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Artifact^{VM}: Exploring Culturally Meaningful Presentations and User Interactions in Virtual Museums

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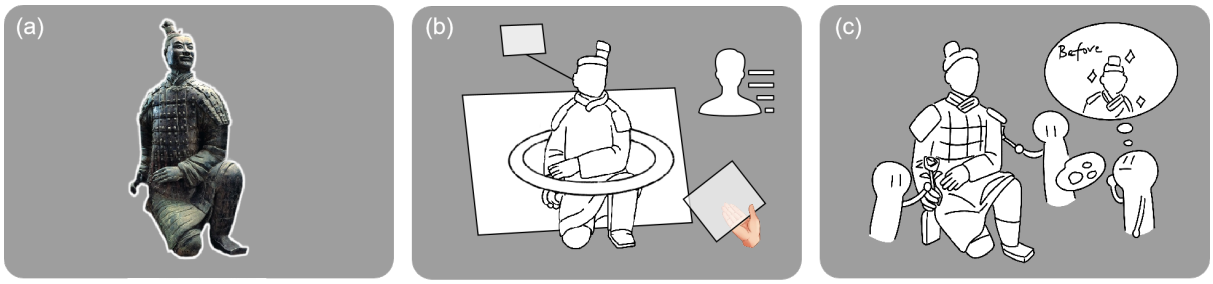

Figure 1: *Illustrations of artifact interactions in a virtual museum: (a) a 3D model of the Kneeling Archer, (b) example presentation approaches: information board, tooltips, hand-held guide, DanMu, and virtual guide, and (c) an illustration of users' perceived affordances with the 3D artifact: brush and restore the original color.*

Abstract

Virtual Museums (VMs) serve as an extension of physical museums, delivering content in digital formats. Virtual Reality (VR) technologies afford the creation of interactive virtual museum experiences with 3D artifacts, enhancing cultural dissemination by narratives based on historical artifacts for educational and entertainment purposes. However, there are notable gaps in exploring the ways to interact with virtual artifacts in VMs. In this work, we conducted workshop studies with non-expert audiences and interviewed domain experts to gather insights into 3D artifacts presentation in VMs. In addition, we investigated the digital affordances of historical artifacts in VMs and discussed opportunities for interaction design. The results provide design guidelines for the forms of presentation and outline interaction possibilities. Our findings provide insights into future forms of content curation and artifact interaction in virtual museums.

CCS Concepts
• ***Human-centered computing*** → ***HCI design and evaluation methods;***

1. Introduction

Museums aim to provide experiences for education, knowledge sharing, enjoyment, and reflection [Int22]. Virtual museums (VMs) extend these goals digitally, offering rich content and interactivity [Sch19]. History museums preserve artifacts to fulfill educational and entertainment roles while promoting social interaction and cultural exchange [SFKP09, LH22]. The rapid development of digital technologies, particularly Virtual Reality (VR), has enabled immersive VM experiences with natural interactions and 3D artifacts [Sch19]. VR transcends physical and temporal constraints, empowering interactive VM designs. Walczak et al. [WCW06] identified two challenges for VR adoption in museums: efficient creation of 3D models and building virtual exhibitions. The *Visualization, Interaction, and Presentation (VIP)* framework [LC22] addresses these challenges by emphasizing three attributes of virtual artifacts: *visualization* (photo-realistic 3D models), *interaction* (transform-

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ing static objects into interactive ones), and *presentation* (media information supporting interpretation and meaning-making). Advances in 3D scanning and photogrammetry have made artifact reconstruction faster and easier. With virtual artifacts now readily created, VM design must move beyond static visualizations to focus on interaction and presentation. Specifically, VMs should utilize their content and interactivity to achieve two goals: (1) facilitating education and knowledge sharing, and (2) offering enjoyable and reflective experiences.

This paper explores the presentation and interaction of 3D artifacts in VMs using VR technologies. We aim to understand user expectations for artifact information and its presentation in VMs, addressing two research gaps: (1) While artifact presentation methods vary [WCW06], a user-centered perspective is lacking. How rich VM content can facilitate education and knowledge sharing remains unclear, highlighting the need for diverse user insights to improve design practices. (2) Although extending physical museum curation into the digital realm offers significant opportunities [Sch19], the digital affordances of VM artifacts remain underexplored. This design space presents opportunities for innovation, requiring deeper investigation into optimizing digital interactions to enrich VM user experiences.

To address these gaps, we explore the research question: *How to design culturally meaningful presentation and interactions in virtual museums based on user-perceived affordances?* We conducted three workshops to gather user requirements, generate ideas, and collect insights. Participants simulated museum curation through hands-on activities and brainstormed interaction possibilities, with results reviewed by domain experts. Our contributions include: (1) User-generated ideas for artifact presentation, emphasizing environment-, object-, and user-based approaches; (2) Concrete examples of artifact interactions, highlighting user-perceived digital affordances based on utility, appearance, and artifact interplay, underscoring the need for intuitive design; (3) Bridging user creativity and expert knowledge by integrating expert opinions into artifact presentation and interaction ideas, enhancing user-generated designs. Combining user workshops with expert interviews, this study provides a holistic understanding of VM design needs, fostering innovation in virtual museum experiences and informing museum curation practices for engaging and educational user experiences.

2. Related work

2.1. Artifact Presentation in Virtual Museums

Aligned with ICOM's definition of museums as spaces for education, enjoyment, reflection, and knowledge sharing [Int22], virtual museums (VMs) aim to (1) facilitate education and knowledge sharing and (2) offer enjoyable and reflective experiences. Artifact presentation in VMs varies widely [RMKH19, WYD20, YL24]. Rzayev et al. [RUG*21] compared three text presentation methods in VMs: (1) world-fixed text: common in physical and virtual museums, it is easy to read but requires users to shift attention between text and the environment; (2) edge-fixed text: it offers mobility by adjusting the angle of the text; and (3) head-fixed text: while allowing continuous visibility, it occludes the field of view, making interaction and reading challenging. Other methods include handheld text panels and object-fixed tooltip text, which links specific information to artifact features [XLW*23]. Given the diversity of methods and limited research, this study aims to understand how users perceive affordances in artifact presentation and how these approaches can be effectively supported to enhance education and knowledge sharing.

2.2. Interaction with Digitized Museum Collections

The museum and heritage sector is undergoing a digital transformation [LZS20]. With advancements in virtual heritage reconstruction technologies and a wealth of digital heritage assets, emerging technologies such as 360-degree virtual tours, virtual museums, and VR and AR applications are opening up new possibilities for interacting with museum collections digitized in 3D. This shift presents researchers and professionals with significant design opportunities. Recognizing the opportunities for digital practices related to collecting, conserving, researching, exhibiting, and communicating cultural heritage [WDY*23], many museums have launched projects based on digitized museum collections. The digitized museum collections can be displayed on the web, in a replica of an actual exhibition space, or a fully realized virtual environment. For example, the Nanjing Museum [Nan24] curated a collection of digital artifacts, each designed with various interactive displays that showcase their shape, structure, and function. This approach enables audiences to intuitively grasp the utility of each item. However, the web-based approach was limited in terms of presence and the degree of control. For the replica environment, most museums choose the 360-degree virtual tour systems [Mus22], which allow very limited interaction with individual 3D artifacts.

Interaction is pivotal in creating an engaging virtual museum environment as it offers the essential affordances that transform static virtual objects into interactive ones [LC22]. The core of interactivity is the reciprocity of action - a visitor acts on the museum artifact, and the museum artifact reacts in some way [AG04]. In virtual exhibitions, there is no glass case or security distance protecting artifacts from being damaged; users can explore exhibits interactively and flexibly [SFKP09]. Basic 3D manipulation tasks such as positioning, selecting, rotating, and scaling of 3D artifacts in the VM context have been researched [WLL23a]. Still, research on interactions that extend beyond basic 3D interactions with museum artifacts is scarce in the academic literature. Our work aims to fill the gap by investigating interaction possibilities with historical 3D artifacts based on user-perceived affordances, aiming to enhance user engagement and enjoyment with museums' 3D virtual collections.

2.3. Affordances and User Perceptions

Affordance was coined by James Gibson in the 1970s [Gib14]. He proposed the affordance theory that the environment may offer 'the animal' a range of 'action possibilities'. This theory has been applied and interpreted by researchers from varying fields, such as psychology [JUC*16] and Human-Computer Interaction (HCI) [Nor88, Nor99]. The significance of perception has been a topic of discussion in the literature on affordances. Norman [Nor88] proposed a definition of affordances from the perspective HCI design, emphasizing both perceived and actual (or real) properties. He argued that helping users recognize the affordances of computer in-

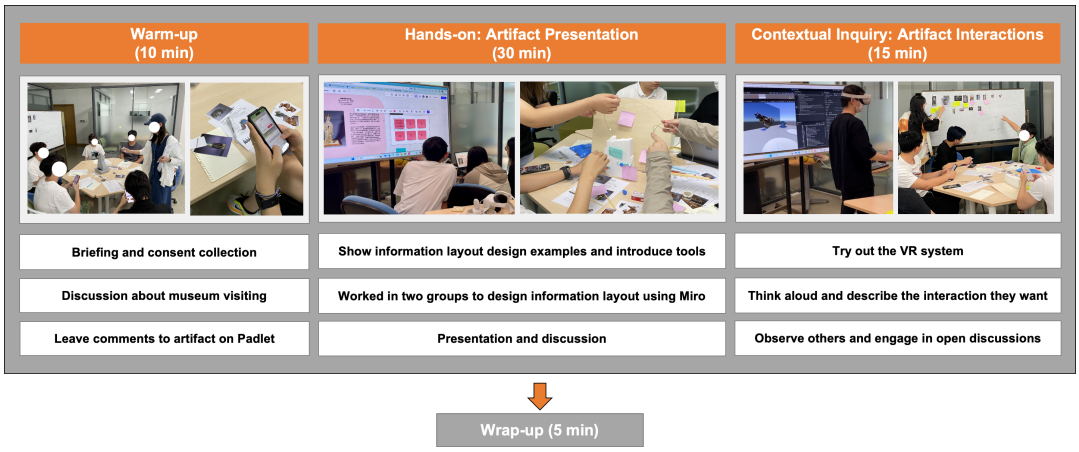

Figure 2: *A flow chart showing the workshop procedure.*

terfaces is fundamental to effective HCI design. Gaver [Gav91] distinguished affordances from perceptible information, arguing that affordance and perception are independent of each other. Affordances was found valuable in examining the psychological implications of artifacts [CK89] and the reasoning behind their designs [MYM89]. Therefore, understanding users' perceived affordances and explicitly incorporating affordances into the design process could provide insights on enhancing the usability of new artifacts. We aim to investigate users' perceived affordances of virtual museums concerning artifact presentation and interaction. By examining these affordances, we hope to identify effective design strategies that can enhance user engagement and understanding. This research will contribute to creating more intuitive and meaningful virtual museum experiences, ultimately fostering a deeper appreciation for cultural heritage through innovative presentations and interactions with 3D artifacts in VR.

3. Study 1: Workshop with Non-Expert Audiences

We conducted workshop studies with non-expert participants unfamiliar with museum curation. Workshops are suitable for our study as they gather researchers and users to clarify challenges and develop new ideas [VCW*13]. This study was approved by the university ethics committee.

3.1. Preparations and Props

To support the study, we prepared digital resources, physical materials, and a VR demo system. **Digital Resources**: we selected 30 artifact images with descriptions from museum websites (see Appendix A for details) and displayed them using *Padlet* and *Miro*. **Physical Props**: participants were provided with materials such as foam boards, paper, pens, plasticine, and craft sticks to create physical artifact presentation designs. **VR Demo System**: a VR system developed by Unity showcased 14 photogrammetric artifacts in their actual scales. The system ran on a PC with an AMD Ryzen 7 4800H CPU, 16GB RAM, and an NVIDIA RTX 2060 GPU. To provide consistent performance and interaction reliability, a standard Meta Quest 2 VR HMD with two handheld controllers was used as the VR display and input device. Users teleported via thumbstick controls, with anchors positioned near artifacts for easy access (Figure 3a). White rays from controllers enabled selection and manipulation. Artifacts could be grabbed, rotated, and adjusted in distance using indirect interaction techniques to handle large objects comfortably (Figure 3b, c). The system provided an immersive platform for exploring artifact interactions in VR.

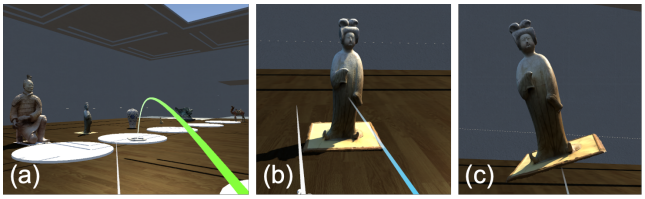

Figure 3: *Basic interactions in the VR system. (a) Teleport locomotion via thumbstick; (b) Raycast selection using the trigger button; (c) Grabbing and rotating artifacts using the grip button.*

3.2. Procedure

The workshop consisted of the following four parts (see Figure 2): (1) **Warm-up**. Researchers introduced the study, collected consent and demographic data, and engaged participants with open-ended questions about physical and virtual museums. Participants explored example artifacts on a *Padlet* board and shared their interpretations. (2) **Hands-on: Artifact Presentation**. Participants brainstormed and designed artifact presentations using physical props and an online whiteboard (*Miro*). Working in groups, they organized information and explained their designs, discussing preferred presentation approaches. (3) **Contextual Inquiry: Artifact Interactions**. Participants interacted with 3D artifact models in VR, exploring basic grabbing interactions while sharing their expectations for artifact interactivity. Observations and think-aloud feedback informed design insights. (4) **Wrap-up.** Researchers summarized findings, addressed questions, and thanked participants for their contributions.

3.3. Data Collection and Analysis

Demographic data, museum visiting habits, and VR experience were collected. Workshops were recorded, transcribed, and manually verified for accuracy. Quantitative data were analyzed using IBM SPSS Statistics (v26), and qualitative data were coded in NVivo (v1.7.1) using theme-based content analysis [NN01]. Cohen's Kappa coefficient ($\kappa = 0.885$) confirmed near-perfect inter-rater reliability.

3.4. Participants

Eighteen participants (5 females and 13 males) aged between 19 and 31 ($M = 23.17, SD = 3.26$) voluntarily signed up for the study. Participants were academics and students from a local university. All participants have used VR devices before. Participants' self-evaluations were recorded on a five-point Likert scale, ranging from 1 (not at all familiar) to 5 (extremely familiar). The responses showed they are very familiar with VR ($M = 3.78, SD = 1.00$) and moderately familiar with interaction design ($M = 3.06, SD = 1.21$). Almost all participants (17/18) visited museums once a year. Participants were slightly more willing to visit physical museums ($M = 4.11, SD = 0.76$) than virtual museums ($M = 3.72, SD = 0.96$). As part of the warm-up session, we gauged participants' motivation and expectations in *physical* and *virtual* museum visiting. More specific demographic information can be found in Appendix B.

Q1: Do you like visiting physical museums? Why (not)? Fifteen of 18 participants enjoyed visiting physical museums, citing motivations such as learning about history and culture ($n = 10$), viewing famous exhibits and architecture ($n = 9$), and socializing with friends and family ($n = 8$). For example, P13 (Female, 23) said, "I would go with a friend to check out the famous museums." Three participants disliked museum visits due to the significant time and effort required. Other reasons mentioned include purchasing creative products or escaping the summer heat in air-conditioned environments.

Q2: What would you expect from a virtual museum? Participants (29 responses) prioritized (1) interaction with artifacts ($n = 14$) and (2) rich information content ($n = 11$). Many wanted to reduce the sense of separation in VMs by enabling actions like grabbing, scaling, and closely inspecting artifacts. P12 (Male, 22) noted, "Artifacts in VMs should be able to be picked up and touched, which isn't possible in physical museums." Participants also emphasized the need for immersive narratives (e.g., contextual scenes, as envisioned by P10: "Seeing a Buddha statue should include viewing a temple scene from its era."). Additionally, they suggested incorporating visual effects ($n = 3$) and gamification ($n = 2$) to enhance artifact information presentation.

3.5. Results

3.5.1. Artifact Presentation

We collected six groups of creative works, each including an online whiteboard, number-matched sticky notes, and a set of physical designs (see Figure 4, top row). Based on their creative works, we generate abstractions of their designs by mapping their content presentation into their spatial arrangements(see Figure 4, bottom row). Aside from highlighting the names of the artifact and museum, we referred to the previous work [YL24] and categorized the presentation content into: (1) **Non-observable** (e.g., era, original function, archaeological excavation, $n = 50$), which deals with questions of 'who', 'when', 'where', and 'how', and reveals object-related content that is difficult to obtain by purely observing it; (2) **Observable** (e.g., size, texture, material, $n = 20$), which involves the physical features of an artifact that are visually perceptible to users; and (3) **Interpretation information** (e.g., unverified legend, user-generated content, $n = 11$), which focuses on the subjective perspectives from experts' view and other users' opinions. As Li et al. [LH22] noted, the experience is a result of engagement and interaction between environments, objects, and people; we classified the spatial arrangement into three aspects.

Environment-based. Environment-based presentations are anchored in the virtual environment and remain static relative to objects and users, such as panels attached to walls or pedestals. Four groups (*a, b, d, f*) placed artifact information behind the object to reduce distractions and clutter. *Group b* suggested including spatial

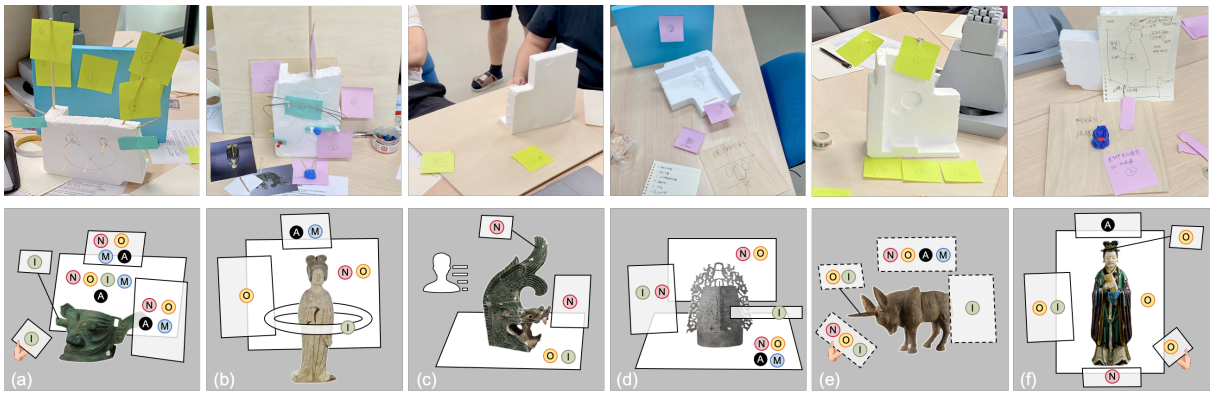

Figure 4: *User-elicited presentation of virtual artifacts: (a, b) from the first workshop, (c, d) from the second workshop, and (e, f) from the third workshop. The colored circles represent* N *non-observable information,* O *observable information,* I *interpretation information,* M *name of museum, and* A *name of artifact. Solid lines indicate permanent display, and dashed lines indicate triggered display.*

Table 1: *Summary of participants' interaction results from the aspects of artifact utility, appearance, and interplay.*

Category	Feature	Action	Example
Utility ($n = 36$)	container ($n = 19$)	fill ($n = 10$)	Fill the *Blue-and-White Vase* with flowers.
		open ($n = 6$)	Open the lid of the *Eight Corners Case*.
		serve ($n = 3$)	Serve some rice into the *Imari Covered Bowl with Floral Sprays*.
	make sound ($n = 8$)	drum ($n = 6$)	Drum the *Ke Clan Bo* to hear the sound.
		tap ($n = 1$)	Tap the *Blue-and-White Bowl with Dragon Clouds Design* to produce music.
		strike ($n = 1$)	Strike the *Bronze Mask with Protruding Pupils* to the ground to make sound.
	ornament ($n = 5$)	wear ($n = 3$)	Wear the *Bronze Mask with Protruding Pupils*.
		take away ($n = 2$)	Take the *Figure of an Assistant to the Judge of Hell* home as an ornament.
	zoomorphic ($n = 4$)	ride ($n = 4$)	Ride the *Tri-Colored Camel*.
Appearance ($n = 26$)	shape ($n = 9$)	disassemble ($n = 3$)	Take the book away from the *Figure of an Assistant to the Judge of Hell*.
		reassemble ($n = 2$)	Put the pieces from *Blue-and-White Bowl with Dragon Clouds Design* together.
		break ($n = 2$)	The *Ke Clan Bo* looks like chocolate and makes me want to break it.
		create ($n = 1$)	Create a seal stamp in the shape of the *Vajrasattva Bronze Statue*.
		attack ($n = 1$)	Use the horn of *Xie Zhi* to attack something.
	pattern ($n = 6$)	view ($n = 5$)	View the pattern on the *Imari Covered Bowl with Floral Sprays*.
		resize ($n = 1$)	Zoom in the pattern on the *Eight Corners Case* for a closer look.
	color ($n = 6$)	paint ($n = 5$)	Coloring the *Kneeling Archer*.
		restore ($n = 1$)	Restore the original color of the *Kneeling Archer*.
	figure ($n = 5$)	converse ($n = 1$)	Discuss Buddhism with *Seated Court Lady*.
		touch ($n = 1$)	Touch the *Vajrasattva Bronze Statue* for good fortune.
		imitate ($n = 1$)	Imitate the smile of the *Seated Court Lady*.
		work ($n = 1$)	See how the *Figure of an Assistant to the Judge of Hell* works.
		eye contact ($n = 1$)	Feel the eye contact with the *Vajrasattva Bronze Statue*.
Interplay ($n = 3$)	two ($n = 2$)	break ($n = 1$)	Break the porcelain (the *Blue-and-White Vase with Peons Scrolls Design*) using the bronze (the *Vajrasattva Bronze Statue*).
		play ($n = 1$)	Play table tennis using the *Vajrasattva Bronze Statue*.
	more ($n = 1$)	build ($n = 1$)	Build blocks with different artifacts.

images of excavation sites to integrate historical context. Instead of vertical displays, *Group d* preferred horizontal presentations beneath artifacts for better accessibility.

Object-based. Object-based presentations move with artifacts, including side/top panels, tooltips, and *DanMu*. All groups used side panels to enhance comprehension, with four (*a, b, e, f*) placing artifact names at the top for prominence. Tooltips were used by four groups (*a, c, e, f*) to highlight specific features, with descriptions linked to artifact details for easier comparison. *Group c* used tooltips for historical narratives and dismissable content to maintain focus. *DanMu*, favored by *Group b* and *Group d*, displayed user-generated content dynamically, enhancing engagement through 3D or horizontal scrolling text.

User-based. User-based presentations move with users, offering on-demand access and dismissal. Three groups used portable hand-held panels for artifact interaction and system control. *Group f* proposed mini-replicas for viewing large artifacts closely, while *Group e* designed panels with buttons for selective content display, minimizing clutter and enabling artifact comparisons. *Group a* used panels for sharing user-generated content, resembling smartphone interfaces. *Group c* focused on virtual guides, including AI-powered conversational agents and anthropomorphized artifacts, inspired by the movie Night at the Museum.

3.5.2. Object Interaction

A total of 65 responses related to artifact interaction were gathered from the workshops. Our analysis revealed that the majority of the perceived affordances are associated with the practical utility ($n = 36$) and visual appearance ($n = 26$) of the artifacts, while some participants expressed an interest in the interplay between different artifacts ($n = 3$). We summarize the interaction results in Table 1.

Perceived Affordances from Artifact Utility. Participants interacted with artifacts based on their inherent utility. For *container* artifacts, actions like "filling," "opening," and "serving" were common (see Figure 5a-b), such as opening the lid of the *Eight Corners Case*. For *instruments*, actions like "drumming" and "striking" were anticipated, extending to sound-producing materials like striking the *Bronze Mask with Protruding Pupils* against the ground (as shown in Figure 5c). For *ornaments*, participants expressed interest in "wearing" artifacts or using them as decorations (see Figure 5d). For *zoomorphic artifacts*, some participants imagined riding them despite their size (see Figure 5e-f for example).

Perceived Affordances from Artifact Appearance. Interactions were influenced by visual attributes like shape, pattern, and color. For example, the *Vajrasattva Bronze Statue* was perceived as a seal stamp due to its shape and size. Participants also engaged in destructive behaviors, such as breaking artifacts for the fun of reassembling them. Delicate *patterns* inspired "zooming in" for closer inspection, while single-color artifacts prompted creative modifications like recoloring (see Figure 5g). *Figure-shaped* artifacts led to interpersonal interactions, such as conversing, imitating, or embellishing them, e.g., placing flowers or a proposal ring on the *Kneeling Archer*'s hands (as shown in Figure 5h).

Perceived Affordances for Artifact Interplay. While engaging with the VR system, participants could grab multiple artifacts in their hands. In this context, we observed that participants tried to explore interactions between various artifacts. Participants showed curiosity about the varying hardness of artifacts made from different materials. Specifically, they tried to test whether porcelain would break if struck by a metal object. They explained that it was intriguing to hear the sound of breaking, an action that cannot be performed in physical museums. Moreover, participants demon-

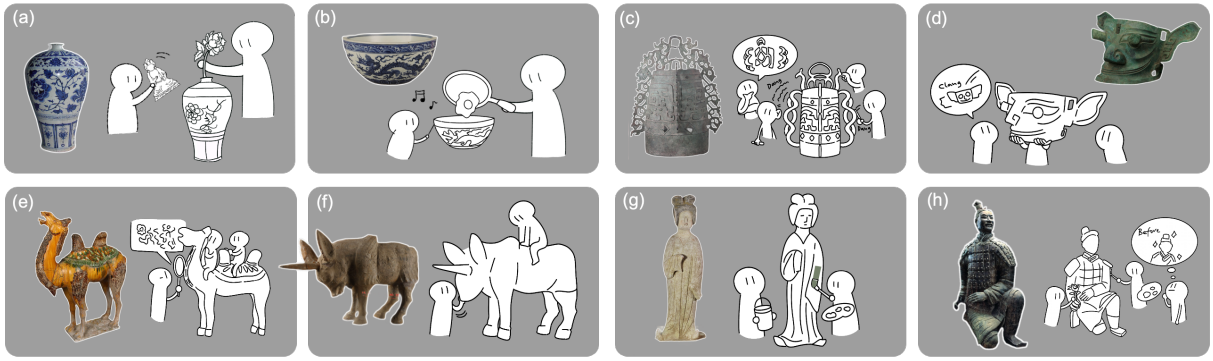

Figure 5: *Illustrations of users' perceived affordances of some museum artifacts, such as (a-b) placing items into the containers, (c) playing / breaking the music instrument, (d) wearing / striking the bronze mask, (e-f) riding the camel and the unicorn, (g-h) painting colors on the figures.*

strated an interest in the spatial arrangement of artifacts, such as stacking various artifacts atop one another, with the objective of determining their stability. This gamification aspect contributes to the overall playful nature of the interaction.

4. Study 2: Interview with Experts

To gain a comprehensive understanding of artifact presentation and interaction from the perspectives of museum experts, and to validate design ideas suggested by users, we conducted interviews with five domain professionals in museum institutions (three female, one male, one prefer not to disclose, age $M = 32.60, SD = 10.31$). The experts hold positions as director, curator, and docent in the museums (see Appendix C for their specific demographic information). Specifically, E1 leads the education department of a museum and has extensive experience in organizing educational workshops and curating exhibitions. E2 has eight years of volunteer experience in a local museum. E3's work primarily caters to international audiences. We included E4 despite of her relatively short work experience because she worked at a museum known for its extensive digital exhibitions, which provided her with valuable hands-on experience with practical cases. E5, aside from being a curator, also oversees a social media account dedicated to sharing museum artifacts online, which has amassed 100K followers. Overall, the experts reported a moderate familiarity with VR technologies ($M = 2.60, SD = 0.89$), but showed a strong willingness to use emerging technologies like VR ($M = 4.60, SD = 0.55$). These were rated on a five-point Likert scale (1 = not at all). The interview study was categorized as low-risk research and approved by the university ethics committee.

4.1. Procedure

The interviews took place in a face-to-face setting and were conducted in the participant's native language. We prepared a gift card for each participant to show our gratitude for their time. At the beginning of each interview, we obtained informed consent from the participants. Similar to the structure of the workshop, the interview was semi-structured by two discussion topics. We first presented previous VM examples using different presentation approaches and asked how they would design the artifact presentation in a virtual museum. Following this, we showed experts the same pictures of museum artifacts and asked them about artifact interaction possibilities. To avoid potential bias on their opinions, the results from the previous workshops were shown to experts at the end of the interview, where they were invited to reflect on their answers and audiences' expectations. Each interview lasted around an hour.

4.2. Data collection and analysis

All interview sessions were audio recorded with participants' consent. We used auto-transcription services in the data pre-processing. Two researchers reviewed the transcribed data together and worked independently on the coding analysis. They then discussed the analysis results and reached a near-perfect agreement on inter-rater reliability (Cohen's Kappa $\kappa = 0.887$).

4.3. Results

4.3.1. What and How to Conduct Artifact Presentation

Similar to the results in the workshop, each expert discussed distinct approaches to presenting artifact information. They anticipated that the appropriate approaches would be selected based on the specific artifacts and curatorial themes involved. Nevertheless, they discussed their opinion about the prioritized content to show and their preferred presentation approaches. Table 2 shows the summary ranking of experts' opinions in VM artifact presentation.

Table 2: *Expert rankings for artifact presentation in virtual museums.* (N) *non-observable information,* (O) *observable information,* (I) *interpretation information,* (M) *name of museum, and* (A) *name of artifact. E = environment-based, O = object-based, U = user-based.*

	What to present					How to present		
	1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}	1^{st}	2^{nd}	3^{rd}
E1	A	N	O	I	M			
E2	A	O	N	I	M	U	O	E
E3	A	N	O	I	M	O	E	U
E4	A	O	N	I	M	U	O	E
E5	A	M	N	O	I	O	E	U

Experts agreed that artifact names are essential, followed by observable and non-observable details to build a narrative. Most preferred placing interpretive information and museum names at the end, though E5 emphasized crediting the museum in virtual museums due to the integration of artifacts from multiple sources. Experts supported incorporating user-generated content for audience engagement. E1 highlighted the value of communication, citing parent-child interactions as meaningful even if some information is inaccurate. E5 liked user comments but noted the need for moderation, which could increase operational costs. E4 and E5 suggested combining virtual and physical exhibitions to connect dispersed artifacts, enhancing their significance.

Experts prioritized object-based presentations for descriptive information, with E3 noting that environment-based displays are suitable for brief details like artifact names. E5 recommended consistent styles, suggesting object-based presentations for small artifacts and environment-based ones for larger items like the Terracotta Warriors. E2 and E4 favored user-based presentations for non-observable information, allowing visitors to access details anytime, akin to a leaflet. E4 noted that user-based approaches could enhance experiences for popular artifacts by providing information while visitors wait. She also expressed interest in using *DanMu* for interpretive content. E5 cautioned against clutter from mixed formats, emphasizing simplicity and consistency.

4.3.2. Artifact Interaction

The interactions suggested by the experts largely align with users' imaginations but were enriched with more detailed elements and reflections on the cultural and historical significance. Figure 6 illustrates some example concepts mentioned by the domain experts.

Education-driven interactions. Experts emphasized the educational value of interactions. E4 suggested "dressing" the *Pottery Figure of a Standing Lady* to reflect Tang Dynasty costumes, stressing historical accuracy over entertainment. E2 proposed interactive storytelling, such as artifacts "speaking" to children to explain their significance. E5 highlighted material-based education, noting differences in durability, e.g., riding a fragile Tang Sancai camel versus a sturdy stone carving. E2 also recommended displaying related artifacts for comparison, such as showing various Terracotta Warriors alongside the *Kneeling Archer*.

Debates About Interaction Boundaries. E1 argued for restricted interactions to prevent misconceptions, suggesting role-playing elements to reinforce ethical boundaries, e.g., users acting as custodians to move artifacts. Conversely, E2 supported diverse interactions, likening them to gaming, where virtual actions don't translate to real-life behaviors. E5 proposed environmental feedback, such as rain, signifying the negative impact of disruptive behaviors, to shape user perceptions.

Responses to Users' Ideas: Restore, Not Destroy. Experts opposed destructive behaviors but accepted them when redirected positively. E1 discouraged actions like dropping artifacts but supported restoration as a learning tool, e.g., fixing broken artifacts or destroying replicas to highlight counterfeiting laws. E5 envisioned restorative interactions, such as removing patina to reveal a bronze artifact's original golden color, describing it as "exhilarating." He likened such interactions to renewal and revival, encouraging exploration with rewarding outcomes.

5. Discussion

Our study aims to understand users' perceived affordances of artifact presentation and interaction in VMs. We discuss our findings on the research question and propose a Cultural Preservation, Artifact Restoration, Recreational Exploration, and Educational Reimagination (CARE) design guideline for a culturally meaningful presentation based on the results.

5.1. Artifact Presentation in VMs: Content and Approach

We examined the use of content (observable, non-observable, and interpretative information) and approaches (environment-based, object-based, and user-based) for artifact presentation in VMs, emphasizing the need to address diverse user needs. Museums and designers must consider audience heterogeneity, as preferences vary widely. For example, some users prefer virtual guides as the sole information source, while others, such as shortsighted users, benefit from hand-held panels with zoom features, and people with dyslexia may find virtual guide conversations more natural. Children may favor user-based approaches for better accessibility. Inclusive designs that reflect diverse perspectives are essential to serving all visitors effectively.

For system developers, environment-based presentations, which mimic real-world exhibitions, create familiarity and are ideal for object-related information (e.g., *observable* and *non-observable information*). Object-based approaches, favored by participants, should use intuitive tools like *tooltips* and youth-friendly formats such as *DanMu*, aligning with familiar 2D mental models. User-based presentations support various media formats, including text, audio, video, AI voice guides [CWTL25], and 3D avatars

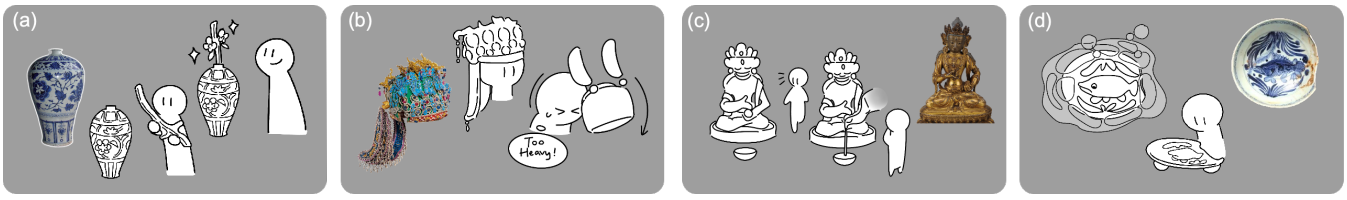

Figure 6: *Illustrations of experts' perceived affordances of some museum artifacts, such as (a) putting withered tree branch into the vase and watch the flowers bloom, simulating the idiom of Ku Mu Feng Chun, (b) wearing the crown and feeling the weight, (c) offering incense and worshiping the Vajrasattva, and (d) observing the simulated seawater ripples in porcelain vessels excavated from shipwrecks.*

[HMAKS21], enabling personalized and customizable experiences. These approaches hold significant potential for enhancing engagement, accessibility, and satisfaction [TLCM22].

5.2. Artifact Interaction in VMs: Make the Impossible Possible

VMs differ from physical museums in their rich digital affordances, which offer a design space that requires in-depth exploration. VMs have the unique capability of transcending physical limitations and digitally realizing interactions that are not readily available in the real world [LCC23]. Our work gives some concrete examples that can provide recommendations for designers based on the utility and appearance of the artifacts, as well as the interplay between artifacts. We conclude the interaction design into a CARE framework, which refers to cultural preservation, artifact restoration, recreational exploration, and educational reimagination.

5.2.1. Cultural Preservation: Grab and Observe

Grabbing represents a fundamental form of 3D interaction in VR. Users anticipate the inclusion of basic 3D interactions, which encompass the ability to grab, rotate, scale, and move artifacts for close examination from multiple perspectives. These interactions pertain to the alterations in the form of 3D models, independent of the artifacts' content, which can be considered as the fundamental interactions. Li et al. [LCC23] categorized the interactivity of artifacts into low, medium, and high levels based on the amount of control implemented on each object, where static objects are low-interactivity objects. The objects that can be grabbed are labeled as medium interactivity, while high interactivity requires artifacts to have additional context-specific interactions. Our investigation of object affordances indicated various types of high object interactivity.

5.2.2. Artifact Restoration: Paint and Add

During our workshop, participants expressed a desire to enhance artifacts by adding content, such as color-painting. These intended interactions are based on artifacts' physical appearance and their utilities. In the meantime, the interactions showed the user's desire to restore and display the original appearance of artifacts. For example, the *Kneeling Archer* was richly colored when excavated, but the existing artifacts are faded. However, by coloring it in VR, it is possible to recreate the appearance of the artifact without harming it. Previously, researchers in Dunhuang mural has demonstrated the benefits of digitally restoring color and content. An interactive VR system was designed to allow users to experience the restoration of Dunhuang frescoes [FZX*20]. This functional interaction can greatly enhance visitors' understanding of the artifacts' aesthetics and cultural significance within their historical contexts. In addition to the restoration of appearances, tangibly marking the artifacts may reflect users' desire for personalization, ownership, and leaving a personal imprint of their visit. Visitors to onsite attractions tend to leave unique markings such as carving their names on the places they visit. Most scholars attribute this behavior to impropriety vandalism and a lack of moral identity [WG18]. This kind of "I was here" syndrome is discouraged, but it is also considered to be a manifestation of self-expression and identity [CK23]. People define themselves and express themselves by adding personal markers [BP16] to make their visit memorable and unique. This behavior helps visitors develop a deeper connection with the artifacts. VM provide an ideal environment for such visitor expectations, as users can add their preferred digital content to artifact models without the risk of causing damage. We believe that incorporating support for UGC in the interaction design of VMs will enhance their personalization and emotional engagement, making them more appealing platforms for visitors.

5.2.3. Recreational Exploration: Break and Destroy

Workshop data showed that 6/18 participants proposed destructive interactions (e.g., breaking artifacts), which experts reinterpreted as opportunities for restoration education. These behaviors, although not allowed in real life, are doable in the virtual environment. We attempt to understand the emergence of such behaviors from the following perspectives. First, it is a novel expression of interactive exploration. Both archaeological excavation and educational work have been carried out with the intention of salvaging and repairing artifacts. Previous work has rarely considered the "destructive" perspective of guiding users to interact with artifacts. Thus, the destruction that participants want to do with artifacts can be seen as an exploration of behavior in VM, rather than outright vandalism. Second, the desire to destroy can be seen as a need for users to control the environment in VMs. Participants expect autonomy in modifying content in the virtual space according to their preferences. By altering the appearance of the artifacts, users can personalize their experience and the resulting presentations. Third, it is essential to recognize that this behavior involves an emotional investment from participants. The desire to destroy can be seen as an expression of strong emotion, meaning the VM triggers a deeper user involvement. Supporting such interactions should also carefully consider the potential negative consequences. As experts noted, allowing users to destroy artifacts within the VM may compromise the intended experience for other visitors or diminish the educational and cultural value of the museum. The boundaries and norms of VMs deserve further exploration.

5.2.4. Educational Reimagination: Game and Takeaway

Participants highlighted opportunities for future design in three areas: artifact interplay, gamification, and takeaways. Museums, as multi-object environments, can enhance visitors' understanding by showcasing the historical, cultural, or artistic connections between artifacts through combined displays. Gamified interactions, such as puzzles or building blocks inspired by artifact shapes, could introduce playfulness and sustain engagement. Additional strategies like treasure hunts and social sharing have proven effective [Ces19]. Souvenir purchasing and gift-giving, common in physical museums, can extend to VMs, where digitized artifacts are more affordable [XLW*23]. Prior research has explored integrating physical and digital artifacts for takeaway experiences [LYL21]. Allowing users to save or export artifact models or create cultural products could foster digital creativity, encourage revisits, and enhance the VM experience.

5.3. Lessons Learned

Virtual museums should aim to achieve two design goals: (1) facilitate education and knowledge sharing, and (2) provide enjoyable and reflective experiences. Based on our findings, we propose guidelines for artifact presentation (**P1-P2**) and interaction (**I1-I2**) to inform future VM designs.

P1: Use object-based presentations for clarity in knowledge sharing. Object-based presentations, combining text panels, tooltips, and *DanMu*, effectively link information with 3D artifacts, enhancing user engagement and interpretation.

P2: Enable personalization and reflection with user-based interfaces. Dismissable presentations, virtual guides, and user-generated content support personalization. User-based interfaces, inspired by mobile mental models, allow tailored engagement, fostering deeper understanding and retention.

I1: Enhance interactions with creative social and cultural activities. Beyond basic 3D interactions (grab, rotate, scale, move), designers should enable resets and introduce artifact-specific interactivity. Activities like restoring colors, dressing artifacts, or conversing with historical figures promote sociocultural engagement and enrich learning contexts.

I2: Balance enjoyment and education in gamified interactions. Gamification, such as disassembling and reassembling artifacts, engages users but may risk undermining educational value. To mitigate this, designers should avoid destructive behaviors, use role-playing scenarios, and incorporate environmental cues to guide interactions responsibly.

5.4. Limitations and Future Work

This study has several limitations. First, it focused on textual descriptions from museum websites, excluding other enriching methods like multimedia, interactive visualizations, immersive storytelling [XLL*24], and gamification [LZLD25], which could enhance user engagement and learning. Future research should adopt a more holistic approach. Second, participants were young adults familiar with VR, a key demographic for VR technology [OGB21], but their insights may not generalize to novice technology users or other age groups. Expert interviews provided alternative perspectives, but caution is needed in applying findings to broader audiences. Additionally, the study primarily examined ancient Chinese artifacts, excluding cross-cultural comparisons and other artifact types such as 2D works, recent artworks, or born-digital pieces, which could reveal new insights. Besides, given the exploratory and comparative nature of this study, we prioritized controller-based interaction for its reliability and lower technical overhead. Future research may explore hybrid approaches that combine natural gesture input with controller support to further enhance immersion [WLL23b]. Finally, the qualitative nature of workshops and interviews has inherent limitations in validity and reliability. To address this, we triangulated data sources, based the study design on related works, and involved both inside and outside coders to improve reliability. Future work will implement and evaluate the design ideas in experimental studies, explore user behavior modeling for predicting interaction intentions, and integrate interactive exhibits with AI guides powered by large-language models [CWTL25].

6. Conclusion

In this paper, we conducted a study on the presentation and interaction of 3D artifacts in virtual museums and distilled our findings into design recommendations. By utilizing the richness of content and interactivity inherent in virtual museums, we aim to create engaging environments that enhance user understanding and appreciation of cultural heritage. Regarding presentation, we gathered insights from users about their expectations for artifact information in virtual museums and analyzed various approaches used to present the artifacts. These insights can inspire future virtual museum curation efforts in selecting and presenting information. In terms of interaction, we explored the digital affordances of artifacts in virtual museums, providing concrete examples that can serve as references for designers based on the artifacts' utility, appearance, and interplay. Our design recommendations offer valuable guidance for virtual museum designers and system developers. Future research can build upon our work to develop comprehensive guidelines for information presentation and interaction in virtual museums by expanding the target user groups, considering cross-cultural differences, and exploring a wider variety of artifacts.

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Appendix A: Artifact Images were Used in Workshops

Figure 7: *Images of 30 artifacts sourced from museum websites. Artifacts (a-n) were included in the VR system.*

Appendix B: Participants Demographic Information

Table 3: *Demographic information of the workshop participants.*

Participant ID	Age	Gender	Familiarity with VR	Familiarity with interaction design	Frequency of museum visiting	Willingness to visit physical museums	Willingness to visit virtual museums
P1	27	Female	5	5	Frequently (a couple of times a year)	5	5
P2	25	Female	3	4	Very frequently (once a month or more)	5	4
P3	19	Female	3	2	Rarely (once a year or less)	2	2
P4	26	Male	5	4	Occasionally (2-3 times a year)	5	4
P5	19	Male	4	3	Occasionally (2-3 times a year)	4	5
P6	19	Male	3	2	Rarely (once a year or less)	4	4
P7	20	Male	4	2	Frequently (a couple of times a year)	4	4
P8	21	Male	5	2	Rarely (once a year or less)	4	4
P9	31	Male	5	5	Frequently (a couple of times a year)	5	4
P10	21	Male	3	2	Never	4	4
P11	25	Male	5	1	Rarely (once a year or less)	3	3
P12	22	Male	4	2	Rarely (once a year or less)	4	4
P13	23	Female	2	4	Rarely (once a year or less)	4	3
P14	21	Female	2	2	Frequently (a couple of times a year)	4	2
P15	24	Male	3	4	Frequently (a couple of times a year)	5	4
P16	25	Male	4	3	Rarely (once a year or less)	4	2
P17	23	Male	4	4	Rarely (once a year or less)	4	5
P18	26	Male	4	4	Rarely (once a year or less)	4	4

Appendix C: Expert Demographic Information

Table 4: *Demographic information of the experts.*

Expert ID	Age	Gender	Role	Year of experience	Familiarity with VR	Willingness to use VR
E1	33	Male	Director	6	3	5
E2	49	Female	Docent	8	4	5
E3	33	Female	Docent	3	2	5
E4	22	Female	Docent	1	2	4
E5	26	Female	Curator	6	2	4