

Article

Designing Authentic Virtual Heritage Experiences for Sustainable Cultural Heritage Communication: A Mixed-Methods Study

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Abstract

Perceived authenticity may strengthen the credibility of virtual cultural heritage communication and foster sustained cultural engagement, yet authenticity theory remains insufficiently translated into actionable design guidance. This study employed an exploratory sequential mixed-methods design comprising ten qualitative interviews, exploratory and confirmatory factor analyses with two independent samples ($n = 200$ each), framework construction, and a between-group prototype evaluation ($n = 61$). The analyses indicated a context-specific two-factor structure: constructive authenticity, integrating evidence-based judgment, contextual interpretation, and narrative plausibility; and existential authenticity, encompassing participation, emotional engagement, personal meaning, and cultural connection. Objective authenticity converged with constructive authenticity rather than emerging independently, suggesting that users interpreted historical evidence through digitally mediated representations. These findings were translated into six coordinated design dimensions: historical environment design, historical information transparency, narrative plausibility, stylistic atmosphere, experiential immersion, and interactive engagement. In a single-theme comparison, the framework-guided prototype was associated with higher loyalty, satisfaction, cultural identity, and behavioral intention than the conventionally designed prototype (Hedges' $g = 1.265$ – 1.636). Overall, the study offers a context-specific theoretical account and an actionable, evidence-informed framework that may support continued engagement and cultural transmission; long-term sustainability outcomes and cross-context transferability require further investigation.

Keywords: cultural heritage; virtual exhibition; authenticity; user experience; experience design



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1. Introduction

The application of virtual and digital technologies has expanded cultural heritage practice from preservation and restoration to virtual reconstruction, interactive exhibition, public education, and cultural communication. Cultural heritage institutions have consequently evolved from repositories of objects into complex cultural systems that integrate conservation, interpretation, dissemination, and audience experience. Within this transformation, virtual exhibitions have become an important means of broadening public access, presenting heritage values, and supporting new forms of cultural engagement.

Research on virtual cultural heritage exhibitions has gradually shifted from technical fidelity and digital representation toward narrative, interaction, learning, emotional engagement, and user experience. Nevertheless, technological applications and specific exhibition formats have received substantially more attention than the psychological mechanisms through which audiences understand and experience virtual heritage. Because virtual exhibitions seek not only to communicate historical information but also to construct sensory, cognitive, and emotional experiences, audience experience has become an important criterion for evaluating their cultural effectiveness.

Authenticity has long been regarded as a central dimension of heritage experience and has increasingly been examined in virtual environments. Existing studies have explored how authenticity is constructed in online heritage experiences, how users assess the credibility of virtual content, how different forms of authenticity influence virtual heritage experiences, and how perceived authenticity relates to satisfaction, cultural attachment, and behavioral intention [1–3].

Authenticity is not merely an experiential attribute but an important condition for the sustainable communication and development of virtual heritage. The long-term preservation of digital representations does not automatically ensure the continuity of heritage meanings, which also depends on credible information sources, context-sensitive interpretation, and a clear explanation of the boundary between historical evidence and conjectural reconstruction [4–8]. Authenticity is also closely related to public trust, because non-specialist audiences often rely on provenance, institutional credibility, scholarly authority, and reconstruction transparency when they cannot independently verify historical content [1,9]. Liu et al. [10] demonstrated that effective communication strategies in educational contexts significantly influence long-term knowledge retention and behavioral outcomes—a principle that applies equally to cultural heritage communication, where perceived authenticity may drive sustained engagement and conservation behavior. Moreover, sustainable heritage communication requires audiences not only to access content but also to understand, remember, and connect it with their cultural identities and lived experiences. Perceived authenticity and heritage involvement have been associated with memory, attachment, cultural identity, satisfaction, heritage responsibility, and future behavioral intentions [2,11–13]. Documenting sources, uncertainty, and interpretive decisions further enhances the verifiability, reuse, and long-term governance of virtual reconstructions [7,14,15].

In response to the growing importance of audience experience, researchers have proposed various frameworks for virtual cultural heritage design. User-centered approaches have addressed usability, interface design, contextual presentation, and educational engagement [16]. Integrated VR/AR frameworks have combined virtual reconstruction, storytelling, gamification, and interaction to enhance accessibility and participation [17]. Narrative and embodied-interaction models have examined how users engage with heritage content through culturally contextualized stories and participatory roles [18], while broader design frameworks have considered collaborative design practice and the production of digital heritage knowledge [19]. More recent models have also systematized relationships among perception, cognition, emotion, learning, immersion, usability, and behavioral intention [20].

Although these frameworks have substantially advanced the design of virtual heritage experiences. However, their primary objectives generally concern overall experience quality, technological integration, usability, immersion, learning, or participation, rather than perceived authenticity as a distinct design objective. Authenticity is often addressed indirectly through technological realism. Yet technological realism does not necessarily ensure that users perceive heritage content as historically credible, culturally plausible,

or personally meaningful. Even visually convincing reconstructions may obscure their evidential basis, conceal conjectural elements, or fail to establish a meaningful connection between audiences and heritage.

Many existing models are also more effective in explaining or evaluating experience than in guiding concrete authenticity-related design decisions. They identify relationships among technology, immersion, emotion, satisfaction, and behavioral intention, but provide limited guidance on how practitioners should coordinate historical evidence and creative reconstruction, maintain narrative plausibility, construct culturally appropriate atmospheres, or support personal meaning-making. Recent authenticity-oriented recommendations for XR heritage represent an important step in this direction, but they remain preliminary, relatively general, and primarily derived from practitioner perspectives [21].

The main research gap is thus not the absence of virtual heritage experience models, but the lack of an operational connection among authenticity theory, users' authenticity perceptions, and design practice. Although existing models identify various important experiential factors, they do not systematically explain, from the perspective of perceived authenticity, how historical credibility, cultural plausibility, and emotional or existential involvement jointly shape users' authenticity experiences or how these mechanisms can be translated into actionable design strategies.

To address this gap, the present study develops an authenticity-oriented experience design framework for virtual cultural heritage exhibitions. It first investigates how non-specialist users perceive and organize authenticity in conventional virtual environments, particularly those based on accessible PC and mobile technologies. This perceptual structure is then translated into interconnected design dimensions and strategies, establishing a continuous pathway from authenticity theory and user evidence to design practice. The resulting framework is subsequently examined through a prototype-based pilot evaluation.

The contribution of this study lies in linking authenticity theory, user perception, and virtual heritage design. Empirically, it clarifies how different forms of authenticity are organized within virtual heritage experiences, with particular attention to the perceptual convergence of objective and constructive authenticity. Practically, it translates this structure into six design dimensions: historical environment design, historical information transparency, narrative plausibility, stylistic atmosphere, experiential immersion, and interactive engagement. Rather than replacing general user experience frameworks, the proposed framework complements them by treating authenticity as a specific design objective and an important condition for credible and sustainable cultural heritage communication.

The remainder of this article reviews relevant research, explains the exploratory sequential mixed-methods design, presents the investigation of authenticity experience, develops the design framework and its strategies, and reports a prototype-based pilot evaluation. The final sections discuss the implications, limitations, and future directions of the study.

2. Literature Review

2.1. Design of Virtual Cultural Heritage Exhibitions

In recent years, the research focus in the design of virtual cultural heritage exhibitions has shifted significantly, moving from an early emphasis on the technical concerns of digital preservation and image representation toward the exploration of cultural meaning-making and the construction of deep experiences. Around this goal, existing studies have advanced the field on multiple fronts. In terms of presentation technologies, the generation of digital content no longer settles for high-fidelity modeling but instead pursues the integration of archaeological authenticity with narrative creativity. For example, research on the restoration of Tang Dynasty mural costumes has established a complete technical

workflow—from rigorous historical examination to three-dimensional virtual stitching—and has introduced an evaluation mechanism to verify cultural credibility [22]. Similarly, the creation of advanced digital exhibits such as “digital humans” employs high-precision sculpting and narrative integration to position them as dynamic agents that embody and transmit culture [23]. In the practice of large-scale sites like Liangzhu, multiple technologies have been integrated to construct interactive, large-scale virtual spaces, thereby three-dimensionally reconstructing the integrity of historical scenes [24].

The application paths of interactive technologies have also demonstrated pluralistic explorations tailored to specific contexts. AR/VR technologies aim to enhance immersion and interactive experiences, with related studies not only validating the potential of high-end equipment but also confirming the feasibility of low-cost solutions based on ordinary mobile devices in resource-limited regions, and revealing usage differences among users of different generations [25]. At the same time, to strengthen the credibility and permanence of digital information, technologies such as blockchain have been introduced and integrated with AR systems, which have been shown to effectively increase users’ sense of data trust in the experience [26]. These technological explorations support the shift in exhibition modes from “viewing” to “participating.”

Faced with the common challenges of narrative fragmentation and the disconnection between virtual and physical experiences in virtual exhibitions, constructing systematic narrative and experience models has become key to deepening research. Existing studies have sought to develop integrative frameworks that organically connect digital content with physical spaces. For instance, one study used embodied interaction design to guide users to participate in historical scenarios through a first-person role [18]. Furthermore, a more theoretically integrated “spatiotemporal overlapping narrative experience model” has been proposed, which, by constructing a framework of multi-dimensional spatiotemporal correspondences, pursues a deep synchronization of virtual narrative threads with the physical visiting flow and rhythm, thereby creating a coherent experience of cultural meaning [27]. Correspondingly, evaluation research has become increasingly nuanced, with the focus turning to the psychological dimensions of user experience. By introducing established theoretical models and mixed methods, studies have analyzed in depth how multiple factors—such as technological characteristics, perceived ease of use, and enjoyment—complexly influence users’ immersion and behavioral intentions [28]. Other research has revealed the non-linear effects of interactive “agency” levels in VR environments on cultural identity, providing important grounds for design [29].

In summary, current research has established a solid foundation in content generation, technology integration, narrative construction, and effect evaluation, revealing a clear trajectory from technological application toward systematic experience design.

2.2. *Heritage Experience Authenticity in Virtual Technology Contexts*

The discussion of authenticity in heritage has a long history. Early research on heritage authenticity centered on the material dimension [30], with scholars advocating a static and objective stance that drew absolute boundaries between the authentic and the inauthentic [6]. However, as the application and study of authenticity expanded, researchers found that relying solely on an objectivist perspective became increasingly inadequate for addressing new issues emerging from contexts such as heritage tourism experience and the transmission of intangible cultural heritage. In response, theoretical perspectives that transcend objectivist, static authenticity were proposed. Within critical heritage studies approaches [31], for instance, scholars refused to treat heritage merely as historical remnants; instead, they embedded it within the processes of cultural reproduction in contemporary society, where it is continually reconstructed and reinterpreted [32,33]. It was observed

that different individuals may construct different understandings and perceptions of authenticity when confronting the same heritage object. Building on this, the concepts of “cool” authenticity and “hot” authenticity were introduced, corresponding respectively to “authenticity as knowledge” and “authenticity as feeling”—the former concerned with whether the object itself exists authentically, and the latter with whether the subject’s feeling is authentic. As a further theoretical development, a four-category framework encompassing objective authenticity, constructive authenticity, existential authenticity, and postmodern authenticity has become widely accepted and has been extensively examined in fields such as heritage tourism experience, museum heritage, and heritage media communication. This body of work provides a theoretical foundation for discussing issues of experience authenticity in virtual contexts such as virtual exhibitions of cultural heritage.

Current research on heritage authenticity experience in virtual technology contexts has largely focused on how different virtual technologies enhance perceived authenticity and their subsequent specific effects on factors such as people’s behavior and willingness to experience [2,34]. Different types of authenticity may exert different levels of influence on audiences’ perceived experiences. For instance, in a study that sought to enhance travel intention by manipulating the authenticity quality of virtual influencers—virtual cultural ambassadors—the effect of constructive authenticity was found to be significantly stronger than that of objective authenticity [35]. Meanwhile, technological differences and user characteristics are also important factors shaping perceived authenticity experience. For example, although both VR and AR are immersive technologies, they differ in their impact on user experience in terms of technological characteristics such as vividness and interactivity [36]. For specific groups such as Generation Z, the authenticity experience of virtual heritage content exhibits a dynamic experiential and cognitive structure that evolves as the experience stage deepens [37]. Although existing research on heritage authenticity experience in virtual technology contexts has been conducted from multiple angles, certain gaps remain at the juncture of theoretical construction and design practice. Specifically, in the actual process of heritage content design and development, virtual heritage exhibition development teams—comprising roles such as heritage managers, service developers, and design teams—need a more direct pathway to gain a clear awareness of the conceptual structure of authenticity and its potential impact. Therefore, investigating authenticity experience within virtual technology contexts and, on this basis, constructing a design framework aimed at the quality of authenticity experience represents a crucial endeavor to propel the field from the pursuit of “technological immersion” toward the evocation of “deep authentic experience.”

3. Materials and Methods

To identify the key dimensions underpinning the design framework for experience authenticity, this study adopted an exploratory sequential design based on the relevant mixed-methods literature [38]. The first phase was a qualitative study, in which the construct dimensions of experience authenticity were determined through semi-structured interviews [39] and a coding analysis informed by simplified grounded theory procedures [40]. Subsequently, factor analysis methods, including exploratory factor analysis (EFA) and confirmatory factor analysis (CFA), were applied to purify and validate these dimensions.

Building on the identified construct dimensions of experience authenticity and drawing on the literature on framework development in the experience design field, a design framework was developed to enhance the quality of perceived authenticity in virtual cultural heritage exhibitions. In the prototype-based evaluation, guided by this framework, an interactive virtual exhibition themed around the ox-cart culture of China’s Jin Dynasty was developed, and participants were recruited to experience it. The study measured

participants' various behavioral intentions and attitudes, and independent-samples *t*-tests were conducted to examine the statistical significance of score differences between the experimental and control groups.

4. Results

4.1. Qualitative Research Process and Results for the Concept of Experience Authenticity

4.1.1. Semi-Structured Interviews

During the qualitative data collection phase, semi-structured interviews were conducted to explore how users perceive and interpret authenticity in virtual cultural heritage exhibitions. The interview guide was developed through a review of relevant literature on authenticity perception in heritage tourism, heritage exhibitions, and virtual heritage games. Participants were recruited through purposive criterion sampling. To ensure that they had an adequate experiential basis for reflecting on the relatively abstract concept of authenticity, eligibility required prior experience with at least one virtual cultural heritage exhibition or comparable heritage-related digital content, such as a heritage serious game.

Before each interview, participants engaged with selected virtual heritage content to establish a shared point of reference and reduce reliance on distant recollection. The subsequent interviews focused on participants' perceptions, judgments, and interpretations of authenticity in the virtual heritage experience. Interviews were conducted through a combination of online and in-person formats. Data collection and analysis proceeded concurrently and continued until no new higher-order categories emerged and the existing thematic structure was considered sufficiently elaborated for preliminary construct elicitation.

A total of 10 participants completed the interviews, including six women and four men. Their mean age was 25 years, ranging from 23 to 31 years. Participants included university students and user experience designers, all of whom had previous experience with virtual heritage exhibitions or related digital heritage content. The interviews generated approximately 15 h of audio-recorded data.

4.1.2. Analysis and Results

Sample adequacy was assessed in relation to the focused purpose of the qualitative phase, the specificity of the participant group, the use of an established theoretical background, and the depth of the interview material. Data collection and analysis proceeded concurrently, and an inductive analysis was conducted using a streamlined, grounded theory procedure [40,41]. Following each interview, the transcript was reviewed and compared with the previously analyzed materials to identify newly emerging initial codes and higher-order categories. The interviews were examined in chronological order to determine whether additional data continued to extend the existing conceptual structure. The final two interviews generated no new higher-order categories and primarily provided further elaboration and illustrative examples for the previously identified themes. On this basis, the data were considered to have reached code saturation and sufficient thematic coverage for preliminary construct elicitation. This judgment does not imply that all possible meanings of authenticity in virtual heritage experiences were exhaustively captured.

The data were analyzed using a two-stage hybrid inductive–deductive procedure. In the first stage, the transcripts were read repeatedly and meaning units related to authenticity judgments and experiences were open-coded. Codes were compared across interviews and grouped into preliminary thematic categories through constant comparison. In the second stage, the inductively derived categories were examined in relation to objective, constructive, and existential authenticity as theoretically sensitizing concepts.

Initial coding was conducted by the primary researcher. Two experts with experience in cultural heritage experience design subsequently reviewed the code definitions, thematic

boundaries, and the mapping of each category onto the theoretical framework of authenticity. Any interpretive disagreements were resolved through discussion until consensus was reached. Two themes—technology-related attentional focus and the perceived presence of the technological medium—were excluded because they showed relatively weak conceptual associations with the experience of authenticity. These themes were primarily concerned with the technical stability and type of the display devices rather than with the perceived authenticity of the heritage content itself. The remaining 16 thematic categories and their associated codes were then mapped onto the corresponding dimensions of authenticity within the theoretical framework, thereby forming a preliminary construct structure of experiential authenticity. Table 1 presents the conceptual dimensions identified in the qualitative phase, together with their definitions, illustrative quotations, and preliminary theoretical mappings. Representative verbatim quotations are reported alongside the principal thematic categories to demonstrate the analytical connection between the original data and the resulting construct structure.

Table 1. Qualitative-phase conceptual dimensions, definitions, illustrative quotations, and preliminary theoretical interpretations.

No.	Thematic Category	Description	Illustrative Quotation	Preliminary Theoretical Interpretation
01	Historical Information Credibility	Users' preliminary judgments, based on prior knowledge, common sense, or accessible information, regarding whether the historical settings, figures, events, and heritage objects represented in virtual heritage content are consistent with established historical facts.	"The content of the game is connected to factual evidence; it has a basis and is historically consistent."—P4	Objective authenticity
02	Quality of Historical Detail Reconstruction	Users' evaluation of whether scenes, character representations, costumes, artefacts, and other visual and auditory details are carefully reconstructed and correspond to the period-specific and cultural characteristics of the represented heritage context.	"The settings, the characters' clothing, and the in-game props all fit the historical period and are consistent with the historical context."—P2	Objective authenticity
03	Credibility of Authoritative Endorsement	Users' assessment of the professionalism and credibility of virtual heritage content based on the participation, recognition, or endorsement of museums, research institutions, expert teams, or other authoritative bodies.	"If it clearly states which museum collaborated on the project and which team produced it—and that team is well known—I would find it much more convincing."—P1	Objective authenticity

Table 1. Cont.

No.	Thematic Category	Description	Illustrative Quotation	Preliminary Theoretical Interpretation
04	Transparency of Evidence Sources	Users' perception of whether virtual heritage content is supported by identifiable historical evidence, traceable information sources, and explicit rationales for reconstruction. The clearer the sources and inferential process, the more likely users are to regard the content as evidence-based rather than arbitrarily fabricated.	"I would look at whether it is connected to factual evidence, whether it has a clear basis, and whether it is historically consistent."—P4	Objective authenticity
05	Historically Congruent Atmosphere	The overall atmosphere created through visual style, sound, colour, lighting, and environmental elements, and the extent to which this atmosphere is congruent with a specific historical period and cultural context, thereby shaping users' authenticity judgments.	"The setting of the ox-cart game fits the historical context, and even the sound effects feel appropriate to the period."—P8	Constructive authenticity
06	Plausibility of the Narrative Context	When users cannot directly verify all historical details, they infer credibility from whether the narrative setting, relationships among characters, event configurations, and cultural context appear coherent and plausible.	"If the historical background, characters, and events are presented well, I would feel that the narrative logic is clear."—P4	Constructive authenticity
07	Plausibility of Narrative Progression	The extent to which event development, character actions, and the disclosure of information follow a coherent chronology, causal structure, and behavioural logic appropriate to the represented historical context, allowing users to perceive the unfolding narrative as reasonable and credible.	"I may not be able to judge whether every historical detail is accurate, but if the later plot developments follow logically from the earlier setup, I would consider the narrative reasonable."—P3	Constructive authenticity
08	Congruence with Stylistic Expectations	The extent to which the visual representation, character imagery, sound, language, and environmental style of virtual heritage content correspond to users' historically informed expectations and culturally shaped mental images.	"Although I cannot determine whether every detail is completely historically accurate, the costumes, colours, and sounds match how I imagine an ancient setting, so the presentation feels credible overall."—P6	Constructive authenticity

Table 1. Cont.

No.	Thematic Category	Description	Illustrative Quotation	Preliminary Theoretical Interpretation
09	Internal Narrative Consistency	The extent to which background settings, character behaviour, causal relationships among events, and information presented at different points remain mutually coherent and free from obvious contradiction.	"If the text or characters contain historical statements that are clearly inconsistent with the facts or simply illogical, the content feels inauthentic to me."—P1	Constructive authenticity
10	Deep Immersion	A state in which users' attention is continuously absorbed by the virtual content, their awareness of the physical environment and the passage of time diminishes, and they may enter a state of intense concentration or flow.	"It feels like entering a state of flow and almost forgetting the surrounding real-world environment."—P2	Existential authenticity
11	Experiential Participation	The extent to which users feel personally involved in or present within the historical situation rather than positioned as external observers. This shift in experiential position strengthens perceived realism and personal involvement.	"'Being present' means personally experiencing the environment that has been created, rather than watching other people go through it like a spectator; it feels as though you are genuinely experiencing it yourself."—P2	Existential authenticity
12	Emotional Engagement and Immersion	The extent to which characters, events, narrative elements, and audiovisual atmosphere elicit emotional responses; such emotional engagement can further intensify attentional involvement, immersion, and the perceived authenticity of the experience.	"It does more than help me understand the content; it also engages my emotions. When the story moves me, I become more immersed and the experience feels more authentic."—P7	Existential authenticity
13	Cultural Familiarity and Affinity	The sense of familiarity, closeness, and cultural affinity that arises when the heritage theme, cultural symbols, and narrative mode correspond to users' familiar cultural backgrounds or prior understandings.	"This theme is close to the cultural background I am familiar with, so it feels personally familiar and makes it easier for me to believe that it represents authentic life within that culture."—P5	Existential authenticity

Table 1. *Cont.*

No.	Thematic Category	Description	Illustrative Quotation	Preliminary Theoretical Interpretation
14	Overall Experience Evaluation	Users' holistic evaluation of content quality, narrative, technical performance, interaction fluency, and emotional experience. Noticeable deficiencies in the overall experience may spill over into authenticity judgments and reduce trust in the content.	"The smoothness of the exhibition and whether it contains bugs affect my overall experience. Even minor technical flaws can make me trust the exhibition less."—P1	Existential authenticity
15	Embodied Interactive Experience	Users' direct participation in heritage-related activities through manipulation, bodily action, or sensory feedback, thereby producing bodily sensations of contact, agency, and engagement with historical practices.	"It is not just a matter of watching through a screen; you can actually interact with it. For example, assembling parts of the heritage object or imitating the original action makes you feel that this is how people would have done it at the time."—P8	Existential authenticity
16	Perceived Meaningfulness of the Experience	Users' understanding, through virtual experience, of the function and cultural value of a heritage object and its relationship to historical life, together with their perception that the experience has cognitive, cultural, or personal significance.	"You first need to understand how the heritage object was used at the time and under what circumstances; only then can you further understand its cultural value and significance."—P3	Existential authenticity

Note: P1–P8 denote anonymized participants. Quotations were lightly edited for readability without altering their substantive meaning.

4.2. Quantitative Research Process and Results for the Construct Dimensions of Experience Authenticity

4.2.1. Questionnaire Design and First-Round Distribution

Based on the qualitative findings, we developed a questionnaire grounded in the construct of experience authenticity, which comprised three sections. In the first section, considering that some potential respondents might not have prior experience with virtual exhibitions, we embedded an introductory video of a cultural heritage virtual exhibition and instructed respondents to imagine themselves interacting with the project on a PC platform while watching the video. An attention check item was also included to exclude those who did not watch the video attentively. The second section contained survey items based on the three authenticity dimensions. The final section gathered demographic information, including gender, age, educational attainment, and occupation. All items were measured on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree) to assess respondents' perceived authenticity of the virtual cultural heritage exhibition experience.

On 7 February 2026, we distributed and collected 257 questionnaires through the survey platform Credamo (a Chinese online survey panel), with monetary compensation provided to respondents. After excluding cases that failed the attention check, had excessively short completion times, or exhibited uniform response patterns, 200 valid questionnaires were retained for analysis. Considering that potential audiences for cultural heritage virtual exhibitions may be more highly educated, and to further minimize the negative impact of educational level on item comprehension, we restricted participants' educational attainment to a bachelor's degree or above, thereby better aligning the sample with the characteristics of the actual target population.

4.2.2. Exploratory Factor Analysis and Results

To identify the latent factor structure of the experience authenticity construct, this study applied exploratory factor analysis (EFA) using principal component analysis with SPSS 27 to the 19-item variables, followed by a varimax orthogonal rotation. We examined the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy to establish the appropriateness of the data. A value equal to or above 0.60 is required for good factor analysis [42]. The KMO measure was 0.883, and Bartlett's test of sphericity was significant ($p < 0.001$), indicating that the sample was appropriate for factor analysis. Factors were extracted based on the following criteria: (1) eigenvalues greater than 1; (2) absolute factor loadings greater than 0.40 for each component; (3) no item cross-loading on multiple factors; (4) at least three indicators or items per factor; and (5) the interpretability of the extracted components [43,44].

Based on two iterations of factor analysis, two dimensions were identified, explaining 45.9% of the total variance. Seven items (Q1, Q2, Q4, Q5, Q8, Q10, Q18) were excluded, yielding a 12-item experience authenticity scale. These two dimensions were interpreted as constructive authenticity and existential authenticity. Notably, some items originally categorized under objective authenticity and constructive authenticity loaded on the same factor, whereas items originally belonging to existential authenticity consistently loaded together on the other factor. Common method bias (CMB) was examined using Harman's single-factor test. The results indicated that the variance extracted by the first factor accounted for 23.4% of the total variance, which is below the threshold of 40%, confirming that common method bias in this study's dataset was acceptable. Table 2 presents the absolute factor loadings of the items on their respective dimensions.

The qualitative findings offered a plausible explanation for the discrepancy between the dimensions identified through exploratory factor analysis and the theoretically hypothesized dimensions. In actual experience, respondents' judgments of objective authenticity exhibited the following pattern: when they possessed accurate historical knowledge about the heritage being experienced, they were able to clearly determine whether the heritage content was objectively authentic; however, when confronted with unfamiliar heritage objects, they tended to regard the content as authentic as long as no obvious errors were present in the technological presentation and narrative logic. A possible reason for this result is that, in actual experience, respondents were unable to make expert judgments regarding the authenticity of virtual heritage content with high technological fidelity. Consequently, even when the heritage content they experienced did not conform to objective history, they still subjectively tended to perceive it as authentic. This conflation of historical accuracy and historical authenticity on the part of the respondents [45] reduced the empirical separability of objective and constructive authenticity in the context examined within the context of this study. We therefore consider the two-factor solution obtained through exploratory factor analysis to be theoretically meaningful.

Table 2. Items Retained after Exploratory Factor Analysis and Their Factor Loadings.

Items Retained After EFA.	Original Code	Factor 1	Factor 2	Final Label
I feel that the details of this virtual heritage content have been carefully researched and restored.	Q3	0.657		Constructive authenticity
The virtual heritage objects and scenes presented in the media bear a realistic resemblance to their real-world counterparts.	Q6	0.688		
I consider this virtual heritage content to be authoritative in terms of academic reference.	Q7	0.658		
This experience aligns with my overall imagination of this cultural or historical context.	Q9	0.655		
Even when I cannot judge the historical details, the experience still makes the historical setting feel plausible.	Q11	0.465		
The narrative approach used in the experience is consistent with my understanding of this culture.	Q12	0.644		Existential authenticity
During the experience, I felt that I was participating in the historical setting.	Q13		0.626	
During the experience, I felt emotionally moved.	Q14		0.753	
During the experience, I felt a sense of connection with the history or culture presented.	Q15		0.659	
During the experience, I was able to temporarily forget my real surroundings and become immersed in the experience.	Q16		0.619	
This experience holds important personal meaning for me.	Q17		0.647	
During the experience, I felt a sense of cultural resonance.	Q19		0.576	
Eigenvalue		4.273	1.238	
Total variance explained		45.923%		

Note: Factor 1 = constructive authenticity; Factor 2 = existential authenticity. Only factor loadings ≥ 0.40 are reported, and blank cells indicate loadings below 0.40. Principal component analysis with varimax rotation was used. The two factors jointly explained 45.923% of the total variance.

4.2.3. Second-Round Questionnaire Distribution

On 2 March 2026, we distributed the questionnaire containing the retained 12 items again via the Credamo platform, with monetary compensation provided to respondents, and collected 246 questionnaires. The screening criteria remained identical to those applied in the first round. Cases that failed the attention check, had excessively short completion times, or exhibited uniform response patterns were excluded, resulting in 200 valid questionnaires retained for analysis. The participant selection criteria also remained consistent with the first round of distribution.

4.2.4. Confirmatory Factor Analysis and Results

A confirmatory factor analysis (CFA) was conducted on the 12 items representing the two latent constructs derived from the exploratory factor analysis using AMOS 24. The fit indices for the 12-item model were as follows: $\chi^2 = 63.369$; $p = 0.156$; $\chi^2/df = 1.196$; GFI = 0.97; NFI = 0.84; CFI = 0.97; TLI = 0.96; IFI = 0.97; RMSEA = 0.031; SRMR = 0.05. For model fit assessment, we employed the frequently cited goodness-of-fit indicators, such as χ^2/df , goodness-of-fit index (GFI), normed fit index (NFI), comparative fit index (CFI), Tucker–Lewis index (TLI), and incremental fit index (IFI), with values greater than 0.80 considered acceptable [46]. According to these criteria, the two-factor model with 12 items demonstrated good fit, with all values falling within the acceptable range [47]. All freely estimated factor loadings were statistically significant ($p < 0.001$). The standardized loadings ranged from 0.386 to 0.557 for constructive authenticity and from 0.460 to 0.657 for existential authenticity, as reported in Table 3.

Subsequently, we verified the item-construct associations for each individual dimension. Cronbach's alpha values were 0.743 for constructive authenticity and 0.766 for existential authenticity, both exceeding the commonly used threshold of 0.70 [48,49]. The corresponding CR values were 0.629 and 0.747. The CR of constructive authenticity was below the conventional 0.70 criterion but remained above the 0.60 reference point often used in exploratory construct development, whereas the CR of existential authenticity exceeded 0.70 [46]. The AVE values were 0.223 and 0.333, respectively, both below the conventional criterion of 0.50 [50]. Accordingly, the results support good overall model fit and acceptable alpha-based internal consistency, while also indicating that the reliability of constructive authenticity and the convergent validity of both factors require further refinement, as reported in Table 3.

To assess whether the low AVE values were primarily attributable to a single weak indicator, sensitivity analyses were conducted by separately removing Q3 and Q19, the lowest-loading item within each factor. Removing Q3 increased the AVE of constructive authenticity only from 0.223 to 0.229, while its CR decreased from 0.629 to 0.595. Removing Q19 increased the AVE of existential authenticity from 0.333 to 0.358, while its CR decreased from 0.747 to 0.735. In neither case did AVE approach 0.50, and both deletions reduced composite reliability. The low AVE values therefore cannot be attributed to one isolated indicator, and mechanical item deletion would not materially improve the measurement model.

The two indicators were retained because they represented nonredundant theoretical content identified during the qualitative phase. Q3 captures the evidence-based reconstruction of historical detail and maintains the connection between objective-authenticity judgments and the broader constructive-authenticity factor [45]. Q19 captures cultural resonance, which represents a personal and cultural connection to heritage and is related to, but not interchangeable with, immersion or general emotional arousal [2,30]. Removing either item would narrow the theoretical coverage of the authenticity dimensions used to construct the design framework, while the sensitivity analyses showed that deletion did not resolve the low-AVE problem. Accordingly, the retained two-factor structure provided a theoretically grounded and empirically interpretable basis for the subsequent construction of the design framework.

Table 3. Standardized CFA loadings, construct reliability, and convergent validity.

Dimension After EFA	Original Code	Item	Std. Loading	Construct Metrics
Constructive authenticity	Q3	I feel that the details of this virtual heritage content have been carefully researched and restored.	0.386	Cronbach's $\alpha = 0.743$ CR = 0.629 AVE = 0.223
	Q6	The virtual heritage objects and scenes presented in the media bear a realistic resemblance to their real-world counterparts.	0.464	
	Q7	I consider this virtual heritage content to be authoritative in terms of academic reference.	0.488	
	Q9	This experience aligns with my overall imagination of this cultural or historical context.	0.497	
	Q11	Even when I cannot judge the historical details, the experience still makes the historical setting feel plausible.	0.557	
	Q12	The narrative approach used in the experience is consistent with my understanding of this culture.	0.419	
Existential authenticity	Q13	During the experience, I felt that I was participating in the historical setting.	0.657	Cronbach's $\alpha = 0.766$ CR = 0.747 AVE = 0.333
	Q14	During the experience, I felt emotionally moved.	0.604	
	Q15	During the experience, I felt a sense of connection with the history or culture presented.	0.533	
	Q16	During the experience, I was able to temporarily forget my real surroundings and become immersed in the experience.	0.556	
	Q17	This experience holds important personal meaning for me.	0.631	
	Q19	During the experience, I felt a sense of cultural resonance.	0.460	

Note: CR = composite reliability; AVE = average variance extracted. All freely estimated unstandardized factor loadings were significant at $p < 0.001$; one marker loading per factor was fixed at 1.00 for identification.

5. Design Framework Construction and Strategy Generation

5.1. Design Framework

Based on the findings of the exploratory sequential mixed-methods study, we developed an authenticity-oriented experience design framework for virtual cultural heritage exhibitions. Unlike general-purpose exhibition frameworks, the proposed framework is not intended to provide a comprehensive guide to all aspects of usability, accessibility,

interface design, or technical production. Instead, it complements existing digital heritage and experience design frameworks by treating perceived authenticity as a specific design objective and by translating authenticity-related user evidence into actionable design domains [19,51,52].

Building on the qualitative categories, the two-factor structure supported by the EFA and CFA, and the relevant design literature, we developed a design framework that was subsequently applied in the design workshop. The central task of framework construction was to translate the experiential structure of perceived authenticity into actionable design concerns. At the experiential level, the empirical findings supported two broad dimensions: constructive authenticity, encompassing evidence-based judgment, contextual interpretation, and narrative plausibility; and existential authenticity, encompassing participation, emotional engagement, personal meaning, and cultural connection. At the design-translation level, the categories and indicators associated with these dimensions were reorganized into areas that practitioners could address through content research, historical reconstruction, narrative development, visual design, and interaction design. This consolidation followed four criteria: empirical traceability to the interview or survey evidence, theoretical consistency with authenticity theory, practical actionability within the design process, and conceptual distinctiveness from adjacent domains. The translation therefore represented a design-oriented synthesis of the empirical findings rather than a direct replication of the psychometric factor structure.

This process yielded six design dimensions: historical environment design, historical information transparency, narrative plausibility, stylistic atmosphere, experiential immersion, and interactive engagement. The first four primarily translate the evidentiary, contextual, and interpretive concerns associated with constructive authenticity into specific design actions, whereas the latter two translate the participatory, emotional, and meaning-making concerns associated with existential authenticity into corresponding experience-design requirements. Together, the six dimensions constitute the proposed authenticity-oriented design framework. Figure 1 summarizes the progression from empirical and theoretical evidence to the six-dimensional design framework.

Although the framework contains six design dimensions, these dimensions should not be interpreted as six psychometrically validated or completely independent subconstructs. They are coordinated design levers that operate at different stages and on different objects within the same authenticity experience, and their practical effects may overlap. This qualification does not alter the six-dimensional structure or the way in which it was applied during the design workshop. Rather, it clarifies the conceptual status and boundaries of the dimensions.

To make the relationships among the six dimensions easier to understand, we further organize them into four analytical positions through a supplementary two-by-two matrix, as shown in Table 4. The first axis distinguishes the principal design object—heritage content and representation versus the user’s encounter and experience—while the second distinguishes the dominant authenticity route—cognitive–interpretive judgment versus affective–embodied involvement. The resulting four-part organization is an explanatory aid for clarifying the connections and boundaries among the six dimensions; it is not an alternative four-dimensional framework and does not retrospectively change the six-dimensional framework used in the design practice. Each dimension is positioned according to its primary mechanism rather than an exclusive location, because interactive engagement can also elicit emotion and stylistic atmosphere can also shape cognitive judgments.

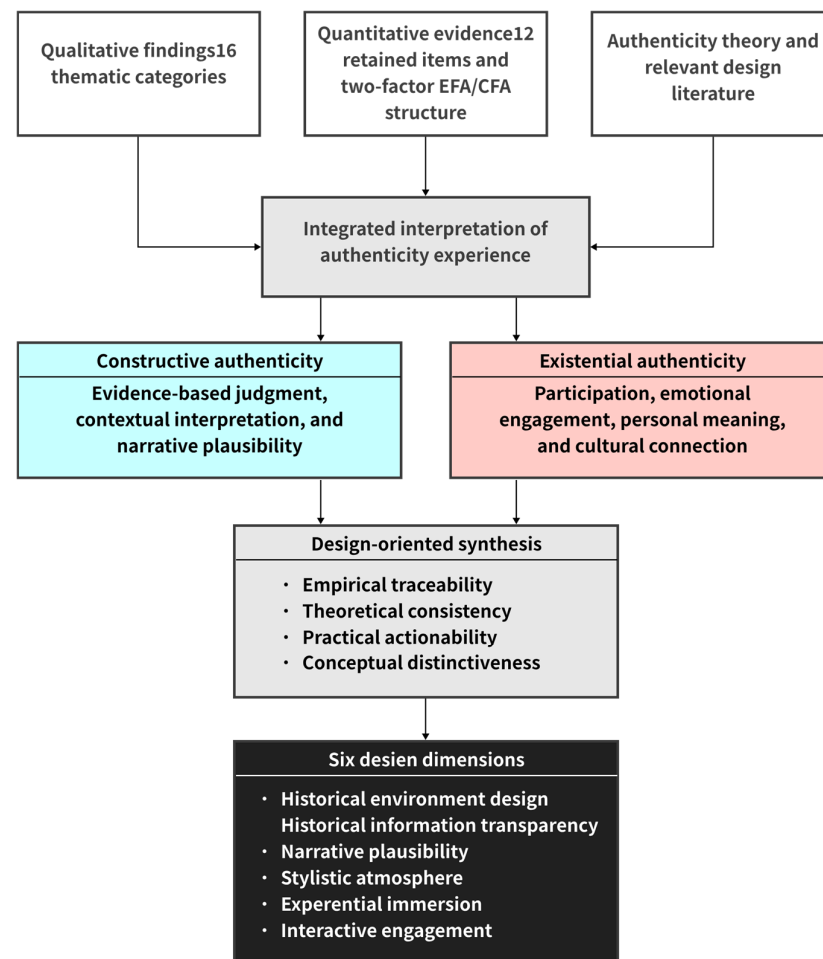


Figure 1. Evidence-to-design translation process underlying the six-dimensional authenticity experience design framework.

Table 4. Four-part two-by-two organizing matrix for the six design dimensions.

Dominant Authenticity Route	Heritage Content and Representation	User Encounter and Experience
Cognitive–interpretive	Historical environment design; historical information transparency; narrative plausibility	Interactive engagement, particularly embodied manipulation, action-based understanding, and interpretive feedback
Affective–embodied	Stylistic atmosphere	Experiential immersion

The matrix also helps distinguish dimensions that may initially appear to overlap. Historical environment design addresses what is represented and whether its material, spatial, and period-specific features are historically defensible; stylistic atmosphere addresses how visual, auditory, linguistic, and temporal cues operate together as a culturally congruent perceptual whole. Historical information transparency addresses why the audience should trust the content by exposing provenance, authority, evidence, and uncertainty; narrative plausibility addresses whether events, character actions, and interpretive extensions unfold coherently. Experiential immersion concerns the user’s state of sustained attention, presence, and emotional absorption, whereas interactive engagement concerns agency, embodied action, and feedback. The boundaries are summarized in Table 5.

Table 5. Primary contribution and conceptual boundaries of the six design dimensions.

Design Dimension	Primary Design Object	Unique Contribution to Perceived Authenticity	Boundary from Adjacent Dimensions
Historical environment design	Heritage objects, architecture, costumes, spatial settings, and environmental details	Provides materially and historically defensible representations grounded in archaeological, documentary, and period-specific evidence	Concerns the evidential and structural plausibility of what is represented, rather than the overall sensory mood of the exhibition
Historical information transparency	Provenance, scholarly authority, evidence level, reconstruction rationale, and uncertainty	Provides traceable grounds on which non-specialists can evaluate credibility and distinguish documented information from interpretive reconstruction	Concerns why the content should be trusted, rather than whether the story itself is causally or chronologically coherent
Narrative plausibility	Chronology, causality, character motivation, event progression, and reasoned narrative extension	Maintains coherence between historical anchors and the interpretive narrative used to fill evidential gaps	Concerns how the represented world unfolds over time, rather than the accuracy of individual visual objects or the disclosure of their sources
Stylistic atmosphere	Visual tone, color, materiality, sound, lighting, language, and editing rhythm	Creates a culturally congruent perceptual gestalt that corresponds to historically informed expectations and supports felt plausibility	Concerns the integrated sensory and affective field, rather than the factual correctness of each artifact or the user's degree of attentional absorption
Experiential immersion	Attention, presence, emotional absorption, narrative continuity, and sensory enclosure	Supports the subjective sense of being situated within and emotionally involved in the represented historical world	Describes an experiential state and the conditions supporting it, rather than the user's ability to act on or alter the experience
Interactive engagement	Agency, manipulation, choice, embodied participation, feedback, and action-based learning	Enables users to construct personal and cultural meaning through situated action and responsive participation	Concerns what the user can meaningfully do, rather than passive absorption, visual atmosphere, or narrative coherence alone

The six dimensions are intended to operate as an interconnected system. Historical environment design and historical information transparency provide the evidentiary resources of authenticity; narrative plausibility and stylistic atmosphere organize these resources into an interpretable and culturally coherent representation; experiential immersion and interactive engagement enable users to encounter that representation as a personally meaningful experience. The framework is therefore transferable in intent but not assumed to be universally equivalent across heritage types, cultural settings, or technological formats. Its relative emphasis and specific implementation should be adapted to the heritage subject and subsequently examined in additional contexts.

5.2. Historical Environment Design

Historical environment design concerns whether the spatial and material world represented in a virtual heritage exhibition can be justified by historical evidence and period-appropriate inference [53]. Its primary task is to determine what is shown and whether

the representation is consistent with available knowledge of the period. Archaeological evidence, historical documents, material remains, and specialist appraisal should therefore guide the reconstruction of natural settings, architecture, artifacts, clothing, and other visible elements. Replicated objects should remain structurally and visually consistent with their sources, while conjectural elements should follow period-appropriate materials, construction methods, and formal logic. Evidence-based reconstruction can improve both historical accuracy and contextual intelligibility [54], and XR heritage research similarly emphasizes rigorous research and historically informed rendering [55]. Where evidence is incomplete, designers should use defensible inference rather than unrestricted invention.

Historical evidence alone does not ensure that audiences can readily understand a virtual reconstruction. Users interpret reconstructed environments through prior knowledge, collective memory, and culturally formed expectations. Historical environment design should therefore situate evidence-based elements within clear contextual relationships, such as regional architectural conventions, period-specific costume systems, and characteristic artifact types. Culturally familiar cues may facilitate recognition, but they should not replace historical evidence or reinforce stereotypical representations. The aim is to make historically grounded representations intelligible while clearly distinguishing documented features from reasoned reconstruction.

5.3. Historical Information Transparency

Historical information transparency concerns the explicit communication of why audiences should trust the content presented in a virtual heritage exhibition. Whereas historical environment design addresses the defensibility of the representation itself, transparency addresses the visibility of its evidentiary basis, interpretive decisions, and uncertainty. Museum transparency calls on heritage institutions to disclose how knowledge is produced in order to sustain public trust [56]. In virtual heritage, this principle extends to artifact provenance, documentary and archaeological sources, modeling decisions, degrees of conjecture, and gaps in the available evidence [15]. Such information enables audiences to distinguish documented reconstruction from interpretive extension and to evaluate credibility without requiring specialist expertise.

Transparency is particularly important when audiences have limited familiarity with the heritage subject and must rely on external credibility cues [57]. It can be operationalized through layered annotations, source links, reconstruction notes, evidence-versus-inference labels, and concise indications of uncertainty. Institutional or scholarly endorsement may further strengthen trust, but it should complement rather than replace disclosure of the underlying evidence and reasoning. Research links perceived trust in heritage experiences to provenance integrity and exhibition transparency [9]. Accordingly, effective transparency makes the reconstruction process inspectable while keeping supporting information proportionate to the audience and exhibition format.

5.4. Narrative Plausibility

Narrative plausibility refers to the chronological, causal, and cultural coherence of the events and interpretations through which heritage content is presented. It differs from historical environment design by focusing on how the represented world unfolds rather than on the accuracy of individual objects or settings. Ryan's possible-worlds theory proposes that a narrative world must follow internally consistent rules and remain cognitively accessible in relation to the audience's understanding of reality [58]. In virtual heritage exhibitions, this requires consistency among event sequences, character motivations, behavioral logic, material practices, and the historical context. Obvious anachronisms or contradictions weaken plausibility even when individual visual elements appear credible.

Because historical and archaeological records are often incomplete, narrative development inevitably involves inference. Such inference should begin from reliable historical anchors and extend them through period-consistent characters, events, and material details. Scholarship and historically accurate presentation remain important foundations of authentic heritage experience [21], but factual information alone does not ensure a coherent narrative. Designers must also coordinate pacing, information disclosure, sensory cues, and opportunities for action so that interpretive additions remain understandable and defensible. Narrative plausibility is therefore achieved by balancing evidentiary constraint with carefully bounded storytelling, rather than by presenting conjecture as established fact.

5.5. Stylistic Atmosphere

Stylistic atmosphere is the holistic perceptual impression produced by the coordination of visual, auditory, linguistic, and temporal design elements. It does not reside in any single feature; character design, color, material texture, sound, dialogue, typography, lighting, editing, and pacing work together to create a recognizable experiential whole [59,60]. Böhme conceptualizes atmosphere as a perceptual field emerging through the encounter between the subject and the environment rather than as an objective property of the setting [61]. In virtual heritage exhibitions, these expressive cues jointly shape users' perception of whether the represented world is culturally and temporally coherent. Stylistic atmosphere therefore concerns the consistency with which design elements evoke historical-cultural associations, rather than the general quality of the user experience.

Users interpret these cues through prior knowledge and experience with related cultural representations. Digital heritage immersion depends not only on technical fidelity but also on whether audiences can enter a perceptible and interactive situation [62], while the sensory characteristics of an environment jointly influence emotional response [63]. Designers should therefore coordinate cross-modal cues so that the exhibition feels culturally and temporally coherent, while avoiding generic nostalgia or stereotyped period imagery. Stylistic congruence can make a representation easier to recognize and emotionally engage with, but it should not be treated as evidence of factual accuracy; its distinctive contribution is perceptual and affective coherence.

5.6. Experiential Immersion

Experiential immersion refers to a user's state of sustained attention, presence, and emotional absorption within the represented historical world. It is an experiential outcome rather than a property of a particular device. Large or curved displays, head-mounted displays, spatial audio, and fluid interfaces can support sensory enclosure, but immersive hardware alone does not guarantee a convincing sense of self-presence [64,65]. Across technological formats, immersion depends on the coordination of spatial cues, narrative continuity, interaction fluency, and the reduction in distractions that interrupt users' engagement with the heritage content.

Psychological immersion also depends on narrative pacing and emotional relevance. When users connect historical content with their own knowledge or lived experience, the exhibition may acquire personal meaning associated with existential authenticity [66]. Immersion and interaction can work together to strengthen spatial presence and psychological engagement in tourism and digital heritage experiences [64,67]; nevertheless, they remain conceptually distinct. Immersion concerns the user's state of involvement and absorption, whereas interactive engagement concerns the actions, choices, and feedback through which that state may be supported.

5.7. Interactive Engagement

Interactive engagement concerns the agency, situated action, and responsive feedback through which users participate in a virtual heritage experience. Its purpose is not simply to increase the number of interface operations, but to connect user action with the interpretation of cultural content. Interaction is both a component of user experience and a potential mechanism for participation and meaning-making [59,68]. By moving users from passive observation toward purposeful involvement, interactive engagement can help them examine relationships among heritage objects, historical practices, and cultural significance.

This dimension can be implemented through two complementary routes. At the narrative level, first-person or embodied perspectives, context-triggered tasks, and immediate feedback can strengthen the user's role within the represented situation. At the operational level, historically meaningful actions—such as inspecting, comparing, disassembling, re-assembling, or manipulating artifact components—can help users understand structural and cultural relationships through action. This process of action-based understanding can transform abstract information into embodied experiential meaning, provided that the interaction remains integrated with the historical context rather than functioning as decorative gamification [59].

Through purposeful action and feedback, interaction may support participation, personal interpretation, and a sense of cultural connection associated with existential authenticity [69]. Interactive engagement should therefore be understood as a proposed design route through which authenticity-related experience may be facilitated, not as an empirically established mediator. Its distinctive contribution lies in what users can meaningfully do within the exhibition, in contrast to the attentional and emotional state captured by experiential immersion.

6. Design Prototype Development and Evaluation

6.1. Design Workshop

To examine the practical potential of the proposed framework, we conducted a course-based design workshop on the virtual exhibition of ancient Chinese vehicle heritage at a design school. The shared task was to develop an interactive narrative virtual exhibition based on historically documented wheeled vehicles. The participating postgraduate students were divided into two development groups. Separate groups were used to reduce design contamination and intentional differentiation that might arise if the same group was asked to develop both the framework-guided and conventional versions. According to the professional judgment of the expert instructor who assisted in organizing the workshop, the two groups were broadly comparable in their overall design capabilities before the development process, although no formal baseline assessment of group ability was conducted. Both groups worked within the same five-week workshop period, addressed the same heritage subject—ox-drawn vehicles from China's Wei-Jin period—and were required to produce an interactive narrative exhibition prototype. Holding the theme, task requirements, and development period constant reduced variation arising from differences in heritage familiarity and task scope. Nevertheless, the workshop remained a design-development comparison rather than a controlled laboratory manipulation of a single design variable.

Group A received the authenticity-oriented design brief derived from the six-dimensional framework. The brief required the team to: ground visible historical objects and environments in period-appropriate evidence; expose the basis on which historical information and reconstructed details were presented; maintain chronological, causal, and cultural plausibility in the narrative; establish a coherent period-related stylistic atmosphere; support

sustained attention, presence, and emotional involvement; and use interaction to promote participation and action-based understanding. These requirements functioned as design questions rather than as a fixed visual or technological template, allowing the team to select specific narrative and interaction solutions while keeping perceived authenticity as an explicit design objective.

Group B followed the general exhibition experience-design brief used in the course. The brief was consistent with established user-centered and digital cultural heritage design principles, emphasizing understandable information organization, coherent navigation, visual consistency, usability, engaging interaction, and technical feasibility [16,19,20]. However, it did not provide the six-dimensional authenticity framework or require the team to systematically distinguish historical evidence from interpretive reconstruction, document reconstruction uncertainty, or connect design decisions to constructive and existential authenticity. Group B was not instructed to disregard historical credibility; rather, historical content was addressed through the team's ordinary design process without the structured authenticity-oriented prompts used by Group A. This distinction enabled a realistic comparison between a framework-guided process and a conventional course-based design process.

After five weeks, both groups produced interactive narrative exhibition prototypes based on the same heritage subject, historical figure, and source materials. Both exhibitions centered on the history of Wang Meng, a scholar of the Eastern Jin Dynasty, and used the same historical materials concerning the forms, social roles, and uses of ox-drawn vehicles during the Wei–Jin period. The principal procedural difference concerned the design guidance provided to each group: Group A explicitly applied the proposed six-dimensional framework throughout the development process, whereas Group B followed the conventional exhibition-design brief without the structured authenticity-oriented framework. Figures 2 and 3 show representative interfaces from the two prototypes.

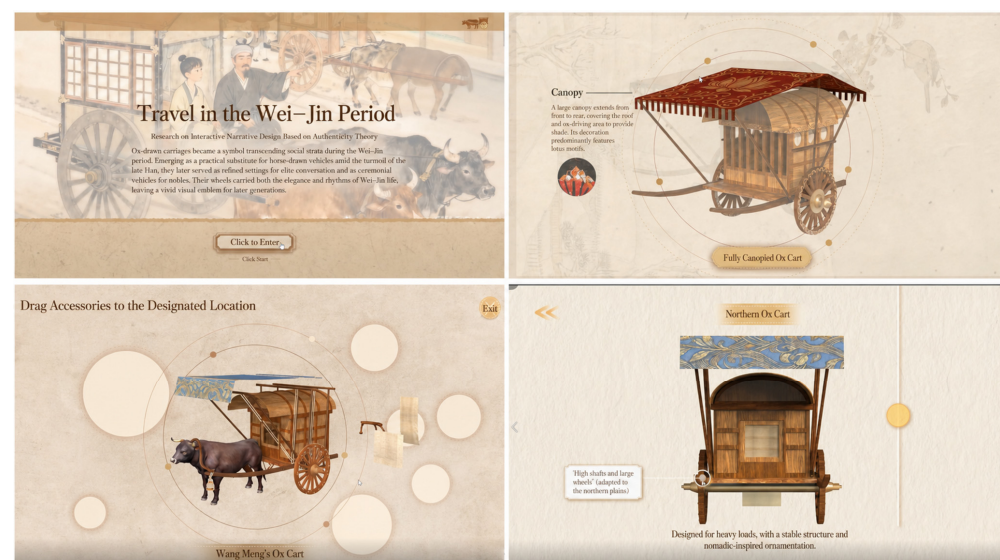


Figure 2. Design outcomes of Group A.

Table 6 makes the translation from the framework to Group A's prototype explicit. The table reports the design requirement associated with each dimension and the corresponding feature implemented in the prototype.



Figure 3. Design outcomes of Group B.

Table 6. Operationalization of the six design dimensions in the Group A prototype.

Design Dimension	Framework-Derived Design Requirement	Implementation in the Group A Prototype
Historical environment design	Base the form and structure of heritage objects and their setting on period-appropriate archaeological, documentary, and comparative evidence.	The prototype used three-dimensional reconstructions of Wei–Jin ox-drawn vehicles, annotated structural components, and comparisons among cart forms to communicate differences in vehicle form, function, and regional or historical use.
Historical information transparency	Make the basis of reconstruction and interpretation visible rather than presenting the digital model as self-evidently authoritative.	Annotated model views, component descriptions, and comparative explanations exposed part of the reasoning behind the vehicle reconstruction and linked visible features to period-related information. The workshop prototype did not implement a complete paradata system or graded uncertainty labels; its transparency function was therefore preliminary.
Narrative plausibility	Connect historical anchor points through a chronologically and causally coherent narrative in which characters, events, and material practices remain culturally plausible.	A three-act narrative structured around Wang Meng connected successive uses and social meanings of the ox-drawn vehicle. Historical information was disclosed through a progressive journey. Rather than being presented as isolated facts, historical information was integrated into the broader narrative network and progressively communicated in relation to the exhibition’s plot development, character experiences, and relevant historical and cultural contexts.
Stylistic atmosphere	Coordinate visual, textual, and temporal cues into a culturally congruent perceptual whole instead of relying only on object-level realism.	Muted earth colors, paper-like textures, period-referential illustrations, restrained typography, and a consistent visual rhythm were used across the interface to establish a unified historical atmosphere.

Table 6. *Cont.*

Design Dimension	Framework-Derived Design Requirement	Implementation in the Group A Prototype
Experiential immersion	Support sustained attention, narrative continuity, emotional involvement, and a sense of progressing through a historically situated experience.	Users followed a route-based sequence across the three narrative acts. Progressive information disclosure, continuous scene transitions, and the character-centered journey were used to maintain experiential continuity and encourage identification with the historical situation.
Interactive engagement	Use agency and responsive action to help users understand the structure, use, and meaning of the heritage object.	Users could inspect and manipulate vehicle models, drag components to designated positions, assemble or compare cart elements, and complete context-related tasks. Immediate visual feedback linked the interaction to structural and cultural information rather than using interaction solely as decoration.

The six dimensions were implemented as a coordinated design package rather than manipulated independently. As described above, separate teams were used to reduce cross-condition contamination and intentional differentiation, and the expert instructor judged the two groups to be broadly comparable in their overall design capabilities before development. Both groups addressed the same heritage subject, used the same historical materials, followed the same task requirements, and worked within the same five-week period. Under these matched workshop conditions, the subsequent user comparison provided preliminary evidence regarding the practical performance of the framework-guided design process relative to the conventional design brief. Because the six dimensions were applied jointly, the findings should be interpreted at the level of the overall framework rather than as estimates of the independent contribution of any single dimension.

6.2. Prototype Evaluation

To obtain preliminary comparative evidence concerning the downstream attitudinal outcomes associated with the framework-guided prototype, we developed a questionnaire based on existing research. The questionnaire included four outcome dimensions: user loyalty, user satisfaction, cultural identity, and behavioral intention [2,69,70]. These variables were treated as proximal indicators of users' responses to the overall heritage experience. All items were rated on a seven-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree).

A total of 61 participants were recruited from among faculty members and students at a design school. The sample comprised 32 women (52.5%) and 29 men (47.5%). Participants had a mean age of 25.43 years ($SD = 3.61$; range = 19–36 years), and their educational attainment ranged from undergraduate to postgraduate level. Participants were randomly assigned to one of two independent conditions: 31 participants experienced Exhibition A and 30 experienced Exhibition B. All participants signed an informed consent form before taking part in the experiment. Each participant experienced only the exhibition assigned to their condition, thereby avoiding order, learning, and carryover effects associated with repeated exposure. Participants were instructed to complete the full virtual exhibition experience under the same procedural requirements. Immediately after completing the assigned exhibition, they completed the same measurement questionnaire. Administering the questionnaire at the same point in both conditions ensured a consistent assessment interval and limited potential recall delay.

The hypothesis was that participants who experienced Exhibition A would report higher user loyalty, user satisfaction, cultural identity, and behavioral intention than those who experienced Exhibition B. For each dimension, a dimension score was calculated by averaging the corresponding item scores. Independent-samples *t*-tests were conducted using IBM SPSS Statistics, version 27, to compare the two conditions on the four prespecified dimension scores. All tests were two-sided, with a nominal significance level of $\alpha = 0.05$. To control the family-wise error rate across the four comparisons, a Bonferroni-adjusted threshold of $\alpha = 0.0125$ was applied. Mean differences and Hedges' *g* values were reported with 95% confidence intervals.

Levene's tests were non-significant for all four dimensions, providing no evidence of unequal variances. Accordingly, the equal-variance results were interpreted. As shown in Table 7, participants who experienced Exhibition A reported significantly higher user loyalty, user satisfaction, cultural identity, and behavioral intention than those who experienced Exhibition B (all $p < 0.001$). All four comparisons remained significant after Bonferroni correction. The mean differences ranged from 1.323 to 1.634 scale points, with all 95% confidence intervals lying above zero, while Hedges' *g* values ranged from 1.265 to 1.636. These findings support the hypothesis across all four questionnaire dimensions. A sensitivity power analysis based on the achieved group sizes, a two-sided Bonferroni-adjusted $\alpha = 0.0125$, and power of 0.80 indicated a minimum detectable effect of $d = 0.88$; the observed effects exceeded this threshold, suggesting adequate sensitivity to the large differences identified. Wang et al. [71] demonstrated that AI-generated review summaries significantly influence tourist decision satisfaction, but their study employed a large-sample design ($N > 500$) to ensure robust effect estimation—a methodological standard that the current validation study, with its small sample, cannot yet meet.

Table 7. Independent-samples *t*-test results for the four questionnaire dimensions.

Outcome	Exhibition A <i>n</i> = 31; M (SD)	Exhibition B <i>n</i> = 30; M (SD)	<i>t</i> (59)	<i>p</i>	Mean Difference [95% CI]	Hedges' <i>g</i> [95% CI]
User loyalty (UL)	5.56 (0.72)	4.23 (1.08)	5.657	<0.001	1.323 [0.855, 1.791]	1.430 [0.867, 1.984]
User satisfaction (US)	5.69 (0.92)	4.11 (1.14)	5.962	<0.001	1.577 [1.048, 2.106]	1.507 [0.937, 2.067]
Cultural identity (CI)	5.81 (0.85)	4.48 (1.20)	5.003	<0.001	1.329 [0.797, 1.860]	1.265 [0.715, 1.806]
Behavioral intention (BI)	5.73 (0.93)	4.09 (1.04)	6.472	<0.001	1.634 [1.129, 2.139]	1.636 [1.055, 2.208]

Note: Mean differences were calculated as Exhibition A minus Exhibition B. *p*-values are two-sided. All comparisons remained significant at the Bonferroni-adjusted threshold of $\alpha = 0.0125$. M = mean; SD = standard deviation; CI = confidence interval.

7. Discussion

Grounded in authenticity theory, this study sought to bridge the gap between conceptual discussions of authenticity and actionable design guidance for virtual cultural heritage exhibitions. An exploratory sequential mixed-methods approach was adopted. A qualitative study was first conducted to identify how users judge and experience authenticity, after which factor analyses were used to examine the organization of these perceptions. The findings were subsequently translated into a six-dimensional design framework. Within the conventional technological conditions for virtual heritage examined in this study, authenticity experiences were primarily organized into two interrelated dimensions: constructive authenticity and existential authenticity. The former integrates evidence-based

judgment, contextual interpretation, and narrative plausibility, whereas the latter involves participation, emotional engagement, personal meaning, and cultural connection. The most theoretically significant finding was that objective authenticity did not emerge as an independent experiential dimension but instead converged with constructive authenticity.

This convergence represents more than a statistical reduction in three theoretical categories to two factors; it may reflect a change in the mechanism through which authenticity is judged in virtual environments. Tourism research has traditionally distinguished objective authenticity, which concerns the correspondence between an object and its historical origin, from constructive authenticity, which concerns interpretations formed through socially constructed meanings and expectations [66]. However, Cohen [72] noted that “cool authentication,” typically conferred by institutions or experts, and “hot authentication,” emerging through participation and social interaction, often overlap in practice. Similarly, Rickly-Boyd [73] and Jones [74] argued that authenticity does not reside solely in the inherent properties of an object but is formed through relationships among objects, places, cultural traditions, and those who experience them. These perspectives provide a theoretical basis for interpreting the convergence of objective and constructive authenticity identified in this study.

The present study extends these theoretical perspectives to the context of virtual cultural heritage. Objective authenticity has neither disappeared nor become irrelevant; rather, virtual environments alter the conditions under which users evaluate it. Users encounter not the original heritage objects themselves but representations mediated through digital reconstruction and institutional presentation. Moreover, most users lack the specialist knowledge required to determine independently whether every reconstructed detail corresponds to historical evidence. They must therefore rely on directly accessible cues, including the historical research underpinning the reconstruction, the quality of the digital representation, the authority and traceability of information sources, the coherence of the historical context, and the plausibility of the narrative. Although these cues are grounded in objective evidence, their credibility must still be interpreted by users. Accordingly, within the context examined here, objective authenticity functions more as an evidentiary input incorporated into the formation of constructive authenticity judgments than as an experiential dimension that is clearly separable from other forms of authenticity.

The consistency between the qualitative and quantitative findings supports this interpretation. The interviews indicated that participants with relevant historical knowledge were more capable of forming relatively independent judgments of objective authenticity. When encountering unfamiliar heritage content, however, participants relied more heavily on information authority, contextual coherence, and content plausibility. Correspondingly, the factor analysis showed that items concerning evidence-based historical reconstruction and historically credible representation loaded on the same factor as items concerning contextual imagination, narrative coherence, and cultural understanding. This result is also consistent with museum research showing that authenticity, interactive authenticity, and emotional authenticity are positively related and jointly constitute a hybrid experiential structure [75]. Research on technologically mediated heritage experiences has similarly found that constructive and existential authenticity can significantly predict satisfaction, whereas objective authenticity may have no direct effect [76]. Object-related authenticity may also influence user experience indirectly through presence and activity-related authenticity [77]. Taken together, these studies indicate that objective evidence remains an important foundation of authenticity experience, but its experiential effects are realized through processes of user interpretation and participation.

The theoretical contribution of this study therefore lies in distinguishing between “authenticity resources” and “authenticity as experienced by users.” Historical evidence,

source information, reconstruction accuracy, and institutional endorsement can be understood as resources or antecedent conditions of authenticity. Constructive authenticity describes how users interpret and integrate these resources, whereas existential authenticity concerns the personal and cultural meanings generated through participation and emotional engagement. This interpretation provides a basis for the theoretical integration of objective and constructive authenticity but does not exclude the influence of methodological limitations. The convergence observed in this study may reflect the mediated process through which non-specialist users encounter historical evidence in virtual environments. However, it may also have been reinforced by the demographic homogeneity of the samples, respondents' limited familiarity with the heritage theme, the wording and content coverage of the indicators, the use of a video-based stimulus during the survey phase, and the relatively low factor loadings and average variance extracted (AVE) values. The finding should therefore be characterized as a context-specific empirical convergence consistent with theoretical integration, rather than as definitive evidence that objective and constructive authenticity are indistinguishable under all conditions.

This interpretation also provides directions for future research and design practice. Future studies could compare expert and non-expert users, physical and virtual heritage environments, and different technological formats. They could also investigate whether prior knowledge, cultural background, source transparency, and technological affordances moderate the relationship between objective evidence and constructive authenticity. From a design perspective, the findings suggest that visual realism alone is insufficient to establish authenticity in virtual heritage experiences. Designers should ensure that historical sources are traceable, clearly distinguish content supported by documentary evidence from interpretive reconstruction, appropriately communicate uncertainty in the reconstruction process, and maintain consistency among historical evidence, narrative presentation, and cultural context. These measures can enable objective evidence to be transformed, through users' constructive interpretation, into an authenticity experience that is both credible and meaningful.

The preceding theoretical explanation also underpins the practical contribution of the study. Based on the two dimensions of authenticity experience, a six-dimensional authenticity experience design framework was developed, comprising historical environment design, historical information transparency, narrative plausibility, stylistic atmosphere, experiential immersion, and interactive engagement. Historical environment design and historical information transparency primarily provide the evidentiary and contextual foundations for authenticity judgments. Narrative plausibility and stylistic atmosphere organize this information into a coherent and culturally congruent representation, while experiential immersion and interactive engagement further translate content credibility into emotional engagement, meaning construction, and cultural connection. The framework thus connects the evidentiary foundations and interpretive processes of authenticity with users' actual experiences. The prototype-based comparison provided supportive evidence of the framework's potential to enhance user satisfaction, cultural identity, and behavioral intention, demonstrating its practical potential as an integrated design system. However, these findings do not imply that its effects can be directly generalized to all heritage themes and technological environments.

Although the two-factor confirmatory factor analysis model demonstrated good overall fit, the AVE values for constructive authenticity and existential authenticity were 0.223 and 0.333, respectively, both below the commonly applied benchmark of 0.50 [49]. The composite reliability of constructive authenticity ($CR = 0.629$) was also below the commonly used reference value of 0.70. The convergent validity of the two dimensions should therefore be interpreted with caution. However, sensitivity analyses showed that removing

the lowest-loading indicator from either factor did not substantially resolve this issue and would instead have narrowed the conceptual coverage of the design framework. Based on the combined consideration of theoretical interpretability and conceptual completeness, the two-factor structure was retained as the theoretical foundation for framework development. The relevant indicators nevertheless require further refinement and examination in independent samples.

This study makes three principal contributions. First, at the theoretical level, it provides empirical evidence that objective authenticity may operate through constructive interpretation in virtual cultural heritage experiences rather than necessarily emerging as an independent experiential dimension. This finding reinterprets the relationship between historical accuracy and user interpretation and offers a context-specific extension of authenticity theory in tourism, museology, and cultural heritage research.

Second, at the methodological level, the study integrates qualitative evidence, exploratory factor analysis, confirmatory factor analysis, indicator-removal sensitivity analyses, and prototype-based evaluation, thereby connecting users' interpretive accounts of authenticity with the factor structure and its implications for design.

Third, at the practical level, the study translates abstract concepts of authenticity evaluation into six coordinated design dimensions. It thus provides cultural heritage institutions and design teams with a structured pathway for shifting virtual heritage communication from a predominantly technology-driven approach toward one that is user-experience-centered and informed by historical evidence.

This study nevertheless has several limitations. First, it focused on a heritage theme with a specific cultural background, and the participants were predominantly young and highly educated. The relationship between objective and constructive authenticity should therefore be further examined among participants with different levels of historical knowledge, cultural backgrounds, and familiarity with the heritage content, as well as across different forms of tangible and intangible cultural heritage. Second, the relatively low AVE values and the comparatively low composite reliability of constructive authenticity indicate that the current indicators do not yet capture the shared variance of the relevant dimensions with ideal precision. Future research should further examine the wording and content representativeness of the indicators, particularly in relation to the evidence-based judgment, contextual interpretation, emotional engagement, and cultural connection identified during the qualitative phase, and assess the robustness of the two-factor structure in additional independent and more diverse samples. Finally, different technological formats and application objectives—including cultural education, cultural tourism, heritage interpretation, and entertainment—may alter the relative importance of the six design dimensions and the relationships among them. The research of Qiao et al. [78] on perceived accessibility and behavioral attitudes among tourists further underscores the need to examine the proposed framework across different visitor groups and application contexts. Cross-context comparative and longitudinal studies are therefore needed to determine the conditions under which objective authenticity remains relatively distinct and those under which it becomes incorporated into constructive judgments.

In conclusion, this study identified a contextually meaningful two-dimensional structure of authenticity experience and explained why objective authenticity may converge with constructive authenticity in virtual heritage environments. Historical evidence remains an essential foundation of authenticity experience; however, for many users, its authenticity value becomes perceptible only through mediated interpretation, trust in information sources, contextual coherence, and narrative plausibility. By clarifying this mechanism and translating it into an actionable six-dimensional design framework, the study offers both a new theoretical account of authenticity under conditions of digital

mediation and a practical pathway for designing virtual heritage experiences that are more credible, meaningful, and conducive to cultural engagement. The findings provide a foundation for subsequent theoretical examination and framework refinement, while the current measurement results appropriately qualify the strength and generalizability of the conclusions.

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