

The Application of Interactive Design in Exhibition Spaces

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Abstract: With the rapid development of technology and the increasing demand of audiences for personalized and immersive interactive experiences, traditional exhibition forms can no longer meet the expectations of modern audiences. To address this issue, the design of interactive exhibition Spaces has significantly enhanced the interactivity, immersion and personalized experience of exhibitions by introducing innovative technologies such as augmented reality (AR), virtual reality (VR) and haptic feedback. This article mainly explores how to enhance the audience's sense of participation and emotional connection through technological integration by analyzing successful cases at home and abroad. Case analysis shows that the application of AR and VR technologies can effectively enhance the participation and educational value of exhibitions, especially in places such as science and technology museums and museums. The integration of technologies enables visitors to experience exhibits in a more vivid and interactive way, greatly increasing the appeal of the exhibitions. Meanwhile, the introduction of haptic feedback technology further enriches the sensory experience of the audience, making the interactive process more vivid and emotionally rich. The conclusion indicates that the integration of technologies such as AR and VR has become an important means to enhance exhibition effects. In the future, exhibition design should pay more attention to multi-sensory integration and promote the development of exhibition forms towards a more personalized and interactive direction. Policy recommendations include encouraging cultural institutions to increase investment in science and technology, promoting the digital transformation of the cultural industry, and enhancing the innovation of exhibition Spaces and the comprehensive experience of visitors.

Keywords: Interactive exhibition space; User experience; Augmented reality; Virtual reality; Immersive experience.

1. Introduction

With the rapid advancement of information technology, traditional exhibition methods have gradually exposed their limitations in failing to meet the needs of modern audiences. Especially among young audiences, traditional static displays often fail to arouse their interest in the exhibition content. To address this issue, interactive exhibition Spaces have emerged. By introducing innovative technologies such as augmented reality (AR), virtual reality (VR), and haptic feedback, the interactive exhibition space not only enhances the multi-dimensional interactivity of exhibit display but also enables visitors to have in-depth interactions with the exhibition content as if they were on the spot, thereby significantly increasing their sense of immersion and participation. The core objective of interactive design is to transform the audience from passive viewers to part of the exhibition, experiencing and exploring the stories, history and culture behind the exhibits.

In recent years, the research and application of interactive exhibition Spaces have gradually become a hot topic in both the academic and practical fields. Several comprehensive studies have laid the foundation for this research. Trunfio et al. [1] explored mixed reality experiences in museums and their impact on visitor engagement. Ribeiro et al. [2] addressed the challenges of integrating VR, AR, gamification and AI in cultural heritage contexts. Cheng [3] investigated the relationships between augmented reality quality, immersion, and the technology acceptance model. Santos et al. [4] discussed the new landscapes created by interactive spaces in art museums. Adão et al. [5] proposed a user experience model and design strategies for VR-based museum exhibitions. Especially the application of AR, VR

and multi-sensory design has become an important way to enhance the interactivity and immersion of exhibitions. By analyzing multiple successful cases both at home and abroad, this article aims to explore how to enhance the audience's sense of participation, emotional connection and educational effect in exhibitions through the integration of innovative technologies. Unlike traditional exhibition design, the design of interactive exhibition Spaces not only emphasizes the display of exhibits but also focuses on how to stimulate the audience's interest through multi-dimensional interaction and immersive experiences, and enhance their understanding and memory of the exhibition content.

The innovation of this article lies in integrating multi-sensory design and intelligent technology to propose a personalized interactive exhibition space design scheme that meets the needs of different audiences. By integrating case analysis with theory, this paper explores how to enhance the interactivity, immersion and educational value of exhibitions through the fusion of technology and design, providing innovative ideas and practical basis for future exhibition design.

2. Literature Review

In recent years, the design and application of interactive exhibition Spaces have made remarkable progress worldwide, especially in the application of technologies such as AR and VR. The following are the key research achievements on the design of interactive exhibition Spaces at home and abroad:

2.1. The application of augmented reality (AR) technology

AR technology is widely applied in exhibitions of

museums and science and technology museums, helping visitors obtain more information and background knowledge on the basis of physical exhibits. Through a study of the Smithsonian Museum in the United States, it was found that AR technology can break the spatial limitations between physical exhibits and visitors [1]. By superimposing virtual images, it enhances the visualization effect of exhibition content and simultaneously increases the interactivity of the exhibition. For instance, in some historical museums, AR technology is employed to recreate historical events, allowing visitors to view historical figures and scenes through their mobile phones or smart glasses, thereby better understanding the historical context. In his investigation of Chinese museums, Li [6] found that the introduction of AR technology has provided an enhanced information layer for the exhibits, allowing visitors to obtain in-depth interpretations of the exhibits through mobile devices and greatly improving the exhibition experience.

2.2. Immersive experiences of virtual reality (VR) technology

VR technology is regarded as a key tool for achieving immersive experiences. In some historical and cultural exhibitions, VR technology enables visitors to immerse themselves in a virtual environment and personally "participate" in historical events or experience cultural sites. Research shows that VR can not only enhance the understanding of history and culture, but also evoke emotional resonance among the audience through deep immersion. For instance, in some cultural heritage protection exhibitions, VR technology helps visitors virtually tour damaged ancient buildings and experience the weight of history [7]. Through research, Zhang [7] demonstrated that VR technology can bring the audience into a completely immersive virtual world. Exhibitions are no longer merely knowledge transmission but an immersive emotional and cultural experience.

2.3. The combination of haptic feedback and multi-sensory design

Haptic feedback technology simulates the texture and temperature of objects, enabling the audience to experience the materials and physical properties of the exhibits during interaction, further enhancing the immersion of the exhibition. Wang and Li [8] found that haptic feedback technology can provide audiences with realistic tactile experiences through vibration, temperature and pressure, especially among children and adolescents, haptic interaction can effectively enhance their learning interest and participation. The Shenzhen Museum has successfully enhanced the interaction between exhibits and visitors through haptic feedback technology [8]. Especially by incorporating simulated haptic experiences in exhibitions, visitors can perceive the materials of ancient artifacts through touch and gain a more three-dimensional exhibition experience.

2.4. Design of personalized experience

With the development of big data and artificial intelligence technologies, personalized experiences have gradually become an important topic in interactive exhibitions. Through real-time analysis of audience behavior data, customized interactive content can be provided for the audience [9]. Chen and Liu [9] pointed out that this personalized exhibition path can recommend exhibits based on the audience's interests,

background and interaction habits, thereby enhancing the audience's sense of satisfaction and achievement. For instance, MoMA's AR exhibition application analyzes the preferences of the audience and recommends artworks related to their personal interests, enhancing the sense of participation and educational value of the exhibition.

2.5. The marginal contribution of research

Although existing research provides valuable guidance for interactive exhibition design, there are still some deficiencies. Firstly, most studies focus on the application of a single technology, lacking in-depth exploration of the integration of multiple technologies [11,12]. Secondly, the differences in the demands of various audience groups, especially the needs of those with different ages and cultural backgrounds for interaction design, have not been fully studied [9,13]. Finally, although there have been some studies on vision and touch, the integration of multi-sensory interaction design is still not perfect, especially in the application of olfaction and hearing, where there is a significant gap [10,14]. To address these gaps, Zhao and Zhou [10] systematically reviewed multi-sensory interaction design in museum exhibitions; Li and Wang [11] discussed the integrated application of VR and AR; Zhang and Li [12] examined technology integration in exhibition space design; Wang and Liu [13] designed a personalized museum tour guide system; Chen and Li [14] summarized research progress on immersive experience design; and Zhao and Wang [15] focused on user experience in museum exhibition space design. The innovation of this research lies in the combination of multi-sensory design and intelligent technology, which proposes a new interactive exhibition space design framework [14,15]. By exploring the integration of AR, VR technology and haptic feedback technology, as well as the implementation of personalized design, the gaps in existing research are filled, aiming to enhance the interactivity, immersion and educational experience of the audience.

3. Influence Mechanism or Comparative Analysis

In the design of interactive exhibition Spaces, the application and integration of different technologies have had a profound impact on the audience's sense of participation, immersion and educational effects. This article aims to reveal the influence mechanisms of various technologies and conduct comparative analyses by analyzing the working mechanisms of technologies such as augmented reality (AR), virtual reality (VR), and haptic feedback, as well as their application effects in different exhibitions, in order to evaluate the advantages and limitations of different technologies.

3.1. A comparative analysis of Augmented Reality (AR) and Virtual Reality (VR)

As the most popular immersive technologies at present, AR and VR each have their own characteristics in the application of interactive exhibitions, and their influence mechanisms are significantly different.

3.1.1. The influence mechanism of augmented reality (AR)

AR technology breaks the spatial limitations between physical exhibits and the audience by superimposing virtual elements on the real world, making the exhibition content

more interactive [1,6]. The core advantage of AR lies in its integration of virtual information with the real world. Viewers can interact through devices such as smartphones, tablets or smart glasses without wearing specialized equipment (such as VR headsets). For instance, in the AR application of the Smithsonian Museum in the United States, visitors can view the virtual information layer of the scanned exhibits through smart devices, such as historical background, detailed explanations and dynamic demonstrations, which enhances their understanding and sense of participation in the exhibits [1].

The influence mechanism of AR is mainly reflected in the following aspects:

Information Enhancement: AR enables viewers to obtain richer background information than traditional displays by providing real-time information overlay, deepening their understanding of the exhibits [1,6].

Enhanced interactivity: Visitors are not only recipients of the exhibition content but can also interact with the exhibits through the devices, experiencing multi-dimensional perceptions, such as adjusting the angles of the exhibits and viewing more details [1,6].

Convenience: Compared with VR, AR has lower requirements for hardware. Smartphones can serve as interactive media, making it easier to be widely applied in exhibitions of different scales [1,6].

3.1.2. The influence mechanism of virtual reality (VR)

Unlike AR, VR technology enables viewers to fully immerse themselves in a virtual environment, allowing them to experience the exhibition content as if they were there [7,10]. For instance, research has shown that VR enables viewers to "personally" enter the recreated scenes of historical events or cultural sites, thereby enhancing their understanding and emotional resonance of historical culture [7].

The influence mechanism of VR is mainly reflected in the following aspects:

Immersion: VR offers a panoramic immersive experience through head-mounted displays or virtual reality devices, allowing viewers to escape the real world and immerse themselves in a virtual environment, experiencing a stronger sense of immersion and participation [7,10].

Emotional resonance: Through the design of virtual scenes, VR can evoke emotional resonance among the audience. Especially in historical and cultural exhibitions, viewers can experience a strong sense of time travel, thereby deepening their identification with historical events and cultural heritage [7,10].

Educational value: The highly interactive and realistic virtual experience provided by VR technology enables viewers to understand complex historical and cultural backgrounds more intuitively and vividly, enhancing educational effectiveness [7,10].

3.1.3. Comparative analysis

The main difference between AR and VR lies in the depth of their immersion. AR technology is more about an augmented reality experience. Viewers remain closely connected to the real world. The application of this technology is more about enhancing interactivity and information richness [1,6]. VR, on the other hand, emphasizes complete immersion. Viewers are placed in a completely virtual world. This all-round sense of immersion makes it more attractive and educational in certain scenarios [7,10]. AR is suitable for exhibitions that require real-time information updates and interaction, while VR is more

appropriate for those that need deep immersion, virtual reproduction or emotional resonance [11,12].

3.2. The influence mechanism of haptic feedback technology

Haptic feedback technology simulates the physical properties of objects such as texture, temperature or pressure, allowing the audience to perceive the characteristics of exhibits through touch, thereby enhancing the immersion and interactivity of the exhibition [8,10].

The influence mechanisms of haptic feedback include:

Rich sensory experience: Haptic feedback enables exhibitions to no longer rely solely on vision and hearing, but adds the important sense of touch, greatly enriching the experience levels of the audience [8,10].

Emotion and memory Enhancement: Research shows that tactile experiences can help people better remember and understand information. By perceiving the material and temperature features of the exhibits through touch, the audience can form a deeper impression and enhance their emotional connection with the exhibits [8,10].

Enhanced learning motivation: Especially among child and adolescent audiences, haptic feedback can stimulate their curiosity and desire to explore the exhibits, thereby enhancing their learning motivation and interactive participation [8,9].

For instance, the tactile interactive exhibition at the Shenzhen Museum enhances the audience's sense of participation and emotional connection with the exhibits by simulating the materials of historical artifacts [8]. Through vibration, temperature changes or simulating the texture of objects, haptic feedback technology enables the audience to "touch" the materials of ancient artifacts, enhancing the authenticity and sensory experience of the exhibition [8,10].

3.3. The influence mechanism and advantages of technology integration

The greatest advantage of technological integration lies in its ability to complement different technologies, thereby enhancing the overall interactivity, immersion and educational effect of the exhibition [11,12]. For instance, the integration of AR and VR technologies can make exhibitions more three-dimensional, offering both virtual immersive experiences and enhanced information from the real world [11,12]. The introduction of haptic feedback technology can further enrich the multi-sensory experience of the audience, allowing them to be stimulated simultaneously in terms of vision, hearing, and touch, and increase the sensory richness and participation of the exhibition [10,14].

All-round experience: By integrating AR, VR and haptic feedback technologies, viewers can not only enjoy an immersive virtual experience, but also receive haptic feedback during the interaction with actual exhibits, enhancing their understanding and emotional connection with the exhibits [11,12,14].

Enhancing interactivity and personalized experience: The integration of technology enables exhibitions to offer customized interactive content based on the interests and behaviors of the audience [9,13]. For instance, visitors can obtain information through AR technology, experience immersive scenes through VR, and then perceive the materials of objects through haptic feedback, thus forming personalized visiting paths [9,13].

Enhancing educational effectiveness: The integration of multiple technologies not only offers a richer interactive

experience but also helps the audience better understand the exhibition content through a comprehensive and multi-sensory approach, thereby enhancing educational effectiveness [10,14].

Through a comparative analysis of the influence mechanisms of AR, VR, haptic feedback technology and their integration, the following conclusions can be drawn: The application of different technologies in interactive exhibitions has its own advantages and disadvantages. AR is suitable for information enhancement and light interaction, VR is suitable for providing deep immersion and emotional resonance, while haptic feedback offers a multi-sensory deep experience for exhibitions. The integration of technologies can maximize the interactivity, immersion and educational effect of exhibitions. Future interactive exhibition design should take into account the characteristics of these technologies comprehensively and apply them flexibly to meet the needs of different audience groups and enhance the exhibition effect [13,15].

4. Case Analysis

4.1. The virtual reality (VR) exhibition at the Science Museum in London

As one of the world's most influential science museums, the Science Museum in London is dedicated to showcasing the advancements in science and technology and attracting global audiences through innovative exhibitions. In recent years, with the rapid development of virtual reality technology, museums have been actively exploring the application of VR technology in exhibitions. The "Virtual Reality Adventure" exhibition at the Science Museum in London is a typical case of its application of VR technology. This exhibition uses head-mounted VR devices and spatial tracking technology to lead visitors through historic scientific breakthroughs such as the moon landing and deep-sea exploration, presenting an immersive scientific experience. Viewers can not only understand scientific principles more intuitively through VR technology, but also perceive a deep connection with the virtual world through interactive feedback [7].

The success of this exhibition demonstrates how VR technology can enhance the audience's sense of participation and immersion in museum exhibitions, making scientific exploration more vivid and attractive. Meanwhile, the Science Museum in London has enhanced its competitiveness among museums worldwide with this innovative exhibition and attracted more young visitors and technology enthusiasts.

However, despite the positive feedback the exhibition received, the wide application of VR technology still faces some challenges. The first is the high cost of hardware. VR equipment and its maintenance costs are relatively high, and it requires specialized technical support and operators, which puts pressure on the museum's financial and human resources. In addition, the popularity of VR technology remains limited, and some viewers have difficulty adapting to head-mounted devices, especially the elderly and those with physical disabilities. In addition, the physical discomfort that may be caused by wearing VR devices for a long time (such as motion sickness, etc.) is also a problem that needs to be solved in exhibition design.

4.2. The application of haptic feedback technology in Shenzhen Museum

The Shenzhen Museum has always been committed to

enhancing the exhibition experience through innovative technologies. With the gradual maturation of haptic feedback technology, museums have introduced it into exhibitions, aiming to provide visitors with a more diverse multi-sensory experience. In the haptic feedback exhibition at the Shenzhen Museum, visitors not only perceive the exhibits through vision and hearing, but also experience the materials, texture and weight of the exhibits through touch [8]. Especially in exhibitions targeting children and teenagers, haptic feedback technology has significantly enhanced the audience's interest and sense of participation in the exhibits, while also improving the educational value of the exhibitions.

The successful application of this technology has broken through the limitations of traditional exhibition methods, not only enhancing the interactive experience of the audience, but also increasing the educational value and communication effect of the exhibits. Through haptic feedback, when visitors experience historical relics and technological exhibits, they can deepen their understanding and emotional connection with the exhibits through the simulated texture and haptic stimulation [8].

Although the application of haptic feedback technology in the Shenzhen Museum has achieved positive results, the popularization of this technology still faces certain challenges. First of all, the high cost of technology is a significant issue. Haptic feedback devices require precise design and have relatively high maintenance and upgrade costs. Secondly, the compatibility and comfort of the equipment are also areas that need improvement. How to enable the audience to experience haptic feedback more naturally during the interaction process and avoid the interference of devices on the user experience is a difficult problem that needs to be solved in technical design. In addition, the realization of haptic feedback requires the coordination of vision, hearing and touch, which places high demands on the comprehensiveness of the technology and makes it difficult to enhance the multi-sensory experience [10].

4.3. The AR application in the Museum of Modern Art (MoMA) in New York

As one of the world's leading museums of modern art, the Museum of Modern Art (MoMA) in New York has always been committed to integrating technology with art to offer cutting-edge exhibition experiences. MoMA's AR exhibition utilizes augmented reality technology to provide visitors with information such as the creation process, historical background, and the artists' ideas of the artworks through smart devices. Visitors can view virtual information related to the exhibits in real time by scanning the QR code or using dedicated devices, further enhancing their understanding and sense of participation in the artworks [1,6].

The AR exhibition of MoMA has successfully promoted the integration of art and technology, attracting the attention of a large number of technology and art enthusiasts, and also providing strong support for the museum's transformation in the digital age. This exhibition not only enhanced the audience's participation but also made the interpretation of the artworks more vivid and multi-dimensional, providing a new approach for art education.

However, despite the successful application of AR technology in the MoMA exhibition, there are still some challenges. The first issue is device dependency. Viewers need to use smartphones or dedicated devices to experience AR content. However, the popularity and usage habits of

these devices vary, and some viewers may develop a resistant attitude towards new technologies. Secondly, the information provided by AR technology may be overly complex or lengthy. If the content is not carefully designed, it may confuse the audience or cause information overload, affecting the experience effect. In addition, the update and maintenance of AR content is also a continuous challenge. How to keep the content fresh and educational requires museums to invest continuous resources.

4.4. The AR application in the Liangzhu Museum in Hangzhou

As a renowned cultural heritage museum in China, the Liangzhu Museum in Hangzhou is committed to enabling visitors to better experience the unique charm of Liangzhu culture through modern technological means. The museum has introduced the world's first smart AR navigation glasses. After wearing the AR glasses, visitors can see the multimedia information of cultural relics during on-site visits and also witness the recreation of historical scenes. Through AR technology, the architectural complexes and scenes from five thousand years ago have been recreated, making visitors feel as if they have traveled back to ancient times and enjoying an extremely immersive visiting experience [6].

This exhibition fully demonstrates the huge potential of AR technology in the reproduction of cultural sites and historical scenes. By combining ancient culture with modern technology through augmented reality, it not only enhances the visiting experience of tourists but also deepens their understanding and recognition of the Liangzhu Culture.

Although the AR glasses exhibition at Liangzhu Museum was warmly welcomed by visitors, there are still several challenges in the wide application of AR technology. First of all, the use of AR glasses requires tourists to have a certain ability to accept technology. Some tourists may feel strange or unaccustomed to high-tech products. Secondly, the comfort and portability of the equipment still need improvement. Wearing glasses for a long time may cause discomfort and affect the experience of tourists. In addition, the high cost of AR glasses and the technical maintenance expenses are also important issues that museums need to consider. How to balance innovation and cost-effectiveness and ensure the sustainable application of the technology is one of the challenges faced by this project.

Through case studies of the Science Museum in London, the Shenzhen Museum, MoMA and the Liangzhu Museum in Hangzhou, it can be seen that technologies such as virtual reality, haptic feedback and augmented reality have significant advantages in enhancing the experience of interactive exhibition Spaces, especially achieving remarkable results in improving the immersion, interactivity and educational value of the audience [1,6,7,8,10]. However, the high cost of technology, the issue of equipment compatibility, the audience's acceptance of technology, and the accuracy of content design remain important challenges currently faced by exhibition design. Museums and cultural institutions need to strike a balance between technological innovation and resource allocation to ensure that technology can truly serve the experience and educational goals of the audience.

5. Existing Problems or Challenges Faced

Although interactive exhibition space design has made remarkable progress by introducing innovative technologies such as augmented reality (AR), virtual reality (VR), and haptic feedback, it still faces many problems and challenges in practical application. The following are the main existing problems:

5.1. The limitations of technological integration

At present, the application of technologies such as AR, VR and haptic feedback in interactive exhibitions often remains at the experimental stage of a single technology, lacking in-depth cross-technology integration and collaborative design. Although different technologies can play unique roles in specific scenarios, their combined application still faces many challenges [11,12]. For instance, the hardware requirements for VR and AR are different. VR demands high-performance computers and dedicated equipment, while AR can be carried out through smartphones or tablet devices. This makes it a technical challenge to coordinate the application of the two in an exhibition space. The integration and complementary design of technologies still lack mature practical cases. Therefore, how to effectively integrate these technologies to enhance the exhibition experience remains an unsolved problem.

5.2. Hardware costs and equipment popularization

AR and VR technologies require certain hardware support, and the high cost and popularity of related devices remain the main problems faced by interactive exhibitions at present. VR headsets, AR glasses and other devices require a relatively high technical investment. Moreover, for some cultural institutions with limited funds such as museums and science and technology museums, these devices may have considerable procurement and maintenance costs [1,6,7]. In addition, the use of the equipment requires certain technical support and training, which brings additional burdens to the operation of the exhibition space. Therefore, in terms of the popularization of hardware equipment and cost control, how to balance the innovation of technology and the economic affordability of exhibition institutions remains an urgent problem to be solved.

5.3. The differentiation and personalized design of audience demands are insufficient

Although the introduction of technology has brought a richer interactive experience to the exhibition, the diversity of audience demands remains an undeniable challenge in the design. Audiences of different age groups, cultural backgrounds and interests have very different demands for exhibitions. However, most of the existing interactive exhibition designs tend to be highly universal solutions, and personalized designs have not received sufficient attention [9,13]. Especially for some groups (such as children, the elderly, people with disabilities, etc.), there is still a lack of sufficient research and practice on how to adjust the application of technology and exhibition content according to their specific needs. Although functions such as personalized

path recommendation and customized interactive content have great potential in theory, they still face technical implementation difficulties in practical applications.

5.4. The excessive reliance on technology and its compatibility with traditional exhibition content

With the continuous development of technology, exhibition Spaces are gradually relying on new technologies for upgrading and replacement. However, this has also led to compatibility issues between traditional exhibition content and technology. In some museums and science and technology museums, the integration of traditional exhibits and modern technology is often difficult to coordinate. Some exhibitions overly rely on technological display methods, causing exhibits that originally had rich cultural and historical value to lose their original charm. For instance, some VR or AR exhibitions may overly focus on virtual experiences while neglecting the historical and cultural connotations of the physical exhibits, thereby weakening their educational and cultural dissemination functions [7,10]. Therefore, how to strike a balance between modern technology and traditional exhibition content and ensure that the application of technology does not affect the essential value of the exhibits is another major challenge faced by exhibition design.

5.5. The implementation difficulty of multi-sensory design

Multi-sensory design (including the combination of multiple senses such as vision, hearing and touch) is regarded as an effective way to enhance immersion and interactivity. However, in practical applications, how to effectively integrate multiple sensory elements and achieve cross-sensory interaction remains a huge challenge [10,14]. Although there are already some application cases of haptic feedback and visual design, the integration of senses such as smell and hearing is still in its infancy. For instance, how to convey specific emotional information or historical background through smell, and how to enhance the authenticity of the experience through the combination of sound and vision, are both current technical and design practice challenges. In addition, the compatibility of technology and the coordination of equipment also bring complexity to the realization of multi-sensory design.

5.6. The speed of technological updates and the adaptability of design

With the rapid update of technology, interactive exhibition design is confronted with the issue of how to adapt to technological changes and maintain long-term appeal. Technologies such as AR and VR are constantly evolving, and the update speed of hardware and software is relatively fast. This makes some technical equipment and design schemes that have been put into use likely to be phased out soon or require frequent upgrades [1,7]. For long-term operating cultural institutions such as museums and science and technology museums, how to flexibly respond to technological updates and changes while ensuring the quality of exhibition content and guaranteeing the sustainability of technological investment is a practical issue faced by exhibition design.

5.7. The deep emotional resonance of the audience and the risk of excessive commercialization

Interactive exhibition Spaces enhance the audience's sense of immersion and participation through technological means, but this may also lead to a superficial emotional resonance. Interactive experiences that overly rely on technology may cause the audience to pay more attention to the shock of technology while neglecting the educational significance and cultural depth of the exhibition content itself [7,10]. Furthermore, overly commercialized exhibition design may lead to technology being used to enhance entertainment rather than education, thereby affecting the academic and cultural nature of the exhibition. For instance, some museums might incorporate too many entertainment elements to attract visitors, causing the exhibitions to lose their serious cultural value. Therefore, when designing, how to balance technological innovation with the depth of education and culture and avoid the superficial effects brought by technology is a key issue that needs to be considered in the design process.

5.8. Privacy and data security issues in technological applications

With the application of personalized design and big data analysis, a large amount of information such as the audience's behavioral data and interest preferences has been collected and utilized. This involves issues of data privacy and security. In some interactive exhibitions, visitors may need to provide personal information and behavioral data to obtain customized interactive content. However, how to ensure that these data are not misused and how to prevent data leakage and privacy infringement have become an important challenge in the application of technology [9,13]. Exhibition designers need to strike a balance between the application of innovative technologies and the protection of audience privacy, ensuring the legality and security of data.

Although interactive exhibition space design offers visitors a brand-new experience through technological innovation, it still faces a series of challenges such as technology integration, hardware costs, personalized design, content compatibility, and the implementation of multi-sensory design. To overcome these problems, exhibition designers need to conduct in-depth thinking in aspects such as the selection and application of technology, the way exhibition content is conveyed, and the differentiation of audience demands. Through interdisciplinary cooperation, technological innovation and practical accumulation, they should gradually improve the design concept and implementation path of interactive exhibition Spaces.

6. Results

Through case studies of the London Science Museum, Shenzhen Museum, Modern Art Museum, and Hangzhou Liangzhu Museum, it can be observed that virtual reality (VR), augmented reality (AR), and haptic feedback technologies have demonstrated significant effectiveness in enhancing the immersion, interactivity, and educational value of interactive exhibition spaces [1,6,7,8,10]. The research results indicate that these technologies have effectively increased the audience's engagement, enabling them to more deeply understand the exhibition themes through multi-sensory immersive experiences. For instance, VR technology

recreates historical scenes virtually, allowing visitors to "be there" and experience cultural events in person [7]; AR technology enhances the visual information of physical objects through digital overlay [1,6]; and haptic feedback technology enables visitors to have richer sensory participation during interactions, thereby forming dual connections of memory and emotion [8,10].

However, the research also reveals several challenges that arise during the application of technology. Firstly, the high costs of equipment and maintenance limit the large-scale promotion of technology; secondly, the differences in technology usage among different audience groups (such as the elderly, children, and people with disabilities) result in an imbalance in the experience; moreover, some museums have not yet achieved effective integration between exhibition content and technological presentation, leading to the use of technology being merely formal and lacking in deep educational value [11,12]. The research also found that although technology can significantly enhance the appeal of exhibitions, its educational significance and cultural dissemination effect still depend on the quality of exhibition content design and the completeness of narrative logic. Therefore, personalized design has become an important direction for improving the audience experience in the future. By customizing interfaces and content for different groups based on their differentiated needs, the satisfaction of audiences and learning effectiveness can be effectively enhanced [9,13]. The research also pointed out that the government and cultural institutions should play a leading role in promoting the integration of technology and culture, including providing financial and policy support, promoting cooperation between museums and technology enterprises, improving equipment compatibility and penetration rate, etc. Multi-sensory interaction design and data privacy protection should also become key research and practice directions in the future [10,14,15].

7. Conclusion

The application of virtual reality, augmented reality and haptic feedback technologies in interactive exhibition spaces has significantly enhanced the immersion and participation of visitors, and strengthened the educational function of museums [1,6,7,8,10]. However, problems such as high technical costs, audience heterogeneity and insufficient content integration still restrict the further development of these technologies [11,12]. Future research should continue to explore in the areas of technology accessibility, personalized experience design and multi-sensory integration [9,13,14]. At the same time, greater attention should be paid to data security and privacy protection. The government and cultural institutions should collaborate to promote the combination of technological innovation and cultural inheritance, establish a sustainable technical support system, and promote the popularization of interactive exhibitions and the long-term

development of cultural dissemination [15].

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