance interest and immersion in museum environments. However, it is not yet clear how the AR display in museums affects visitors' restorative experiences, stress aspects, and the specific manifestations of visitors' psychology. At the same time, little is known about which elements in the AR display of museums generate restorative experiences and stress changes.

In theory, stress and anxiety can also be affected when visitors are in museum AR scenes, but existing research has not yet conducted empirical studies to prove the level of stress and anxiety of visitors in museum AR scenes. In addition to serving as a treasure trove for disseminating cultural and educational knowledge, museums can also serve as an environment for promoting cognitive revival and enhancing purposeful actions. Therefore, this study referred to the concept of attention recovery theory and examined which factors exhibited by museum AR had an impact on visitors' psychology. Given the research gaps in the literature, our study was guided by the following research questions:

RQ1. Has the AR environment of the museum formed a restorative environment?

RQ2. How do AR displays affect visitors' immersion and restorative experience?

RQ3. To what extent does AR impact visitors' stress and anxiety?

RQ4. How does the psychology of visitors guide the design of AR displays in museums?

Methods

Research design

When selecting museums for the research objectives, we examined museums with AR displays, and after the examination, we believe that the Shanghai Astronomy Museum, which integrates science and technology and nature, is a relatively suitable choice in China. Because it is one of the largest planetariums in the world that integrates education, research, collection, display, and interactive functions for science popularization infrastructure [56]. Shanghai Astronomy Museum builds an immersive cosmic space experience environment through light and sound effects and high-fidelity scene simulation means, and the use of somatosensory interaction, data visualization, augmented reality, virtual reality, biometrics, and other technological means, integrating the sensory experience of sight, sound, and touch.

At the same time, the AR display space of Shanghai Astronomy

Museum shows many astronomical landscapes to visitors, and its AR display is full of charming and unknown sights. At the same time, this kind of environment can interact with human beings, and people can change the sights of the AR display in front of them very simply through their actions, and carry out explorations and independent creations, in the process of exploring, people can be immersed in the whole environment. With more than 50 % of interactive exhibits in the Shanghai Astronomy Museum, visitors can easily find AR displays and experience them in the venue. Therefore, we choose the planetarium as a case study of AR displays in museums for evaluation. (As shown in Fig. 1)

Sampling

Contemporary AR research streams [56–58] point out that young consumers (20–30 years old) are currently the most important and willing to use AR. Wang showed that in this age group, young consumers are more open to innovative technologies. At the same time, because young people are very impressed by the AR devices they have experienced and have some unique insights, we mainly use young people as samples for research.

In this case, we defined sampling based on two specific criteria:

(1) having visited the Shanghai Astronomy Museum, and (2) having been exposed to AR experiences within the museum space he/she visited.

Procedure and questionnaire design

This study firstly conducted in-depth interviews and secondly conducted questionnaire research. In this study, we first conducted in-depth interviews with some of the target users to collect the users' feelings about their experience of the AR display at the Shanghai Astronomy Museum during the interviews. During the interviews, we first recruited young subjects willing to participate in the interviews through online communities and social media platforms, and used Snowball sampling to find interviewees who had already been to the Shanghai Astronomy Museum, each of whom was interviewed online for more than 30 min at a Tencent meeting, and spent three weeks conducting in-depth interviews, interviewing a total of 11 people, with the questions centering around how they felt about experiencing the AR The questions centered around the experience of the AR display (e.g., Did you feel your concentration was restored? Did you feel relaxed? Do you feel less stressed? etc.). The final report is 172,328 words. From the results of the interviews, most of the users indicated that they felt a strong sense of immersion, restored concentration, and were more relaxed when experiencing the AR display at the Shanghai Astronomy Museum, but the interviewees could not pinpoint which aspects they felt good about.

Subsequently, to more accurately quantify the level of attention recovery, stress, and anxiety of the users, we chose to create a questionnaire based on the scales we determined to use based on the interviews.

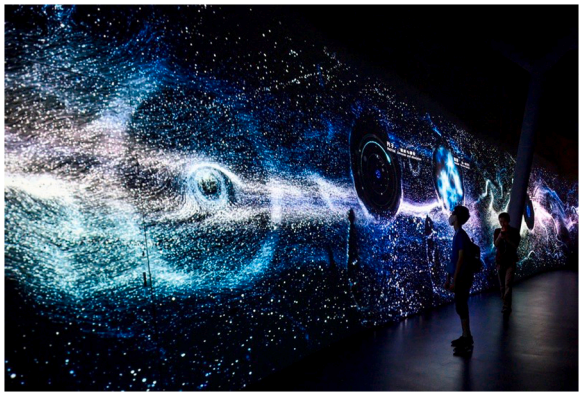

Fig. 1. The AR display in the Shanghai Astronomy Museum.

The online questionnaire was distributed in universities and youth communities, and it took four weeks to test and collect data, with a total of 281 questionnaires distributed and 279 valid questionnaires returned. Most of the participants were in the age range of 20 to 30 years old and had a bachelor's degree.

The questions in the questionnaire were all based on existing scales and were adjusted according to the actual AR display in the Shanghai Astronomy Museum. The measurement of a Restorative Environment adopts the existing "Perceived Restorativeness Scale" (PRS) [58], which is divided into four dimensions: being away, fascination, extent, and compatibility. The scale has 22 questions (e.g., the "being away" category has questions such as "Being here helps me to relax my focus on getting things done."). The scale measures the degree of restorative experience of the visitor. The measurement of Stress level adopts the existing Perceived Stress Scale (PSS) [59]. Totaling 11 questions (e.g., Does it feel like you can't control and handle the important things in your life?), the scale reflects visitors' stress levels The measurement of Anxiety level adopts the existing Self-Rating Anxiety Scale (SAS) [60]. Totalling five questions, (e.g., Do you feel irritable or feel panicky and have physical reactions) the scale serves as a supplement to the stress scale, which reflects the anxiety level of visitors. The results of these scales provide a somewhat quantitative response to the user's psychological situation.

Results

The questionnaire contained quantitative measures of attention level, stress level, and anxiety level. A total of 281 questionnaires were distributed. Questions were set to test attention and validity, and after excluding invalid responses according to the validity test, a total of 279 valid questionnaires were obtained. We collected the gender and education of the users, basically for the young people's group, in 279 people male 116 (41.6 %), female 163 (58.4 %), gender male and female ratio is more balanced, the subjects' education is mainly undergraduate, to ensure that there is no comparative complication of the differences arising from education and age. The overall reliability and validity of the questionnaire were good, with a reliability Cronbach's alpha of 0.766 (Table 1) for the total scale, a structural validity KMO value of 0.791 (Table 2), and an ANOVA $p < 0.01$, making the data significant.

Perceived Restorativeness Test

The Perceived Restorativeness Test (PRS) was set up in the questionnaire, and we chose the existing "The Perceived Restorativeness Scale" [58], which is categorized into four dimensions, namely, being away, fascination, coherence, and compatibility. It's used to analyze and compare the mean scores and standard deviations of the questions categorized according to each dimension. The range of scores that users can choose from in the PRS is from 1 to 7, with 1 representing strongly disagree and 7 representing strongly agree.

The results of most of the questions were found to be normally distributed with a structural validity KMO value of 0.803 and ANOVA $p < 0.01$, making the data significant. The results show that in the museum scenario, several questions in the being away category get a total score of $M = 5.27$, an SD=1.024, and several questions in the fascination category get a total score of $M = 5.39$, with an SD=1.065, and a total score of $M = 5.39$. SD=1.065, the total score for the questions in the coherence category is $M = 4.335$, SD=1.122, and the total score for the questions in the compatibility category is $M = 4.335$, SD=1.122. The total score for the compatibility category is $M = 5.328$, SD=1.073.

Table 1
Reliability Statistics.

Cronbach's Alpha	N of Items
.766	39

Table 2
KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.764
Bartlett's Test of Sphericity	Approx. Chi-Square	2969.809
	df	741
	Sig.	.000

Over 95 % of users chose scores on the high end of the 4–7 scale. In summary, the mean scores of being away, fascination, and compatibility are over 5, and the mean score of Coherence is over 4, all of which exhibit high scores with a standard deviation of about 1. A high mean score represents a good Perceived Restorativeness and a standard deviation of 1 indicates that a large number of users feel similarly, and this law is somewhat generalizable. (As shown in Table 3)

Stress test

Stress Test was set up in the questionnaire, we chose the existing Perceived Stress Scale (PSS) [59], in which users can choose a score range of 1–5, with 1 representing strongly disagree and 5 representing strongly agree.

The results were found to be normally distributed with a KMO value of 0.793 and ANOVA $p < 0.01$, making the data significant. For the questions that indicated a positive direction for low-stress levels, users mostly chose high scores i.e., 4 -For the negative questions indicating high-stress levels (e.g. I didn't notice what I was doing, often daydreaming and worrying about the outside world) users mostly chose the low scores of 1–2 ($M = 2.1$, SD=0.618), while for the positive questions indicating high-stress levels (e.g. I am good at describing my emotions in words, especially in environments that make people easily immerse themselves? $M = 2.1$, SD=0.963), all positive questions (5 questions in total) were rated as $M = 4.06$, SD=0.71, and all negative questions (5 questions in total) were rated as $M = 2.13$, SD=0.82. Higher ratings for the positive questions indicated that the users were at a low level of stress, and lower ratings for the negative questions also indicated that the users were at a low level of stress. Thus, the composite score indicates that users reported low-stress levels after experiencing the museum's AR installation. (As shown in Fig. 2.) Fig. 2 shows the results of the PSS scale. The x-axis is the question number, corresponding to the five positive and five negative questions, and the y-axis is the mean score for each question. The blue curve is the score for the positive questions and the orange curve is the score for the negative questions.

The five positive comments are listed below:

(1). I am good at describing my emotions in words, especially in environments that allow for easy immersion.

(2). I feel that I can successfully deal with the troublesome emotions and trivialities in my life, especially in environments that allow for easy immersion.

(3). I feel that they are coping effectively with changes in their lives, especially in environments that allow for easy immersion

(4). I feel confident in dealing with personal issues or scheduling, especially in a relaxing and immersive environment.

(5). Feeling comfortable and able to manage everything, especially in immersive environments.

The five negative questions are listed below:

(1). I often feel that I have a mountain of difficulties that I can't overcome

(2). I am often distracted and easily interrupted when I am doing things

(3). I don't notice what I'm doing and often daydream and worry about the outside world.

(4). I get irritated or angry when unexpected things happen to me.

(5). I feel that I am unable to control and deal with the important things in my life.

Table 3
Results of PRS.

Dimension	Question	Mean	Std. Deviation	Mean	Std. Deviation
being away	Can I have a state of attention that doesn't require tension when I come here, to gain comfort?	5.62	0.84	5.27	1.024
	Can coming into such an immersive environment temporarily allow me to escape reality?	4.83	1.125		
	Will spending time in such an immersive experience temporarily relieve me of the work I need to do?	5.67	0.995		
	Can this place keep me away from all the distractions?	4.64	1.076		
	Can it help me relax my focus on task completion here?	5.59	1.082		
fascination	Does this place have any characteristics that attract you? (such as exhibition content, immersive experience, etc.)	5.11	1.099	5.39	1.065
	Will my attention be attracted by the many interesting and novel exhibitions and installations here?	5.6	1.04		
	Do I want to gain a deeper understanding of this exhibition?	5.2	1.156		
	Is there much worth exploring and discovering here?	5.54	1.055		
	Do I want to spend more time admiring the surrounding environment?	5.28	1.145		
	Is the environment here (such as AR light and shadow space) fascinating?	5.61	0.895		
extent	Is the exhibition content in this place easy to understand?	5.52	1.082	4.335	1.122
	Are there many distractions in this place that distract me?	3.15	1.162		
compatibility	Is it suitable for my nature to come here (without forcing myself to come here)?	5.52	0.992	5.328	1.073
	Can I do what I like here?	4.99	1.086		
	Do I have a sense of belonging here (such as AR immersion scenes)?	5.59	1.125		
	Can you find a feeling to enjoy here?	5.16	1.024		

(*continued on next page*)

Table 3 (*continued*)

Dimension	Question	Mean	Std. Deviation	Mean	Std. Deviation
	Is there a feeling of integration in the environment here?	5.68	1.071		
	Is there a landmark here that can help me identify the direction?	5.13	1.027		
	Can I easily form a map or sense of direction here in my mind?	5.44	1.248		
	Is it easy to find a way here?	5.08	1.088		
	Is it easy to see the combination or arrangement of exhibition content (such as the display method of new technologies and exhibition hall layout)?	5.36	0.993		

Anxiety Test

Anxiety Test was set up in the questionnaire, and we chose the existing Self-Rating Anxiety Scale (SAS) [60], in which users can choose a score range of 1–4, with 1 representing strongly disagree and 4 representing strongly agree.

The results were found to be normally distributed with a KMO value of 0.781 and ANOVA $p < 0.01$, making the data significant. For the questions that indicated a negative direction of high anxiety levels (e.g., I am prone to getting angry or feeling scared, and have physical reactions such as anger, panic, shaking hands and feet, etc.) users mostly chose low scores, i.e., 1–2 ($M = 1.79$, SD=0.63), and for the positive questions indicating low levels of anxiety (e.g., I often have a calm body state, can sit still, and my hands are often dry and warm, especially in some relaxed and immersive environments (such as AR immersion space) users mostly chose high scores i.e. 3–4 ($M = 3.27$, SD=0.69). The average rating for all negative questions was ($M = 1.84$, SD=0.75), and for all positive questions ($M = 3.27$, SD=0.69). Lower ratings for the negative questions also represented users at low levels of anxiety, and higher ratings for the positive questions represented users at low levels of anxiety. Thus, the composite scores indicate that users reported low anxiety levels after experiencing the museum's AR installation. (As shown in Table 4)

The results of this test confirm that AR displays in museums can create a restorative environment, as visitors can report a higher level of restorative experience after experiencing AR displays in museums. At the same time, lower levels of stress and anxiety also help verify visitors' restorative experience. AR plays a role in providing visitors with a more immersive and relaxing emotional experience in this restorative environment, thereby enhancing the overall tourist experience in museums.

Discussion

The results of our research reveal a positive influence of AR displays

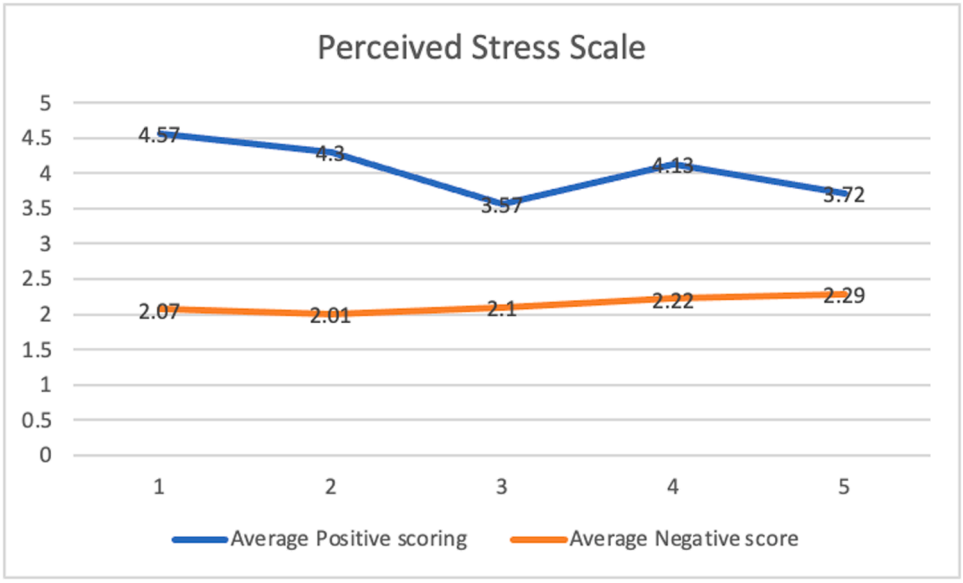

Fig. 2. The result of the Perceived Stress Scale.

Table 4
Results of SAS.

	Question	Mean	Std. Deviation	Mean	Std. Deviation
negative questions	I feel more nervous and anxious than usual, sometimes even losing my sanity	1.87	0.847	1.845	0.75625
	I am prone to getting angry or feeling scared and have physical reactions such as anger, panic, shaking hands and feet, etc	1.79	0.635		
	I feel distressed due to headaches, neck and back pain, stomach pain, indigestion, rapid heartbeat, weakness or fatigue	1.88	0.829		
	I have a feeling of fainting, numbness and tingling in my fingers and toes, and frequent urination	1.84	0.714		
positive question	I often have a calm body state, can sit still, and my hands are often dry and warm, especially in some relaxed and immersive environments (such as AR immersion space)	3.27	0.692	3.27	0.692

on the overall visitor experience in astronomy museums, offering a more enriched and restorative engagement, a significance pertinent to both these museums and the broader digital exhibition domain.

To address RQ1, our study examined how AR environments in astronomy museums construct restorative settings. Users, as assessed through the Perceived Restorativeness Scale (PRS), assigned high ratings to AR displays in astronomy museums, particularly in the dimensions of "fascination," "being away," and "compatibility." These high scores indicate that users perceive the AR museum as a space for distancing from everyday life, fostering deep engagement, and holding their attraction—a reflection of restorative environmental characteristics.

For RQ2, we delved into the impact of AR displays on visitors' immersion and restoration experiences. Our findings suggest that AR displays significantly enhance visitors' immersion and restoration experiences. The high PRS scores and moderate scores for "coherence" hint that visitors consider the AR museum environment conducive to immersive experiences with enhanced perceptions of restoration. The synergy between AR technology and visitors' inherent proclivities significantly bolsters immersive experiences, furthering their perceptions of restoration.

Subsequently, RQ3 examined the effect of AR displays on visitors' stress and anxiety levels. Our results show that the use of AR displays in astronomy museums is associated with lower stress levels among visitors. Visitors reported lower stress levels post-experience, as evidenced by high scores on positive questions within the stress test. This indicates that AR's immersive and captivating features contribute to the creation of a relaxed and stress-reducing environment in astronomy museums, ultimately reducing visitors' stress levels. An insight into why the astronomy museum environment can provide significant stress relief came from the feedback provided by a section of the visitor group. Their feedback highlighted that the content in astronomy museums tends to be far removed from their everyday life, while the casual and extraordinary environment created by AR allows them to escape from the mundane. Hence, immersive AR technologies cater to astronomy content and significantly reduce visitor stress levels.

Likewise, the results from the anxiety test also demonstrate that visitors have lower anxiety levels. Visitors primarily opted for higher scores on positive questions, indicating that AR displays contribute to a calmer and less anxious atmosphere. This further reinforces the perspective that AR technology in museums positively impacts visitors' emotional states.

Lastly, while RQ4 was not directly addressed in the results, our findings indirectly suggest that the design of AR displays should prioritize elements that enhance immersion and restoration experiences. Astronomy museums should focus on creating AR displays with attractive, coherent content that aligns with visitors' expectations. Moreover, an emphasis should be placed on reducing stress and anxiety by providing immersive and stress-reducing experiences.

The interactivity and immersion of AR display can let visitors participate in the change of the exhibition content by themselves so that the fusion of interactive art and display art makes visitors feel more innovative and possible. Exhibition design has witnessed a profound transformation with the incorporation of interactive art. The traditional static display has given way to a dynamic approach, embracing the interactive and immersive features inherent in digital art. Consequently, exhibitions now possess the capability to adapt and respond to the body movements of visitors, thereby creating a more engaging and personalized experience. When visitors see that their body movements bring changes to the surrounding environment, they will feel the recognition and feedback given by the environment during the interaction, allowing visitors to recognize the new environment that has been changed. The museum's AR display environment can be expanded in the direction of helping visitors to relax and heal.

In summary, the study findings underscore the positive impact of AR technology in astronomy museums, enhancing restoration experiences, reducing stress and anxiety levels, and improving immersion. These discoveries hold significance not only for astronomy museums but also for providing visitors with experiences beyond the realm of conventional knowledge. To maximize these benefits, museums should strategically design AR content to cater to visitors' psychological needs and preferences.

Theoretical implications

The theoretical significance of this study lies in its application of attention restoration theory, stress relief theory, and restoration environment theory in a practical context, from the perspective of AR technology. Firstly, this study explicates how AR displays in museums facilitate recovery from fatigue by creating attractive and pleasant scenes, linking attention restoration theory with the restoration environment concept, and introducing it into the context of AR-empowered museums. Secondly, stress relief theory provides insights into how AR displays can alleviate psychological stress among visitors. Additionally, the immersive experience reestablishes the significance of the body as a vital interactive interface that enhances the experience. The study supports the integration of AR and similar virtual technologies, enabling direct access to information and cognition. This interplay of technology and physical experience transforms previously distant landscapes into digital panoramas, contributing to the theoretical domains of attention restoration, stress relief, and restoration environments in social psychology.

Practical implications

The findings of this study hold practical implications for museum exhibit design and user experience. Firstly, the results underscore the potential of AR technology to create restorative experiences in museum settings. Incorporating AR elements into exhibits can enhance visitors' psychological and emotional experiences, promoting attention restoration, stress reduction, and anxiety alleviation. The interactive exhibits in the astronomy museum validate the previous research's understanding of AR, which suggests that incorporating interactive and interpersonal features through AR technology within a virtual context can enhance cognitive development and emotional elevation [56]. This, in turn, results in favorable user experiences in such environments. Moreover, the study supports the concept of museums as restoration environments, positioning them not only as venues for cultural dissemination, education, and entertainment but also as spaces for revitalizing psychological energy [57]. The practical significance of this research extends to guiding cultural institutions, including museums, on how to create more attractive and restorative exhibit environments through AR technology to better cater to visitors' psychological needs [58].

This study lays the foundation for further exploration of the restorative effects of AR technology in museum environments, providing valuable insights for both research and practice. By delving deeper into these effects, we can better understand the potential of AR technology to enhance user experiences and psychological well-being, offering inspiration for innovative exhibit design and user experience strategies. Future research could delve into the application of AR technology in various types of museum exhibits and its impact on different user groups. The research framework and methods can be applied to other types of museums, cultural institutions, or virtual exhibitions. Future studies could investigate the restorative effects of AR technology in natural history museums, art galleries, or historical museums. Moreover, combining other psychological theories with the concept of restoration environments could provide a more comprehensive understanding of users' experiences and effects within AR displays.

Limitations

While this study has provided valuable insights into the positive impacts of AR displays in museum environments, several limitations

should be considered. The sample in this study was predominantly composed of young individuals, mainly undergraduate students, potentially limiting the generalizability of the results to different age groups and educational backgrounds. Future research should expand the sample to enhance the findings' universality. The reliance on self-report measures for indicators like attention, stress, and anxiety introduces the potential for subjective bias. Although efforts were made to design objective and accurate questionnaires, subjective bias cannot be eliminated. The study primarily focused on the short-term effects of experiencing AR displays, neglecting potential long-term effects. Future research could track long-term changes in user experiences to better understand the lasting impact of AR displays on user well-being. Despite these limitations, this study offers preliminary insights into the effects of AR displays in museums on attention restoration, stress, and anxiety. Future research can further explore these limitations' effects and investigate ways to overcome them, facilitating a more comprehensive understanding of AR technology's potential value in museum environments.

Conclusion

AR has emerged as a pivotal medium within museum exhibitions, transforming these spaces into environments that restore attention, alleviate stress, and reduce anxiety. This study delves into the potential of AR to create museum environments conducive to restoration, underscoring its significant impact on visitors' psychological well-being. While museums traditionally serve as platforms for knowledge dissemination, AR enriches the museum experience by providing immersive, engaging, and adaptable interactions, effectively redefining them as novel restorative environments. Moreover, AR acts as a stress-relief mechanism, allowing visitors to escape urban pressures and immerse themselves in digitally crafted sanctuaries. The fusion of reality and virtuality, real-time interactivity, and 3D localization exponentially amplify the potential for psychological restoration.

This study emphasizes the transformative potential of AR within museums, seamlessly integrating digital innovation with restorative environments, and transcending conventional visual service functions. By leveraging multiple dimensions of restorative environments, AR experiences within museums offer visitors comprehensive attention restoration. Utilizing AR as an innovative tool to alleviate stress and anxiety enriches the museum's essence, positioning them as urban oases for addressing contemporary psychological challenges. With the evolution of AR technology, integrating it into museum spaces creates a fusion of experiences for urban residents with cutting-edge visual innovation, resulting in novel "flow" experiences and inspiring new functionalities for other public spaces.

CRediT authorship contribution statement

Jiawei Shen: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Ming Yin:** Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Wei Wang:** Methodology, Supervision, Project administration. **Min Hua:** Methodology, Supervision, Project administration. **Youngok Choi:** Supervision, Writing – review & editing, Project administration, Funding acquisition. **Vanja Garaj:** Supervision, Funding acquisition. **Busayawan Lam:** Investigation. **Kwon Hyejin:** Investigation.

Declaration of competing interest

None.

Data availability

The data that has been used is confidential.

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