Textual Information Presentation in Virtual Museums: Exploring Environment-, Object-, and User-based Approaches

Yuexin Yao   Yue Li*

School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China

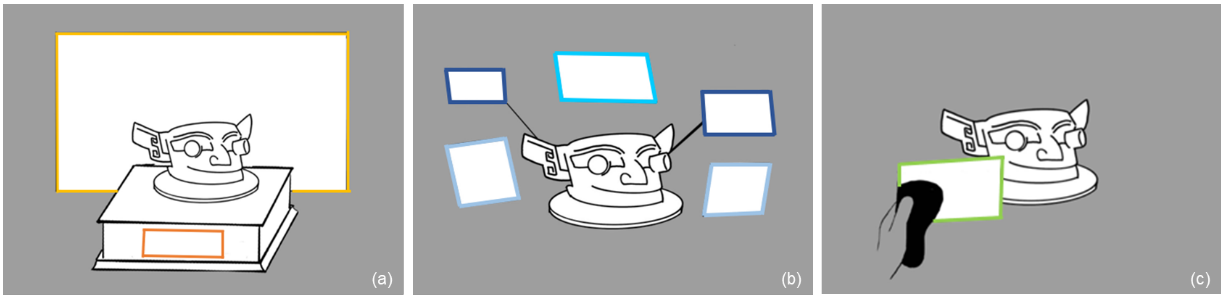

Figure 1: Illustrations of textual information presentation in virtual museums using three types of layouts: (a) environment-based layout: panels fixed in the environment (e.g., on the wall, on the artifact pedestal); (b) Object-based layout: panels placed around the artifact and move with it (e.g., on the top, by the side, using tooltips). (c) User-based: panels triggered around the user's body and move with the user (e.g., handheld panels).

Abstract

In a physical museum, text descriptions are typically displayed on placards or signage next to exhibits. Within a virtual museum environment, these text descriptions can be presented in various ways, such as fixed in the virtual environment, attached to the exhibits, or held in users' hands. By seamlessly integrating text descriptions into the virtual environment and allowing users to engage with the content, the information presentation can be highly interactive. However, the design space of artifact information presentation in virtual museums was under-explored. In this paper, we investigated appropriate ways to present text descriptions of artifacts in immersive virtual museums. Specifically, we studied (1) users' perceived importance of various information dimensions (observable, non-observable, and interpretation), (2) users' expected display of text panels (shown or hidden), and (3) the relationship between the artifact information dimensions and layout types (environment-, object-, and user-based). Our results showed that participants rated significantly higher importance for non-observable information than observable and interpretation information. In addition, we summarize a design space for artifact information presentation using different layout types with prioritized options. Our work provides insights for the interaction design of artifact information in virtual museums and the presentation of text in virtual reality.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—Human computer interaction (HCI)—HCI design and evaluation methods—User studies

1 Introduction

In the era of digitization, Virtual Museums (VMs) have become an important way to preserve and disseminate cultural artifacts. The VMs offer unique opportunities for exhibits, facilitating connections between artifacts and visitor that are unattainable in physical museum settings [27]. A fundamental attribution of VMs is the ability to go beyond museum-specific exhibitions, combining the collections and resources of multiple institutions in a single exhibition. Consequently, the realm of Virtual Reality (VR) allows for the creation of an exhibition without the physical constraints of space and type of artifacts on display [28], presenting a significant curatorial potential. Moreover, it enables the development of interactive simulations featuring museum collections, mitigating the risk of detrimental effects on the artifacts themselves.

One of the most fundamental aspects of virtual museum design is the appropriate presentation of artifact information. Despite various multimedia can be adopted in VR, such as audios and video, text descriptions of museum artifacts remain the default approach to presenting and communicating artifact information. Thus, our study aims to answer this research question: *How should the text descriptions of artifacts be presented in virtual museums?* First, we identify that previous research lacked a user-centered perspective in the information presentation of artifacts. The text descriptions of museum artifact were often written by professional following organizational and institutional guidelines, but visitors may be reluctant to read long paragraphs [25]. Despite it was suggested that visitors' interest and needs should be considered in artifact information presentation [22], it is not clear which dimensions are seen important by users. Thus, we first explore how users perceive the importance of various dimensions of artifact information. Furthermore, existing research suggests diverse spatial layouts for presenting textual information in VR, such as text panels in the environment and tooltips attached to objects. However, there is a gap in linking artifact information to spatial arrangements. Existing guidelines on museum artifact information only provide instructions for the construction of content, but not the layout. In the meantime, duplicating the physical layout of museum in VR does not take full advantage of its spatial enclosure for object interactivity and user engagement. Nevertheless, there is a lack of design guideline related to artifact display in virtual museum settings. Therefore, we aim to investigate the relationship between artifact information dimensions and spatial layout types in virtual museums.

In this paper, we present a study conducted with 24 participants to understand users' expected information presentation in VMs. Specifically, a VR system comprising six scenes was developed, each of which consists of a 3D museum artifact and multiple information

*Corresponding author: yue.li@xjtlu.edu.cn

2473-0726/24/$31.00 ©2024 IEEE
DOI 10.1109/ISMAR62088.2024.00067

panels with sentences of text descriptions of the artifact. We collected participants' importance ratings for each information panel, invited them to freely design the spatial layout of the information panels, and recorded their design results in the VR system. Considering the form of textual information matters in virtual museums [4], we also collected user's preferences for showing or hiding the presentation of information panels. Our study showed three main findings. (1) Name of artifact was rated the greatest importance, followed by non-observable information, name of museum, interpretation information, and observable information. The results also indicated that participants made a greater use of information panels that were perceived important. (2) Environment-based layout is applicable to almost all information dimensions. This layout type contributes to replicating the physical museum settings that users are familiar with; object-based layout was the most favored approach among users, for it facilitates the connection between text descriptions and artifacts and contributes to artifact interactivity. It was found particularly suitable for observable information; user-based layout demonstrated advantage in mitigating information overload and the ease of reading at a close proximity. It was found suitable for interpretation information. (3) Users preferred displaying artifact information at all times. However, information presented using tooltips (object-based) and handheld panel (user-based) approaches were often hidden by default and accessed as needed.

Our work makes the following contributions. First, we provide insights into the perceived importance of user's perceptions of different dimensions of artifacts information in virtual museums, highlighting the need to prioritize non-observable information (e.g., era, original function, archaeological excavation, restoration) when presenting artifact textual information. Second, our study elucidated the relationship between artifact information dimensions and spatial layout types in virtual museums. A design space is summarized for artifact information presentation in virtual museums, suggesting layout types (environment-, object-, and user-based) that can accommodate diverse information dimensions. The findings in our work will inspire future design of virtual museums and provide insights for optimizing textual information presentation in virtual environments.

2 Related Work

2.1 Artifact Descriptions in Virtual Museums

Textual descriptions in museums provide detailed and rich information about the artifacts, serving as the fundamental avenues through which visitors access information on diverse artifacts [11]. While VR demonstrates great advantage in its immersion through multimodal presentation, reading remains a key activity for consuming information in both the real and digital worlds. Text remains an important way of conveying information as it is one of the most common and prominent ways of acquiring knowledge [16]. The textual descriptions of museum artifact are often rich in content. One of the greatest challenges in curation is determining the text descriptions of artifact to present to visitors [6]. These descriptions are often written by museum professionals, following institutional or organizational guidelines. For instance, the International Committee for Documentation of the International Council of Museums has issued the *CIDOC Information Categories* [9], which include 22 groups of information, each containing one or more sub-dimensions. Similarly, museums in China would follow the *Standards for the Registration of Cultural Relics in Cultural Institutions*, issued by the State Administration of Cultural Heritage in China [30]. This guideline encompasses 27 categories of artifact information. These guideline documents demonstrated that the information about a single artifact in museums spans multiple categories in their documentation. However, these classifications are more geared towards the storage and management of artifacts. Many information dimensions are used for preservation purposes, such as the registry number and warehouse location, which are not presented to visitors.

The text descriptions of museum artifact shown to users often start with some information that is ***observable*** or can be perceived by looking at the artifact, including the size and weight (measurement information), texture, material and technique. Observable information also include basic situation and descriptions, subject depicted information about the appearance, such as marks and inscriptions, as well as parts and components. In addition, some other factual descriptions that are ***not observable*** from the artifact itself are also included. These descriptions pertains to aspects that cannot be physically observed, but are known through research, historical records, or scientific analysis. To name a few, the era, artifact circulation experience, authoring information, archaeological excavation, original function, restoration records, and information related to the object production, collection, and association. While most text descriptions of museum artifacts are objective, some artifact information also includes descriptions that are not yet confirmed or provide a subjective lens, such as unverified legend, the appraisal information showing curatorial ***interpretation***, as well as user-generated content [15]. On top of the three dimensions, the ***name of artifact*** and the ***name of museum*** are often treated separately – these are included in the simplistic labels even when other textual descriptions are not available.

Reitstätter et al. [22] studied the reading patterns in museums. Their study results showed that museums should take a consideration of visitor's interest and their need for artifacts information. Previous research has shown that visitors do not read all of the information on display, nor do they read them in a prescribed order [25]. Instead, their reading process tends to prioritize the information they consider important and combine key pieces to interpret the theme. In the study on the use of interactive displays in museums, Roberts et al. [23] suggested that using less text-heavy displays could entice visitors to interact, and layers of content are needed to sustain user engagement. The authors also highlighted that information-on-demand approach works well when visitors are curious about the objects. However, to the best of our knowledge, there is no existing study that took a user-centered perspective to understand the information dimensions that were found important by museum visitors. In particular, virtual museums are more than digital duplicates of physical ones, but affords significant opportunities in technology-enhanced interactions and gamified learning. It is thus important to understand user preferences so that designers can explore new ways to present these text descriptions and effectively communicate the historical and cultural significance. Thus, we propose **RQ1**: *How do users perceive the importance of various dimensions of artifact information?*

2.2 Textual Information Presentation in VR

The design space of textual information presentation in VR encompasses numerous factors. Notably, information density and length are critical factors, as there is a negative correlation between length and readers' attention span [31]. To convey as much knowledge as possible in a short time, museums often risk including too much text. Bitgood [2] suggests that a safe word count for each exhibit description should be between 30 and 75 words, though shorter texts can also be effective. Partitioning long texts into multiple small segments can enhance reading efficiency and interest [1, 32]. Previous research suggested that reading shorter texts repeatedly can lead to improved reading rates and accuracy compared to reading longer texts [20]. These findings suggested that compared to long paragraphs, using short texts such as sentences and words in VMs is likely to be more effective.

Previous research also examined a range of visual elements related to text display in virtual environments. Grout et al. [8] studied the presentation of desktop interfaces within immersive virtual environments. They found that users could do standard reading activities in an immersive virtual environment with performance that was almost identical to that of the real world. Jankowski et al. [10] compared different text drawing styles, image polarity, and background style on readability. Their study results showed that the text displayed on a *semi-transparent* panel leads to the fastest and highest performance. Moreover, *negative* presentation (i.e., white text on a black semi-transparent panel or white text with black outlining or a black shadow) outperforms positive presentation (i.e., black text on a white semi-transparent panel or black text with white outlining or a white shadow). Kobayashi et al. [13] conducted a study on text settings for reading lengthy texts in Japanese, providing guidelines on font type, size, and the optimal distance for reading. Additionally, they found that participants favored *stationary* text panels in VR over panels that moved with the user's position and gaze. Büttner et al. [3] found that the rotation of the board surface (at 0-60°) has little impact on text reading. Dingler et al. [5] asked participants to position and adjust the text panels to suit their comfort regarding the size, distance, and content. Although the findings offer valuable guidelines for determining comfortable reading positions, there was considerable variability in the results. These studies examined various visual elements for reading in VR. Existing knowledge on the panel settings, including text font, size, color, and panel color, rotation, and distance helps inform the design of text panels in VR.

Chernbumroong et al. [4] compared existing virtual museums and highlighted the need to consider the form in which the textual information appears. Most of the existing virtual museums adopts two approaches: either displaying them all the time or popping up when they are approached. The authors argued that pop-up descriptions that provide detailed information about each artifact can significantly enhance the learning experience. Moreover, McNamara et al. [19] proposed a method for strategically placing information labels in complex virtual environments, driven by the goal of enhancing information delivery in VR without overwhelming the user. This technique utilizes eye-tracking technology to show labels related to objects of interest only when the user focuses on them, thus keeping other information hidden. Previous works also examined the spatial layout of text annotations and addressed the issue of occlusions [7]. Considering the potential impact of textual information visibility on user experience, we proposed **RQ2**: *What are the expected displays of information panels in virtual museums (shown or hidden)?*

The review of related work indicated that virtual museums could benefit from short texts presented on multiple panels. Satriadi et al. [26] explored hierarchical multi-view layouts and their impact on user arrangement preferences. Their investigation revealed that participants tended to favor *a spherical cap* layout when arranging views around themselves. On the other hand, Liu et al. [17] explored the integration of small multiplexed displays in 3D immersive environments. Specifically, they investigated the effect of curvature size on the user's ability to perform comparison and trend analysis tasks related to specific structures. They proposed that *flat layouts* are more efficient when dealing with multiples of small quantities. Kim et al. [12] proposed a strategy for efficient VR multi-view navigation wherein the main view and sub-views are strategically positioned within the human field of view, spanning 60° to 110°, as opposed to occupying the entire VR space. Comparing these varying approaches, Liu et al. [18] assessed the impact of three different layout curvatures (flat-wall, semicircular-wraparound, and circular-wraparound) on visuo-spatial memory tasks within a virtual environment. Their findings indicate that participants were able to remember spatial patterns more accurately and provided higher subjective ratings for the *flat-wall* layout compared to the circular-wraparound layout. While these studies provided valuable insights into how the layout of multiple views in a VR environment, these information panels were primarily based on the surrounding environment of the user. They were not linked to any specific objects or the user themselves.

2.3 Layout Types of Text Panels in VMs

Previous works adopted some typical approaches to presenting text panels in VMs. Some examples are shown in Table 1. Rzayev et al. [24] conducted a study to compare three different methods of text presentation and location in VMs: world-fixed, edge-fixed, and head-fixed. Their results showed that world-fixed text, common in both physical and virtual museums, is user-friendly as it mimics real-world scenes. The edge-fixed text allows users' freedom of movement but limits adjustments to only the text angle. Lastly, the head-fixed text, although immersive, partially blocks the user's view and complicates interaction within the virtual environment. Their study did not take into account the importance of text and how different layout types affect the VR reading experience. For the edge-fixed location, they solely focused on the vertical direction. However, horizontal tilting could also be beneficial, particularly when text in the virtual environment is displayed above or below an artifact. In some commercial VR applications, handheld text panels serve as a convenient medium for presenting text information. For instance, Smithsonian American Art Museum's '*Beyond Walls*' exhibition employs handheld guide, along with text panels placed by the side of exhibits [29]. The CubeMuseum [35] demonstrated an object-centered approach, where text descriptions of museum artifacts was linked to hotkeys placed around an artifact. In the VR museum designed by Wang et al. [33], both static labels on the back of the artifact and floating tags were used. Lappayanant and Shigemasu's [14] work presented an information panel on top of the artifact once the user activates it.

Table 1: Some typical layout types of text panels in virtual museums.

Layout type	Text presentation	Text length	Reference
Environment-based	World-fixed	Paragraphs	[24]
	World-fixed	Words	[24]
	Wall panel	Paragraphs	[33]
Object-based	Edge-fixed	Paragraphs	[24]
	Edge-fixed	Words	[24]
	Side of the artifact	Paragraphs	[29]
	Above the artifact	Paragraphs	[14]
	Floating tags	Sentences	[33]
	Hotkeys	Words	[35]
	Text annotations	Words	[7]
User-based	Head-fixed	Paragraphs	[24]
	Head-fixed	Words	[24]
	Hand-held	Paragraphs	[29]

Previous research has proposed various text presentations in VMs. To better facilitate the design, we synthesized them into three broad layout types: environment-based, object-based, and user-based layouts (see Figure 1). More specifically, environment-based spatial layouts are fixed within the virtual environment, remaining static relative to the surroundings and objects. Within a VM, panels are often attached to the museum environment, such as the wall and the pedestal used to place the artifact. Object-based layouts are directly linked to the artifacts and move along with them. This category encompasses placements in various locations, such as alongside an artifact, on top of it, and tooltips that indicate specific parts of the artifact. User-based layouts are designed to be highly accessible, moving with the user. They can be easily activated or dismissed as needed, offering features such as handheld guides. Informed by the previous works, this study aims to investigate appropriate design of information panels in VMs, aiming to answer **RQ3**: *What are the relationships between artifact information dimensions and spatial layout types in virtual museums?*

3 System Design and Implementation

The VR system used in our study was developed in Unity (version 2021.3.26f1c1) and deployed on a computer equipped with AMD Ryzen 7 4800H CPU, 16GB RAM, and NVIDIA GeForce RTX 2060 GPU. A Meta Quest 2 VR HMD with two handheld controllers was used as the VR display and input device, with a resolution of 1832 $\times$ 1920 pixels per eye and a refresh rate of 72 Hz. We used the XR Interaction Toolkit (version 2.3.2) for the system implementation. The Universal Render Pipeline (URP) was employed to achieve realistic graphics rendering.

3.1 Virtual Museum Environment

The VR system comprised six scenes (see Figure 2, a1-6). Each scene consisted of an artifact and multiple artifact information panels. The six artifact scenes featured photogrammetric 3D models created using RealityCapture [21]. These models were retopologized and textured using Blender before being imported into Unity for lighting and rendering adjustments. Each model has a rigidbody and mesh colliders that closely match the geometry of the artifact.

3.2 Panel Setup

In total, there were 59 information panels in the six test scenes, including 6 name of artifact, 6 name of museum, 22 observable information, 17 non-observable information, and 8 interpretation information. The text descriptions were captured from the official websites of the museum artifacts and categorized based on into the three categories of observable (O), non-observable (NO), and interpretation (I) information [9, 30]. Some example panels are given below. The panels included simplified Chinese characters, with an average number of 22.17 ($SD = 18.43, Min = 2, Max = 65, Median = 17$). Informed by the guidelines for using text in VR [5, 10], we used white *Kaiti* font, size 22, on a dark background for the texts.

- O *The instrument is inscribed with 79 characters.*
- O *The young woman has a plump figure; long, attenuated brows and lashes; a small peach-shaped mouth; round face; and a composed expression.*
- NO *The unicorn is also called Xie Zhi, a beast that symbolizes justice. It is said that its horn is dedicated to those who are unjust in law enforcement.*
- NO *Hell in Chinese popular belief is modelled on a bureaucracy where souls plead before ten courts.*
- I *These bronze wares of the Ke clan provide important evidence for research into the political systems and military activities of the late Western Zhou period.*
- I *The figure displays the realistic style of Tang art, embodying for us the natural appearance of Tang noblewomen.*

3.3 User Interactions

3.3.1 Locomotion

Users used two handheld controllers to move freely in VR using the steering-based locomotion technique. Specifically, users can move along the direction of the right-hand joystick push, and rotate their views using the left-hand joystick.

3.3.2 Panel Interactions

Users were allowed to select, move, and rotate panels using the raycasting technique. Each panel had a slider underneath to allow users to resize the panel. We configured **magnetic placeholders** to avoid the need for precise manipulation (see Figure 2b-d). When a panel approached a preset placeholder, it displayed a blue preview block indicating where the panel will be positioned upon release. Once the user released the panel, it was snapped into place on the placeholder with proper alignments, facing forward.

3.3.3 Spatial Layouts

We introduce six spatial layouts that fall into the environment-, object-, and user-based approaches. Figure 2 illustrates the supported functions and example scenarios.

(1) Environment-based: wall and pedestal. By default, the environment showed a large wall panel with 12 preset magnetic placeholders on the back of each artifact (see Figure 2, b1-2). When an information panel was close to the wall panel, the nearest magnetic placeholder was highlighted. In addition, pedestals were set up for reasonably sized artifacts. Users could place the information panels around the pedestal (see Figure 2, b3). These two environment components consist of environment-based layouts, displaying panels that are fixed in the environment.

(2) Object-based: top, side, and tooltips. Placing panels around the artifact, such as fixed aside and on top, is a typical way to present artifact information (see Figure 2, c1). In addition, we configured triggers around the features of artifacts that were mentioned in the textual descriptions (see Figure 2, c2). A trigger appeared and a haptic feedback was given when the controller ray collided with a feature (e.g., the ear of the bronze mask in Figure 2, c3). By pressing the grip button on the controller, users could activate a tooltip. The end point of a tooltip can be adjusted by grabbing the cube indicator or the magnetic placeholder (see Figure 2, c4-5). When the user interacted with the artifact (e.g., by picking it up), these object-based panels (e.g., positioned on the top, by the side, using tooltips) moved along with it, maintaining a relative position and rotation.

(3) User-based: handheld. User-based panels are triggered around the user's body (e.g., hand, wrist, arm) and move with the user. We implemented a handheld panel that can be shown or dismissed by pressing the `B` button on the controller. Similar to the wall panel, users could attach information panels to the handheld panel (see Figure 2, d1-2). It also contained checkboxes to control the visibility of the wall panel, tooltips, and all information panels.

4 Study Design

4.1 Research Question

The study aims to answer the research question: *How should the text descriptions of artifacts be presented in virtual museums?* Specifically, we aim to investigate (1) users' perceived importance of artifact information dimensions; (2) the expected display of information panels (shown or hidden); and (3) the appropriate layout type for each information dimension. This breaks down our research question into three sub-questions.

- **RQ1** How do users perceive the importance of various dimensions of artifact information?
- **RQ2** What are the expected displays of information panels in virtual museums (shown or hidden)?
- **RQ3** What are the relationships between artifact information dimensions and spatial layout types in virtual museums?

4.2 Experimental Procedure

The general procedure of the experiment is illustrated in Figure 3. At the beginning of the experiment, we briefly introduced the study purpose and collected informed consent and demographic information from participants. The experiment included six sessions. Participants at the start of each session were asked to read the paper-printed information panels and assign a score to each panel, reflecting their subjective assessment of the importance of the panel. Importance was rated on a 5-point Likert scale (5 = extremely important) outside the VR environment. After completing the importance ratings, they entered the VR scene, reviewed text information panels, chose the ones they wanted to display, and arranged the spatial layouts. Participants were specifically told to disregard the visual design of information panels (e.g., text font, size, margin, color, alignment, etc.), but to focus only on the *content* and the *layout type* to use for the panels. Once they completed the panel set up, participants were

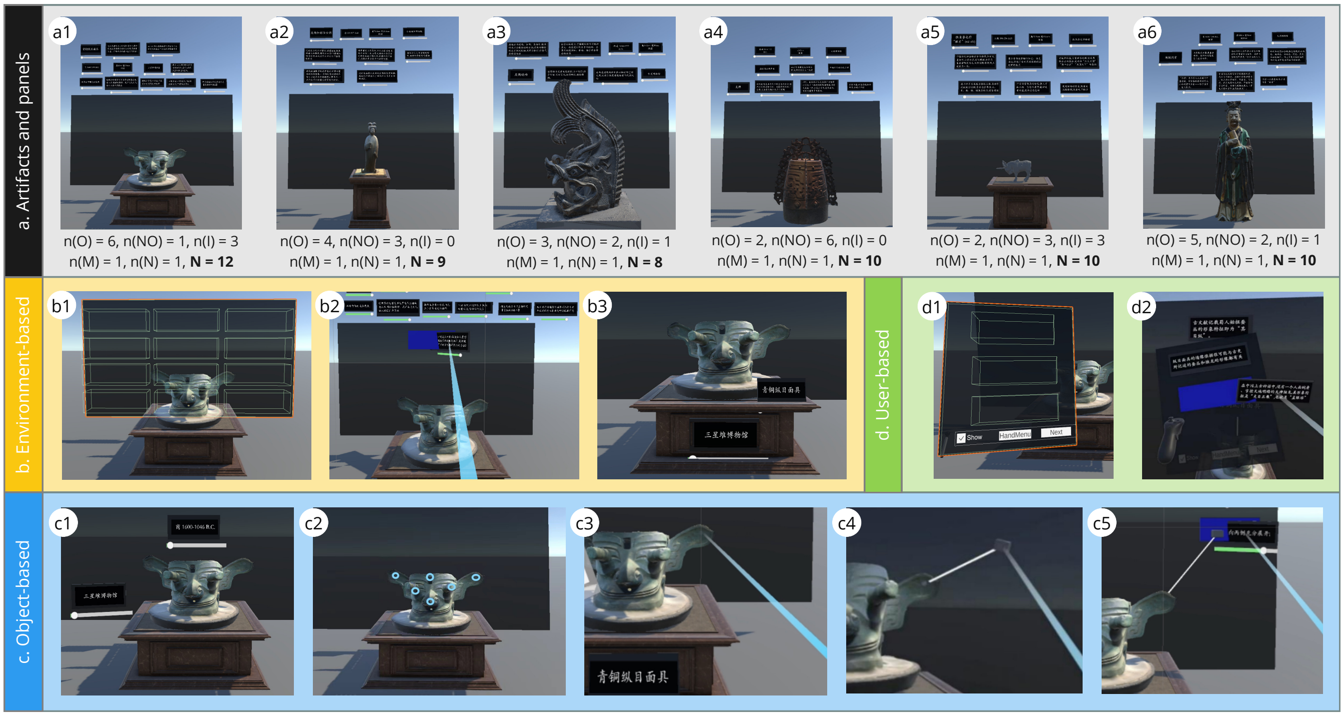

Figure 2: VR environment and spatial layout types: (a1-a6) Six artifact scenes, each with a 3D model of a museum artifact on a 1:1 scale and multiple information panels; (b1-b2) Wall panel on the back of an artifact with magnetic placeholders; (b3) Panels around the pedestal; (c1) Panels on top of and by the side of an artifact; (c2) Tooltips trigger around artifact features, highlighted in blue circles; (c3-5) Activate a trigger using ray selection, adjust end point distance, and snap a panel to the magnetic placeholder of tooltips; (d1-d2) Handheld panel with magnetic placeholders.

asked to select and discuss which panels they would like to hide. We repeated the above process for all six scenes. A Latin square design was used to counterbalance the sequential effects. After completing six sessions, participants were asked to conduct a structured interview with three questions: 1) What considerations and specific factors influence your decision when determining the layout of artifact information panels? 2) How did you decide whether to show or hide the information panels? 3) Overall, which artifact information layout(s) do you prefer? Why? The entire experiment took about 70 minutes for each participant. The study was approved by the ethics committee of our university.

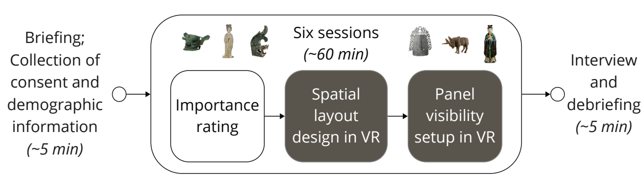

Figure 3: The experimental procedure.

4.3 Participants

Twenty-four participants (14 females and 10 males) aged between 18 and 27 ($M = 21.58, SD = 2.08$) voluntarily signed up for the study. Participants were academics and students from multiple disciplines (10× Sciences, 4× Engineering, 3× Business, 6× Design, and 1× Humanities) in a local university. In terms of VR technology use, participants' self-evaluation showed that many (37.5%) reported being somewhat familiar with VR, followed by a tie between those who are slightly and moderately familiar (20.83% each), while a smaller proportion of participants expressed being not at all familiar (12.5%) and a few (8.33%) indicated that they are extremely familiar with VR. On a 5-point Likert scale (5 = extremely familiar), participants were somewhat familiar with VR ($M = 2.92, SD = 1.14$). Among the participants, more than half (58.33%) used VR devices sparingly, engaging with the technology less than once a month. Over half of the participants (58.33%) have experience with virtual museums or exhibitions. Overall, participants indicated that they are somewhat familiar with virtual museums or exhibitions ($M = 2.71, SD = 1.12$).

5 Results

We examined the 1416 (59 panels × 24 participants) pieces of panel data in the six test scenes, out of which 1239 panels were used in participants spatial layout design. Each piece of data included whether the panel was used by the participant, its information dimension, layout type, display status, importance score, coordinates, rotation angle, and size. Data analysis was performed using IBM SPSS Statistics and Python. Shapiro-Wilk tests showed that the importance ratings were not normally distributed ($p < .001$). Thus, we conducted non-parametric tests for the comparisons.

5.1 Importance Ratings and Panel Use (RQ1)

5.1.1 Information Dimension

We first examined users' ratings for the three information dimensions. The comparison results are shown in Figure 4. The Kruskal-Wallis H test revealed a significant difference in importance ratings across the three information dimensions, $H(2) = 33.939, p < .001$. Post-hoc comparisons with a Bonferroni correction showed that users perceived significantly greater importance for non-observable information than observable and interpretation information ($p < 0.001$). In responses to **RQ1**, results highlight the importance of non-observable information.

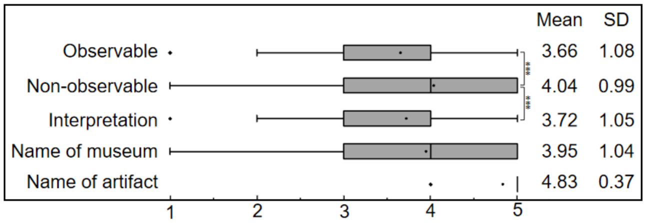

Figure 4: Box plots displaying the distribution of perceived importance ratings for artifact information.

5.1.2 Use of Panel

All panels showing the name of artifacts were used (100%, 144 out of 144), followed by the non-observable information (92%, 374 out of 408), observable information (84%, 444 out of 528), the interpretation information (83%, 159 out of 192), and the name of museum (82%, 118 out of 144)). In summary, the data elucidates a high frequency of information panel utilization (88%). Figure 5 shows the results of important ratings for the panel used and not used. The Mann-Whitney U test showed a statistically significant difference: the used panels (*mean rank* = 860.47) was found significantly more important than the panels not used (*mean rank* = 371.25), $z = -16.595, p < .001$.

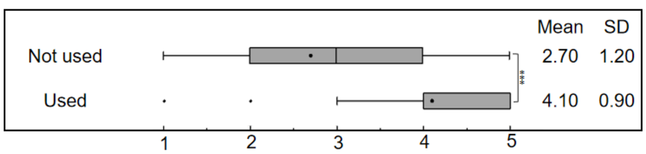

Figure 5: Boxplots showing the distribution of importance ratings for panels used and not used.

5.2 Information Dimension and Panel Layout (RQ3)

Figure 6 shows the frequency of using the six layout types for each information dimension. Notably, **observable** information panels have the highest frequency of use of the *tooltip* layout, followed by the wall panel and side panels. For the **non-observable** information panels, the *wall panel* garnered the highest frequency of use at 0.29. It is closely followed by the *side* layout, with a frequency of use at 0.26. Similarly, the *wall panel* layout exhibited the highest frequency for the **interpretation** panels, with a value of 0.49, signifying a strong preference for this layout. This is contrasted by a complete absence of the *pedestal* layout within the same category.

The *wall panel* again showed the greatest frequency (0.34) for the **name of museum**. Meanwhile, the *pedestal* (0.24) and *top* (0.25) layouts shared similar frequencies. For the **name of artifact**, there was a notably high frequency (0.43) of using the *pedestal* layout. In contrast, the *wall panel* had the lowest frequency at 0.05.

In responses to **RQ3**, the data revealed distinct preferences in panel layout for different information dimensions. Overall, environment-based and object-based layouts were preferred over the handheld layout. Specifically, *tooltips* were preferred for **observable** information; the *wall panel* and the *side* panels were found appropriate to present **non-observable** information. **Interpretation** information favored the *wall panel*, but not the *pedestal*; however, these two layouts were found appropriate to display the **name of museum**. The **name of artifact** was often placed on the *pedestal*.

5.3 Information Dimension and Panel Visibility (RQ2)

Figure 7 shows the results of the panel visibility being mapped with the information dimensions and layout types. Each layout type

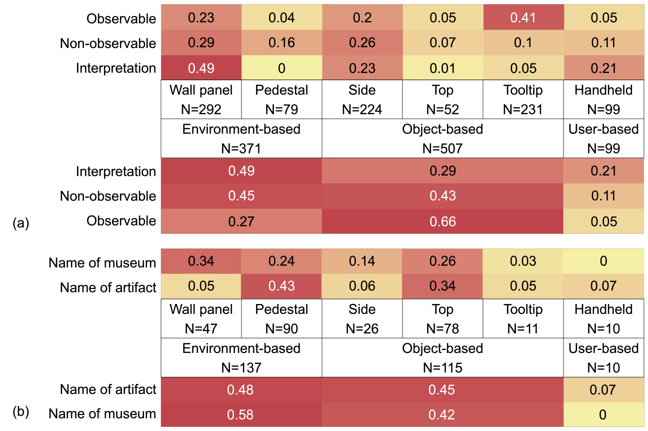

Figure 6: Heatmaps showing the use of different layout types for (a) observable, non-observable, and interpretation information, and (b) name of museum and name of artifact.

presents distinct patterns in terms of the panel visibility (shown or hidden). For the *environment-based* layout, the information panels showed a high tendency to remain visible. Wall panels and pedestals had a visibility rate of 0.86 and 1, respectively, indicating that most of the information categories tend to be displayed rather than hidden. In particular, panels on the pedestals were shown at all times and the name of the artifact and name of museum were made visible by all means. For the *object-based* layout, the side and top panels showed a high tendency to remain visible, with a display rates of 0.89 and 0.94, respectively. However, less than half of the tooltips were shown (0.42). A great portion of hidden tooltips (0.45/0.58) was used for presenting details about observable information. Conversely, the *user-based* layout presented a stark contrast: all categories were predominantly chosen to be hidden by default. These results contribute to the understanding of **RQ2**.

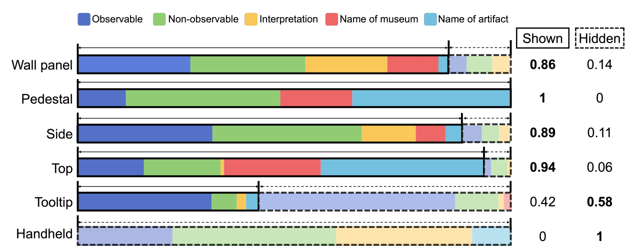

Figure 7: Mapping the spatial layouts with the information dimensions and panel visibility (shown or hidden).

5.4 Interview Findings

We used NVivo (version 1.7.1) to analyze the transcribed audio recordings of the interviews. For Q1: *What considerations and specific factors influence your decision when determining the layout of artifact information panels?* Seventeen participants mentioned they considered the dimensions of panels information. For example, P5 (female, 21) stated that

> *"First of all, the basic information of the artifact, I think it should be put at the top of that artifact, like the name of artifact, the era, and the museum; for the introduction of the artifact itself, like the material, the description, I think it should be on the tooltips, and then its background description, or the mythological origin, I put them on the wall panel."*

Eight participants mentioned they would consider the importance of artifact information. For instance, P19 (female, 20) stated that

> *"For me, the higher I scored the information, the greater prioritize I gave to its display and visibility."*

Four participants considered the symmetry of the layout. For example, P12 (male, 22) stated that

> *"I'm mainly thinking about symmetry. I want it to be tidy and neat. It doesn't matter what the message is."*

Four participants considered their interest in the information, and two participants mentioned they would consider the length of the information in panels. For example, P8 (male, 22) stated that

> *"I'm more inclined to have long segments of text on the handheld panel."*

For Q2: *How did you decide whether to show or hide the information panels?* Four participants mentioned they considered the importance of artifact information in deciding whether to hide the panel or not. For example, P15 (male, 22) stated that

> *"For me, the name of artifact and its source (name of museum) are the most important. The description details and such are less important, so these can be hidden first so that at a glance it looks clean and tidy."*

Four participants mentioned they considered the interaction of artifact information. For instance, P15 (male, 22) stated that

> *"I hide the tooltips because I wanted to make the virtual museum a little more interactive. Then, when visitors want to learn more about it, they can click on it to show the panel."*

Three participants mentioned they considered the length of the information in panels, and they prefer to hide long texts by default. Two participants mentioned that they considered the dimension of the information, and chose to hide the detailed descriptive information that is observable.

For Q3: *Overall, which artifact information layouts do you prefer? Why?* Interview findings from this question showed consistent results with the frequency of panel use: most participants preferred the object-based approach. Fourteen participants voted for tooltips and thirteen of them preferred side and top panels. Compared to quantitative data analysis, where environment-based and object-based were both frequently used, users' preference for object-based layout was found more prominent: only four participants selected the wall panel (environment-based) and three participants selected handheld panel (user-based) as their most preferred layout.

For tooltips, 10 out of 14 participants mentioned that this approach was able to create a strong link between the information and the artifact. For example, P5 (female, 21) stated that

> *"Because it (tooltip) can be specific to a certain point to describe the artifacts. I can see more accurately about the information displayed on this panel and its corresponding part of the artifact. The guidance shows a very strong link."*

Three out of 14 participants mentioned that tooltips provided a sense of interaction and engagement. However, two participants (P10 and P19) disliked tooltips because they felt the connecting lines looked cluttered and blocked the view of other information.

For side and top layouts, 10 out of 13 participants mentioned that these layout types made them more immersed in the environment. P19 (female 20) stated that

> *"Side and top panels gave me a strong three-dimensional feeling of being surrounded and immersed inside the panels with the artifact."*

Three out of 13 participants mentioned that side and top layouts are simple, intuitive, and visually appealing. For the wall panel (environment-based), 2 out of 4 participants mentioned that it does not interfere with the artifact surroundings, thus made the scene neat and tidy. Participants who favored the handheld panel endorsed its effectiveness and convenience in text reading, as they could bring the panel close to their views.

6 Discussion

Our study investigated user's perceived importance of various information dimensions, expected display of information panels (shown or hidden), and the relationship between the artifact information dimension and spatial layout in VMs. Based on the results, we discuss our findings and provide design recommendations. A design space is presented in Figure 8, summarizing the insights from participants' spatial design results and interview comments.

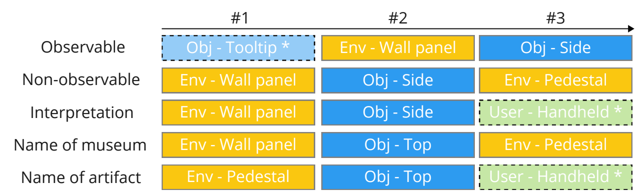

Figure 8: A design space for artifact information presentation using environment-, object-, user-based layout types in VMs with prioritized options. *Hidden by default.

6.1 Replicate physical museum settings using environment-based layout in VR

In the environment-based layout, high utilization rates are observed across all information categories, with notably high rates for name of museum (0.58) and name of artifact (0.48). Nearly half of the interpretation (0.49) and non-observable information (0.45) were also displayed using this layout. According to insights gathered from interviews, the environment-based layout effectively replicates the manner in which artifacts are viewed in real-world settings. Specifically, participants showed a strong tendency to display name of artifact on the pedestal (0.43) and interpretation information on the wall panel (0.49). In addition, the name of museum (0.34) and non-observable information (0.29) were also frequently placed on the wall panel.

Participants demonstrated a preference of not hiding the environment-based panels. As P10 (female, 23) mentioned in the interview, it is necessary to show all the information to know what the artifact is, whereas the wall panel effectively presents this information in an intuitive and organized manner, ensuring it is not overlooked if otherwise hidden. The hidden information would indeed require extra efforts to explore. In addition, the user may not be aware of how to trigger the information once it is hidden in the environment. Moreover, names were mainly displayed using this layout type and that users tended to show the information they found important. This also accounts for the tendency to show the panels.

6.2 Build connections and facilitate immersive reading experience using object-based layout

The object-based layout demonstrates a predominant use for observable information (0.66), largely facilitated by the utilization of tooltips. This preference was supplemented by the strategic placement of name of artifact information at the top and non-observable information by the side, as indicated by participants (P4, P5, P19) during interviews. They emphasized the importance of positioning essential basic information such as name of artifact in highly visible locations. Additionally, participants (P5, P14) reported that tooltips effectively aided in visually identifying specific parts of artifacts, enhancing the readability and interaction with the displayed content. Participants (P1, P6, P7) also highlighted that tooltips contributed to a dynamic and engaging user experience, creating an interactive and lively presentation of information. Many participants ($n = 10$) mentioned in the interview that the object-based layout types provided an immersive experience, evoking a sense of being surrounded by information. This sentiment corroborates previous findings [26].

More than half of the participants (14 out of 24) identified tooltips, an object-based layout, as their favorite layout type. The total amount of panels placed around objects ($n = 507$) were also greater than that in the environment ($n = 371$). Nevertheless, the actual usage of tooltips ($n = 231$) was lower than that of the wall panel ($n = 292$). We speculate two reasons for the difference. First, the space surrounding an artifact was limited, compared to the greater area on the wall panel. In addition, the operations of placing tooltips (identifying a trigger, adjusting the location, and positioning the label) were more complex than that of the wall panel.

While most panels of object-based layout were chosen to be shown, participants expressed the preference to hide tooltips. Some participants found that tooltip lines can clutter the screen, making it difficult to read additional information. Other participants found the triggering the tooltips added interactivity to the artifacts.

In summary, we recommend the use of object-based layout for observable information, particularly through tooltips (hidden by default). This helps strengthen the link between text descriptions and specific parts of an artifact. Furthermore, this could be used together with the name of artifact at the top and non-observable information by the side to form an immersive surroundings for text reading, as suggested by participants in the interview.

6.3 Reduce information overload and facilitate reading at a close proximity using user-based layout

Compared to environment- and object-based layouts, the user-based layout demonstrated a notably lower frequency of use. Similar to the set up of tooltips, there were two challenges in the use of handheld panels: the limited space on the handheld panel restricted the amount of information that can be displayed on the same page; users needed to adjust the size of the text information panel to fit it into the handheld device, which adds complexity to the operation. Despite these challenges, the user-based layout maintained a usage rate of 0.21 for interpretation information, close to that of the object-based layout. P23 commented that the handheld panel was similar to a mobile device, where they expect to see subjective interpretations. In contrast, they expected panels displayed in the environment and around the objects to be more objective. Participants (P11 and P18) also mentioned the ease of reading at a close proximity using the handheld panel. The handheld panel should remain hidden by default and only become visible when users intentionally retrieve it.

6.4 Limitations and future work

The current work has some limitations. First, the information panels in our study were exclusively in simplified Chinese. Given the structural differences between Chinese and English texts [34], this may limit the applicability of our results to settings where information panels are presented in languages based on Latin alphabets. Existing works have explored some ways to present English paragraphs in a short and concise manner, such as the rapid serial visual presentation approached used in [24]. Further examinations are needed to allow for a comparison of user engagement and comprehension across languages and enhance the generalized of the findings to a broader range of cultural and linguistic contexts. Second, our system design allow each information panel to be used once within a scene. This restricts users from duplicating and placing the same panel using multiple layout types. Nevertheless, this limitation was not highlighted by any users during the experiment, suggesting that it may not have been a critical factor in their experience. However, to enhance system flexibility and user satisfaction in future design, research could explore the possibility of allowing multiple instances of the same panel to be active in different positions within a scene. For example, information presented on wall panels can perhaps be duplicated in the handheld guide. Such an enhancement could potentially uncover new ways users interact with and value the information presented, leading to more dynamic and user-friendly exhibition designs. Third, our study examined a single artifact at a time. The setup does not replicate real-world museum environments and the controlled setting could impact the applicability of our findings to multi-object environments. Given that our study focused on the relationship between artifact information dimensions and layout types in a virtual museum, the separation allows for a clear analysis of individual artifact placement without the confounding variables that might arise in a more integrated setting. However, to further enhance our understanding of spatial dynamics in virtual museum settings, future research could explore the effects of displaying multiple artifacts together. Investigating how these artifacts interact and influence visitor expectations of their information dimensions and information layout types when presented in a shared space, which could provide valuable insights into more complex, real-world exhibition environments. Fourth, our study focused on general layouts and user perceptions, without exploring specific interaction techniques or strategies to mitigate occlusion. Future research could investigate these aspects to enhance user experience and information comprehension in VR. Finally, our participants were mainly young adults which may not fully represent diverse visitor groups. Future studies could include a larger and more diverse participant pool to obtain more generalizable results.

7 Conclusion

In this paper, we presented a study investigating the textual information presentation of artifacts in virtual museums and provided design recommendations. We gather insights into users' perceived importance of artifact information dimensions, their expectations regarding the visibility of artifact text information, and the appropriate layout type for each information dimension. Our findings suggest that users found non-observable information more important than observable and interpretation information. It is thus suggested to prioritizing the presentation of panels showing non-observable information, such as the era, original function, archaeological excavation, restoration, etc. Aside from tooltips around artifacts and handheld panels, most participants preferred the information panels to be shown at all times. Our result shows that environment-based layouts are appropriate for all information dimensions, as they mimic the physical museum settings and align with users' mental models of museum visiting. On the other hand, object-based layouts are suitable for displaying observable information. Users appreciated the meaningful link between tooltips associated with artifacts and the immersive reading experience facilitated by the surrounding panels. Finally, using user-based layouts to present lengthy texts could reduce the information overload in the environment and facilitate the ease of reading at a close proximity. Our work provides a valuable reference for designers and developers of virtual museums. The findings also bring insights into the design of interactive systems that require presentations of textual information.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (62207022). We thank our participants for their time and the reviewers for their constructive comments and suggestions.

References

[1] M. Bastug and H. K. Keskin. The role of text length in repeated reading. *European Journal of Educational Studies*, 6(3):111–119, 2014.

[2] S. Bitgood. *Engaging the visitor: Designing exhibits that work*. Museums, 2014.

[3] A. Büttner, S. M. Grünvogel, and A. Fuhrmann. The influence of text rotation, font and distance on legibility in VR. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 662–663, 2020. doi: 10.1109/VRW50115.2020.00182

[4] S. Chernbumroong, P. Worragin, N. Wongwan, K. Intawong, P. Homla, and K. Puritat. Digitization of Myth: The HimmapanVR Project's Role in Cultural Preservation. *Heliyon*, 2024.

[5] T. Dingler, K. Kunze, and B. Outram. VR Reading UIs: Assessing Text Parameters for Reading in VR. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI EA'18, p. 1–6. Association for Computing Machinery, New York, NY, USA, 2018. doi: 10.1145/3170427.3188695

[6] A. Gazi. Writing text for museums of technology the case of the Industrial Gas Museum in Athens. *Museum Management and Curatorship*, 33(1):57–78, 2018.

[7] T. Götzelmann, K. Hartmann, and T. Strothotte. Annotation of Animated 3D Objects. In *SimVis*, vol. 7, pp. 209–222, 2007.

[8] C. Grout, W. Rogers, M. Apperley, and S. Jones. Reading text in an immersive head-mounted display: An investigation into displaying desktop interfaces in a 3D virtual environment. In *Proceedings of the 15th New Zealand Conference on Human-Computer Interaction*, CHINZ 2015, p. 9–16. Association for Computing Machinery, New York, NY, USA, 2015. doi: 10.1145/2808047.2808055

[9] International Committee for Documentation of the International Council of Museums. International Guidelines for Museum Object Information: The CIDOC Information Categories. https://cidoc.mini.icom.museum/wp-content/uploads/sites/6/2020/03/guidelines1995.pdf, 1995.

[10] J. Jankowski, K. Samp, I. Irzynska, M. Jozwowicz, and S. Decker. Integrating Text with Video and 3D Graphics: The Effects of Text Drawing Styles on Text Readability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '10, p. 1321–1330. Association for Computing Machinery, New York, NY, USA, 2010. doi: 10.1145/1753326.1753524

[11] J. Kim, C. Lee, J. Kim, and J.-H. Hong. Interactive description to enhance accessibility and experience of deaf and hard-of-hearing individuals in museums. *Universal Access in the Information Society*, pp. 1–14, 2023.

[12] M. Kim, Y. Lee, and J. Lee. Multi-view layout design for vr concert experience. In *Proceedings of the 30th ACM International Conference on Multimedia*, pp. 818–826, 2022.

[13] S. Kobayashi, K. Kanari, and M. Sato. An Examination of View-Settings for Long Texts in VR Reading. In *ACM SIGGRAPH 2021 Posters*, SIGGRAPH '21. Association for Computing Machinery, New York, NY, USA, 2021. doi: 10.1145/3450618.3469164

[14] S. Lappayanant and H. Shigemasu. Effects of Interactive Experiences on Memory in a Virtual Museum. In *2024 16th International Conference on Knowledge and Smart Technology (KST)*, pp. 1–5, 2024. doi: 10.1109/KST61284.2024.10499660

[15] Y. Li, E. Ch'ng, and S. Cobb. Factors Influencing Engagement in Hybrid Virtual and Augmented Reality. *ACM Transactions on Computer-Human Interaction*, 30(4):1–27, Aug. 2023. doi: 10.1145/3589952

[16] R. W. Lindeman, J. L. Sibert, and J. K. Hahn. Towards usable VR: an empirical study of user interfaces for immersive virtual environments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '99, p. 64–71. Association for Computing Machinery, New York, NY, USA, 1999. doi: 10.1145/302979.302995

[17] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer. Design and Evaluation of Interactive Small Multiples Data Visualisation in Immersive Spaces. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 588–597, 2020. doi: 10.1109/VR46266.2020.00081

[18] J. Liu, A. Prouzeau, B. Ens, and T. Dwyer. Effects of Display Layout on Spatial Memory for Immersive Environments. *Proc. ACM Hum.-Comput. Interact.*, 6(ISS), nov 2022. doi: 10.1145/3567729

[19] A. McNamara, K. Boyd, J. George, W. Jones, S. Oh, and A. Suther. Information Placement in Virtual Reality. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 1765–1769, 2019. doi: 10.1109/VR.2019.8797891

[20] D. Puspitasari. The effect of text length on the reading comprehension of senior high school students.

[21] RealityCapture. RealityCapture - 3D Models from Photos and/or Laser Scans. https://www.capturingreality.com/.

[22] L. Reitstätter, K. Galter, and F. Bakondi. Looking to read: How visitors use exhibit labels in the art museum. *Visitor Studies*, 25(2):127–150, 2022.

[23] J. Roberts, A. Banerjee, A. Hong, S. McGee, M. Horn, and M. Matcuk. Digital exhibit labels in museums: promoting visitor engagement with cultural artifacts. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pp. 1–12, 2018.

[24] R. Rzayev, P. Ugnivenko, S. Graf, V. Schwind, and N. Henze. Reading in VR: The effect of text presentation type and location. In *Proceedings of the 2021 CHI conference on human factors in computing systems*, pp. 1–10, 2021.

[25] D. Samson. *Reading Strategies Used by Exhibition Visitors*, pp. 135–153. La Société des Musées Québécois–Musée de la Civilisation, Québec, 1995.

[26] K. A. Satriadi, B. Ens, M. Cordeil, T. Czauderna, and B. Jenny. Maps Around Me: 3D Multiview Layouts in Immersive Spaces. *Proc. ACM Hum.-Comput. Interact.*, 4(ISS), nov 2020. doi: 10.1145/3427329

[27] W. Schweibenz. The" Virtual Museum": New Perspectives For Museums to Present Objects and Information Using the Internet as a Knowledge Base and Communication System. *Isi*, 34:185–200, 1998.

[28] W. Schweibenz. The virtual museum: an overview of its origins, concepts, and terminology. *The Museum Review*, 4(1):1–29, 2019.

[29] Smithsonian American Art Museum. Beyond the Walls: Experience the Smithsonian American Art Museum in Virtual Reality. https://americanart.si.edu/beyond-the-walls, 2024. Accessed: 08 May 2024.

[30] State Administration of Cultural Heritage in China. Specification for registration of cultural relics in the collection of cultural institutions. http://www.ncha.gov.cn/module/download/downfile.jsp?classid=0&filename=2108051110392047492.pdf, 2013.

[31] H. Strachan. Developing Effective Museum Text: A Case Study from Caithness, Scotland. 2017.

[32] A. S. Suleiman. Modifying text appearance and display properties to improve reading efficiency, 2018.

[33] Y. Wang, Y. Li, and H.-N. Liang. Comparative Analysis of Artefact Interaction and Manipulation Techniques in VR Museums: A Study of Performance and User Experience. In *2023 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 761–770, 2023. doi: 10.1109/ISMAR59233.2023.00091

[34] Z. Wang, N. Bukhari, and Q. Tang. The Basic Differences of Textual Cohesion between English and Chinese. In *SHS Web of Conferences*, vol. 159, p. 01018. EDP Sciences, 2023.

[35] N. Xu, Y. Li, X. Wei, L. Xie, L. Yu, and H.-N. Liang. CubeMuseum AR: A tangible augmented reality interface for cultural heritage learning and museum gifting. *International Journal of Human–Computer Interaction*, 40(6):1409–1437, 2024.