

Efficiency of Museum Interactive Devices Based on the CIDPE Framework

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ABSTRACT

With the advancement of global cultural digitization, museums are facing a participation crisis, where special groups, although physically present, lack a sense of cultural presence. Traditional service models face two main challenges: basic accessibility renovations fail to meet the needs of visually impaired individuals, while high-cost technological upgrades offer limited improvements. This paper uses the CIDPE framework and a mixed research method to explore how to achieve a two-way enhancement of experiences between accessibility design and interactive design, aiming to optimize the cultural participation of both special groups and general audiences. Through a 2×3 factorial experiment conducted in three museums, the results show that the CIDPE infrastructure significantly improved the cultural cognitive depth of disabled groups and the participation depth of general audiences. The tactile-audio cross-sensory system increased cultural cognition by 57% for visually impaired individuals while also increasing participation by 33% for general audiences. The multimodal pressure-sensing voice system reduced stress responses by 43% for the autism group. The proposed modular renovation plan can reduce costs by 43% while increasing participation by 180% for disabled groups, driving museums from “physical accessibility” to true cultural empathy.

Keywords: Museum digital transformation, Cultural inclusive, interactive experience, Human-computer interaction (HCI)

INTRODUCTION

Research Background

In the digital era, artificial intelligence (AI) is reshaping how we understand and appreciate art and design through its distinctive creative potential. Beyond a mere technological innovation, AI has evolved into a cultural phenomenon that increasingly influences everyday life, particularly within the realms of art exhibitions and design. As vital spaces for cultural preservation and creative exploration, traditional exhibition models are encountering both unprecedented challenges and new opportunities. The integration of AI technologies to enrich audience engagement and interactive experiences has therefore become a key point of convergence between the art world and the technology industry.

Purpose of the Study

This paper explores the application of AI-driven installations in art exhibitions and their role in enhancing audience engagement and interactivity. Through a literature review, it examines the evolution and current use of AI technology in the arts and constructs a theoretical framework to analyze its impact on visitor experience. Empirical cases from the TeamLab exhibition and the Macao Sanxingdui exhibition illustrate how AI installations shape audience interaction. The findings reveal that AI not only enriches artistic expression but also inspires new approaches to exhibition design. As AI technology continues to advance, it promises to bring more diverse and immersive experiences to art exhibitions, offering valuable insights for the future development of visual communication and interactive art.

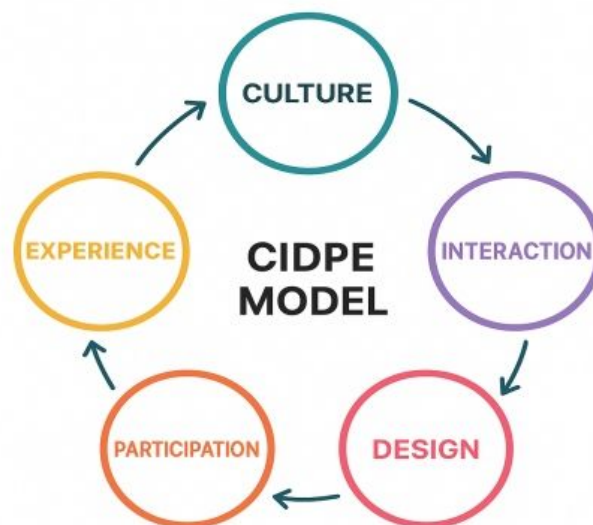


Figure 1: CIDPE framework.

Materials and Methods

Application of AI in Art Installations

In the digital age, artificial intelligence (AI) has become a driving force in transforming traditional exhibitions into immersive and participatory experiences. Beyond technological innovation, AI acts as a cultural catalyst, bridging art and audience engagement. This shift challenges conventional exhibition models and inspires new explorations of interactivity and cultural participation. AI-driven art highlights collaboration and audience involvement rather than isolated creation (Sidar, 2011). For example, the Macao Sanxingdui Exhibition combines cultural heritage with interactive media, while VR projects such as the F3 Power Racer Challenge and the 360° Racing Project immerse visitors in simulated experiences.

These cases illustrate how AI integrates technology and culture to create dynamic, participatory exhibitions.

Theories of Audience Participation and Interactive Experience

Interactive experience design transforms audiences from passive observers into active participants. Centered on user engagement, it emphasizes multi-sensory immersion—visual, auditory, and tactile—to foster emotional resonance and sustained interaction. Technologies such as AR, VR, and AI expand this potential, enabling personalized and story-driven experiences that enhance coherence and user satisfaction.

Moreover, interactive design extends beyond individual engagement to social interaction, encouraging shared experiences and cultural dialogue. It also integrates educational and entertainment dimensions, offering both cognitive and emotional value. Representative cases such as *Team Lab* and the *Macao Auto Show* exemplify how interactive art installations can deepen cultural engagement through sensory and emotional participation.

Research Limitations and Gaps

Despite growing scholarship on interactive design, several research gaps remain. Quantitative studies on user engagement in art exhibitions are still limited, especially across different cultural contexts. Existing work often overlooks how emerging technologies such as AI and VR influence audience participation and emotional flow. Furthermore, research rarely examines whether interactive systems foster genuine voluntary engagement rather than forced participation (Kaidi, 2021). Addressing these gaps is essential for understanding how technology-driven experiences reshape aesthetic and cultural interaction.

Research Questions and Focus

This study identifies three core dimensions of inquiry:

(1) Technological Implementation

How can multi-modal interactive systems using pressure-sensitive and dynamic voice technologies balance diverse audience needs?

Can tactile-auditory cross-modal systems simultaneously enhance cultural cognition for visually impaired visitors and participation for general audiences?

(2) Experience Evaluation

Does accessibility-oriented design reduce the experiential quality for non-disabled audiences?

Can inclusive interaction design deepen engagement for both special and general audiences?

(3) Practical Application

How can modular renovation strategies reduce costs while significantly improving participation among disabled groups?

Research Methodology

Building the Foundation of a Theoretical Framework

AI-driven devices integrate advanced technologies such as sensors, machine learning, and real-time data processing to enhance interactivity and user experience. By responding intelligently to user behavior and environmental changes, they create adaptive and immersive forms of engagement. In the *Team-Lab* exhibition, visitors experience full-body immersion as AI systems dynamically react to movement and collective behavior, demonstrating continuous learning and design optimization.

Personalization is another defining feature. In the *Sound Playground* project, AI-powered sound sculptures adjust auditory output based on users' gestures and positions, producing unique real-time experiences. Similarly, research from the Central Academy of Fine Arts shows how AI transforms abstract artistic concepts into tangible visual forms, deepening spatial immersion and aesthetic expression.

The interdisciplinary nature of AI art extends its application across aesthetic education, industrial design, and technological innovation. With predictive and adaptive capabilities—such as self-learning and self-sustaining systems—AI-driven installations represent a new generation of intelligent, evolving art forms.

Basic Concepts and Functions of AI-Driven Devices

AI-driven installation art integrates advanced artificial intelligence technologies to enhance audience interaction and engagement. These installations dynamically respond to user behavior and environmental changes through the use of sensors, machine learning algorithms, and real-time data processing.

Audience survey data from the *Team-Lab* exhibition show that 51.72% of visitors expressed strong interest in the fusion of technology and art, underscoring the appeal and cultural value of AI-driven installations. The intelligent responsiveness and adaptive learning of these systems—enabled by powerful data analysis and flexible sensor integration—allow continuous optimization of user interaction and operational performance.

Moreover, personalization has become a defining feature of AI installations. According to the same survey, 89.66% of visitors selected *TeamLab*'s works primarily for their artistic value, reflecting how AI-powered personalization deepens aesthetic experience and strengthens emotional connection between audiences and artworks.

Definition and Classification of Interactive Language

Interactive language serves as the bridge connecting audiences with AI devices, encompassing diverse communication forms such as physical interaction, voice interaction, and visual interaction. Analysis of the subjective experience survey questionnaire from *Team-Lab*'s exhibition reveals visitors' strong desire and enthusiasm for interactive experiences. Specifically, over half of the audience (51.72%) expressed keen interest in the fusion of technology and art, highlighting the central role of interactive language in

AI devices. The classification of interactive language is multidimensional, including not only physical, voice, and visual interactions but also potentially additional communication methods. The definition of interactive language.

The classification shows the breadth and depth of interaction. With physical, voice and visual interactions, AI devices can provide users with a richer and more customized experience.

Analyze the Language and Behavior of the Audience

Interacting With the AI Device

AI-driven installations integrate artificial intelligence technologies such as sensors, machine learning, and real-time data processing to create responsive and immersive interactions. These systems adapt dynamically to user behavior and environmental changes, enhancing engagement and participation.

Survey data from the *TeamLab* exhibition show that 51.72% of visitors were strongly interested in the fusion of art and technology, confirming the cultural appeal of AI-based installations. Their intelligent responsiveness and adaptive learning enable continuous optimization, while personalized experiences—recognized by 89.66% of visitors as a key attraction—deepen emotional connection and elevate artistic value.

Comparative Analysis

Comparison of Data Between Team-Lab Exhibition and Macao Sanxingdui Exhibition It Can be Found That Team-Lab Exhibition Has Obvious Advantages in the Following Aspects

The Team-Lab exhibition shows strong appeal among young audiences, with 75.86% of visitors aged 18–25, compared to 57.14% at the Macao Sanxingdui Exhibition. Its fusion of technology and art attracted 51.72% of visitors interested in this integration, while Sanxingdui's audience focused more on cultural heritage. In terms of interactivity, 44.83% of Team-Lab visitors engaged with all projects and 58.62% were willing to wait for popular installations, reflecting high enthusiasm and participation.

Both exhibitions attracted a predominantly female audience (58.62% and 59.52%), demonstrating the broad appeal of AI-based art. Demographically, students accounted for 54.76% of Sanxingdui visitors, while 34.48% of Team-Lab attendees worked in art-related fields, showing strong recognition from creative professionals. Overall, AI technology plays a vital role in enhancing interactivity, personalization, and cultural accessibility in exhibitions, offering valuable insights for the future integration of art and technology.

Table 1: Questionnaire collection form.

	Team-Lab	Macau Museum of Art-Ji Jin Yaohua
Gender	The female audience station ratio was 58.62%, and the male audience station ratio was 41.38%	Female audience station ratio 59.52% male audience station ratio 40.48%
Age	The audience station ratio of 18–25 is as high as 75.86%	Among them, 57.14% of the viewers aged 18–25 years stood higher
Information acquisition pipeline	65.52% of the audience learned about the exhibition through the official website or social media 72.41% of the audience learned about through short video platforms such as TikTok and Xiaohongshu	78.57% of the audience learned about the exhibition through online social media, and 28.57% of the audience learned about traditional media such as TV, radio and newspapers
Visit the purpose	51.72% of the audience were interested in the form of combining technology and art, and 44.83% of the audience visited because of their love for Team-Lab art works	71.43% of the audience are interested in Sanxingdui cultural creation, and 64.29% of the audience love the bronze ware relics
Interactive project	44.83% of the audience wanted to experience all the interactive projects, and 58.62% were willing to wait for the most popular interactive projects	85.71% of the audience was interested in the interactive experience related to Sanxingdui IP

Research Methodology

Literature Analysis Method

This study conducted a literature review on AI-driven devices, audience participation, and interaction modes to construct a theoretical framework and propose research hypotheses. An empirical questionnaire survey was also carried out at the *Team-Lab* and Macao *Sanxingdui* exhibitions to test the framework and validate the hypotheses. Findings show that AI technology enhances interactivity and audience engagement. At *Team-Lab*, 75.86% of visitors were aged 18–25, indicating strong appeal to younger audiences, while 38.1% of *Sanxingdui* visitors held a master's degree or higher, reflecting attraction to highly educated audiences. These results highlight differences in audience composition and demonstrate that AI-driven interactions can significantly enrich participation and experience. Overall, *Team-Lab* shows

clear advantages in integrating technology with art, offering valuable insights for future exhibitions and AI applications in the arts.

Data Collection and Analysis Process

This study collected audience feedback data from the team-Lab exhibition and the Sanxingdui Macao exhibition by designing and implementing the questionnaire. The questionnaire includes the audience's interactive experience, participation and satisfaction with the AI device. Following are the detailed data collection and analysis processes

Data Analysis

1. Data processing: The collected questionnaire data is first cleaned to exclude invalid questionnaires and outliers.-Data are entered into an electronic database for facilitating subsequent statistical analysis.
2. Statistical analysis: Conduct descriptive statistical analysis of the data, including frequency, percentage, mean value, etc.-For the scale questions in the questionnaire, the mean score for each dimension was calculated to assess the overall feelings of the audience.
3. Comparative analysis: Compare the data of Team-Lab exhibition and Macao Sanxingdui exhibition, and analyze the differences between the two exhibitions in terms of interactive experience, participation and satisfaction.
4. Interpretation of the results: Combining the literature review and theoretical framework, the analysis results are interpreted to explore the impact of AI devices on the audience experience. Identify evidence where research hypotheses are supported and discuss possible practice applications. Through this rigorous data collection and analysis process, this study aims to provide empirical support for the application of AI installations in art exhibitions, and to provide guiding recommendations for future exhibition design. In particular, by comparing audience feedback from Team-Lab and Sanxingdui Macao, this study provides a deep understanding of the interactive effects of AI installations in different exhibition contexts, providing valuable insights into exhibition planning and the application of AI technology.

Data Analysis and Discussion

Interactive Experience of Audiences in Different Contexts

Through data analysis, this study finds that the interactive experience in the Team-Lab exhibition is more immersive and innovative, while the Macao Sanxingdui exhibition pays more attention to the display and education of traditional culture. According to the questionnaire, the audience of the Team-Lab exhibition showed a high interest in the form of combining technology and art, and 51.72% of the audience said that this was the main reason for their visit. In contrast, the audience of the Sanxingdui exhibition in Macao pays more attention to the historical background introduction of the cultural relics and the interactive experience related to the Sanxingdui IP, and the lack of interaction is boring. Team-Lab exhibition provides a new art experience for the audience through its immersive and interactive

characteristics, while Macao Sanxingdui exhibition retains the exhibition mode of traditional museums. Team-lab is far more participants than the Sanxingdui exhibition in Macao, and the audience's enthusiasm for the interactive experience is far higher than the traditional exhibition.

How AI Drives Generate Works of Art by Tracking Movements or Facial Expressions

AI-driven devices in the Team-Lab exhibition, such as *Cloud Without Phase: Between Sculpture and Life*, generate unique artworks by tracking audience movements and expressions in real time. This intelligent interactivity enhances both engagement and the aesthetic appeal of the artworks, allowing visitors to become active participants in the creative process. In contrast, the Macao Sanxingdui Exhibition employs VR technology to provide immersive experiences but lacks deep integration with AI systems. While Team-Lab's AI-generated works captivate audiences through personalization and interaction, Sanxingdui's appeal remains largely tied to cultural interest rather than technological immersion.

Interpretation of the Study Results

The results of this study highlight the crucial role of AI technology in enhancing audience interactivity in art exhibitions. Analysis of feedback from the *Team-Lab* and Macao *Sanxingdui* exhibitions shows that AI-driven installations not only increase participation but also enrich personalized experiences. At *Team-Lab*, 75.86% of visitors were aged 18–25, indicating strong interest among younger audiences in immersive, technology-integrated art. In contrast, 38.1% of visitors to the *Sanxingdui* exhibition held a master's degree or higher, reflecting its appeal to highly educated audiences and the exhibition's cultural and educational value. Both exhibitions successfully attracted female visitors (58.62% at *Team-Lab*; 59.52% at *Sanxingdui*), suggesting the broad aesthetic appeal of AI art. Professionally, 34.48% of *Team-Lab* attendees were art-related professionals, while students accounted for 54.76% at *Sanxingdui*, highlighting differing audience compositions. Overall, these findings demonstrate AI's potential to enhance interactivity and personalization across diverse cultural contexts, offering valuable insights for future exhibition design.

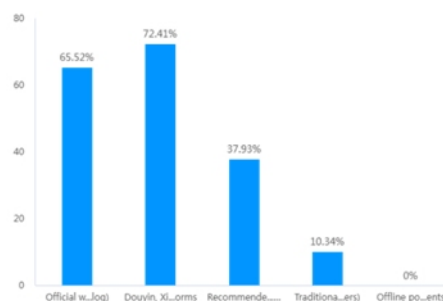


Figure 2: How did you find out about TeamLab exhibitions?

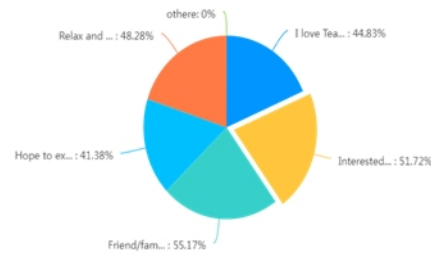


Figure 3: The main reason you chose to visit this exhibition?

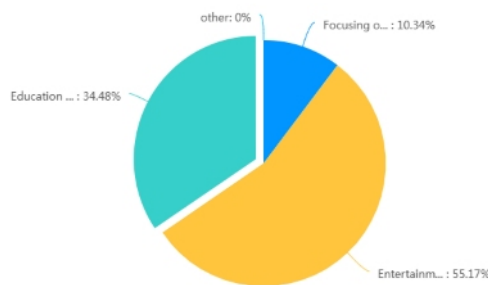


Figure 4: What do you think theTeamLab?

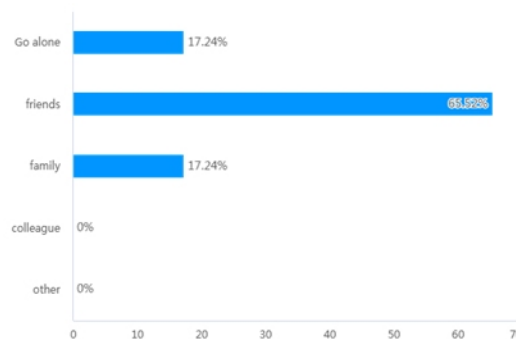


Figure 5: Who did you visit the exhibition with?

How AI Technology Enhances the Specific Mechanism of Interactive Experience and Audience Sense of Participation

AI technology enhances the audience’s interactive experience and sense of participation through mechanisms such as instant response, personalized generation and immersive experience. The average score of interactivity, creativity and artistic expression in Team-Lab is more than 4.2, demonstrating the effectiveness of AI technology in improving the exhibition

experience. In contrast, although Sanxingdui Exhibition is trying to improve interactivity through VR technology, its attraction to the audience is still limited to its interest in Sanxingdui culture.

Future Research Directions

Future research could further explore the application of AI technology across various art forms and how these applications shape audience experiences. Additionally, the role and impact of AI in artistic creation warrant deeper investigation. Particularly in education, the implementation of AI technologies requires careful consideration of its effects on educational equity and teaching quality.

Application Prospects of AI-Driven Devices in Other Fields (Such as Education, Entertainment, Etc.)

AI-powered devices hold vast potential for applications in fields like education and entertainment. By delivering interactive and personalized experiences, AI technology can enhance engagement and user satisfaction, thereby improving educational outcomes and entertainment experiences. In the realm of education, AI implementations such as smart tutoring and personalized learning have demonstrated remarkable potential, enabling customized teaching content tailored to students' learning progress and individual styles.

Recommendations and Questions for Further Study

Future research could explore how to integrate AI technology in creating more interactive and immersive art installations. Moreover, balancing technological applications with the humanistic values of artistic creation remains a critical issue worth addressing. In the education sector, studies should focus on how AI can enhance educational equity and evaluate its practical effectiveness in teaching processes.

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Appendix A

Questionnaire Results of the Team-Lab Exhibition Survey

This appendix presents the summarized data collected from the questionnaire survey on visitors' experiences at the *Team-Lab* exhibition.

Q1. What is your gender?

Option	Count	Percentage
Female	17	58.62%
Male	12	41.38%
Valid responses	29	100%

Q2. What is your age group?

Option	Count	Percentage
Under 18	0	0%
18–25	22	75.86%
26–35	4	13.79%
36–45	2	6.9%
46 and above	1	3.45%
Valid responses	29	100%

Q3. In which city did you visit the TeamLab exhibition?

(Open-ended question; detailed responses available upon request.)

Q4. Are you engaged in an art-related field?

Option	Count	Percentage
Yes	10	34.48%
No	19	65.52%
Valid responses	29	100%

Q5. How did you learn about the TeamLab exhibition? (Multiple choice)

Option	Count	Percentage
Official website or social media	19	65.52%
Short video platforms (e.g., TikTok, Xiaohongshu)	21	72.41%
Recommendations from friends/family	11	37.93%
Traditional media (TV, newspaper)	6	20.69%
Offline posters or advertisements	3	10.34%
Others	0	0%
Valid responses	29	100%

Q6. Who did you visit the exhibition with?

Option	Count	Percentage
Alone	5	17.24%
Friends	19	65.52%
Family	5	17.24%
Colleagues	0	0%
Others	0	0%
Valid responses	29	100%

Q7. What is your main reason for visiting the exhibition? (Multiple choice)

Option	Count	Percentage
Interested in TeamLab's works	13	44.83%
Interested in the fusion of art and technology	15	51.72%
Recommended by friends/family	16	55.17%
Want to experience immersive interaction	12	41.38%
Entertainment or novelty-seeking	14	48.28%
Others	0	0%

Q8. Is this your first time visiting a TeamLab exhibition?

Option	Count	Percentage
Yes	26	89.66%
No	3	10.34%

Q9. What is your main purpose of visiting the exhibition?

Option	Count	Percentage
Education (learning about art/technology)	3	10.34%
Entertainment (relaxation, enjoyment)	16	55.17%
Both education and entertainment	10	34.48%
Others	0	0%

Q10. How long did you spend at the exhibition?

Option	Count	Percentage
Less than 1 hour	5	17.24%
1–2 hours	20	68.97%
2–3 hours	3	10.34%
More than 3 hours	1	3.45%

Q11. Did you participate in all interactive installations?

Option	Count	Percentage
Yes, I wanted to try all	13	44.83%
No, I only chose some	6	20.69%
Not sure / depended on situation	10	34.48%

Q12. Did you wait in line for the most popular interactive projects?

Option	Count	Percentage
Yes, I was willing to wait	17	58.62%
No	0	0%
Depends on wait time	12	41.38%

Q13. What do you think is a reasonable waiting time?

Option	Count	Percentage
Within 10 minutes	14	48.28%
10–30 minutes	13	44.83%
30 minutes–1 hour	2	6.9%
More than 1 hour	0	0%

Q14. What services or facilities would improve the waiting experience?
(Multiple choice)

Option	Count	Percentage
Rest area	23	79.31%
Entertainment (e.g., mini games, videos)	24	82.76%
Information updates (e.g., estimated wait time)	22	75.86%
Fast-pass option	8	27.59%
Others	0	0%

Q15. Did the exhibition meet your expectations? (5-point scale; average score 4.34)

Aspect	1	2	3	4	5	Mean
Interactivity	0	0	2 (6.9%)	14 (48.28%)	13 (44.83%)	4.38
Creativity	0	0	2 (6.9%)	13 (44.83%)	14 (48.28%)	4.41
Artistic expression	0	0	2 (6.9%)	18 (62.07%)	9 (31.03%)	4.24
Technological use	0	0	2 (6.9%)	16 (55.17%)	11 (37.93%)	4.31
Overall Mean						4.34

Q16. What feelings did you experience during the exhibition? (Multiple choice)

Option	Count	Percentage
Visual shock	26	89.66%
Healing / calming feeling	17	58.62%
Deep thinking or inspiration	12	41.38%
Immersive experience	21	72.41%
Others	0	0%

Q17–Q20. Open-ended Questions

Q17: Which area or work impressed you most, and why?

Q19: Please summarize your overall impression of the TeamLab exhibition in one sentence.

Q20: What are your expectations or suggestions for future exhibitions?

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