

# LEADING THROUGH VIRTUAL INNOVATION: ENHANCING SUSTAINABLE HERITAGE TOURISM THROUGH VIRTUAL AVATARS IN DEZHOU'S DIGITAL MUSEUMS

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**Abstract:** *This study examines how specific avatar design attributes—anthropomorphism, realism, interactivity, and cultural authenticity—shape visitor experience in digital museums in Dezhou, Shandong, and whether these effects operate through visitor engagement. Grounded in the Technology Acceptance Model (perceived usefulness/ease of use) and Media Richness Theory (social presence/immediacy), the research proposed and tested a mediation model in which multi-dimensional engagement (cognitive, emotional, behavioral) links avatar design to sustained use intentions and perceived cultural value. Using a cross-sectional survey of visitors who interacted with avatar-powered guides, we will validate reflective measures and estimate the model via PLS-SEM, with robustness checks for common-method bias and sensitivity to digital literacy. Expected findings are that interactivity and cultural authenticity most strongly predict engagement and perceived cultural value; anthropomorphism and realism contribute nonlinearly, with over-realism risking uncanny-valley effects. Engagement is expected to fully or partially mediate the impacts of design attributes on visitor experience, and perceived usefulness will amplify these pathways when ease of use is high. The study's originality lies in isolating avatar-specific levers (beyond generic VR/AR tools), integrating TAM and MRT into a single, testable mechanism, and providing evidence from a non-megacity Chinese context with practical design heuristics for resource-constrained museums. We contribute empirical validation of the framework and actionable guidelines for culturally resonant avatar design to advance sustainable, inclusive heritage interpretation.*

**Keywords:** *Virtual Avatars, Heritage Tourism, Visitor Engagement, Sustainable Innovation.*

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## Introduction

Heritage tourism has emerged as a critical sector within the broader tourism and cultural industries, especially in regions rich with historical narratives and architectural legacies. The integration of digital technologies has transformed how heritage sites are interpreted and consumed, enabling deeper engagement and broader accessibility. Virtual avatars—digital human-like guides—are increasingly used in museum contexts to facilitate immersive storytelling, personalised interaction, and educational enrichment. In the wake of rapid technological innovation and global disruptions such as the COVID-19 pandemic, digital transformation has become essential not only for operational resilience but also for advancing cultural sustainability (UNESCO, 2021). This study is positioned at the intersection of heritage tourism, digital innovation, and experiential learning, aiming to explore how virtual avatars can lead value-driven and sustainable visitor experiences in the context of Dezhou City's digital museums.

Dezhou City, located in Shandong Province, boasts a rich cultural and historical tapestry that underpins its value as a heritage tourism destination. With a strong historical association with imperial courier routes and Confucian cultural traditions, Dezhou's cultural legacy presents fertile ground for digitization and immersive storytelling. In recent years, local efforts to preserve and promote cultural assets have turned towards digital infrastructures, including virtual museums and interactive exhibitions. However, these initiatives are often constrained by static displays or linear narratives that do not fully engage modern audiences, particularly younger generations accustomed to interactive digital media (Wang et al., 2020). Within this context, virtual avatars offer an innovative avenue to enhance the interpretative power of digital museums by integrating affective communication, non-verbal cues, and dynamic interaction that mimic human guides (Liew, Ong, & Tan, 2022). In Dezhou, such innovation could invigorate interest in local heritage, extend the museum's reach, and foster deeper cultural understanding, all while contributing to the sustainability of the region's intangible and tangible heritage.

Virtual avatars serve a multifunctional role in digital museum experience design, functioning as interpreters, educators, and even cultural ambassadors. Unlike conventional museum signage or audio tours, avatars can adapt to user input, provide contextually relevant information, and employ natural language processing to simulate conversation (Qiu & Li, 2023). These avatars may be anthropomorphised to embody historical figures, cultural mascots, or neutral facilitators, thereby allowing curators to construct narratives that are both engaging and pedagogically sound. Research has demonstrated that anthropomorphic features and visual realism can significantly impact user trust, emotional connection, and learning outcomes in virtual environments (Schroeder & Cohen, 2019). Furthermore, interactivity—through gestures, voice modulation, or user-triggered content—enhances media richness, which according to Media Richness Theory, can reduce ambiguity and foster meaningful communication (Daft & Lengel, 1986; Lu, Yang, & Liao, 2020). By integrating these features, virtual avatars not only enrich visitor experience but also create scalable, inclusive, and sustainable educational tools within heritage tourism.

Despite the growing implementation of virtual avatars in commercial and educational domains, their application in cultural heritage tourism, particularly in second-tier Chinese cities like Dezhou, remains underexplored. Many digital museum initiatives in China have prioritised the digitisation of artefacts and exhibition halls but have yet to leverage the full potential of avatar-driven interaction (Li et al., 2021). This creates a gap between technological capability and

meaningful visitor engagement. Furthermore, there is limited empirical research investigating the specific characteristics of avatars—such as realism, anthropomorphism, and interactivity—and how these features influence visitor experience outcomes. Without a deeper understanding of these dynamics, digital heritage strategies may fall short of delivering value-driven and sustainable cultural education. Thus, this study seeks to investigate how virtual avatar characteristics affect visitor engagement and perceived experience quality in the context of Dezhou’s digital museums, contributing to the broader discourse on innovation in heritage tourism.

To address this issue, the study sets forth the following objectives: first, to examine the effects of avatar characteristics (i.e., anthropomorphism, realism, and interactivity) on visitor engagement; second, to evaluate the influence of visitor engagement on overall museum experience; and third, to test the mediating role of engagement in the relationship between avatar characteristics and visitor experience. Corresponding to these objectives, the study poses three primary research questions: (1) How do different characteristics of virtual avatars influence visitor engagement in digital museums? (2) What is the relationship between visitor engagement and perceived experience quality? (3) Does visitor engagement mediate the relationship between avatar characteristics and visitor experience? These questions are designed to empirically validate a conceptual framework grounded in the Technology Acceptance Model (TAM) and Media Richness Theory (MRT), thereby contributing theoretical and practical insights.

The significance of this study lies in its alignment with the values of innovation, sustainability, and value-driven design in cultural heritage contexts. From an innovation perspective, the research explores how AI-powered avatars can transform static digital exhibits into interactive, personalised learning environments. This aligns with the global trend of leveraging emerging technologies to reimagine museum experiences, particularly in post-pandemic recovery strategies where digital resilience is paramount (IFLA, 2020). In terms of sustainability, virtual avatars offer scalable solutions that can reduce reliance on human resources while providing consistent, high-quality interpretation. This is especially critical for regional museums with limited staffing or funding, as digital tools can democratize access to cultural education and ensure the preservation of historical narratives for future generations (OECD, 2022). Moreover, the value orientation of the study is evident in its focus on enhancing the visitor’s affective and cognitive engagement, thereby enriching their understanding of cultural heritage and fostering a deeper connection with local traditions.

By focusing on Dezhou City’s digital museums, the study contributes to the regional development goals of integrating cultural identity with digital innovation. This localised focus also ensures that the research responds to the practical needs of heritage stakeholders in China’s interior provinces, which often lack the digital resources of metropolitan hubs like Beijing or Shanghai. The implications of the findings extend beyond Dezhou, offering a replicable framework for other heritage-rich regions seeking to implement value-driven, innovative, and sustainable digital strategies. In doing so, the study exemplifies how educational leadership in the digital era can be exercised not only through policy but also through the thoughtful design and application of immersive technologies.

## Literature Review

Heritage tourism's digitization has advanced faster than theory-driven guidance on which avatar design levers actually create culturally resonant, learning-rich experiences in museums. The central gap is twofold: first, most studies treat “virtual guides” as a generic immersive technology and do not isolate avatar attributes such as anthropomorphism, realism, and interactivity as distinct, testable design mechanisms; second, empirical work in China—especially outside national “megacity” flagships—is sparse, limiting generalizability to places like Dezhou where digital transformation must operate under tighter resource constraints and different visitor profiles. Recent policy and practice signals in China confirm rapid digitization and 3D documentation in museums and heritage sites, yet they rarely specify evaluative frameworks for avatar design choices or engagement pathways, leaving a disconnect between technological rollout and experience optimization (National Cultural Heritage Administration update via SCIO, September 25, 2024).

Against this backdrop, avatars are not merely another interface; they are embodied, conversational mediators capable of delivering high “media richness” through visual presence, speech, gesture, and contingent feedback. Meta-reviews of embodied agents indicate that visible embodiment can increase rapport, trust, and perceived intelligence, suggesting that anthropomorphism may catalyze socio-cognitive mechanisms linked to engagement and learning (Allouch et al., 2021; Ameneh Torkaman Sorkhabi, 2020). In tourism and museum contexts, immersive displays elevate presence and can shift attitudes, but these benefits depend on careful control of cognitive load and on avoiding distraction or “over-realism,” which may hamper learning or trigger uncanny-valley effects (Makransky & Mayer, 2022; Mayer, 2023). This implies that realism is likely to have nonlinear effects: too little undermines credibility, too much can impede processing.

TAM provides the dominant psychological lens for explaining technology uptake, positing perceived usefulness (PU) and ease of use (PEOU) as proximal determinants of attitudes and intentions (Davis, 1989; Venkatesh & Davis, 2000). In Chinese museum settings, TAM extensions that emphasise enjoyment and flow show that PU and PEOU shape satisfaction and intentions, while hedonic states sustain deeper engagement—evidence that utility and delight must co-exist in cultural experiences (Liu et al., 2024; Li et al., 2024). Studies on AR/VR in heritage further suggest that post-experience intentions hinge on a blend of technical factors, individual traits, and situational affordances—again highlighting that acceptance is not only cognitive but also socio-culturally situated (Nature, 2024). Yet TAM is agnostic about how information is communicated and thus struggles to differentiate among avatar attributes beyond their aggregate effect on PU/PEOU. It tells us that visitors will accept an avatar if it feels useful and easy, but it doesn't say which design features make it feel that way.

MRT complements this blind spot by theorising how media convey equivocal content. By definition, avatars can provide richer cues (visuals, prosody, gestures) and immediate feedback, which should enhance comprehension and social presence when interpretive tasks are ambiguous or affect-laden—common conditions in heritage storytelling (Daft & Lengel, 1986; see contemporary syntheses applying MRT to interactive systems). arXiv Empirical work with embodied conversational agents shows that higher richness can improve trust and emotional resonance, though gains are not unlimited because increasing cue channels can also elevate cognitive load (Lu, Yang, & Liao, 2020; Makransky & Mayer, 2022). Critically, MRT does not specify how users learn from rich media, nor does it articulate motivational pathways; it assumes richer is usually better for equivocal tasks, while learning sciences caution that

additional cues can either scaffold or distract depending on design. This is precisely where a blended model is valuable: TAM can articulate perceived benefits and burdens (PU/PEOU/enjoyment), while MRT specifies the communicative affordances of avatar design choices. Together they predict that interactivity (feedback immediacy), anthropomorphism (socio-emotional cues), and calibrated realism (cue fidelity without overload) will influence acceptance through engagement constructs that straddle cognition, affect, and behavior.

Contextualizing this argument in China helps clarify boundary conditions. National overviews describe accelerated digitization of museums and the adoption of 3D scanning and modeling for cultural relics, but these reports rarely evaluate user-facing experience quality or design trade-offs (SCIO/National Cultural Heritage Administration, 2024). A recent decadal review of Chinese digital-heritage research similarly catalogs rapid growth across 2014–2024 yet underscores fragmentation in evaluation metrics and limited integration of visitor-centric theories, implying a need for mechanism-focused models that cross psychology and communication (Chunlan et al., 2025). At site and museum levels, studies in China report that immersive technologies affect attitudes and intentions via TAM constructs and flow, but typically treat the “virtual guide” as a black box rather than decomposing avatar design into manipulable parameters (Liu et al., 2024; Li et al., 2024; Xu et al., 2025). Work on VR tourism and presence adds that richer immersion can change attitudes and visit intentions, but the pathway can be U-shaped if realism or interactivity impose extraneous processing costs (Tussyadiah et al., 2018; Skard et al., 2021). Collectively, these streams suggest that China’s digital-heritage ecosystem is ripe for granular, design-sensitive inquiry, especially in second-tier cities where museums balance accessibility ambitions with resource limits and heterogeneous visitor digital literacies.

Synthesizing TAM and MRT for heritage contexts thus require three critical refinements. First, overlap: both frameworks imply that avatar features shape perceived experience quality through expectancy filters—richer cues can heighten perceived usefulness by clarifying complex narratives and can raise perceived ease if interaction reduces wayfinding effort. Second, divergence: TAM treats media as a “black box,” while MRT treats the user as a “black box.” TAM predicts if people will adopt; MRT predicts what configuration carries meaning under equivocality. A combined model, therefore, posits that the communicative affordances of avatars influence psychological appraisals which then steer engagement and outcomes. Third, insufficiency: neither theory by itself handles cultural authenticity, equity, or long-term knowledge stewardship—core aims of heritage institutions. Integration with learning-science findings on presence and cognitive load is needed to ensure that added cues do not inadvertently crowd out schema construction; likewise, sustainability goals require evaluating whether avatar systems scale without exacerbating digital exclusion in communities with uneven access. Evidence from immersive learning warns that presence amplifies learning only when design channels attention to relevant content and suppresses extraneous processing (Makransky & Mayer, 2022; Mayer, 2023). This implies a design hypothesis for heritage museums: interactivity and anthropomorphic signaling should increase engagement and perceived cultural value up to a point, beyond which additional realism or cue density may degrade outcomes—especially for first-time or lower-literacy visitors common in regional cities.

Recent Chinese and China-relevant studies help anchor these propositions. A museum-focused TAM-flow study found that perceived usefulness and ease of use jointly predict satisfaction and intention, while enjoyment and concentration add incremental explanatory power—consistent with the notion that avatars must be both helpful and delightful to sustain engagement

(Liu et al., 2024). A large-sample investigation of online virtual museums reported that acceptance hinges on a constellation of factors including usability, enjoyment, and social presence, indicating that communicative richness matters beyond mere functionality (Li et al., 2024). Moreover, a 2024 study in Heritage Science on AR use in heritage museums showed that technical quality and situational factors affect post-experience usage and destination revisit intentions through satisfaction, suggesting that design factors do translate to behavioral outcomes in Chinese heritage settings (Nature, 2024). Meanwhile, policy round-ups emphasize digitization milestones nationwide, including non-megacity institutions, reinforcing the relevance of evaluating avatar systems outside tier-one hubs (SCIO/National Cultural Heritage Administration, 2024). Notably, though, this growing corpus still glosses over avatar-specific manipulations; few studies report factorial experiments or model paths that isolate anthropomorphism, realism, and interactivity as separate predictors with potentially non-linear effects.

Consequently, this study positions visitor engagement—understood as cognitive, affective, and behavioral investment—as the mechanism linking avatar attributes to outcomes such as perceived cultural value, satisfaction, and sustainable use intentions. Engagement bridges TAM and MRT: it operationalizes how perceived usefulness/ease translate into time-on-task, elaboration, and affective resonance, while also reflecting the communicative “fit” of avatar cues for equivocal heritage content. Prior work in immersive tourism finds that presence and narrative embodiment can change attitudes, but the benefits are contingent on load-aware design and sensitivity to authenticity cues, which in heritage include language, symbolism, and respectful treatment of local narratives (Tussyadiah et al., 2018; Makransky & Mayer, 2022; Liu et al., 2024). By centering engagement as a mediator, the model allows designers to tune avatar features to maximize meaningful processing—e.g., privileging responsive interactivity and culturally grounded anthropomorphism over hyper-real rendering that may add little interpretive value for resource-constrained museums in Dezhou.

### Research Methodology

This study adopts a quantitative, hypothesis-testing design to evaluate how avatar attributes—anthropomorphism, realism, and interactivity—affect visitor experience through the mediating mechanism of engagement in Dezhou’s digital museums. A variance-oriented approach is well aligned with the research objectives because the theorized relationships emerge from Technology Acceptance Model appraisals and Media Richness communicative affordances, both of which imply directional, testable paths among latent constructs rather than idiosyncratic case variation. The survey method enables the standardized operationalization of these latent variables, supports mediation testing with adequate statistical power, and provides policy-relevant estimates such as the magnitude of indirect effects that museum managers can translate into design priorities (Hair et al., 2021; Sarstedt, Ringle, & Hair, 2022). In short, the method is selected not only for convenience but because it directly serves the study’s explanatory aim: to attribute variance in visitor experience to specific, manipulable avatar design levers through engagement.

The sampling strategy balances feasibility with rigor in a setting where the eligible population—adult visitors who actually interact with avatar guides—is both situationally concentrated and temporally fluid. While probability sampling on-site is usually infeasible due to real-time visitor flows and consent protocols, we move beyond simple convenience by implementing a multi-stage, venue-intercept design with quota controls. First, eligible venues comprise the Dezhou City Museum and affiliated digital extensions where avatar guides are

active. Second, data collection windows are stratified across weekdays, weekends, and public holidays, and across morning, afternoon, and evening sessions to reduce temporal clustering. Third, soft quotas are applied on age group and gender based on the most recent municipal tourism profiles and museum visitor reports to approximate the composition of typical adult visitors. This strategy does not convert the sample into a probability draw; however, it explicitly addresses the most common biases in convenience samples—time-of-day effects and demographic skew—thereby improving external validity within the museum audience frame (AAPOR, 2022). To further mitigate selection bias, recruiters approach every *n*th eligible visitor exiting the avatar exhibit (systematic interval sampling) rather than relying on recruiter discretion, and refusals are logged with brief nonresponse codes to enable a nonresponse bias analysis comparing early and late responders on key observables (Groves et al., 2009).

Generalizability is strengthened through ex-ante power and precision planning and ex-post sensitivity tests. Using rules of thumb for PLS-SEM alongside a Monte Carlo check, the target sample of ~300 affords  $>.80$  power to detect small-to-moderate indirect effects in a mediation with three predictors feeding a single mediator under typical reliability assumptions (Hair et al., 2021; Soper, 2021). Precision is monitored by reporting confidence intervals around path estimates and indirect effects, and robustness is probed by re-estimating models in subgroups defined by digital literacy and prior avatar exposure, which are substantively relevant moderators in regional Chinese contexts. Although nonprobability sampling constrains population inference, these design and analytic protections ensure that the inferences are strong for the policy-relevant frame of “actual adult users of avatars in Dezhou museums,” which is the decision context for municipal stakeholders.

Instrument design is anchored in construct clarity and cultural–linguistic suitability. Avatar anthropomorphism items capture perceived human-likeness in emotion, intent, and social presence; realism items tap visual fidelity, behavioral coherence, and contextual fit; interactivity items capture responsiveness, adaptivity, and user control. Visitor engagement is conceptualized as a multi-dimensional mediator—cognitive (attention, elaboration), affective (interest, enjoyment), and behavioral (effort, time-on-task)—consistent with contemporary engagement frameworks (Hollebeek et al., 2014). To ensure content validity, items are adapted from prior scales where possible and re-specified only when heritage semantics demand it, preserving comparability while avoiding construct drift. Critically, because engagement semantics can vary by culture and by setting, we execute a structured adaptation protocol: bilingual forward translation by two independent translators, reconciliation by a methods panel, back-translation by a third translator blind to the originals, and expert review by two Chinese museum educators for cultural appropriateness and domain coverage (Beaton et al., 2000; van de Vijver & He, 2016). Cognitive interviews with 12 local visitors probe comprehension, retrieval, judgment, and response mapping, and think-alouds identify terms that risk social desirability or ambiguity in Mandarin. Revisions focus on clarifying valence anchors, simplifying compound clauses, and adding brief examples for abstract terms like “control” or “responsiveness” that may be interpreted as technical rather than experiential.

Evidence for the cultural suitability of the engagement measure is established through multiple validity lenses. First, response-process validity is documented from cognitive interviews and post-pilot debriefs that show respondents interpret items as intended (American Educational Research Association [AERA] et al., 2014). Second, internal structure is assessed via reliability (Cronbach’s  $\alpha$ , composite reliability) and convergent validity (average variance extracted), targeting  $CR \geq .70$  and  $AVE \geq .50$ . Third, discriminant validity is evaluated using HTMT, with

conservative thresholds of .85 for closely related facets (Henseler, Ringle, & Sarstedt, 2015). Fourth, measurement invariance of the composite engagement construct is tested using the MICOM procedure across key subgroups (gender, age strata, digital literacy), seeking configural, compositional, and mean invariance; partial invariance, if detected, is addressed by freeing noninvariant indicators before comparing structural paths (Henseler, Ringle, & Sarstedt, 2016). Fifth, to guard against wording artifacts, we include both positively and negatively keyed items within subscales and test for acquiescence or extreme-response bias; if necessary, we model a method factor and examine whether results are stable net of stylistic variance (AERA et al., 2014).

Data collection uses a mixed-mode, privacy-respecting protocol that also enhances data quality. On-site recruitment occurs immediately after avatar interaction; participants scan a QR code to complete the survey on Wenjuanxing, which is familiar to Chinese respondents and supports secure data handling. To limit inattentive responding, the instrument includes an instructed-response item, a long-string detection check, and minimum engagement time thresholds per page; records failing multiple checks are flagged for exclusion before analysis (Meade & Craig, 2012). Duplicate entries are curtailed through device fingerprinting and IP screening; where families share devices, de-duplication relies on timestamps, dwell metrics, and distinct demographic profiles. The instrument captures exposure quality—time spent with the avatar and number of interaction turns—so that analyses can adjust for dosage and test whether relationships hold among minimally versus deeply exposed visitors, a crucial consideration when interventions vary in length in real settings.

Analytically, PLS-SEM is chosen for its strengths with prediction-oriented models, complex mediator structures, and potentially non-normal indicators that are common in field data (Sarstedt et al., 2022). The two-stage approach evaluates the measurement model first, then the structural model. For the former, we examine indicator loadings ( $> .70$  preferred), CR, AVE, HTMT, and residual diagnostics; we retain theoretically essential but marginal indicators only if their removal would impair content coverage and if cross-loadings remain acceptable. For the latter, we estimate direct and indirect effects with percentile bootstrap confidence intervals using 5,000 resamples; mediation is inferred from the significance and size of the indirect path and evaluated alongside the direct path to determine full versus partial mediation (Zhao, Lynch, & Chen, 2010). We report  $R^2$ ,  $Q^2$  (predictive relevance), and  $f^2$  effect sizes to characterize explanatory and practical import. To address potential common method variance, we employ ex-ante remedies (psychological separation of predictors and outcomes, varied scale formats) and ex-post diagnostics (full collinearity VIFs  $\leq 3.3$ ; marker-variable sensitivity), reporting whether substantive paths remain robust (Podsakoff et al., 2003; Kock, 2015).

Interpretively, the analysis is designed to speak directly to managerial trade-offs. Nonlinear terms for realism test whether incremental fidelity yields diminishing or adverse returns, consistent with cognitive-load theory and uncanny-valley concerns. Interaction terms probe whether high perceived usefulness attenuates the burden of complexity, consistent with TAM's expectancy logic, and multi-group comparisons examine whether lower digital literacy dampens gains from interactivity, informing inclusive design guidelines for regional museums. As an additional robustness check, we estimate a covariance-based SEM on a reduced model to verify that conclusions do not hinge on estimation paradigm; while CB-SEM requires larger samples and stricter distributional assumptions, convergent conclusions across methods would strengthen credibility (Kline, 2016).

Ethical safeguards are integral to a study embedded in cultural interpretation. Prior approval will be obtained from the university IRB. Informed consent screens outline purpose, voluntary participation, data uses, and withdrawal rights; no direct identifiers are collected. Data reside on password-protected servers with role-based access, and retention follows institutional policies consistent with GDPR principles and China's Personal Information Protection Law for minimal data collection and de-identification of any open-ended responses (Zhou & Sun, 2023). Cultural sensitivity is addressed by involving local museum educators in instrument review, explicitly screening items for ethnocentric assumptions, and inviting respondents to flag content they deem culturally inappropriate. Any flagged items will be reported and, if necessary, removed from analysis to preserve respect for heritage narratives.

In combination, these design choices ensure that the methodology is not only technically sound but also fit for purpose in Dezhou's practical context. The sampling plan targets the real decision population and mitigates the typical weaknesses of nonprobability intercepts; the instrument undergoes rigorous cultural–linguistic adaptation and invariance testing, which strengthen the validity of the engagement mediator; and the analysis strategy explicitly tests theoretically motivated nonlinearity and mediation while guarding against method biases. Consequently, the study will yield interpretable, design-actionable evidence on how specific avatar features drive meaningful engagement and, through it, elevate visitor experience in resource-constrained, second-tier Chinese museum settings.

### Expected Contributions and Implications

This study's theoretical contribution is purposely bounded yet substantive: it specifies how avatar attributes map onto acceptance pathways and communicative affordances in a heritage setting, and it demonstrates those links empirically rather than by assertion. TAM is extended by decomposing “system characteristics” into three manipulable attributes—anthropomorphism, realism, and interactivity—and by testing whether their effects on perceived usefulness and ease of use are transmitted through multi-dimensional engagement. Empirically, this will be shown by (a) comparing a baseline TAM model to an augmented model that adds avatar attributes and an engagement mediator, (b) reporting improvements in explanatory and predictive power ( $\Delta R^2$ ,  $\Delta Q^2$ ), and (c) bootstrapping indirect effects to establish whether engagement carries the influence of each attribute to experience outcomes (Zhao, Lynch, & Chen, 2010; Hair et al., 2021). MRT is advanced by operationalizing “richness” not as a generic property of media but as a bundle of avatar features that increase cue multiplicity and feedback immediacy; realism will be modeled with a quadratic term to test for a hypothesized nonlinearity (benefits at moderate levels, detriments at high fidelity), while interactivity will index contingent feedback. If the augmented model outperforms the TAM-only specification and if the realism nonlinearity is supported, that pattern would constitute empirical leverage for refining both theories in cultural storytelling contexts (Makransky & Mayer, 2022; Mayer, 2023).

Practically, the study will yield design heuristics calibrated to Dezhou's operational realities rather than universal prescriptions. Museums in second-tier cities often face heterogeneous digital literacies and tighter staffing and infrastructure constraints; therefore, implications will be derived from subgroup and sensitivity analyses rather than generalized globally. For example, multi-group models will test whether effects differ across low versus high digital literacy segments; if interactivity boosts engagement primarily among higher-literacy visitors, designers might prioritize guided scripts and simpler branching for novice audiences while reserving open-ended dialogue for advanced users. Similarly, if the realism curve peaks at moderate levels, resource-constrained institutions can avoid costly hyper-real rendering and

reallocate budget toward responsive behaviors or culturally grounded scripting, which the model expects to be more engagement-efficient. These choices translate into concrete procurement criteria, such as setting target ranges for latency in avatar responses, minimum thresholds for emotion expressivity, and ceilings for visual fidelity beyond which returns diminish.

The contribution to policy and governance is intentionally scoped. Findings will inform municipal and provincial cultural authorities on when avatar systems are justified as cost-effective complements to human interpretation in Dezhou-like settings, using effect sizes and predictive checks to estimate plausible gains in perceived educational value and revisit intention. Rather than asserting global significance, the study proposes a decision template that authorities can adapt: identify visitor segments, calibrate avatar features to engagement profiles, and monitor outcomes with simple dashboards derived from the validated constructs. In parallel, ethical guardrails are emphasized. Algorithmic bias and stereotyping risks arise if training data or scripts privilege dominant narratives; the study will recommend content governance checks that align with UNESCO's guidance on inclusive representation and participatory cultural narratives (UNESCO, 2021) and with contemporary AI ethics principles emphasizing fairness, transparency, and accountability (Mehrabi et al., 2021). Where staff capacity is limited, lightweight pre-deployment audits—checking language registers, symbolic references, and portrayal balance—can be institutionalized before new avatar stories go live.

A critical stance also requires acknowledging potential downsides and designing around them. First, cognitive overload and distraction are credible risks when cue density is high; immersion enhances learning only when extraneous processing is minimized (Makransky & Mayer, 2022; Mayer, 2023). If analysis reveals that high realism depresses engagement among novices, the implication is to prioritize clear gestures, stable eye gaze, and concise turn-taking over photorealism, perhaps with adaptive “detail throttling” that reduces animation complexity for first-time users. Second, authenticity can suffer if avatars over-personalize or dramatize at the expense of historical nuance; the study will interpret any negative paths from anthropomorphism to perceived cultural value as a caution against excessive emoting or anachronistic speech, encouraging “respectful personification” that centers primary sources and local voices. Third, digital fatigue and accessibility constraints matter: always-on screens and animated guides can tire visitors or marginalize those with sensory sensitivities. If the data show lower engagement for longer sessions, designers can implement time-boxed interactions and opt-out pathways, and museums can provide parallel low-stimulation interpretive modes to ensure inclusivity (Wiederhold, 2020). Fourth, privacy and data governance are salient; even anonymous interaction logs can create perceived surveillance. The implications will therefore include transparent data notices, on-device processing where feasible, and minimal telemetry consistent with China's Personal Information Protection Law and international good practice (Zhou & Sun, 2023).

Methodologically, the study contributes by demonstrating a validation pipeline that other regional museums can reuse. Measurement invariance tests will indicate whether the engagement construct functions similarly across demographic and literacy segments; if partial invariance is detected, adjusted scoring rules will be documented so that institutions can make fair comparisons over time. Predictive checks will clarify the conditions under which avatar investments are likely to “pay off,” enabling phased rollouts that start with the most responsive exhibits. Additionally, reporting negative or null results—such as nonsignificant effects of anthropomorphism in certain subgroups—will guard against technology boosterism and will help practitioners avoid costly misallocation.

Finally, the implications extend to collaborative innovation without overreach. Dezhou’s museums can partner with local universities to iteratively test content variants using the same metrics, building cumulative knowledge about culturally resonant scripting and interaction pacing. Vendors can be asked to deliver configurable realism and interactivity “dials,” allowing curators to tune experiences to audience profiles and to evaluate changes with pre-post quasi-experiments. Over time, this evidence-based approach to avatar governance aligns sustainability with inclusion by reducing wasteful upgrades, centering cultural authenticity, and prioritizing accessible interaction. The contribution, therefore, is not a universal blueprint but a rigorously tested, context-aware framework that clarifies when, how, and for whom virtual avatars enhance heritage interpretation—and when restraint, simplification, or alternative media may better serve visitors and communities.

### Conclusion

This study moves beyond describing avatar-enabled exhibits to clarify how specific design levers—anthropomorphism, calibrated realism, and contingent interactivity—translate into culturally meaningful visitor experiences through the mechanism of engagement. By integrating the expectancy logic of TAM with the cue-affordance logic of MRT, the findings framework specifies that avatars influence perceived usefulness and ease of use insofar as they deliver the right mix of social presence, feedback immediacy, and narrative clarity. Conceptually, this synthesis yields two actionable insights for heritage settings: first, engagement is not a by-product but the primary conduit through which avatar features shape learning value and satisfaction; second, realism likely exhibits diminishing returns, implying that museums should privilege expressive behavior and responsive dialogue over costly photorealism when resources are constrained.

The study also reframes digital innovation as cultural stewardship. Avatars, when designed with attention to authenticity and inclusion, can extend access, diversify voices, and scaffold self-directed exploration without overwhelming visitors. In Dezhou’s context, this means specifying procurement targets—latency thresholds for responses, minimum standards for emotion expressivity, and clear guardrails for culturally respectful scripting—so that technology choices are anchored in visitor outcomes rather than vendor capabilities alone. For policymakers, the model provides a decision template that links investment in particular avatar attributes to forecasted gains in perceived cultural value and revisit intention, enabling phased, evidence-based rollouts.

Several limitations temper interpretation. The geographic scope centers on Dezhou and analogous second-tier Chinese museum environments; transferability to megacity flagships or international contexts should be tested. The venue-intercept, nonprobability sampling strategy constrains population inference and may underrepresent low-frequency segments despite quota controls. Self-report measures raise the possibility of common-method variance, and cross-sectional data limit causal claims even with mediation tests. Finally, the study focuses on short-term outcomes; durability of effects and learning retention remain open questions.

Future work should pursue multi-site, longitudinal designs that track behavioral traces (e.g., dwell time, return visits) alongside surveys, and should experimentally manipulate avatar attributes to estimate nonlinearities with greater precision. Mixed-methods research can probe how authenticity cues are interpreted across groups and how ethical safeguards—privacy, bias mitigation, narrative balance—affect trust. Comparative studies that benchmark avatars against alternative media (human guides, audio, AR overlays) will clarify substitution and

complementarity. Together, these extensions would consolidate an evidence-based, culturally grounded playbook for avatar design that advances sustainable, inclusive heritage interpretation.

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