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Research article

การศึกษาเชิงประจักษ์เกี่ยวกับอุปสรรคและข้อจำกัดภายในสภาพแวดล้อมทางกายภาพของการจัดแสดงนิทรรศการภายในพิพิธภัณฑ์ที่มีสื่อดิจิทัล ภายใต้แนวคิดการออกแบบเพื่อคนทั้งมวล กรณีศึกษาพิพิธภัณฑ์เซี่ยงไฮ้อาคารตะวันออก ประเทศจีน

Empirical Research on Barriers and Limitations in Museum Exhibition Environment Containing Digital Media Regarding the Universal Design - A case study in China Shanghai Museum East Campus

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บทคัดย่อ

เทคโนโลยีสื่อดิจิทัลถูกนำมาใช้อย่างแพร่หลายในการจัดแสดงนิทรรศการของพิพิธภัณฑ์มรดกทางวัฒนธรรม เพื่อสร้างประสบการณ์และสร้างการมีปฏิสัมพันธ์ที่ดีขึ้น อันเนื่องจากข้อจำกัดในการสื่อสารเผยแพร่ข้อมูลเรื่องราวของสิ่งต่าง ๆ ในพิพิธภัณฑ์มีจำกัด อย่างไรก็ตามสื่อดิจิทัลยังพบว่ามีปัญหาอยู่บ่อยครั้งในการถูกใช้งานและตั้งอยู่ภายในพิพิธภัณฑ์ อาทิ จำนวนการถูกใช้งานต่ำ การประเมินผลความพึงพอใจและประสิทธิภาพของสื่อดิจิทัลโดยส่วนใหญ่ถูกประเมินเพียงทัศนคติหลังการเยี่ยมชมภายในพิพิธภัณฑ์ ซึ่งไม่มีการประเมินหรือศึกษาเชิงประจักษ์อย่างละเอียดเกี่ยวกับองค์ประกอบของสภาพแวดล้อมในพื้นที่จัดนิทรรศการ รวมกับการตรวจสอบเกี่ยวกับพฤติกรรมมนุษย์กับการปฏิสัมพันธ์กับสภาพแวดล้อมสรรค์สร้าง ในงานวิจัยนี้จึงนำแนวคิดและหลักการออกแบบเพื่อคนทั้งมวลมาใช้สำหรับการประเมินสภาพแวดล้อมภายในพิพิธภัณฑ์ของการจัดนิทรรศการที่มีการใช้สื่อดิจิทัล และการสังเกตพฤติกรรมของผู้เข้าชมพิพิธภัณฑ์ เพื่อตรวจสอบเชิงประจักษ์ถึงอุปสรรคที่ส่งผลต่อประสิทธิภาพในการเข้าชม

งานวิจัยนี้ใช้แนวทางเชิงประจักษ์ (empirical approach) ที่ใช้วิธีการวิจัยเชิงคุณภาพ โดยดำเนินการสำรวจที่พิพิธภัณฑ์เซี่ยงไฮ้อาคารฝั่งตะวันออก (Shanghai Museum East Campus) 2 ครั้ง ได้แก่ หนึ่ง : การประเมินสภาพแวดล้อมทางกายภาพในการจัดนิทรรศการโดยใช้สื่อดิจิทัลในพิพิธภัณฑ์ภายใต้หลักการการออกแบบเพื่อคนทั้งมวลและการสัมภาษณ์ความคิดเห็นของผู้เข้าชม และ สอง : การตรวจสอบการเข้าถึงการใช้พื้นที่โดยการเข้าใช้บริการจริง (การวิจัยเชิงคุณ ภาพ) ผลการวิจัย พบว่า ในห้องจัดแสดง 4 ห้อง และบันทึกกลุ่มผู้เข้าร่วมที่มีความหลากหลายจำนวน 77 กลุ่ม ประเด็นปัญหาที่พบ

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ได้แก่ การมองเห็นถึงตำแหน่งของสื่อดิจิทัลได้อย่างชัดเจน หรือขาดข้อมูลแนะนำที่ชัดเจน ขนาดพื้นที่ที่ไม่เหมาะสมทำให้เกิดความแออัดในจุดนิทรรศการ อุปสรรคด้านการสื่อสารเพราะมีเพียงภาษาจีน และปัจจัยอื่น ๆ ที่ลดทอนความสามารถในการเข้าถึงนิทรรศการ นอกจากนี้ สภาพบรรยากาศภายในพื้นที่ไม่เอื้อต่อการใช้งาน ยังทำให้ปัญหาดังกล่าวรุนแรงขึ้น โดยใช้การประเมินผลตามหลักการออกแบบสากล (Universal Design - UD) วิเคราะห์ปัญหาทั้งหมดและเสนอแนวทางแก้ไขที่เหมาะสม

คำสำคัญ: การท่องเที่ยวเชิงวัฒนธรรม นิทรรศการพิพิธภัณฑ์ ปฏิสัมพันธ์กับสื่อดิจิทัล การออกแบบสากล พฤติกรรมสิ่งแวดล้อม

Abstract

Digital media technology is widely used in heritage museum exhibitions to create unique sensory experiences because of its ability to expand information within limited physical space. Unfortunately, digital media has not achieved the desired effect in the current museum exhibitions, with significant issues of low usage rates. When relevant scholars evaluate the effectiveness of digital media, they mainly conduct surveys on the attitudes after visits, without giving much scrutiny to the exhibition environment, interactive environment, and so on. Therefore, this study introduced universal design principles in the measurements of the environment containing digital media interaction and behavioural observation of the museum visitors to identify obstacles affecting visitation efficiency within the environment. This study focuses on two main issues: (1) the measurement and collection of environmental characteristics of the exhibition environment containing digital media, including location, space, information display, and interactive forms, and whether they meet the requirements and/or are suitable for all visitors, and (2) the behaviour of different types of visitors when entering the exhibition space and interacting with digital media, with a focus on the relationship between behaviour and issues. The study adopted an empirical approach, combining qualitative methods, conducting surveys at the Shanghai Museum East in two stages. The first phase is environmental measurement and audience survey (qualitative research), and the second is scenario assessment. The study has identified the problems for 4 galleries and has recorded 77 groups of participants of different types. The issues discovered include the difficulty in noticing the location or the lack of specific guidance information, spatial scales that are unreasonable, leading to congestion, communication barriers, etc., which reduce the accessibility of the exhibition, while a poor spatial atmosphere exacerbates the problem. The evaluation results of UD have speculated on all the issues and proposed corresponding solutions.

Keywords: Cultural Tourism, Museum Exhibition, Digital Media Interaction, Universal Design, Environmental Behaviour

1. Introduction

The museums in the 21st century have embraced the new trend of "Museum + Cultural Tourism" (Furferi et al., 2024; Mo, 2022). The 'visitor-centred' concept of museum exhibition design has increased

interest in visitor experience and methods to improve it across various research fields (Loboda, 2022; Packer, 2016; Waltl, 2006). In recent years, museums that have been newly established have become popular tourist destinations due to their emphasis on new media technology and immersive cultural tourism experience (Mo, 2022; Ning et al., 2022; Tuomi et al., 2023).

However, after a preliminary investigation and literature review, this study focuses on two important issues faced by digital media interaction in museum cultural tourism. The first is that despite digital media providing momentum for cultural tourism, the lack of visitor diversity remains one of the main problems (Kasemsarn et al., 2023). The second is that numerous issues with the practical application of digital media interaction, such as low usage rates and technical misuse, prevent the realisation of intended design goals (Ken, 2003; Lo et al., 2023; Ning et al., 2022; Lo et al.).).

Although researchers recognise the benefits of digital media to museum exhibitions, few studies have addressed the visitors' behavioural perceptions and barriers within the exhibition environment, to explore the efficiency issues of visits formed by the composition of the exhibition environment containing digital media interactive technologies (Wu, 2014). The literature further indicates that operating and clicking on digital media devices cannot enhance the experience, but rather it is the exhibition environment influenced by digital media that changes the perception of visitors, thereby affecting the visiting experience (Mason, 2020; Phillips, 2011). Therefore, it is essential to measure and evaluate digital media interactions within the exhibition environment.

To make cultural heritage tourism accessible to a wide range of visitors (Kasemsarn et al., 2023) and to engage all audiences in museum tourism (Banasiak, 2020; Filová et al., 2022), this study introduces and utilizes the 7 principles of universal design. To create a high-quality exhibition environment for all museum visitors, it is necessary to consider the requirements of different visitors in both museum exhibition design and digital media interactive design, that is, people of different ages and those with different abilities or disadvantages (Filová et al., 2022; Phaholthep et al., 2016; Mason, 2020).

This concept is consistent with the universal design paradigm (Phaholthep et al., 2017). Universal design is a principle and philosophy that aims to provide equal benefits to everyone, and to be inclusive of all physical limitations, gender, age, etc. It believes that differences in physical abilities are a regular condition of humanity, focusing on the usability of all different physical abilities, aiming to create environments, products, and services that are accessible to everyone without barriers—everyone can access them (Filová et al., 2022; Vardia et al., 2018). The exhibition design works of modern museums are cultural education institutions open to the entire society (JI & Wang, 2024), no longer solely for individual users or a group of users (such as children, and students). Instead, they are designed to actively meet the needs, requirements, and interests of visitors of different ages and characteristics, based on the diversity of potential tourists (Mason, 2020).

The quality of museum exhibitions is being measured and improved through exhibition technological enhancements and visitor satisfaction surveys, yet important environmental factors and visitor-related factors are often overlooked (Ken, 2003; Lo et al., 2023). The researcher involved in this article is contributing to a study titled "The Utilisation Guideline of Digital Media Intervention Techniques in Museum Exhibition

Design for Motivating Visitors' Interest and Interaction: A Case Study of the Most Popular Cultural Tourism Museums in China." The project encompasses an empirical research process that evaluates the environmental composition made up of digital media and museum exhibition design guidelines, focusing primarily on enhancing exhibition efficiency and appeal through the use of digital media interactions to meet the behavioural characteristics and visit motivations of different types of visitors.

2. Research Objectives

This study aims to investigate the barriers and limitations in the exhibition environmental composition containing digital media interaction from the Shanghai Museum East (including the physical environment dimension, content information dimension, and interactive operation dimension), and how these elements and barriers affect the visiting behaviour of different types of visitors. Suggestions for potentially improving accessibility and attractiveness are proposed where appropriate. The research objectives are as follows:

Objective 1: To analyse the environment and functional accessibility of museum exhibitions containing digital media interaction from the perspective of environment composition elements, focusing on environmental issues and barriers, as well as the needs of visitors.

Objective 2: To analyse the obstacles and limitations that cause a level of inaccessibility and prevent digital interactions from attracting visitors under different environmental factors through the UD checklist, focusing on the relationship between visitor behaviour and the environment.

Objective 3: To analyse the segment between the elements of the environment composition and the 7 principles of universal design, by combining the results of objectives 1 and 2, and propose corresponding design recommendations.

3. Related Concepts and Theories

3.1 The museum and cultural tourism

The modern museums built in recent years and exhibitions are held in cultural tourism and emphasize the interactive and experiential design of museum exhibitions (Ning et al., 2022; Wang, 2015). Exhibition design focuses on attracting a variety of tourists to participate in cultural tourism, highlighting personalised experiences (Mason, 2020).

The motivation and personal background of tourism both influence visitors' decisions on whether to visit museums, and in this process, the physical environment of the museum acts as a mediating factor (Zhang et al., 2018). The trend of audience segmentation research in museums has emerged: for instance, research targeting family audiences with children, research targeting young audiences, and research targeting elderly audiences (Li, 2021). However, it needs to be pointed out that existing classification studies on tourists still lack a fixed classification. Identifying the diversity of tourists in museums is the most challenging task for designers (Kasemsarn et al., 2023). If research could start with the classification of the audience and proceed to study the behavior and perception of the museum visitors, exploring the characteristics of digital

media that can enhance appeal and interaction in museum exhibitions, and proposing relevant principles for museum display design, it would contribute to building a more attractive and communicative museum.

Figure 1 summarises the general target audience classification from the literature review as well as the target audience selected for this study.

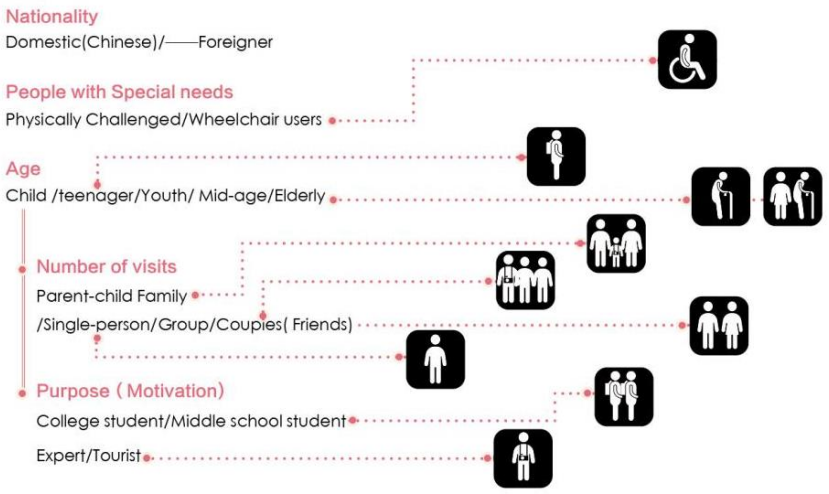


Figure 1 The target groups.

3.2 Theories related to research or study

Initially, the purpose of applying digital media technology in exhibitions was to expand and explain exhibition content. Later, it evolved into providing visitors with more diverse and interactive options through digital technology, such as rapid access to information, audio-visual stimulation, depth and breadth of the exhibition, and expanding considerations in entertainment and education (Ken, 2006). With the introduction of the experience design paradigm, an increasing number of new digital media technologies, such as digital holographic projection, VR, AR, XR, 3D scanning, and other technical means, have been applied to museum exhibitions. These technologies are used to create immersive scenes, turn thematic stories into experiences, and employ gamification, situational audio-visuals, and interactive facilities with engaging elements to design products or services that stimulate the five senses of the experiencer and evoke resonance (Chen, 2023; Ken, 2006; Ning et al.,2022; Tong, 2020; Wang, 2015). **Table 1** summarises the theories and characteristics related to the research of museum digital technology.

Table 1 Theories and Features of Digital Media Interactive Technology Applications in Museums.

Theories and Authors	Features
• According to the division of numbers and spatial narration. • (Tong, 2020; Mason, 2020)	• Interactive narrative in 3d scenes • Immersive narrative of historical culture • Game-based learning narratives

Theories and Authors	Features
	• AI narrative simulating human thought • The visual narrative of scientific research
• According to the division by digital technology and type. (Ken, 2006; Wang, 2015)	• Multimedia and Theatre: Including IMAX theatres, optics, sound and image displays, and a large integration of computer graphics, providing real-time interaction for the audience • The evolution of audiovisual technology: Multi-technology, multi-sensory constructs a futuristic exhibition space. • Computers and the Internet: Information Retrieval and Consultation Dissemination
• According to the type of interactive experience. (Ning et al., 2022)	• Sensory interaction • Contextual Interaction Technology • 3d imaging, 2D digital imaging, immersive dome • Scene composition technology

In a broad sense, museum exhibition spaces include physical and informational environments. After the intervention of digital media interactive technology, the original exhibition environment has become more complex, forming a complex experiential space where physical space, informational space, and digital space are intertwined. (Loboda, 2022; Mason, 2020; Phillips, 2011; Tong, 2022). Digital media interaction is exerting significant potential by influencing/altering the physical environment of exhibitions. However, empirical studies have also suggested that the current effects of digital media interaction applications are not significant, and there is no direct evidence to prove that the communication effectiveness and visitor experience of exhibitions have been enhanced (Lo et al., 2023).

3.3 Exhibition Environment and Visitor Behaviour

The visitors are the target of museum services, and museum designers and staff need to better understand the needs of visitors. Therefore, in terms of human living environments or the practicality of space, when planning museum architecture, space, and exhibitions, it is necessary to prioritise the study of "human behaviour" as a key element (Ken, 2003). A better way to understand the audience's needs is to focus on the audience's behaviour during the visit (Li, 2021). Researching the behaviour of visitors in exhibition spaces relies on the discipline that studies the environment and behaviour - environmental behaviour science (Wineman & Peponis, 2016; Yan, 2009).

In behavioural psychology, "behaviour" can be explained as behaviour, attitude, or behavioural patterns; Watson (1878~1958) explained behaviour and the environmental factors that cause behaviour in his theory using "stimulus" and "response," thus behaviourism has the intention to study human behaviour and subsequently predict and control it (Wu, 2012).

The introduction of "environmental behaviourism" theory into the field of museums is a research direction of visitor behaviour. Environmental behaviourism focuses on the relationship and interaction between the environment and human behaviour. American psychologist J.B. Watson believed that the object of psychology is not consciousness but behaviour and proposed the basic formula "S-R". E C Tolman proposed the "S-O-R" formula, believing that human behaviour is influenced by environmental, physiological, and other factors. S-O-R, that is, the stimulus-organism-response model, refers to the influence of environmental stimuli on people, causing internal emotional responses, thereby affecting human behaviour. The behavioural tendency of the audience under environmental stimuli is divided into two types: approach and avoidance (Li, 2021). The visitor behaviour generated by the museum environment is the behaviour that occurs after the audience processes the relevant information about the museum environment through the emotional process of environmental perception. This can include both the physical environment (e.g., display configuration, display methods, etc.) and the psychological environment (e.g., factors such as the audience's own expectations, values, and experiential feelings).

Table 2 shows the three factors affecting visitor behaviour proposed by Bitgood and others (Wu, 2012).

Table 2 Three factors influence audience visiting behaviour.

Factors	Details
• Design factors	• The presentation of exhibition content and quality, no obstacles to visiting, and attractive exhibitions are conducive to the conduct of visiting behaviour.
• Visitors	• Visitors use interest, motivation, knowledge, and past experiences as the basis for deciding whether to stay or leave.
• Environmental factors	• Consider the museum as a holistic environment where visitors receive stimuli from environmental messages, such as the scenarios, atmosphere, and the techniques and forms of the exhibits.

Source: Stephen & Chen (1992); Wu, 2012.

From environmental behavioural psychology, utilising digital media interactive technology elicits human responses in exhibition environments, and alters visitors' perceptions to create new visiting experiences (Phillips, 2011). This is a new paradigm that does not separate the digital experience from the overall museum experience (Mason, 2020). This study continues to participate in this discussion, exploring how integrating different design elements supports the design of museum information spaces.

3.4 Universal Design

During the literature review process on topics related to museum exhibitions, digital media technology, museum exhibition visitors, environmental behaviour, and visitor experience, a highly relevant topic was discovered: inclusive design. According to the "Encyclopedia of China, Volume on Cultural Relics and Museums" (1993, p. 43), museums have become cultural educational institutions open to the entire

society since modern times, regardless of age, culture, belief, race, and social class, as long as one has personal freedom, they can become museum visitors (Lin, 2016). The purpose of introducing inclusive design into museum exhibition design and digital media design for museum exhibitions is to promote museum visits as an activity within cultural tourism, better reflect the diversity of its potential audience, and actively meet their needs, demands, and interests (Kasemsarn et al., 2023). According to WHO (World Health Organisation's new definition of disability), the International Classification of Functioning, Disability, and Health (ICF2001) uses Universal Design (UD) as a measurement method for the accessibility level of service facilities, providing equal usability for everyone. Universal design was first explicitly proposed by an American architect named Ron Mace. It primarily targets physical products and environments but has later been applied to digital products as well, which encompasses seven design principles. The principles of UD were first applied to museum architecture by Mace and colleagues in 1997 (Filová et al., 2022).

UD1. Equitable Use

Design meets the needs of everyone. No user is excluded or isolated due to architectural barriers. Designing for everyone in museum design aims to ensure that all visitors are provided opportunities for cultural engagement.

UD2. Flexibility in Use

Design can adapt to many choices or methods, allowing visitors to choose from several route options, sequences, and spatial timings. Flexibility is also important for exhibits and exhibition spaces.

UD3. Simple and Intuitive Use- Intuitive moving and wayfinding are very important for every user. The layout should be clear, and spatial legibility enables people to see or predict activities in space.

UD4. Perceptible Information - When different modes are combined, communication is effective. Providing information in a multi-sensory way, for example, through exhibitions, should be interactive, supporting hands-on activities and multi-sensory approaches.

UD5. Tolerance for Error - The environment is risk-free, with dangers and errors minimised.

UD6. Low Physical Effort - The design should minimise fatigue and repetitive movements. Layouts should not require unnecessary walking, which could lead to fatigue and discomfort.

UD7. Size and Space for Approach and Use - These components are visible, accessible, and within reach for users standing or sitting, including those of various body sizes, such as children. The spatial solutions of the exhibition hall must accommodate a wide range of users.

The guidelines designed by LMB and Berlin emphasise the application of UD principles to the positioning and guidance, exhibits, content, and access of museums (Antona & Stephanidis, 2022). **Table 3** displays the main criteria considered when evaluating museum exhibitions based on 7 principles of UD, including the environmental dimension, content dimension, and digital interaction dimension, with a total of 65 details not shown.

Table 3 The sample of main criteria for evaluating museums is based on 7UD principles.

The UD principles and Main characteristics	Implementation in a museum exhibition
• **UD1 Equitable Use** • Satisfy the needs of all different groups without exception. • Provide all users with the same usage method, otherwise an equivalent.	• All visitors can enter the space/area equally.
	• Accessible entry and routes (horizontal and vertical), rather than creating separate accessible solutions.
• **UD2 Flexibility in Use** • The environment can adapt to a wide range of individual preferences and abilities. • Several means of vertical communication (using various methods to enhance accessibility to achieve the same purpose).	• Use movable partitions to connect or divide media exhibition spaces. • Different route choices and time schedules • Flexible routes also support the structure of the exhibition.
	• Using elevators, ramps, stairs, escalators, and innovative vertical circulation methods
	• Enough channels allow for flexible entry and exit.

Source: The author's compilation based on a systematic literature review.

4. Research methods

4.1 Research sample and Participants

This study is based on the concept of "museums designed for all," aiming to enhance the museum visiting experience for different types of visitors across various age groups through universal design principles. A comprehensive understanding of the diverse needs and satisfaction levels of all visitor types is crucial. Therefore, the target visitors of this study are grouped into categories based on classification criteria such as age, visitation characteristics (number of people, behavioural traits), cultural background, and motivations and purposes (Kasemsarn et al, 2023), with the target audience segmented as follows: 1). Parent-child families (FC): Family combinations consisting of children aged 7-12 accompanied by either father, mother, or both parents; 2). Teenage student group (TS): Defined as a middle school student organisation consisting of 3 or more individuals aged 13-18; 3). ~~Alone~~ Single visitors (A): In this study, single visitors specifically refer to young and middle-aged individuals (19-59 years old) visiting alone. When participants are university students, they are first categorised as 4). College Students (CS); 5), Visitors with companions: In this study, visitors with companions refer to visiting groups such as couples, spouses, friends, etc.; 6). The elderly (E): This study defines visitors aged 60 and above as elderly visitors (China's retirement age 7). Visitors with special needs (SP): Due to the limited number of both foreign and disabled visitors in this study, they were categorised collectively as visitors with special requirements. During the Environmental Assessment Phase, interview records from 29 participants were documented. In the UD Evaluation Phase, 77 participants were recorded. The specific types and numbers of visitors are shown in Table .

During the data collection process, the authors randomly selected different types of visitors on-site and explained the research objectives and details to them. Visitors who agree to participate should be chosen as

research participants. It is important to note that visitors who are touring exhibitions, looking for directions, or have already shown signs of visitation fatigue should be excluded.

Table 4 The number of participants for the scenario access audit.

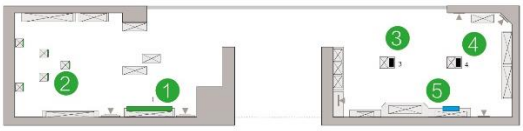
	Gallery	Visitor type							Total
		FC	W	A	CS	TS	E	S	
1	Ancient Chinese Bronze Gallery	2	2	2	2	3	2	2	15
2	Ancient Chinese Jade Gallery	6	4	3	2	2	2	0	19
3	Chinese Numismatics Gallery	6	6	5	2	3	4	0	26
4	Ancient Ceramics Gallery	4	2	3	2	2	2	2	17
	Total	18	14	13	8	10	10	4	77
	Visitor interview in four galleries	3	6	5	5	5	3	2	29

The survey was conducted at the Shanghai Museum East Campus on January 15 (Wednesday) and January 18 (Sunday), 2025.

4.2 Case studies

The survey was conducted at the Shanghai Museum East every Wednesday and Saturday in January 2025. During this phase, the fundamental issues of the study were clarified through analysis and discussion. Shanghai Museum East has a total of 8 permanent galleries. The Ancient Chinese Bronze Gallery, the Ancient Chinese Jade Gallery, the Chinese Numismatics Gallery, and the Ancient Ceramics Gallery are the cases studied in this research. The basis for the selection of cases is 1) permanent galleries; and 2) digital media interaction in various forms. Based on the literature review, the digital media interactions in the four galleries are categorized into four categories: viewing media; trigger viewing media; interaction display, and interactive game. In **Figure 2**, a description of the category and characteristics of digital media within each gallery is provided, with channels and digital media also indicated.

Ancient Chinese Bronze Gallery



	Category	Interactive form	Description
1	Interaction display	Multi-touch	Animation; By clicking on the screen to expand the information
2	Trigger viewing	Click to playback	Transparent screens with the cabinet, playing the details of bronze
3	Interaction display	Click to query	Interactive desktop; query results are video playbacks instead of text.
4	Interaction display	Click to query	Interactive desktop; query results are video playbacks instead of text.
5	Interactive game	Content interaction	Click, and follow the prompts to manufacture weapons and combat.

(a)

Ancient Chinese Jade Gallery			
	Category	Interactive form	Description
1	Viewing media	Knowledge interpretation	The projection of the jade origin map
2	Viewing media	Knowledge interpretation	The small monitor plays the knowledge of jade
3	Viewing media	Art aesthetic	Projection plays abstract artistic animation
4	Viewing media	Knowledge interpretation	A small monitor plays jade knowledge on the low desk
5	Viewing media	Art aesthetic	Projection plays abstract artistic, Chinese calligraphy
6	Viewing media	Knowledge interpretation	Animation style, mall monitor plays the knowledge of jade
7	Viewing media	Movie space	Rest seats, monitor plays the development history of jade
8	Viewing media	Knowledge interpretation	Small monitor plays the knowledge of jade

(b)

Chinese Numismatics Gallery			
	Category	Interactive form	Description
1	Interaction display	multi-touch	Animation, by clicking on the screen to expand the information
2	Interaction display	Screen control	Interactive desktop; By manipulating the screen, rotating and zooming to view the details of ancient numismatics.
3	Viewing media	Knowledge interpretation	Playing the manufacturing process of currency on a black mirror
4	Interaction display	Click to query	Click the screen to expand the information.
5	Viewing media	Knowledge interpretation	Playing the manufacturing process of currency on a black mirror
6	Viewing media	Knowledge interpretation	Animation, a small monitor plays the knowledge of currency
7	Interactive game	Clicker games	Click to combine your coins
8	Viewing media	Movie space	No rest seat, projection plays the history of coin manufacturing;

(c)

Ancient Ceramics Gallery			
	Category	Interactive form	Description
1	Viewing media	Knowledge interpretation	Transparent screens integrated with cabinet, playing the production process of ancient ceramics
2	Viewing media	Art aesthetic	Projection play abstract art images at the top of the large cabinet
3	Viewing media	Knowledge interpretation	The TV on the wall plays the production process of the ceramics
4	Viewing media	Art aesthetic	Projection play abstract art -Chinese Calligraphy
5	Interaction display	multi-touch	Clicking to view pictures and introductions of ceramics.
6	Viewing media	Knowledge interpretation	The TV on the wall plays the production process of the ceramics
7	Viewing media	Knowledge interpretation	The TV on the wall plays the production process of the ceramics
8	Interaction display	Screen control	By manipulating the screen, zooming to view the ceramic seal.

(d)

Figure 2 The category and characteristics of digital media.

4.3 Research methods and tools

This study is empirical research that employs an innovative research method combining quantitative and qualitative approaches. The survey research was carried out within the China Shanghai Museum East, where the exhibition environment containing Digital Media of the Ancient Chinese Bronze Gallery, Ancient Chinese Jade Gallery, Chinese Numismatics Gallery, and Ancient Ceramics Gallery was measured and evaluated. The study is divided into three phases, employing behavioural observation, unstructured interview, and scenario access audit. The heuristic evaluation method (HEM) was adopted during the research process to ensure its validity.

Phase 1 — Qualitative Research: Through environmental assessment and visitor surveys, general issues concerning the exhibition environment, including digital media, have been identified. This phase identified issues and obstacles in three aspects and a total of 16 dimensions, including the physical environment (routs, layout, spatial scale, environmental atmosphere, signage information), exhibition content (exhibition interpretation, artistic expression, knowledge points), and interactive forms (operation, instructions), as shown in **Table 5.**

Randomly select visitors in the exhibition hall for interviews to investigate their behavioural perceptions and attitudes. The questions that may be asked of the interviewees include, but are not limited to: How do you feel about the design of the digital exhibits and content? Did it meet your expectations? Did you use the interactive facilities? How was the overall operation process? Do you have any bad experiences? What do you think are the reasons for these bad experiences?

Table 5 Details of environmental feature measurement.

Design features and elements, and Evaluation criterion *A. Physical environment, B. Interaction, and C. Content	Level		
	Good	Fair	Poor
A1. The location of the exhibition items is clear and easy to access		√	
A2. There is plenty of space to interact and watch		√	
A3. The movement of exhibition items is clear, and there is no obstruction to the tour route			√
A4. Flexible visiting routes and ignoring the time will not affect the exhibition structure	√		
A5. Interactive exhibit items can be identified and recognised			√
A6. Light and shadow express matters, not too much or too little			√
A7. The audio and light and shadow are suitable and will not affect the surrounding exhibits		√	
B1. Have clear operating instructions or an introduction			√
B2. The scale of interaction is reasonable, and there are no difficulties			√
B3. The exhibit is running normally and can be operated as expected		√	
B4. The exhibit is ergonomically designed, with appropriate viewing/operating space/scale			√
C1. The display content is clear and logically related to the exhibition content		√	
C2. Content expansion or inquiry			√
C3. Artistic expression, consistent with the exhibition content, and clear	√		
C4. Clear information conveyed, which will not confuse people	√		
C5. Interpretation of content and knowledge points			√

Phase 2 — Quantitative Research: This is a scenario access audit completed by observing and recording the experiences of different types of visitors by using the UD7 evaluation checklist. The checklist includes a total of 31 details. The sample of the assessment framework is shown in **Table 6**. The quantitative data obtained were imported into SPSS v27 for recoding analysis and calculation. A match is counted as 1, and a mismatch as 0. Ultimately, the UD scoring rate for each digital exhibit is obtained, and descriptive statistics and cross-table analysis are performed.

Table 6 The sample checklist of digital media design for all is based on the 7 principles of UD

UD1 Equitable Use		Target Visitor							Mark
criteria	Criteria details	F-C	A	T-S	E	W	CS	S	
UD1-1 Can all visitors watch/participate/enter this exhibition area or space?	There are enough channels/entrances to enter	√	√		√	√	√	√	
	There are equivalent entrances with ramps	O	O	O	O	O	O	O	
	There are visual images and guidance suitable for visitors of all types	√							
	The location of the exhibits will not be ignored	√				√			

UD1 Equitable Use		Target Visitor							Mark
criteria	Criteria details	F-C	A	T-S	E	W	CS	S	
	due to the choice of route								
*√-meets the requirements; O- element does not exist									
***FC** - Parent-child family; **A** - Alone visitor; **TS** - Teenager student groups; **E** - Elderly visitors; **W**- with others (friends, partners.); **S** – People with special needs; **CS** - College students.									

Phase 3— Descriptive analysis: By comparing and analysing the results of Phase 1 and Phase 2, comparing the environmental obstacles and the experiences of visitors with the UD7 principles, the reasons for the obstacles were identified, and design suggestions were proposed.

5. Results

The Shanghai Museum East, situated in Shanghai, China, is the newest museum dedicated to ancient Chinese art and heritage, having opened in 2024. Its promotional focus is on being a "visitor-friendly" and "digitally intelligent" museum. Initial investigations have shown that the Shanghai Museum East attracts a significant number of residents, especially parent-child families, as well as young tourists and cultural enthusiasts of all ages. Regrettably, the museum sees a limited number of disabled visitors and international tourists. The Shanghai Museum East features a total of 8 permanent galleries. Among these, the Ancient Chinese Bronze Gallery, Ancient Chinese Jade Gallery, Chinese Numismatics Gallery, and Ancient Ceramics Gallery are the focus of this research. The research results will be divided into environmental measurement result analysis, UD evaluation result analysis, and design suggestions.

5.1 Environment and Barriers Analysis Based on considerations of design elements

Based on the results of environmental assessment and visitor interviews conducted in the first phase, the authors meticulously measured and documented the visitation barriers caused by digital interactive exhibits for different types of visitors across four galleries, while also recording 29 valid interview datasets. According to the grouping criteria for the target visitors, there were 3 Parent-child families, 5 Single visitors, 5 Teenager student groups, 6 Visitors with companions, 3 elderly visitors, 5 College students, and 2 visitors with special needs. The interview duration for each person is 10-15 minutes. The specific results are described as follows:

5.1.1 Environmental Features and Obstacles

The most distinctive feature of the digital media interaction at the Shanghai Museum East is the comprehensive interpretation of cultural relics exhibits and heritage, which includes the historical background and craftsmanship of the objects. The touch screen for professional knowledge explanation seems to have been deliberately downsized and placed on one side of the display case, providing professional or interested visitors with a way to search for information. However, this also raises issues: the unreasonable location and spatial scale have led to congestion among the crowd. In the environmental measurements of the museum,

the issues identified also include the following three points: 1) Most digital media interactions are far from the main route, which makes them easy to overlook by visitors. 2) The spatial scale is unreasonable, causing congestion. 3) Artistic or a lack of relevant interpretation of the exhibits leads to communication barriers.

5.1.2 Obstacles and Visitor Requirements Description

The authors imported the interview transcripts into the iFlytek Tingjian web version to convert them into textual data, which were then categorised according to 7 visitor groups to perform descriptive statistics and analysis. Similar viewpoints were merged to obtain different types of visitors' needs and visiting barriers regarding digital exhibits. By environmental measurement and assessment, analysing three aspects of the 1) physical environment, 2) content information, and 3) interaction, four galleries present different issues. Specific summaries are as follows in **Table 4**.

Table 4 Based on considerations of design elements and the results of environmental reviews

Issues and obstacles	Visitor requirements description (excerpt)
Obstacle 1-1: The digital media exhibit is located at the back of the main route, and visitors will not go there proactively.	1) **Single visitors- Middle aged (45-59)**: I generally don't actively pay attention to this media. I prefer to focus my attention on the exhibits. 2) **Teenager student groups (13-17)**: We wouldn't deliberately go over and poke these screens because we feel like they wouldn't give us the information we want. 3) **College student**: I haven't deliberately ignored it, but sometimes I just don't see these exhibits.
Obstacle 1-2: The inappropriate height and form of the media items will lead to visitors ignoring them.	
Obstacle 1-3: Interactive exhibits lack relevant introductions and guidance. They are difficult to recognise.	1) **Teenager student groups (13-17):** I didn't know this was interactive, he didn't give me a hint. 2). **Elderly (over 60)**: I don't know what this is, I think it's not interesting. 3) **Visitor with special needs- Foreigner**: I don't understand what this is.
Obstacle 1-4: Traffic congestion	1) **Elderly (over 60)**: So many people, it's what young people like, it's not suitable for me. 2) **Elderly (over 60)**: I'm not interested, I won't touch it.
Obstacle 2-1: The interpretation of knowledge points is not lively, deep, and interesting enough.	1) **Single visitors- Middle aged (45-59)**: I think most of the media are unrelated to the exhibition, and the content created is superficial, unable to help understand the exhibition. 2) **Teenager student groups (13-17)**: I hope the explanation of knowledge points is more detailed, for example, this bronze ware, besides wanting to see its photo, I also want to know its manufacturing process.

Issues and obstacles	Visitor requirements description (excerpt)
Obstacle 2-2: The content displayed is abstract and overly artistic, causing visitors to feel confused.	1) **Visitor with special needs- Foreigner:** I don't know what this means, what is this picture? It's hard for me to understand. It seems unrelated to the exhibition. 2) **College student**: I prefer exhibits that explain the process, I hope they can help understand the process, but the current exhibits are mostly about inquiry and entertainment. 3) **College student**: The form of interaction is simplistic and uninteresting, failing to provide interpretations of knowledge points or historical culture, which does not appeal to me. 4) **Single visitors- young aged (19-44)**: Some media is just for the sake of good visuals, but lacks knowledge content; I won't watch that, and I also think it's a waste.
Obstacle 2-3: No clear knowledge points or information, and visitors cannot directly obtain useful information.	
Obstacle 3-1: Interactive exhibits lacking interactive instructions can cause confusion among visitors.	1) **Parent-child family- Child (7-12)**: Can I play with this; can I hit this; does it move. 2) **College student**: Isn't this something that can be looked up? How come it can't be looked up?
Obstacle 3-2: Due to inappropriate scale or ergonomics, visitors are unable to view or participate.	1) **Parent-child family- Parents:** Some exhibits are not suitable for children to interact with, it is suggested that some that are suitable for children could be set up. 2) **Elderly (over 60)**: I think there are too many things for children in the museum, which we cannot use, it's a waste of resources. 3) **Visitor with companions**: These interactions are too childish and meaningless

5.2 Analysis of the assessment results based on the 7UD evaluation checklist

5.2.1 Data processing

The 7UD Evaluation Checklist was utilized. Data from the scenario access audit to four galleries were imported into SPSSv27 for recording by the first author of this paper, for which compliant is recorded as 1, non-compliant is recorded as 0. This resulted in the UD scoring rates for each exhibit item and the UD scores rates of every gallery. Furthermore, through the Cross-calculation and Descriptive statistics, the overall UD7 score rate of the Shanghai Museum East (4 galleries) and the UD7 score rates for target groups as shown in **Table 5** and **Table 9** are obtained, to gain a comprehensive understanding of the UD7 evaluation status of the Shanghai Museum East Campus.

Table 5 The UD7 scoring rates for each gallery based on the 7UD Principles Evaluation checklist.

Results Statistics of UD7 Principles Evaluation Checklist in Shanghai Museum East Campus								
Gallery	UD1	UD2	UD3	UD4	UD5	UD6	UD7	
Ancient Chinese Bronze Gallery	88.65%	63.49%	63.17%	81.25%	61.41%	74.94%	80.92%	72.07%
Ancient Chinese Jade Gallery	86.08%	64.82%	67.25%	67.92%	54.60%	65.75%	71.59%	68.87%
Chinese Numismatics Gallery	79.24%	62.66%	67.39%	73.62%	64.27%	71.77%	60.53%	68.50%
Ancient Ceramics Gallery	80.37%	62.13%	77.69%	77.84%	46.42%	67.79%	64.36%	71.57%
	83.59%	63.28%	68.88%	75.16%	56.68%	70.06%	69.35%	**69.57%**

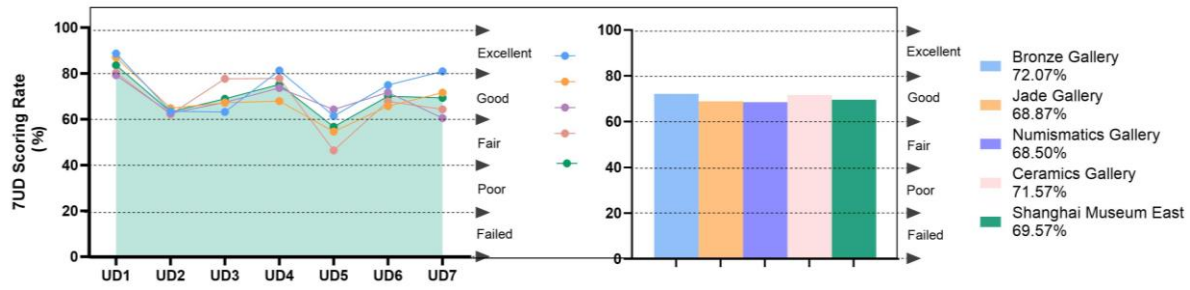
Table 6 The UD7 scoring rates for target groups based on the UD7 Principles Evaluation Checklist.

Results Statistics of UD7 Principles Evaluation Checklist in Shanghai Museum East Campus								
	FC	A	TS	E	W	CS	S	
UD1	86.23C	86.60%	79.20%	78.38%	86.37%	92.15%	76.21%	83.59%
UD2	66.31%	72.32%	47.23%	48.26%	77.38%	79.33%	52.16%	83.59%
UD3	82.56%	68.5%	67.32%	50.12%	81.66%	77.45%	54.52%	68.88%
UD4	77.86%	78.04%	68.60%	64.12%	86.53%	82.69%	68.30%	75.16%
UD5	52.64%	63.68%	58.69%	46.48%	66.25%	65.56%	43.45%	56.68%
UD6	74.66%	85.36%	62.10%	45.69%	85.69%	87.12%	49.78%	70.06%
UD7	69.66%	73.77%	65.00%	61.57%	72.12%	75.61%	67.71%	69.35%
	72.85%	75.47%	64.02%	56.37%	79.43%	79.99%	58.88%	**69.57%**
***FC** - **Parent-child family**; **A** - Alone visitor; **TS** - **Teenager student groups**; **E** - Elderly visitors; **W**- with others (friends, partners.); **S** – People with special needs; **CS** - College students.								

5.2.2 Data Analysis

From the data in **Table 5** and **Figure 3**, it can be seen that the overall 7UD score rate for the Shanghai Museum East is 69.57%, and according to the classification of grades where every 20% is level, it falls into the Good category (UD score rate of 60%-80%), indicating that it has relatively met well the principles of universal design. As can be seen from **Figure 3(a)**, among the four galleries in the Shanghai Museum East, the 7UD Checklist Evaluation results of the Chinese Numismatics Gallery are significantly different. In particular, the scoring rates of UD5, about tolerance rate, is notably insufficient compared to other galleries, whereas the scoring rate for UD3, about operational simplicity, is significantly higher than the other three galleries. However, the scoring rate for UD1 has reached 79.24%, indicating that the digital media interactions in the Chinese Numismatics Gallery can provide good perception and operational instructions for visitors of different types, with excellent accessibility performance, and the main barriers to interaction are interruptions or restrictions during the interactive participation process, which is consistent with the findings of the first phase environmental inspection.

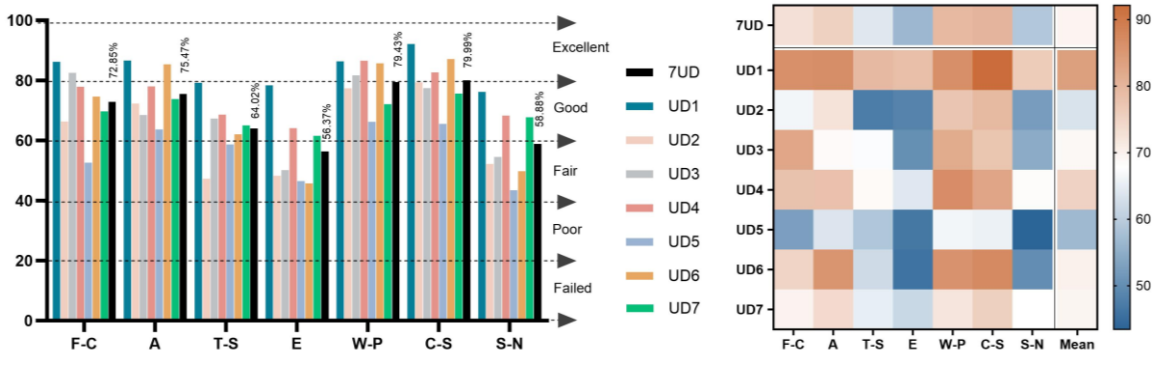
The 7UD Checklist Evaluation results for the four galleries are relatively balanced, all reaching the "Good" level, as shown in **Figure 3(b)** The UD scoring rates for the Ancient Chinese Bronze Gallery, Ancient Chinese Jade Gallery, Chinese Numismatics Gallery, and Ancient Ceramics Gallery are 72.07%, 68.87%, 68.50%, and 71.57% respectively. Among them, the Ancient Chinese Bronze Gallery has the highest comprehensive UD scoring rate, reaching 72.07%. Environmental measurement results based on design elements in Phase 1 of the research also indicate that the Bronze Hall has relatively fewer environmental barriers and restrictions.



(a) (b)

Figure 3 The UD score rates for the four galleries in the Shanghai Museum East

The UD1 score rates for the four galleries are all at or above 79%, and the overall UD1 score rate for the Shanghai Museum East is as high as 83.59%, which falls into the "Excellent" category (UD score rates ranging from 80% to 100%). This indicates that the target audience distribution at the Shanghai Museum East is balanced, allowing various types of visitors to participate in digital media interactions. However, the lower score rate of UD2 and insufficient flexibility in exhibition visiting echo the issues and obstacles found in the exhibition route dimensions of each gallery. Therefore, the application of UD principles in the design of digital media interactions for exhibitions to anticipate potential problems and obstacles and to enhance the feasibility of the design has been strongly validated.



(a) (b)

Figure 4 The UD score rates for the four galleries in the Shanghai Museum East

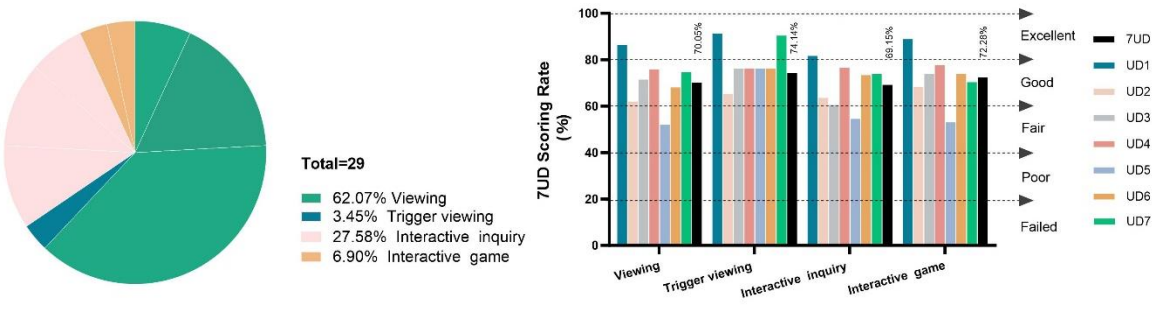
Further analysis of the UD scoring rates for the target audience groups in the four galleries of the Shanghai Museum East was conducted using the dates in **Table 9**. The results indicate that although all types of target

groups performed well in various 7UD Checklist Evaluation, the UD score rates for elderly visitors and visitors with special needs (the sample for this study was international visitors) were 56.37% and 58.88% respectively, which still fall into the "Fair" category (UD scores rate ranging from 40% to 60%), showing in **Figure 4**(a).

The score rates of UD2\UD3\UD5\UD6 for elderly visitors are less than 60%, indicating that although the location and form of digital exhibits pose no accessibility barriers to elderly visitors, there is still a lack of friendliness towards them in terms of flexibility, simplicity, perception, and comfort during their visit. For instance, elderly visitors may consider these digital media unrelated to the exhibition content, and the crowded environment is not suitable for them to visit—this is the conclusion drawn from the first phase of the survey. The heatmap shown in **Figure 4**(b) reveals that although the Shanghai Museum East is committed to creating a visitor-friendly museum that meets the needs of all visitors, the attention given to specific groups, such as teenage students, the elderly, and visitors with special needs, remains insufficient. These results further confirm the necessity and feasibility of applying UD principles to meet the diverse needs of visitors and to anticipate potential problems and barriers in the exhibition environment.

5.2.3 Correlation Analysis of Environmental Barriers and 7ud Checklist Evaluation Results

The study refers to the evaluation process of museum buildings by Čereščová et al., (2018), who evaluate buildings from a UD perspective, but order them according to the premises of the building (rather than each principle of UD individually), because it seems easier to find consistency when evaluating individual parts of a space from various perspectives than when evaluating the entire building according to the 7 principles of UD. Therefore, in Phase 3, according to the environmental characteristics of digital media and the forms of participation of visitors, the digital interaction at the east of the Shanghai Museum is divided into four types, including Viewing, Trigger Viewing, Interactive Inquiry, and Interactive Game, as shown in **Figure 5** (a). A correlation analysis is conducted on the environmental barriers and UD scoring rates of digital media interactions for each category. **Figure 5**(b) shows the proportion of various types of digital media interactions in the Shanghai Museum East and the results of the 7UD Checklist Evaluation.



(a) (b)

Figure 5 Types of digital media in the Shanghai Museum East and their UD evaluation status

As shown in **Figure 5**(a), there is a total of 29 digital media interactions in the Shanghai Museum East, of which 18 are viewing-type digital media, accounting for 62.07% of the total. As shown in Table xx, the Viewing-type digital media are mostly knowledge explanation types, their score rates for UD5/UD6/UD7 are

low, which in turn reduces the number of participants. The corresponding problems found in environmental measurements are the inappropriate location and spatial scale of the exhibits, causing congestion and safety hazards, media time being too long without rest areas, and uncomfortable viewing scales.

After conducting an ANOVA test, there is a significant correlation between the type of digital interaction and the UD score rates, with $p<0.01$. As shown in **Figure 5**(b), there is no significant difference in the UD score rates among the four types of digital media interactive exhibits at the Shanghai Museum East. Only the UD score rate for the interactive inquiry type is below 70%, which is slightly lower than the other three types. The reason for this is that the UD3 score rate for this type of digital interaction is below 60%. That is, it performs inadequately in terms of operational simplicity, which is consistent with the issues identified in the first-stage environmental and barrier analysis. The detailed analysis and targeted design suggestions are fully elaborated in **Table 7**.

Table 7 The problem description and targeted suggestions summary

UD Comply	Description and Suggestion
Viewing-Type	
Not Meet: UD2/ UD5	**Audio-Video Space** -The characteristics of videos/ film are the presentation of easy-to-understand content and the structural display of heritage artefacts, content suitable for visitors of all types, but lacking in identification and introduction. - The narrow entrance poses a safety hazard. - A dark and cramped space, visitors resist entering and are congested at the entrance.
·One common entrance suitable for all visitors and no risk in the environment. ·Conform to the visual image and guidance for visitors of various types. ·Cinema should be located along the main route, with clear and open entrances, but the entrances should not be located at transportation hubs. Appropriate safe evacuation routes should also be considered. ·The lighting for viewing should be appropriate, not too dark or too bright to create excessive contrast with the exhibition environment, and the cinema space should be set appropriately for the size of the screen.	
Not Meet: UD5/UD6/ UD7	**Video- Knowledge Interpretation** - The display is placed in corners, passages, and other wall areas, causing potential safety hazards such as traffic congestion and physical collisions due to visitors' staying. - Insufficient viewing positions and space have been reserved, resulting in visitors needing to stand for long periods, which leads to severe physical fatigue, and visitors are forced to sit on the ground. -The height of the display is not suitable for children to watch.
·The facilities should be placed along the main exhibition outline but not in the traffic, and sufficient viewing space should be left according to the content of the media. ·If possible, place the exhibits on the main exhibition outline clearly visible and easy to find	

UD Comply	Description and Suggestion
·The rest form should be set appropriately based on the duration of the content. ·There is enough space between digital media and physical exhibits or explanatory information.	
Not meet UD4/UD6	**Projection - Artistic** -Artistic projections are used to create an atmosphere in the exhibition, without information. -The meaning conveyed by the screen content is not clear, the projection height is too high, and it is not suitable for viewing.
·If possible, visual and other sensory stimuli should be contacted with the environment ·Information elements are visible, accessible, and approachable to everyone. ·Aesthetic and easy-to-understand signs and pictograms help everyone recognise the function of the exhibits. ·The content is logically clear and conveys the exhibition information explicitly. ·Strongly related to the surrounding exhibits in terms of logic or content, aiding understanding.	
Trigger viewing	
Not meet: UD2/UD3	-The lack of a prominent start button causes exhibits to be overlooked, and the inability to flexibly choose when to start or end leads to a waste of resources.
·Set clear, concise, and explicit instructions at the main location, highlighting effects for identification. ·The elements are visible, approachable, and reachable for all. ·Important information should be placed at the visual centre point.	
Interactive Inquiry	
Not meet UD3/UD5-UD7.	**Linear query (Click-on); Multi-touch** - Visitors can click on the Knowledge points on the screen to watch the content Interpretation, but the interaction Inquiry without operational instructions/the points of interaction trigger content in the display are not prominent, making it difficult to recognise the interactive function. -Equipment operation is unresponsive, or difficulties are caused by poor equipment positioning. -Located on the wall without an exhibition context, making it difficult for the devices to be noticed. -Content is professional, information points are dense, and it is considered not suitable for children or non-professional visitors.
·A well-organised and clearly explained display or instruction will facilitate user operation ·Trigger keys are prominent and easy to activate/Appropriate partitions and dividers for screening. ·Low height workstation and setting error operation prompt ·The location of the exhibit should be at important nodes of the content, with a clear content structure. ·If possible, adopt a visual interpretation form to interpret professional knowledge points as much as possible, suitable for various types of visitors, while setting up further in-depth queries for professional visitors.	

UD Comply	Description and Suggestion
-Not meet UD3/ UD7	**Screen manipulation** -Visitors can rotate and pan the screen to perform a 720-degree rotation or zoom in on details of the three-dimensional images of the heritage, but the scale of the images and the operation can be difficult for children and the elderly. -The console can only be operated and viewed by 1 to 2 people, the inclined angle of the console height is too high for children, and it is easy to be overlooked by visitors. -Lack of operational instructions, not easily identifiable or ineffective tapping and dragging.
· Considering the characteristics of visitors with different body features, reduce the need for fine manipulation. · Various ways of perception and interactive exhibits. · Multiple forms of communication (including prominent location, language, visual icons, and good lighting). · Clear and precise operating instructions to reduce damage.	
Interactive Game	
Not meet UD5/UD6/ UD7	-Puzzle-solving games, where participants can achieve victory by correctly assembling weapons. Children visitors require assistance from parents. But for middle-aged or elderly individuals, this does not belong in their interaction. -For creative interaction game, operation is simple, but the program will automatically play images every ten minutes, causing the game process to forcibly be interrupted, and after a long wait, the game cannot resume its progress. -The height of the screen touch is too high for children.
· A content structure can meet the needs of visitors from any professional background. · Equipment chosen should be as operationally simple has a high fault tolerance and is easy to maintain later on · The interactive program should be concise, with unified functions, ensuring the smoothness of interaction. · If possible, partitioned operations can be adopted to accommodate visitors with any physical characteristics to participate in the interaction.	

6. Discussion

6.1 Discussion of Results

The results of Phase 1 have confirmed the issues highlighted in the literature review: the efficiency of digital media interactive technology in practical applications has not achieved the desired outcomes, with low usage rates and no significant enhancement in visitor experience, irrespective of visitor type. This is inconsistent with previous literature: digital media interaction can enhance visitors' experience (Mason, 2020; Su, 2019). The results of environmental measurements also demonstrate that the issues with digital media applications arise from designs that overlook the behavioural characteristics of people within the environment (Ken, 2003; Lo et al., 2023). This study further deciphers the underlying reasons for the

existence of this phenomenon. When a digital media interactive device is examined in isolation, it is undoubtedly a perfectly designed media interaction. However, when it is placed within an exhibition environment and tasked with attracting visitors and disseminating information, its obstacles and limitations are discovered. This aligns with the viewpoint from Phillips (2011) that what enhances visitor experience is not the interactive actions themselves, but rather the connections and reactions visitors generate with the exhibition environment during interaction. For instance, the location of this digital media device is difficult to access, and there is not ample space for interaction and watching. An interactive query screen is considered for mounting on the exhibition wall without visitors realising it is touch-sensitive. These issues and obstacles are examined from the viewpoint of environmental design elements.

Moreover, the results of the scenario access audit conducted using the UD Checklist during phase 2 further revealed the impact of the environment on visitor behaviour. Digital media interactive devices with low UD score rates are participated in and used by fewer visitors. The digital media interaction in the Shanghai Museum East, with the level of UD2, UD3, UD5, and UD6, has lower UD score rates, indicating issues such as unreasonable visit path design, monotonous interactive forms, the user interface is not easy to recognize, high error rates, and potential safety hazards. These findings are consistent with the conclusions of literature reviews: the application of UD principles can effectively enhance the accessibility of museum exhibitions (Filová et al.,2022). Furthermore, it was discovered that the behavioural characteristics of different visitors vary (Li, 2021; Lo et al., 2023). Elderly visitors are more concerned with UD3 and UD6, hoping to obtain the information points of the exhibition straightforwardly. Teenage students paid more attention to U6 and UD4. They usually participated in group activities without a clear visit objective; thus, they hoped that the exhibits were visually appealing and suitable for small groups to visit together.

In Phase 3, upon comparing the results of Phase 1 with those of Phase 2, it was discovered that the locations of obstacles and restrictions present in the exhibition environment containing digital media correspond to the low UD score rates. For example, narrow cinema space entrances hinder wheelchair users from entering—not meeting UD1; Interactive media at transportation hubs obstruct the visitor path—not meeting UD2; Digital interactions are difficult to recognize, often leading to them being overlooked by visitors—not meeting UD3; Artistic projections situated in prime locations fail to attract visitors to linger because they do not meet UD4; Visitors tend to congregate at the entrance rather than enter audio-visual spaces because of the dim lighting and the glare from large screens, which does not meet UD5; Visitors sitting on the ground to watch heritage interpretation and performance videos are causing traffic congestion, as the device form and duration do not meet UD6, resulting in excessive physical exertion; Elderly and family-child visitors are drawn to the exhibits but refrain from interacting, as the operation of the device does not meet UD7. These results support the feasibility of predicting potential issues in exhibition environments at the early design stage using the 7 principles of Universal Design, as well as the ability to enhance the accessibility and visitor experience of exhibition environments through these principles. These findings confirm the issues encountered by different types of visitors when engaging with digital media

interactions, involving aspects of the physical environment (Lo et al., 2023), exhibition content and information dissemination (Antona & Stephanidis, 2022), as well as interaction aspects (Ken, 2023). Moreover, these barriers can be interpreted and improved through universal design principles to achieve an accessible exhibition environment for all.

6.2 Discussion of limitations

This empirical study was conducted at the Shanghai Museum East Campus in China, where the samples exhibited specific visitation preferences influenced by regional characteristics and community factors. Therefore, future research will incorporate museum cases from different regions to eliminate the impact of regional cultural traits on the results. Secondly, as this study employed the method of scenario access audits and screened participants, it inherently excluded some visitors who lacked understanding of the Universal Design or had no clear concept of digital exhibits. Consequently, the target visitor sample may not fully represent the diverse needs of visitors in a broader, real-world exhibition setting. Future research could introduce prototype designs into actual museum environments, involving real visitors, including those with special needs.

6.3 Conclusion

The researcher of this study conducted two phases of on-site surveys in the four galleries of the China Shanghai Museum East. The first survey aimed to identify issues within the digital media environment from three aspects: the environment, content, and interaction. Interviewed visitors obtain their experiences and feelings after participating in the interaction. The second survey utilised the UD Checklist, employing the scenario access audit to evaluate environmental barriers and limitations, which focused on the relationship between visitor behaviour characteristics and the environment containing digital media.

Through the data analysis and results comparison in Phase 3, it was found that in the UD Checklist evaluation, the low score rates of digital media interaction match the obstacles found in the environmental measurement. It was also discovered that the relationship between visitor behaviour and the exhibition environment, as supplemented by the UD Checklist evaluation, is consistent with the conclusions drawn from visitor interviews. This evidence supports the effective evaluation of barriers and limitations within the museum exhibition environment composition containing digital media, using the seven principles of Universal Design. It also enables the proposal of corresponding solutions to meet the needs of various types of visitors, thereby enhancing the visitor experience.

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