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The Intersection of Digital Wellbeing and Collection Exhibition: A Study on the Impact of AR Interactive Display Models on Visitor Experience

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Abstract. This study presents an innovative AR interaction model for small exhibits, integrating physical and virtual display techniques. Combining hand detection sensors and 3D modeling, it allows direct manipulation of virtual objects, enhancing interactivity and immersion. Specifically, the model utilizes Leap Motion for gesture interaction, enabling intuitive and natural user engagement with virtual exhibits. A mixed-method approach assessed its impact on 200 randomly assigned participants. Results show significant improvements in interactivity, immersion, learning effectiveness, and overall satisfaction compared to traditional methods. Quantitative analysis revealed statistically significant differences (p ¡ 0.001) with large effect sizes (Cohen's d ¿ 0.8). Qualitative findings corroborated these results, highlighting increased engagement and deeper understanding. The practical implications of this research extend to museums and cultural heritage display settings, where the AR interactive model offers a scalable and engaging solution for enhancing visitor experiences. The findings further indicate that this AR interactive display model not only enhanced exhibition effectiveness but also positively impacted visitors' digital wellbeing, notably by fostering social interaction and mitigating digital fatigue.

Keywords: Augmented Reality (AR), Interactive Display, Virtual Exhibit Interaction, Visitor Experience, Digital Wellbeing.

1. Introduction

The rapid development of digital technology has made Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) essential tools for cultural heritage preservation and exhibition. These technologies significantly enhance visitors' immersive experiences and interactivity. Bekele et al. [4] comprehensively reviewed the application of these exhibition technologies in the cultural heritage field, emphasizing their importance in exhibiting and protecting artifacts and cultural heritage. In current exhibition applications, the integration of physical and virtual exhibitions has become a trend in museum exhibitions.

Petrelli et al. [5] pointed out that this combination can provide diverse experiences, meeting the needs of different visitors. Additionally, researchers such as Eghbal-Azar et al. [6] found that digital guide systems have significant advantages in information selection and delivery, further promoting this type of integration.

Immersive experiences and interactivity are at the core of modern exhibition technologies. Younan and Treadaway [7] emphasized the role of 3D digital models in enhancing interactivity and immersion, while Jin et al. [8] confirmed the significant impact of VR and AR technologies on improving visitor experiences. Other related studies have focused on small exhibit exhibitions. Scopigno et al. [9] and Balletti et al. [10] explored the application and integration of digital manufacturing and 3D printing technologies in exhibitions. Recent research [11] has also focused on the potential of gesture recognition technology in cultural heritage exhibitions.

Based on these developments, this study explores a novel interactive exhibition mode that integrates physical and virtual interactive exhibitions within the same showcase. Through hand detection sensors, visitors can directly manipulate virtual exhibits, which is particularly suitable for small artifacts. By utilizing 3D modeling technology to provide rich interactive experiences, this research aims to promote innovation in exhibition technology and provide theoretical and design foundations for future exhibition models. Moreover, this study investigates how AR interactive display technology simultaneously enhances exhibition effectiveness and promotes visitors' digital wellbeing, offering a novel perspective on the role of exhibition spaces in the digital era.

The contributions of this study are threefold:

Development of an Innovative AR Interactive Display Model: This study introduces a novel AR-based framework that seamlessly integrates physical artifacts with virtual interaction, using gesture recognition technology to enhance user engagement, particularly for small-scale exhibits.

Empirical Evidence of AR's Impact on Visitor Experience: Through a mixed-method approach, the study provides comprehensive data demonstrating AR's effectiveness in improving interactivity, immersion, cognitive engagement, and digital wellbeing compared to traditional exhibition methods.

Advancement of Digital Literacy and Inclusive Learning: The research highlights AR's role in promoting digital literacy and fostering inclusive learning environments, emphasizing its potential to support diverse learning styles and enhance accessibility for a broad range of audiences.

1.1. Research Objectives

With the rapid development of digital technology, the application of exhibition technologies in museums and the cultural heritage field has gained increasing attention, especially with the rise of AR, VR, and MR technologies, which have brought significant changes to exhibition methods and visitor experiences [4,5]. The primary objective of this research is to design and develop a novel interactive exhibition mode that integrates physical exhibits with virtual interactive exhibitions within the same showcase. By utilizing hand detection sensors and 3D modeling technology, visitors can directly manipulate virtual exhibits in front of the showcase, such as zooming in, zooming out, and rotating, to achieve a more detailed observation experience.

The study will particularly focus on the following specific objectives:

Design and development of an integrated physical and virtual exhibition model: Based on current trends in exhibition technology, this research will explore how innovative hand detection technology can enhance visitor interactivity and immersion, enabling direct manipulation of virtual exhibits. This design will build upon previous research [6,7], further optimizing and innovating to meet the specific needs of small exhibit displays.

Evaluation of the model's impact on visitor experience: Through experimental design and comparative studies, this research will systematically assess the impact of the exhibition model on visitor interactivity, immersion, and satisfaction. Previous studies have shown that AR and VR technologies can significantly enhance visitor experiences, particularly in terms of immersion and engagement [8,9]. Therefore, this study will employ surveys, interviews, and observations to collect data and conduct detailed analyses to validate the effectiveness of this model.

Technical implementation and challenge analysis: This research will also conduct an in-depth analysis of the technical implementation process of the exhibition model, including the application of projection technology, the practicality of hand detection, and the challenges of system integration [12,13]. The successful application of these technologies will provide valuable insights for future innovation and development in exhibition technology.

The ultimate aim of this research is to design and develop this novel interactive exhibition model, thereby advancing the innovative application of exhibition technology in museums and cultural heritage and providing a theoretical foundation and practical applications for future exhibition models.

2. Related Literature

With the rapid development of digital exhibition technologies, particularly in the fields of museum and cultural heritage exhibitions, the application of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) technologies has become increasingly widespread. These technologies have significantly altered the way visitors experience exhibitions and have brought profound changes to the presentation of exhibition content and methods of interaction. For instance, research indicates that the application of AR technology in museum artifact exhibitions can significantly enhance visitor engagement and learning outcomes, while VR technology has improved visitors' depth of perception and sense of involvement in immersive exhibitions [14,15].

In recent years, the development of Augmented Reality (AR) and Virtual Reality (VR) technologies in education has significantly influenced immersive learning experiences. According to the research "Analyzing augmented reality (AR) and virtual reality (VR) recent development in education." [1], AR and VR enhance cognitive engagement, support personalized learning environments, and foster higher motivation and interaction among learners. This comprehensive review highlights the exponential growth of AR and VR applications in educational contexts, emphasizing their potential to bridge the gap between theoretical knowledge and real-world application. These findings align with the objectives of this study, which explores the integration of AR technologies to improve visitor experiences in exhibition environments.

In addition to AR, VR, and MR, recent advancements in Ambient Intelligence have further expanded the potential of interactive exhibition technologies. Ambient Intelligence refers to environments enriched with embedded sensors, networks, and intelligent systems that proactively support user activities [3]. By integrating AR technologies with Ambient Intelligence, exhibitions can achieve adaptive, context-aware interactions that respond dynamically to visitors' behaviors and environmental conditions. This integration enhances both the interactivity and personalization of exhibitions, providing visitors with immersive and engaging experiences tailored to their preferences.

Furthermore, the integrated application of hand detection technology and 3D modeling technology has also gained widespread attention in exhibition technology. Hand detection technology, by providing intuitive and natural interaction methods, has effectively enhanced visitors' sense of engagement [16]. Concurrently, the development of 3D modeling technology has enabled virtual exhibits to be presented more realistically, improving the authenticity and interactivity of exhibition content [17]. The advancements in these technologies have not only enhanced the interactivity of exhibitions but also significantly increased visitors' sense of immersion. Research shows that interactive exhibition technology can enhance visitors' immersive experience by incorporating elements such as gesture control, while combining AR with hand detection technology can create a more immersive exhibition environment, further improving user satisfaction [18]. Additionally, the integration of Ambient Intelligence concepts supports the creation of intelligent, responsive environments that adapt in real-time to optimize visitor engagement and learning outcomes. These research findings provide important academic background for the design of the exhibition interaction model in this study and lay the technological foundation.

2.1. Current Exhibition Technologies and Interaction Methods

In recent years, exhibition technologies in the fields of museums and cultural heritage have seen continuous development, especially with the advancements in Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). These technologies have significantly transformed exhibition methods and visitor interaction experiences. They provide powerful tools to enhance the interactivity and immersion of exhibition content, turning exhibitions from static displays into dynamic and immersive experiences.

AR and VR technologies have been widely applied in cultural heritage and museum exhibitions, allowing for the virtual recreation of historical scenes or providing additional layers of information. For instance, Blanco-Pons et al. studied how AR and VR technologies can enhance cultural heritage experiences through virtual reconstructions, finding that these technologies significantly boost visitor engagement and learning outcomes [14]. De Paolis et al. explored the usability of VR in cultural heritage from a user perspective and found that VR offers highly immersive experiences, enhancing visitor satisfaction and depth of understanding [19].

Gesture recognition technology has also emerged as a significant highlight in exhibition technologies in recent years. Zerrouki et al. (2024) demonstrated that gesture recognition technology can significantly improve the interactivity of virtual museums, allowing visitors to interact with exhibits in a natural way, thereby enhancing their overall experience [16]. Moreover, Kyriakou et al. explored the combination of gesture recognition and AR technology, finding that this combination can further enhance user experience in virtual museums, particularly in improving immersion and operational convenience [21].

The application of 3D modeling technology is also becoming increasingly widespread, especially in the construction of virtual museums. Carvajal et al. studied the application of 3D modeling technology in virtual museums and pointed out that this technology can accurately digitize physical exhibits, providing richer exhibition content and higher interactivity [17]. These technological advancements provide crucial technical support for the innovative design of exhibition models.

In recent years, the importance of digital wellbeing in exhibition spaces has become increasingly prominent. Studies have indicated that appropriately designed digital interactions can enhance visitors' learning experiences while mitigating digital fatigue [22]. A study conducted on 279 participants to assess the psychological impact of AR museum experiences on visitors revealed that such experiences contribute to improved attention restoration levels, stress reduction, and anxiety alleviation [23]. This research further explores the potential of AR technology in this context.

In summary, the development of current exhibition technologies and interaction methods has not only greatly enhanced visitor immersion and engagement but also laid a solid foundation for the innovative application of exhibition technologies in the future. This study will build on these technological trends to further explore how to effectively integrate these technologies to design more interactive and immersive exhibition models.

2.2. Visitor Experience Research

In exhibition technology, research on visitor experience has always been a crucial topic. In recent years, with the popularization of technologies such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), the methods of museum and cultural heritage exhibitions have undergone significant changes, profoundly impacting visitor experiences. Research shows that these immersive technologies not only significantly enhance visitors' sense of immersion but also improve their learning outcomes and interactive engagement.

The research of Blanco-Pons demonstrated that AR and VR technologies can effectively enhance the experience of cultural heritage exhibitions, particularly in strengthening audience engagement and depth of understanding [14]. Furthermore, The research of Hulusic explored the application of VR technology in cultural heritage, finding that visitors can achieve a higher sense of immersion in virtual environments, which not only increased visitor satisfaction but also enhanced their understanding of exhibits [15].

Regarding gesture interaction technology, Huang et al. investigated the application of gesture recognition technology in museum exhibitions. Their research showed that this technology can provide more natural and intuitive interaction methods, significantly improving visitor experiences [16]. The new research about the further explored the combination of gesture recognition and AR technology, discovering that this integration not only enhanced the immersion of virtual museums but also improved user operational convenience [20].

Moreover, the application of 3D modeling technology in virtual museums has also significantly improved visitor experiences. Carvajal et al. studied the application of 3D modeling technology in virtual exhibitions, pointing out that this technology can digitize physical exhibits, providing more realistic and interactive exhibition content, thereby enhancing the overall visitor experience [17].

These studies indicate that through the application of advanced technologies, exhibition methods are no longer limited to static viewing but have become dynamic, highly interactive, and immersive experiences. The application of these technologies provides important theoretical basis and practical foundation for future innovation in exhibition models.

3. Innovative Exhibition Model Design

This study proposes a novel exhibition model aimed at integrating physical exhibitions with virtual interactive displays, with a particular focus on optimizing the presentation of small exhibits, especially those with details that are difficult to observe with the naked eye. The exhibition model proposed in this research utilizes hand detection sensors and 3D modeling technology, allowing visitors to directly manipulate virtual exhibits, such as zooming in, zooming out, and rotating them, to achieve more detailed observation. The application of this technology not only enhances the interactivity of the exhibition but also improves visitor immersion and satisfaction. The display cabinet designed in this study also incorporates advanced projection technology, ensuring that virtual content is precisely projected onto transparent glass while avoiding issues with glaring light, further enhancing the exhibition's effectiveness. The innovative exhibition model in this study aims to address the shortcomings of existing exhibition technologies, creating a more engaging and educational experience for visitors by combining virtual and physical exhibition methods.

3.1. Visitor Experience Research

The innovative exhibition model proposed in this study aims to break the limitations of traditional exhibition methods by integrating physical displays with virtual interactive technology, providing visitors with a completely new interactive viewing experience. The core concept of this model is to achieve seamless integration of physical and virtual exhibits within the same display case, creating an exhibition environment that is both realistic and highly interactive.

According to research by Dieck et al. [24], mixed reality technology has enormous potential in cultural heritage exhibitions, capable of significantly enhancing visitor engagement and depth of understanding. Based on this concept, the model in this study employs advanced projection technology to accurately present virtual content on the front glass of the display case. This approach not only preserves the authenticity of physical exhibits but also enriches the exhibition content through virtual elements, echoing the idea of enhancing cultural heritage accessibility proposed by Paladini et al. [25].

Another innovation of this model is the introduction of hand detection sensors, allowing visitors to directly manipulate virtual exhibits through gestures. The design of this interaction method was inspired by the research of Trajkova. [26], who found that natural gesture interaction can significantly enhance museum visiting experiences. Through this method, visitors can easily zoom in, zoom out, and rotate virtual exhibits, achieving in-depth observation of small or intricate exhibits, which is difficult to achieve in traditional exhibition methods.

To better illustrate the transparent projection interactive mode of this study, please refer to Figure 1 and Figure 2.

Integration of Transparent Projection Interactive Mode:

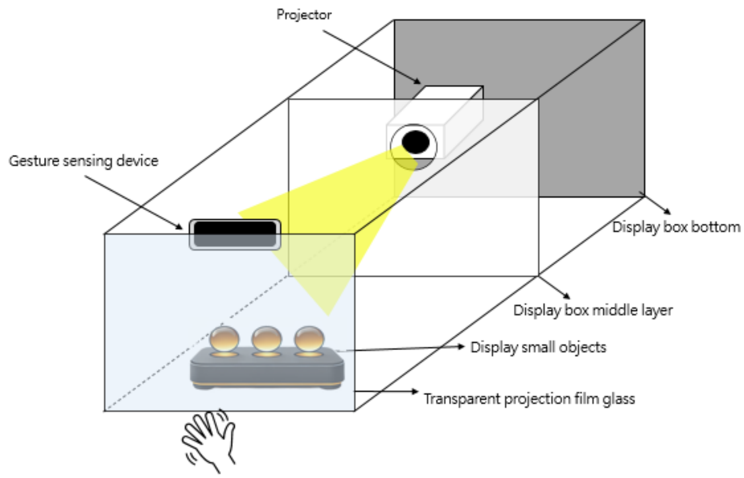

Fig. 1. The Transparent Interactive Projection Framework in this study

(a) Single-hand gesture interface

(b) Dual-hand gesture interface

Fig. 2. Actual operation interfaces of single-hand and dual-hand gesture sensing

To achieve this goal, this study adopts the transparent projection interactive mode as the core technology, as shown in Figure 1. The transparent projection interactive mode is an emerging exhibition technology that cleverly combines physical displays with virtual interactions. By projecting high-resolution images onto transparent screens or glass, visitors can view virtual information and 3D models related to the exhibits through the transparent screen while observing the physical exhibits. This combination of virtual and real exhibition methods not only enriches the exhibition content but also enhances the interactivity and sense of engagement for visitors.

Application of Hand Detection Sensors:

To further enhance interactivity, this study introduces hand detection sensors based on the transparent projection interactive mode, as shown in Figure 2. Visitors can directly interact with virtual content through gestures, such as zooming in, zooming out, rotating virtual exhibits, and even triggering specific animations or information. This intuitive interaction method allows visitors to no longer be passive recipients of information, but to actively explore, creating a more personalized and attractive viewing experience.

Furthermore, the research mode pays particular attention to addressing the glare problem that projection technology may cause. Referring to the research on museum lighting design by Lee. [27], this study employs special projection technology and materials to ensure that virtual content is clearly visible without negatively impacting visitors' visual comfort.

This method of integrating physical and virtual exhibitions is not only suitable for small exhibits but can also be extended to various types of cultural relic exhibitions. As Hauser [28] pointed out, this mixed exhibition method can provide visitors with multilayered information and a deeper cultural experience. By combining 3D modeling technology with physical exhibits, the mode in this research can present different details of the exhibits and a 360-degree all-around viewing perspective, thereby greatly enriching the educational value of the exhibition.

Overall, this innovative exhibition mode successfully combines physical exhibits with virtual interaction organically by integrating various advanced technologies, opening up new possibilities for exhibitions and cultural heritage displays. It not only enhances the interactivity and attractiveness of the exhibition but also provides visitors with a more in-depth and comprehensive way of learning and exploration. In addition to the aforementioned aspects, this study also investigates the impact of AR interactive display models on visitors' digital wellbeing, encompassing dimensions such as social interaction, learning experiences, and comfort levels with technology use. This research objective aligns with the growing significance of digital wellbeing in exhibition spaces and aims to understand how innovative display technologies can contribute to visitors' overall digital health and experience.

3.2. Technical Implementation Details

The technical implementation of this innovative exhibition model is based on the integration and application of various advanced technologies, with the aim of enhancing the interactivity of the exhibition and the immersive experience of visitors. The following are the detailed implementation specifics for each technology.

Hand detection technology plays a central role in this exhibition model, allowing visitors to manipulate virtual exhibits within the display cabinet through gestures. This technology is based on optical gesture recognition, utilizing a depth camera to capture visitors' hand movements and instantly converting them into control commands. The application of this technology has been proven to significantly enhance interactivity and user experience, particularly in interactive exhibition environments such as museums [29]. Moreover, recent studies have shown that the combination of hand detection technology with AR can further enhance user immersion and operational convenience in virtual museums [16].

In this study, Leap Motion was chosen as the hand detection sensor. Leap Motion is a high-precision, low-latency hand tracking device that can capture subtle movements of fingers and palms, providing highly accurate gesture recognition. Through Leap Motion, visitors can interact with virtual exhibits in a natural and intuitive way, performing actions such as zooming in, zooming out, and rotating, as if manipulating real objects. The advantage of Leap Motion lies in its high precision and low-latency gesture recognition capabilities, offering a smooth and natural interactive experience. Additionally, Leap Motion is compact and easy to integrate into the display cabinet, without affecting the overall exhibition effect. The application of Leap Motion in this study's exhibition model enables more precise and intuitive gesture interaction, providing visitors with a richer and more immersive interactive experience.

Fig. 3. 3D modeling image of an exhibit in this study

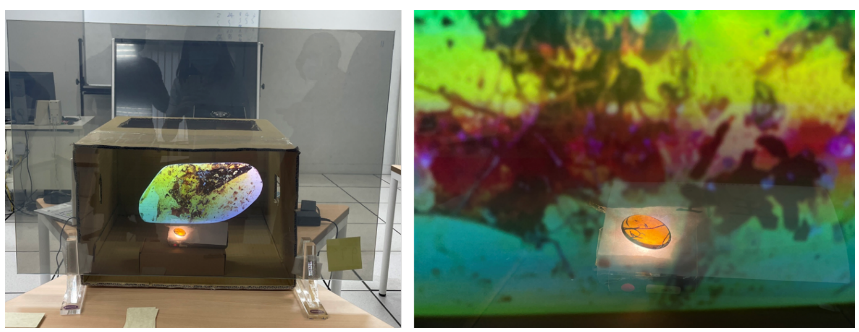

Fig. 4. Testing the transparent projection film (ANSLCF) in the laboratory for image projection and film transparency

This study applies 3D modeling technology to achieve virtual display of small exhibits. Research shows that 3D modeling technology can significantly enhance the realism and interactivity of exhibition content [30], thereby enhancing visitors' immersive experience. This study uses Blender software to model amber exhibits, improving the accuracy and realism of the models through a series of intricate processes. Figure 3 shows a 3D modeling image of one of the exhibits. This process includes high-resolution image acquisition, image processing, photogrammetry, mesh reconstruction, UV unwrapping and texturing, material setup, lighting and rendering, and final optimization. Professional photography equipment is used to capture high-resolution photos, Adobe Photoshop is used for image preprocessing, Blender's photogrammetry plugin is utilized to generate initial

3D point cloud models, and then precise polygon models are created through mesh reconstruction. The UV unwrapping and material setup stages simulate the translucent properties and internal details of amber, while lighting and rendering ensure optimal presentation of the model in various environments. The final optimization step ensures smooth operation of the model in real-time interactive environments. This process successfully creates highly realistic and interactive virtual amber exhibits, not only accurately replicating the appearance of physical amber but also presenting its unique internal structure and optical properties. This allows visitors to explore these small exhibits in unprecedented ways, greatly enhancing the educational value of the exhibition and the experience of detailed observation.

The interactive transparent projection mode in this study employs advanced projection technology to precisely project virtual content onto the transparent glass of the display case. To avoid the glare often associated with traditional projection, the study uses high-contrast projection equipment combined with special light-transmitting materials. This ensures that the projected content is clearly visible in various lighting conditions without compromising visitor comfort. This technology has already been successfully implemented in museum lighting design, demonstrating its potential for enhancing exhibition effectiveness [31].

Specifically, the transparent projection is achieved using the high-transparency projection film (Anisotropic Nano-Structure Light Control Film, ANSLCF) from BENQ MATERIALS CORPORATION. This special projection film combines polymers, liquid crystals, nanoparticles, and optical design. It features high transparency and flexibility, capable of displaying images with up to 8K resolution without being constrained by screen size, allowing for customized designs based on exhibition space requirements. Another significant advantage of the ANSLCF transparent projection film is its 80% light transmission rate, which enables the projection content to display vivid colors without causing glare, while maintaining a clear view through the film. This technology effectively avoids common visual hotspots and light pollution issues seen in traditional projection technologies, offering an ultra-wide viewing angle that provides a consistent viewing experience from different perspectives. Additionally, the film's flexible material makes installation more convenient, allowing for versatile applications in various complex exhibition environments. Figure 4 shows the projection and see-through effects of the high-transparency projection film (ANSLCF) tested in the laboratory. The image demonstrates both the projection on the ANSLCF and the ability to view exhibition objects behind the film through it.

The transparent projection interactive display system designed in this study can dynamically switch based on whether there are visitors in front of the display cabinet, providing an intuitive and interactive exhibition experience. As shown in Figure 5, when no one is present, the display cabinet appears in the same state as a traditional exhibition, directly showcasing the physical exhibits. However, as soon as a visitor approaches the display cabinet, as illustrated in Figure 6, the system immediately activates, displaying a 3D model of the exhibit and related information on the transparent projection screen, thus enriching the exhibition content. The model designed in this study not only captures the attention of visitors but also provides more opportunities for in-depth understanding of the exhibits. Furthermore, as shown in Figure 7, the system supports gesture interaction, allowing visitors to manipulate the virtual 3D exhibits using one or both hands. This in-

Fig. 5. Transparent Projection Interactive Display – Only Showing Regular Exhibits When No Visitors Are Present

teractive method enables visitors to freely zoom in, rotate, or move the 3D amber model for detailed observation, truly allowing them to ”explore” every detail of the exhibit, significantly enhancing the interactivity and depth of the visitor experience.

4. Innovative Exhibition Model Design

This research employed a mixed-method approach, combining questionnaires, interviews, and behavioral observations to comprehensively evaluate visitor experiences. The questionnaire design was based on the Immersive Experience Questionnaire (IEQ) [33], assessing aspects such as immersion, presence, engagement, and enjoyment. Interviews were conducted to explore visitors' subjective feelings and opinions in depth. The experiment was divided into two groups: one experiencing the innovative display mode and the other experiencing the traditional display mode. After data collection, statistical analysis methods were used in the study to compare differences between the two groups and analyze questionnaire and interview data to gain a deeper understanding of visitor experiences.

4.1. Research Design

This study adopted a mixed research methodology, combining quantitative and qualitative analyses to comprehensively assess the impact of the innovative exhibition model on visitor experience. The research design was based on the approach used by Hammady et

Fig. 6. Transparent Projection Interactive Display – Visitor in Front of the Display Cabinet

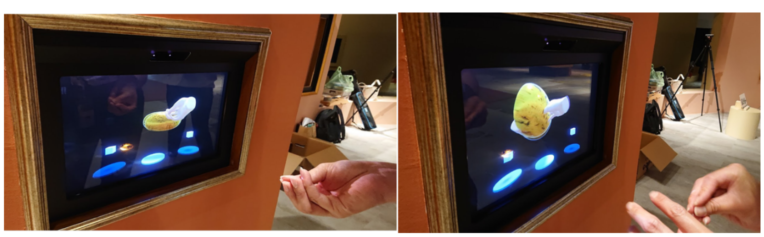

Fig. 7. Visitors can use single-hand or double-hand gestures to operate the 3D amber image in the transparent projection interactive system

al. [33] in evaluating AR applications in cultural heritage and was appropriately adjusted to suit the characteristics of this study.

The study employed a quasi-experimental design, randomly dividing participants into two groups: the experimental group (experiencing the innovative display mode) and the control group (experiencing the traditional display mode). Both groups viewed the same exhibits but presented in different ways. The experimental group used an innovative display case that integrated physical exhibits with virtual interaction, while the control group used standard glass display cases. This design was inspired by the method used by Trunfio et al. [34] in evaluating the impact of mixed reality technology on museum visitor experiences.

This study recruited a total of 200 participants, randomly divided into experimental and control groups, with 100 people in each group. These participants ranged in age from 18 to 45 years old, encompassing students, professionals, and the general public, ensuring diversity and representativeness of the sample. The following description of the data is presented as shown in Figure 8.

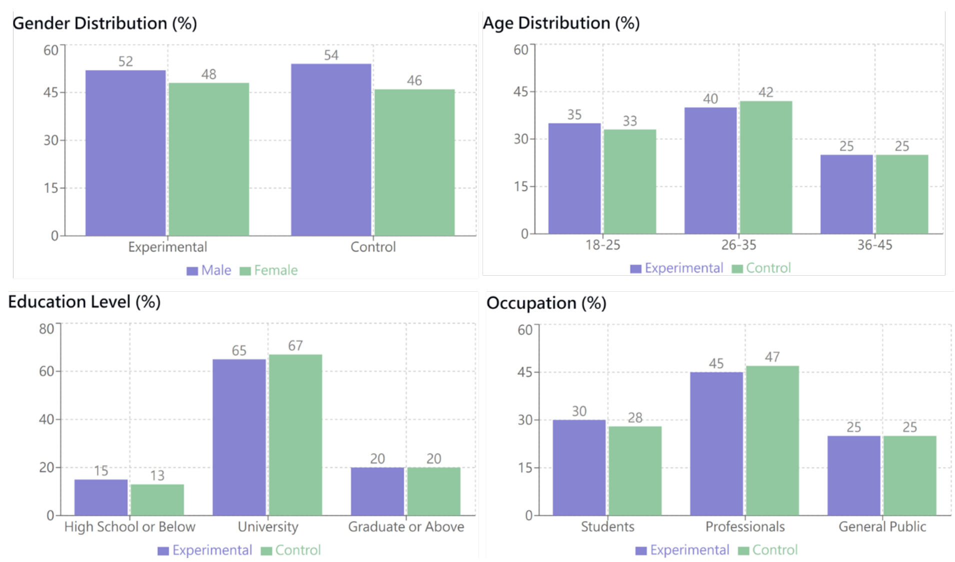

Fig. 8. Demographic information of participants in this study

Regarding participant demographics, the experimental group had a gender ratio of 52% male to 48% female. The age distribution was 35% for 18-25 years old, 40% for 26-35 years old, and 25% for 36-45 years old. In terms of education, 15% had high school education or below, 65% had university degrees, and 20% had graduate degrees or above. Occupation-wise, 30% were students, 45% were professionals, and 25% were from the general public.

The control group had a gender ratio of 54% male to 46% female. The age distribution was 33% for 18-25 years old, 42% for 26-35 years old, and 25% for 36-45 years old. Regarding education, 13% had high school education or below, 67% had university degrees, and 20% had graduate degrees or above. In terms of occupation, 28% were students, 47% were professionals, and 25% were from the general public.

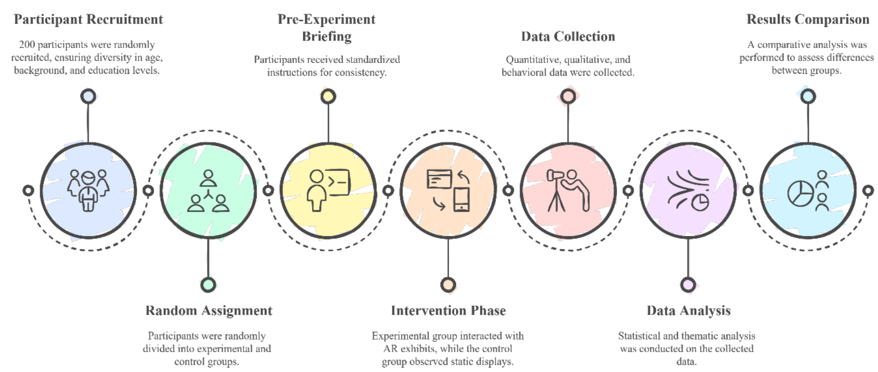

Fig. 9. Experimental design flowchart

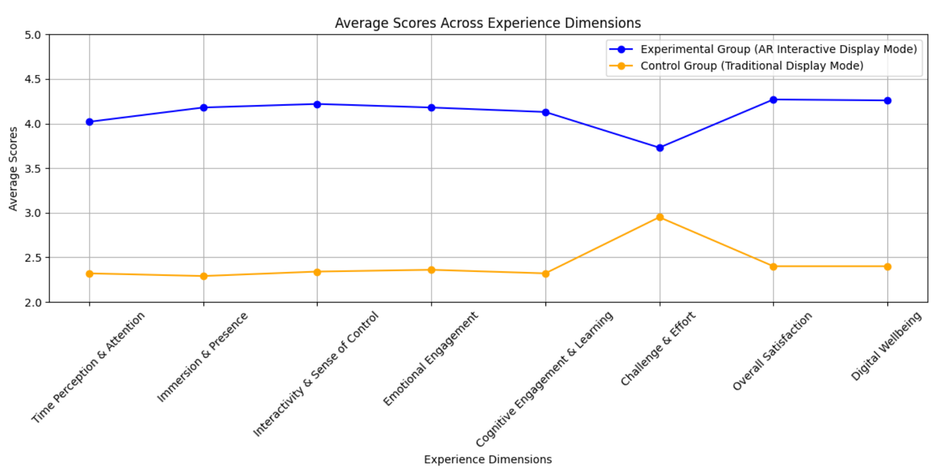

Fig. 10. Mean scores by dimension for the experimental and control groups

By ensuring similarity between the two groups in terms of gender, age, education, and occupational distribution, the research design aimed to reduce potential confounding variables and enhance the comparability and general applicability of the experimental results.

For the questionnaire survey, the study used a modified version of the Immersive Experience Questionnaire (IEQ) [35], assessing participants across 7 dimensions: 1. Time perception and attention, 2. Immersion and presence, 3. Interactivity and sense of control, 4. Emotional engagement, 5. Cognitive engagement and learning, 6. Challenge and effort, 7. Overall satisfaction and willingness to recommend, and 8. Digital Wellbeing. Overall satisfaction and willingness to recommend. This questionnaire included 35 items, evaluated using a 5-point Likert scale.

Regarding semi-structured interviews, 20 participants from each group were selected for in-depth interviews to explore their subjective experiences and opinions. The design of the interview guide was based on research of Vongkusolkit et al. [26].

In addition to traditional data collection methods, this study integrated a cloud-based data collection framework inspired by the work of Alamri et al. (2013). Real-time behavioral data were captured through sensors embedded in the AR interactive display, including gesture interactions, viewing duration, and navigation paths. This data was securely transmitted to a cloud platform for storage and preliminary analysis, enabling efficient, multi-level behavioral tracking and ensuring data integrity. The cloud-based approach facilitated comprehensive interaction analysis, allowing for the identification of patterns in visitor engagement and behavior that were not easily observable through traditional methods.

This study employed both quantitative and qualitative analyses. For quantitative analysis, the statistical methods used included descriptive statistics, independent samples t-tests, and one-way Analysis of Variance (ANOVA) to compare differences between the two groups across various dimensions. For qualitative analysis, thematic analysis was conducted on the interview data from the subjects, using qualitative analysis software to assist with coding and theme extraction. The analysis methods were based on the research of Clini et al. [36].

To enhance the clarity of the experimental design and improve the transparency of the quasi-experimental methodology, a flowchart has been included to illustrate the participant flow and the key steps involved in the experimental and control groups.

Participant Recruitment:

Random Assignment:

Participants were randomly divided into two groups:

Experimental Group (n=100): Exposed to the AR interactive display model with Leap Motion gesture interaction.

Control Group (n=100): Experienced the traditional static display without AR features.

Pre-Experiment Briefing:

Participants received standardized instructions to ensure consistency in understanding the experimental procedure.

Intervention Phase:

Experimental Group: Interacted with the AR-enhanced exhibits using gesture-based controls.

Control Group: Observed traditional exhibits without interactive features.

Data Collection:

Quantitative Data: Collected through the modified Immersive Experience Questionnaire (IEQ).

Qualitative Data: Gathered via semi-structured interviews and observational notes.

Behavioral Data: Captured in real-time through cloud-based sensors for the experimental group.

Data Analysis:

Statistical analysis (t-tests, ANOVA) and thematic analysis for qualitative feedback.

Results Comparison:

Comparative analysis between the experimental and control groups to assess differences in interactivity, immersion, learning effectiveness, and digital wellbeing.

5. Research Analysis

This study employed a mixed research method, combining surveys, interviews, and behavioral observations to comprehensively assess the impact of the innovative exhibition model on visitor experience. The data analysis results showed that the innovative exhibition model outperformed the traditional model across all experience dimensions, with visitors exhibiting significant improvements in interactivity, immersion, and satisfaction.

The questionnaire survey used a modified version of the Immersive Experience Questionnaire (IEQ) to assess participants' experiences across 7 main dimensions. The following sections will explain the results of the experimental group, the control group, and a comparison between the two groups.

5.1. Experimental Group Results

The questionnaire results for the experimental group showed that the average scores for all dimensions were above 4 points (out of a maximum of 5 points), indicating that participants had a high overall evaluation of the innovative display mode. Among these, the dimensions of "Interactivity and Sense of Control" and "Emotional Engagement" scored the highest (both at 4.32), demonstrating that the innovative model performed exceptionally well in these two aspects. On the other hand, the "Challenge and Effort Level" dimension scored relatively lower (2.92), possibly due to the inclusion of reverse-scored items, or indicating that the content of the display was of moderate difficulty for most participants. The overall internal consistency of the experimental group's questionnaire was good (Cronbach's = 0.91), and the internal consistency of each dimension was also within an acceptable range.

5.2. Control Group Results

The questionnaire results for the control group showed that, except for the "Challenge and Effort Level" dimension, the average scores for all other dimensions were below 3 points (the midpoint of the 5-point scale), indicating that participants generally had a lower evaluation of the traditional display method. The "Interactivity and Sense of Control" dimension scored the highest (2.44 points), but still below the midpoint, suggesting that even in traditional displays, this was a relatively better aspect. The "Challenge and Effort Level" dimension scored relatively high (3.56 points), possibly indicating that the traditional display method was more challenging for participants. The overall internal consistency of the control group's questionnaire was good (Cronbach's = 0.83), and the internal consistency of each dimension was also within an acceptable range.

Comparison between Experimental and Control Groups

To confirm whether the differences between the experimental group (innovative display mode) and the control group (traditional display mode) were statistically significant, this study conducted one-way Analysis of Variance (ANOVA) and independent samples t-tests on the mean scores of each dimension. The following are the analysis processes and results, which can be referenced in Table 1.

Statistical Analysis of Data from Experimental and Control Groups

Comparison of Average Scores Across Dimensions

Table 1. Comparison of Average Scores Across Dimensions

From the comparison of mean scores, it can be seen that, except for the "Challenge and effort level" dimension, the experimental group scored significantly higher than the control group in all other dimensions.

The results demonstrate that the Experimental Group (AR Interactive Display Mode) consistently outperforms the Control Group (Traditional Display Mode) across all experience dimensions, highlighting the positive impact of AR technology on user engagement, learning outcomes, and digital wellbeing. Significant performance gaps are observed in key areas such as Interactivity & Sense of Control (4.22 vs. 2.34), reflecting the effectiveness of gesture-based interaction using Leap Motion, and in Overall Satisfaction and Digital Wellbeing (4.27 and 4.26 vs. 2.4), showcasing AR's ability to foster meaningful, engaging experiences. Additionally, the AR model enhances Immersion & Presence (4.18 vs. 2.29) and promotes Emotional and Cognitive Engagement (4.18 and 4.13 vs. 2.36 and 2.32), suggesting deeper learning and emotional connections with exhibits. Notably, the Challenge & Effort dimension shows a smaller gap, indicating that AR enhances engagement without imposing excessive cognitive demands. These findings underscore AR's transformative potential in exhibition environments, with broad applicability in museums, educational settings, and cultural heritage displays, where it enriches visitor experiences while supporting cognitive and emotional development.

Independent Samples t-Test

To determine whether these differences are statistically significant, independent samples t-tests were conducted for each dimension. The test results can be referenced in Table 2.

Experimental hypotheses:

H0: There is no significant difference in mean scores between the experimental group and the control group

H1: There is a significant difference in mean scores between the experimental group and the control group

Significance level: = 0.05

Table 2. Independent Samples t-test Results

The experimental data show that the differences in all dimensions are statistically significant (p ¡ 0.001). This means that the experiment can reject the null hypothesis H0 and accept the alternative hypothesis H1, indicating that there are significant differences in mean scores between the experimental group and the control group across all dimensions.

Effect Size Analysis

To further evaluate the practical significance of the differences, Cohen's d effect sizes were also calculated in the experiment. The results can be referenced in Table 3.

Table 3. Cohen's d Effect Size Analysis

According to Cohen's standards:

d = 0.2 indicates a small effect

d = 0.5 indicates a medium effect

d = 0.8 indicates a large effect

The effect sizes for all dimensions exceed 0.8, indicating that there are large practical differences between the experimental group and the control group.

Reliability and Correlation Analysis Comparison

The overall questionnaire reliability and dimension correlations for the experimental and control groups are compared in Table 4. In Table 4, the average correlation coefficient for the experimental group is 0.748, while the average correlation coefficient for the control group is 0.593. The correlations between dimensions in the experimental group are generally higher than those in the control group, indicating that the various aspects of the experience are more closely connected in the experimental group.

Table 4. Overall Questionnaire Reliability and Relationship between Items and Dimensions Data

Explanation of Reliability and Correlation Analysis Comparison:

Overall Questionnaire Reliability: In the correlation analysis comparison, the overall questionnaire reliability indicators are as follows:

Overall Questionnaire Cronbach's : The experimental group has a value of 0.936, while the control group has a value of 0.889, with a difference of 0.08 between the two groups. Cronbach's coefficient is an indicator used to measure the internal consistency of a questionnaire, with values ranging from 0 to 1. The higher the value, the better the internal consistency of the questionnaire. Generally, an coefficient greater than 0.7 is considered acceptable, greater than 0.8 is regarded as good, and greater than 0.9 is considered excellent. Based on these data, the following conclusions can be drawn.

The Cronbach's coefficient for the experimental group is 0.936, which is a very high value, indicating that the questionnaire in the experimental group has excellent internal consistency. This means that the items in the questionnaire effectively measure the same underlying concept, reflecting the reliability of the questionnaire. The Cronbach's coefficient for the control group is 0.889, which, although lower than the experimental group's, is still within a good range. This indicates that the control group's questionnaire also has good internal consistency. The difference between the two groups is 0.047, which, while present, is not particularly large. This may suggest that the innovative exhibition model somewhat increased the consistency of responses among participants, but the impact is not highly significant. Overall, both groups' questionnaires demonstrate good to excellent internal consistency, which enhances the credibility of the study's results. High internal consistency indicates that the questionnaire can reliably measure the constructs of interest in the study, thereby providing a solid foundation for subsequent analysis and conclusions.

Relationship Between Items and Dimensions: The correlation between dimensions in the experimental group (0.748) is generally higher than in the control group (0.593), indicating that the new exhibition method created a more holistic and cohesive experience.

Overall, the statistical analysis strongly supports the effectiveness of the new exhibition method, as it significantly outperformed the traditional method in almost every aspect and created a more integrated and coherent visitor experience.

5.3. Interviews and Qualitative Analysis

The interview results further support the data from the questionnaire survey. Visitors generally felt that the innovative display mode provided a richer interactive experience, allowing for a more in-depth understanding of the exhibit details. At the same time, behavioral observation data showed that participants in the experimental group spent more time in front of the display cases, interacted more frequently, and were more willing to try different operation methods.

In addition to quantitative research methods, this study also employed thematic analysis to conduct a systematic qualitative study of feedback from subjects in both the experimental and control groups. The thematic analysis method referenced Braun and Clarke's six-step approach, including: familiarizing with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report [33]. The study categorized visitor feedback into four main dimensions and conducted a systematic qualitative analysis for each dimension, covering interactivity and sense of control, immersion and presence, learning experience and cognitive engagement, and overall satisfaction and willingness to recommend.

In the dimension of interactivity and sense of control, visitors in the experimental group generally expressed high satisfaction with the innovative display mode. They felt that this mode provided a smooth interactive experience, allowing them to intuitively operate virtual exhibits and feel in complete control of the display process. For example, Subject 3 stated that operating virtual exhibits through hand detection technology felt very natural and interesting. In contrast, the control group showed significant deficiencies, with visitors generally reporting a lack of interactivity in the traditional display method and difficulty in deeply understanding the details of the exhibits. This contrast clearly demonstrates the significant advantages of the innovative display mode in enhancing interactivity and sense of control.

In the analysis of immersion and presence, visitors in the experimental group reported that the innovative display mode provided an unprecedented immersive experience, making them feel completely absorbed in the exhibition environment. Subject 7, when describing this experience, mentioned feeling as if they were placed within the background story of the exhibits, forgetting everything about the outside world. In contrast, visitors in the control group indicated that the traditional display mode lacked sufficient immersion and found it difficult to evoke strong emotional resonance. These feedbacks suggest that the innovative display mode has significant advantages in creating immersive experiences, effectively transporting visitors into the exhibition content.

In the dimension of learning experience and cognitive engagement, visitors in the experimental group reported that the innovative display mode not only increased their understanding of the exhibits but also sparked deeper levels of interest and curiosity. Subject 23 mentioned that this display method helped them better understand the background and details of the exhibits. In contrast, while visitors in the control group were able to understand the display content, they showed notably less interest and engagement with the exhibits. This reflects that the innovative display mode has advantages over the traditional display mode in promoting learning and cognitive engagement.

Finally, in the dimension of overall satisfaction and willingness to recommend, visitors in the experimental group gave high ratings to the innovative display mode, with many expressing their willingness to recommend this display method to others. Subject 80 explicitly stated that they would recommend friends to experience this innovative display mode. In contrast, visitors in the control group generally gave lukewarm evaluations of the traditional display and lacked a clear willingness to recommend it. This result further confirms the success of the innovative display mode in enhancing visitors' overall satisfaction.

Through qualitative analysis of feedback from the experimental and control groups, this study can draw the following important insights:

Interactivity is key: The innovative display mode greatly enhanced visitors' interactive experience through hand detection and 3D manipulation, which is lacking in traditional display methods. Experimental group participants generally reported higher interactivity and sense of control, such as "feeling adept at manipulating virtual exhibits." In contrast, control group participants expressed interactive limitations, like "finding it somewhat difficult to actually observe physical exhibits." This suggests that future display designs should continue to strengthen interactivity, providing visitors with more intuitive and natural ways of operation.

Immersion creates deep experiences: AR technology and immersive design successfully transported visitors into the world of the exhibits, creating more meaningful and memorable experiences. Experimental group participants often described deeply immersive experiences, such as "feeling as if they were in the natural history of the exhibit." This sense of immersion is particularly important for cultural heritage and science exhibitions, helping visitors better understand and feel the background and significance of the exhibits.

Combining learning and emotion: The innovative model not only promoted cognitive learning but also evoked emotional resonance, a combination crucial for deepening the learning experience. Experimental group participants reported deeper understanding and higher interest, such as "this display method helped them better understand the exhibits." Future display designs should pay attention to the role of emotional factors, enhancing learning effects by stimulating visitors' curiosity and emotional investment.

Balancing technology application: While innovative technology brought significant improvements, attention should be paid to the appropriate use of technology to ensure it doesn't cause operational difficulties for some visitors. The design process should consider the needs of visitors of different age groups and technology proficiency levels, providing appropriate guidance and instructions.

Importance of personalized experiences: Feedback showed high satisfaction among visitors with the ability to control and explore exhibits autonomously. This suggests that future display designs should focus more on providing personalized and self-chosen experiences, allowing visitors to explore exhibits according to their own interests and pace.

Overall satisfaction and willingness to recommend: Participants in the experimental group highly rated the innovative display mode and expressed willingness to recommend it to others. This reflects that the innovative model not only enhanced personal experiences but may also attract more visitors through word-of-mouth effects.

These qualitative analysis results strongly support the effectiveness of the innovative AR interactive display mode. This mode significantly outperforms traditional display methods in enhancing interactivity, immersion, learning experience, and overall satisfaction. These findings not only validate the design concepts proposed in the thesis but also provide valuable empirical foundations and innovative directions for future museum and exhibition designs.

6. Discussion and Future Research Directions

This study explores the comprehensive results of the innovative display mode design and visitor experience research. The integration of physical displays with virtual interactive display technology, particularly for small-scale exhibits, has proven effective in enhancing visitor engagement. Utilizing hand detection sensors and 3D modeling technology, this model offers an unprecedented interactive experience, allowing visitors to freely enlarge, shrink, and rotate virtual exhibits. This highly interactive and immersive display method significantly enhances visitor engagement, cognitive involvement, and overall satisfaction.

The experimental results demonstrate that, compared to traditional display modes, the AR interactive display model offers substantial advantages in terms of interactivity, immersion, learning effectiveness, and digital well-being. Visitors highly praised the ability to manipulate virtual exhibits directly, which provided deeper engagement with exhibit details and enriched learning experiences. This indicates that the innovative display mode is not only technically feasible but also holds significant potential to enhance visitor experiences in practical applications.

Linking these findings to current trends in AR development, this study aligns with the broader digital transformation in museums and cultural heritage fields. AR technologies are increasingly employed not just for content presentation but also for fostering immersive storytelling, real-time interaction, and context-aware experiences. As AR applications evolve, they offer opportunities to create dynamic, personalized exhibitions that adapt to visitors' preferences and learning needs.

Drawing insights from Omonayajo et al. [32], who highlighted the transformative role of AR and immersive technologies in smart education environments, this study further explores how AR interactive display models can positively influence visitors' cognitive engagement and digital well-being. Omonayajo et al. emphasized that AR technologies promote active learning, improve knowledge retention, and foster inclusive learning experiences, particularly through immersive and interactive design elements.

In the context of exhibition spaces, the integration of AR technologies not only enhances visitor engagement but also supports the development of digital literacy. By providing interactive experiences that encourage exploration and critical thinking, AR displays contribute to a more meaningful and personalized learning journey for visitors. Additionally, such interactive environments can foster inclusive experiences, accommodating diverse learning preferences and promoting accessibility for broader audiences.

These insights underscore the broader implications of AR interactive technologies beyond traditional educational settings, suggesting their potential as powerful tools for enhancing both educational outcomes and digital well-being in cultural and exhibition contexts. Future research could investigate the long-term impact of AR-enhanced exhibition experiences on digital literacy development, as well as explore strategies for optimizing these technologies to support inclusive, accessible, and engaging learning environments.

Furthermore, the study highlights AR's role in promoting digital literacy. Interactive AR environments encourage critical thinking, problem-solving, and digital navigation skills, which are essential in today's technology-driven society. Additionally, AR fosters inclusive learning experiences by supporting diverse learning styles and accessibility needs. The multi-sensory, adaptable nature of AR technologies makes exhibitions more engaging and accessible to audiences with varying cognitive and physical abilities.

Future Research Directions: Future studies should investigate the long-term impacts of AR-enhanced exhibitions on digital literacy development. Longitudinal research can explore how sustained exposure to AR environments influences cognitive skills, technological proficiency, and visitor engagement patterns over time. Moreover, examining AR's role in fostering inclusive cultural experiences could provide valuable insights into how immersive technologies bridge accessibility gaps and promote social inclusion. Comparative studies across different cultural contexts may also reveal how AR experiences are perceived globally, informing best practices for museum and exhibition design worldwide.

6.1. Model Advantages

The innovative exhibition model designed in this study demonstrates several advantages over traditional exhibition methods, particularly in enhancing the display of small artifacts and increasing audience interactivity. These advantages stem from the following key factors:

Enhanced Interactivity and Immersion: Through hand detection technology, visitors are no longer passive viewers of the exhibits; they can actively participate by directly manipulating virtual exhibits through gestures. This interactivity not only increases visitor engagement but also allows for a deeper understanding of the exhibits. Additionally, the application of 3D modeling technology enables visitors to observe exhibits from different angles and distances, even zooming in to examine details. This experience closely approximates physically interacting with the exhibits, greatly enhancing immersion.

Application of AR Technology: The integration of AR technology allows for a seamless combination of virtual information with physical exhibits, enriching the content of the exhibition. Visitors can not only see the physical appearance of the exhibits but also access additional information through AR, such as historical context, production processes, and scientific principles, making the viewing experience more educational and engaging.

Addressing the Challenges of Displaying Small Exhibits: Traditional exhibition methods often struggle to provide an ideal viewing experience for small exhibits, especially those rich in detail and requiring close observation. The model proposed in this study, through 3D modeling and magnification features, allows visitors to easily observe every detail of the exhibits, solving the challenges associated with displaying small artifacts.

Improving Overall Visitor Experience: The experimental results show that the innovative exhibition model outperforms the traditional model across all experience dimensions. Visitors exhibited significant improvements in interactivity, immersion, and satisfaction. This indicates that the new model not only enhances visitor engagement and learning outcomes but also leaves them more satisfied with the overall exhibition process.

6.2. Challenges and Future Development

Although the innovative exhibition model proposed in this study shows significant potential in enhancing visitor experiences, it still faces challenges related to technology and cost in practical applications. Technical limitations include potential issues with the accuracy and latency of hand detection and AR technology, as well as the difficulties of applying 3D modeling technology to complex or fragile exhibits. In terms of projection technology, presenting clear virtual content under various lighting conditions is also a major challenge. On the cost side, the economic burden of acquiring, maintaining exhibition equipment, and involving professional personnel cannot be ignored.

To overcome these challenges and further enhance the model‘s application value, future research could focus on the following directions: continuously improving hand detection, AR, and projection technologies to increase accuracy, reduce latency, and enhance stability; exploring more convenient and efficient 3D modeling methods; finding more cost-effective technological solutions; developing more interactive and engaging AR content, such as games and quizzes; offering personalized exhibition content and interaction methods based on visitors‘ interests and needs; and expanding the application scope to include large exhibits and scene displays.

Through ongoing technological innovation and application expansion, this integrated physical and virtual interactive exhibition model is expected to play an increasingly important role in museums, cultural heritage displays, education, and other fields, providing audiences with richer and more inspiring experiences and promoting cultural heritage and knowledge dissemination.

7. Conclusion

This study designed and evaluated an innovative transparent projection interactive display mode, which successfully integrated physical display with virtual interactive technology, particularly suitable for exhibiting small items. The research results show that this new display method significantly enhanced visitors‘ experiences in multiple aspects, including interactivity, immersion, learning effectiveness, and overall satisfaction. Through the application of hand detection sensors and 3D modeling technology, visitors were able to directly manipulate virtual exhibits, achieving an unprecedented interactive experience.

Both quantitative and qualitative analysis results confirmed the superiority of this model compared to traditional display methods, especially in improving visitor engagement and deepening understanding of exhibits. However, the study also identified some technical and cost-related challenges, which point to directions for future research.

Academic Contributions: This study contributes to the academic discourse on AR-enhanced exhibitions by presenting a novel interactive model that integrates physical and virtual display techniques. The mixed-method approach provides robust empirical evidence of the model‘s effectiveness, particularly in enhancing cognitive engagement, emotional involvement, and digital wellbeing. By drawing from contemporary theories of immersive learning and digital literacy, the study bridges gaps in the literature regarding AR’s role in cultural heritage contexts. Furthermore, the integration of real-time behavioral data collection through cloud-based systems introduces a methodological innovation that can be applied in future exhibition studies.

Practical Application Value: The findings have significant practical implications for museums, cultural heritage sites, and educational institutions. The AR interactive display model offers a scalable, cost-effective solution for enhancing visitor experiences without the need for extensive physical space modifications. It supports inclusive learning by accommodating diverse visitors' needs, fostering accessibility, and promoting digital wellbeing through interactive, engaging content. Additionally, the model's flexibility allows for adaptation in various exhibition contexts, including science centers, art galleries, and historical archives, thus broadening its applicability across different educational and cultural environments.

Overall, this study provides new design ideas for museums, science education, and cultural heritage display fields, demonstrating the enormous potential of AR technology in enhancing display effects and visitor experiences. It also lays a foundation for the development of future display technologies. Further research could explore the impact of AR interactive exhibits on visitors‘ digital behavior and wellbeing during their visit, as well as how to optimize such technologies to better serve the educational and social functions across various educational settings. Future studies may investigate the long-term effects of AR-enhanced museum experiences on learning outcomes and visitor engagement. Additionally, researchers could examine the potential of AR technologies to facilitate inclusive and accessible learning environments for diverse audiences in educational institutions.

7.1. Research Contributions

This study has made significant contributions in multiple aspects of display technology. Firstly, it proposed an innovative display model that successfully integrates physical display with virtual interactive technology, addressing the limitations of traditional display methods for small exhibits. This model, utilizing hand detection technology and 3D modeling, significantly enhances the visibility of exhibits and visitor interactivity, providing strong empirical support for the application of advanced technologies in museums, science education, and cultural heritage displays.

Secondly, through experimental comparison, the study systematically evaluated the impact of the innovative display mode on visitor experience, demonstrating its significant advantages in enhancing visitors‘ sense of immersion, interactivity, and overall satisfaction. This enriches the research on the relationship between display technology and visitor experience, providing practical evidence for future display designs.

Furthermore, the study offers detailed technical implementation cases for the integrated application of hand detection, 3D modeling, and advanced projection technologies. This not only provides operational guidelines for display technology practitioners but also lays the foundation for further optimization and innovation of these technologies. This contribution has implications for the cross-disciplinary application of future display technologies, especially in better combining physical and virtual displays.

Overall, this study has made valuable explorations and contributions in innovative design of display technology, visitor experience research, and technical implementation strategies. It has profound implications for the future development of display technology.

7.2. Future Prospects

The innovative display model proposed in this study paints an exciting blueprint for the future development of museums and cultural heritage exhibitions. As technologies such as AR, VR, MR, 3D modeling, and gesture interaction continue to advance, interactive experiences will become more natural and fluid, potentially even allowing interaction with exhibits through voice, eye movements, or brain waves.

Immersive experiences will also deepen further, possibly creating fully virtual environments that make visitors feel as if they are truly present. Moreover, personalized learning experiences will become possible, with display systems potentially providing customized content and interaction methods based on visitors‘ backgrounds and needs.

Looking ahead, the application of this innovative model will not be limited to museums but may expand to fields such as education, healthcare, and retail, bringing new development opportunities to these areas.

Overall, this research not only provides an effective solution for displaying small cultural artifacts but also points the way for the future development of display technology. Through continuous technological innovation and application expansion, it will realize its potential in more fields, creating richer and more inspiring experiences for humanity, promoting cultural inheritance and knowledge dissemination.

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