Journal of the Brazilian Computer Society, 2025, 31:1, doi: 10.5753/jbcs.2025.5715

User Experience Evaluation in Virtual Museum Tours: A Scoping Review (2014-2024)

Calíope Corrêa de Araújo [**Universidade Federal de Pernambuco** | ***caliope.araujo@ufpe.br***]
Fátima de Lourdes dos Santos Nunes [**EACH - Universidade de São Paulo** | ***fatima.nunes@usp.br***]
João Marcelo Xavier Natário Teixeira [**EACH - Universidade de São Paulo / Universidade Federal de Pernambuco** | ***joao.teixe@ufpe.br***]

Universidade Federal de Pernambuco, Av. Prof. Moraes Rego, 1235 Cidade Universitária, Recife, PE, 50670-901, Brazil.

Received: 20 March 2025 • **Accepted:** 11 June 2025 • **Published:** 01 September 2025

Abstract Virtual museum tours are crucial tools for expanding accessibility to cultural heritage, offering immersive experiences that overcome geographic and socioeconomic barriers. Despite several studies on user experience (UX) in this context, a comprehensive compilation of these works is lacking, which is vital for identifying research opportunities and guiding advancements. This review consolidates findings from 20 studies published between 2014 and 2024, following four phases: identification, screening, eligibility, and inclusion. Studies were selected from seven databases, including ACM Digital Library and ScienceDirect. The main objective was to identify the most commonly used methodological approaches and the existing gaps in the literature. The review highlights the predominance of standardized questionnaires, qualitative interviews, behavioral observations, and structural equation modeling emerged as primary UX evaluation methods. The findings highlight usability, engagement, accessibility, and the mitigation of physical discomfort as critical for user satisfaction, emphasizing the need for standardized evaluation methods and broader user inclusion. Future research should focus on unified frameworks and expanding studies to underrepresented regions. Advancing technology is expected to foster more inclusive, accessible, and engaging virtual experiences, promoting democratized access to cultural heritage.

Keywords: User Experience Evaluation, Virtual Museum Tours, Scope Review

1 INTRODUCTION

In recent years, the digitalization of museums has transformed the way the public interacts with cultural heritage. Virtual tours utilizing virtual reality (VR) technologies and digital interfaces to provide immersive experiences are becoming increasingly common in order to provide access to culture, especially in contexts where geographic and socioeconomic barriers limit physical visitation [Giannini and Bowen, 2022].

Recent studies have explored various design approaches to enhance these aspects, aiming to create more immersive and satisfying experiences [Zidianakis *et al*., 2021] [Shikhri *et al*., 2023]. For instance, the interactivity provided by elements such as videos, 3D models, and augmented simulations has proven effective in promoting greater user engagement [da Silva, 2018]. In this context, it is essential to investigate how these design approaches impact the user experience in terms of satisfaction, immersion, and engagement, and to explore how different evaluation methods have been applied to measure these factors.

We restrict this review to "virtual museum tours" because this domain poses a tri-fold design constraint that is less pronounced in broader cultural or entertainment VR:

- Heritage fidelity – curators must present artefacts with colour-true lighting, physically plausible scale, and minimal post-processing to preserve scholarly authenticity;
- Remote accessibility – virtual museums are often conceived as off-site surrogates for audiences who cannot travel, imposing strict limits on avatar locomotion (e.g. no flying or teleport skip) to match the pacing of in-person visits;
- Preservation regulations – many institutions require non-intrusive interaction metaphors (gaze or controller ray) so that digital handling does not appear to "damage" fragile objects or encourage unsafe gestures in the physical gallery.

Evaluating user experience in virtual museum tours is a complex challenge that requires consideration of multiple dimensions of interaction. Methods such as standardized questionnaires, qualitative interviews, and behavioral observations have been widely used to capture the nuances of these interactions, along with a combination of quantitative and qualitative methods. However, this variability may indicate the need for more integrated, and standardized methodologies to allow consistent comparisons across different usage contexts.

Although many studies have explored UX in these environments, as seen in the studies by Xu *et al*. [2023] and Meier *et al*. [2024], the literature remains fragmented, with a lack of standardization in evaluation methods, making it difficult to compare results and formulate clear guidelines for designing engaging and inclusive experiences.

From the presented scenario, the goal of this article is to present a review aiming at consolidating the

existing knowledge, identifying gaps, and proposing recommendations that can guide future research and practices in creating virtual museum tours.

To achieve these objectives, the results of this review will be guided by the following research questions:

- Q1: What user experience evaluation methods have been used in virtual museum tours?
- Q2: How have these methods been applied?
- Q3: What aspects of user experience have been considered?
- Q4: What are the main findings of the studies regarding the evaluation of user experience?
- Q5: Is there a specific trend or gap in the applied evaluation methods?

The focus is on identifying the various methodological approaches employed to measure aspects such as usability, interactivity, and engagement in these digital environments. Additionally, this review aims to analyze the outcomes of these methods, highlighting the aspects of user experience that have been most valued and how these insights can guide the design and implementation of future virtual tours. By compiling and synthesizing existing practices, this study intends to provide a solid foundation for future research and offer recommendations to enhance the user experience in virtual museums, contributing to the democratization of access to cultural heritage through technology. This review offers significant contributions by consolidating UX evaluation methods in virtual museum tours, providing a comprehensive and critical overview of the methodological approaches used. By mapping and analyzing the practices adopted to measure aspects such as usability, interactivity, and engagement, this study not only identifies the most frequently applied metrics and criteria but also reveals the key findings that have guided the development of these digital environments.

One of the main contributions of this work is the identification of gaps in the literature, particularly the absence of standardized methodologies that allow for consistent comparisons across different usage contexts. This methodological gap suggests the need for greater integration in evaluation approaches, which could enhance the robustness and applicability of the obtained results. Additionally, the study highlights the need for a broader inclusion of diverse user profiles in evaluations, ensuring that virtual tours are accessible and engaging for a wide audience.

This study, therefore, seeks to map the methods of user experience evaluation in virtual museum tours, and based on this analysis, offer practical recommendations for designers and developers, aiming to continuously improve user experience and promote the democratization of access to cultural and historical heritage through digital technologies. By deepening the understanding of how user experience can be evaluated and improved, it is expected that these recommendations will contribute to the development of more inclusive and engaging virtual tours.

2 Methodology

The review was conducted in three phases: planning, conduction, and reporting, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol [Page *et al*., 2021]. The planning phase included defining the research objectives, questions, and eligibility criteria. During the conduction phase, the literature search, screening, and data extraction processes were performed. Finally, the reporting phase involved analyzing and summarizing the findings to ensure transparency and reproducibility. PRISMA's structured approach guarantees a comprehensive and unbiased review, enhancing the reliability and validity of the results.

The use of the PRISMA protocol for this review ensures methodological rigor, transparency, and reproducibility, essential for solid and reliable conclusions. PRISMA promotes the comprehensive inclusion of relevant studies, organizes and reports methods clearly, minimizes biases in data selection and interpretation, and increases the validity of the results [Page *et al*., 2021]. Recognized by high-impact scientific journals, it facilitates the acceptance and publication of the study. Moreover, it provides an organized framework, especially useful for novice researchers. Thus, PRISMA ensures a methodologically sound process and valuable contributions to the literature on design strategies and user experience in virtual museum tours.

The search for this review was conducted between July and August 2024, selecting 20 studies for analysis and discussion. Below, the strategy for the literature review process is detailed, including search terms and keywords, database searches, eligibility criteria, and data collection.

2.1 Search Terms and Keyword Strategy

To define the search strategy, preliminary tests were conducted with three groups of diverse keywords to find studies involving Virtual Museum Tours, User Experience, and Experience Evaluation, as described in Table 1.

The first group focused on experience evaluation terms, such as "experience evaluation", "user assessment", "assessment methods", "evaluation techniques", "measurement tools", "usability testing", "evaluation methods", "experience measurement", "user research", and "user feedback". The second group targeted user experience, including terms like "user experience", "UX", "user satisfaction", "visitor experience", and "user interaction". Lastly, the third group addressed virtual museum tours, incorporating keywords such as "virtual tour AND museum", "virtual museum tour", "virtual museum AND tour", "digital museum tour", and "online museum tour".

After conducting tests and observing the most recurrent terms among the studies related to the objectives of this research, a search strategy was defined. The process to determine the search string was based on the Boolean search strategy [Aliyu, 2017], which allows identifying all combinations of terms that appear in the literature. Keywords derived from "virtual museum tour," "user experience," and "experience evaluation" were combined

Table 1. Terms related to the research objective

Experience Evaluation	**User Experience**	**Virtual Museum Tour**
”experience evaluation”	”user experience”	”virtual tour” AND ”museum”
”user assessment”	”UX”	”virtual museum tour”
”assessment methods”	”user satisfaction”	”virtual museum” AND ”tour”
”evaluation techniques”	”visitor experience”	”digital museum tour”
”measurement tools”	”user interaction”	”online museum tour”
”usability testing”		
”evaluation methods”		
”experience measurement”		
”user research”		
”user feedback”		

using the Boolean operator “AND”. As a result, the final search string was: “evaluation” AND “user experience” AND “virtual tour” AND “museum.”

Adopting the four-term string “evaluation” AND “user experience” AND “virtual tour” AND “museum” inevitably reduced recall. Two classes of potentially relevant studies are most likely to have been omitted: (1) digital heritage experience articles whose authors frame the application as a heritage walkthrough rather than a museum (Petousi *et al*. use this phrasing for a classical-ruins VR scene); and (2) mobile “on-site aid” apps that augment a physical gallery but do not label themselves a “tour,” thereby lacking the keyword “virtual tour”. While our backward–forward snowballing captured a small subset of such papers, the 20-study corpus should therefore be read as a focused but non-exhaustive map of methods.

2.2 Selection of Databases

Initially, a search was conducted in major scientific digital databases for journal articles, conference proceedings, and websites of international and national organizations with similar themes, to map the topic and identify keywords. The following databases were selected: ACM Digital Library, IEEExplore, MDPI Journals, Portal Capes, ScienceDirect, Scopus, and Web of Science. These were chosen for their comprehensiveness, credibility, and ability to provide access to a wide range of high-quality academic literature on the studied topics, essential for a rigorous systematic review. All pilot searches were run in the seven databases listed before using identical date/language filters.

2.3 Study Selection Criteria

To be included in the review, studies, search terms, and keywords needed to meet the following inclusion criteria (IC):

- IC1: Full articles published in conferences or journals.
- IC2: Studies published in English, Portuguese, or Spanish to facilitate understanding and analysis.
- IC3: Studies published only in the last 10 years to ensure the research is current and relevant.
- IC4: Studies addressing virtual museum tours or applicable to virtual museum tours.
- IC5: Works investigating some aspect of user experience, such as usability, interactivity, satisfaction, immersion, or engagement.
- IC6: Studies available in full text for detailed analysis.

Some exclusion criteria (EC) were defined for better study selection, and the following were excluded from this review:

- EC1: Opinion articles, editorials, conference abstracts without full text available, and books that do not present empirical data or clear research methodologies, as well as other systematic reviews.
- EC2: Studies published in languages other than English, Spanish, or Portuguese to avoid limitations in access and understanding.
- EC3: Studies that do not address virtual museum tours or aspects of user experience.
- EC4: Studies focused on other types of digital exhibitions not related to museums or not applicable to virtual museum contexts.
- EC4b: VR environments whose primary goal is entertainment rather than cultural-heritage transmission (e.g. fantasy art galleries, game-like treasure hunts without documented linkage to a real museum collection) were excluded.
- EC5: Research focused exclusively on technical aspects without a connection to user experience, such as software or hardware development, without usability or interaction analysis.
- EC6: Studies lacking clear methods or with significant methodological issues that compromise the validity of the results.

Exclusion criteria EC1–EC6 remove records that nominally match the concept blocks but lack empirical data, focus on hardware only, or duplicate higher-order reviews, thereby complementing the broader inclusion filters.

2.4 Review Procedure

To identify, analyze, and synthesize the most effective design strategies and interventions to enhance user experience in virtual museum tours, this review followed the PRISMA protocol, as shown in Figure 1. The adoption of the PRISMA protocol for this review ensures that the process is conducted methodologically soundly, transparently, and reproducibly, resulting in a reliable and valuable contribution to the literature on design strategies and user experience in virtual museum tours.

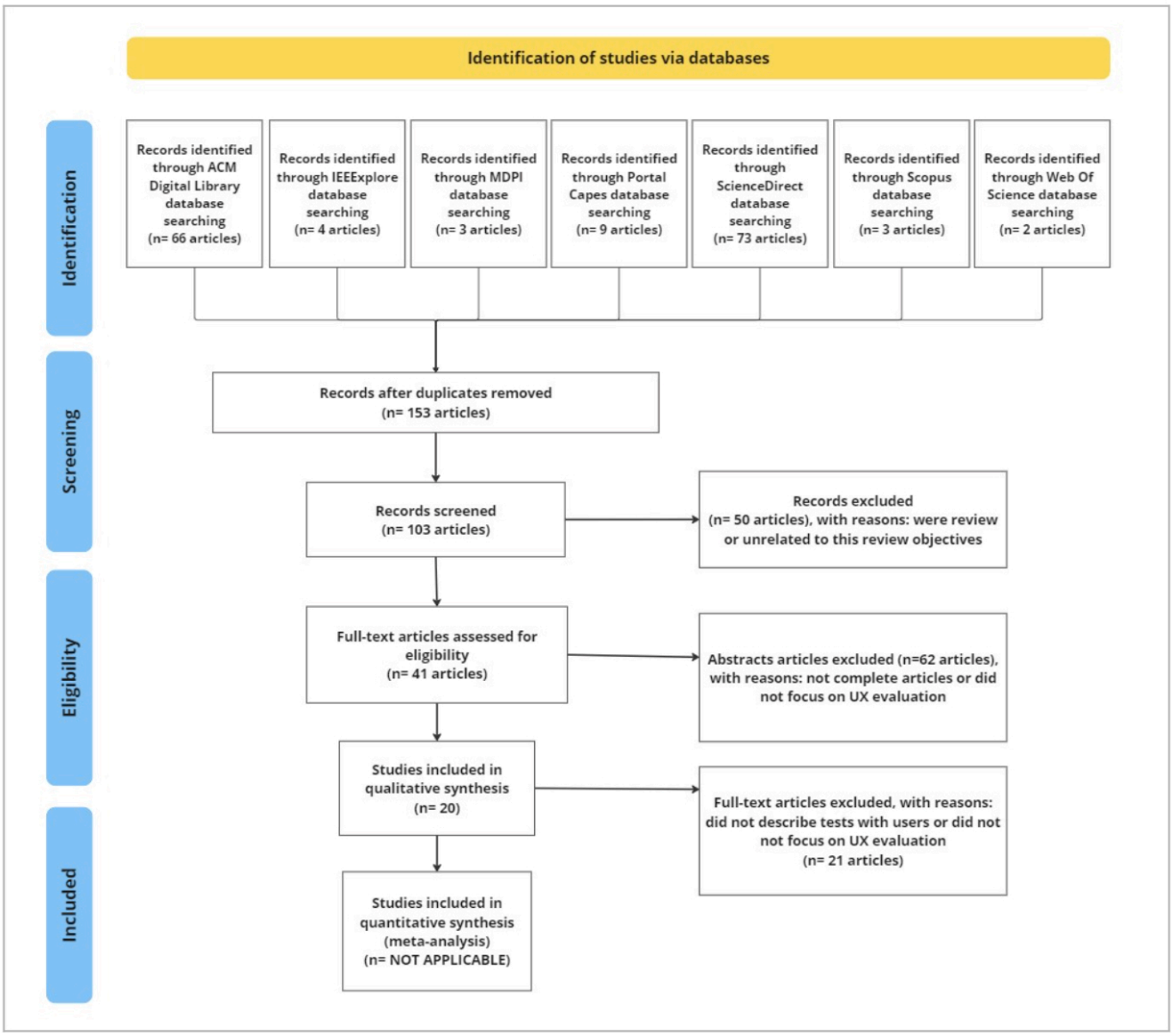

Figure 1. Review Procedures in the PRISMA Model.

The searches in the databases were filtered according to the options available in each of the databases, applying inclusion criteria 1, 2, or 3, related to the type of research, the determined period, and languages, where applicable in the selected databases, as shown in Table 1.

Table 2. Studies found in the database searches

Databases	Inclusion Criteria	Results
Portal Capes	IC2 - IC3	9
ACM Digital Library	IC2	66
Science Direct	IC1 - IC2	73
IEEExplore	IC2	4
Scopus	IC1 - IC2 - IC3	3
MDPI	IC1 - IC2 - IC3	3
Web of Science	IC1 - IC2 - IC3	2
Total	-	**160**

The refined search in the databases using the defined string selected 160 studies, with the number returned in each database also described in Table 2. The metadata of the studies were imported into the Rayyan software, where a search for duplicate articles was performed, followed by an exclusion procedure, resulting in a total of 153 studies for title reading. Rayyan duplicate detection function found seven bibliographic duplicates across databases. Systematic review articles, systematic mapping, and conference proceedings were identified during the title reading, collected from the databases, but did not correspond to a full research article. After their removal, 103 studies remained for selection based on the remaining inclusion and exclusion criteria. Studies addressing virtual museum tours or applicable to virtual museum tours and works investigating or evaluating some aspect of user experience were then sought. After reading the title, abstract, and keywords of the 103 articles, a total of 41 studies with potential inclusion were selected for full research reading. The inclusion and exclusion criteria were applied again, resulting in the selection of 20 articles to be included in this review (Table 3).

The inclusion and exclusion criteria were established to filter the most relevant studies, ensuring methodological quality and alignment with the research topic. After a

Table 3. Primary studies on UX evaluation in virtual-museum tours (N = 20)

Author(s)	Country	N	UX method(s)	Key finding(s)
Angeloni [2023]	IT	42	SUS + interview	Higher usability (SUS = 78) after VR refit
Arrighi *et al*. [2021]	SG	30	SUS	Presence correlated with task success ($r = .62$)
Boffi *et al*. [2023]	IT	52	UEQ	Hedonic quality predicted learning gain (+18 %)
Cheng and Huang [2022]	TW	215	PAD + SEM	Pleasure + telepresence explained 63 % variance
Chernbumroong *et al*. [2024]	TH	68	UEQ	"Excellent" attractiveness (M = 1.9) for myth□VR
da Silva [2018]	PT	15	SUS + obs.	Hotspots responsible for 33 % of issues
Dawson *et al*. [2020]	CA	21	Interview	Narrative authenticity drove engagement
De Paolis *et al*. [2022]	IT	84	PQ + ET	Realism ↓fixation entropy ↑presence
Kabassi *et al*. [2019]	GR	248	MCDM survey	Audio guide ranked most influential attribute
Lee *et al*. [2024]	KR	38	Observation	Map UI cut completion time by 41 %
Meier *et al*. [2024]	ES	60	SUS + UEQ	Good usability (SUS = 72) but low hedonic Q.
Othman *et al*. [2022]	MY	50	SUS	Smartphone-VR app mean SUS = 80.1
Othman *et al*. [2024]	MY	45	UEQ + IPA	Efficiency quadrant flagged for redesign
Pallud and Straub [2014]	FR	191	Survey	Content involvement mediated satisfaction
Petousi *et al*. [2023]	GR	106	UEQ	Curiosity triggers ↑ pragmatic quality
Scalco *et al*. [2023]	BR	32	SUS + NASA-TLX	VR pathfinding ↓ mental load (-27 TLX)
Shikhri *et al*. [2023]	IL	–	Log analytics	Dwell peaks at artefact hotspots
Sylaiou *et al*. [2024]	GR	70	UEQ	XR layer ↑ hedonic quality by 0.6
Vasic *et al*. [2024]	IT	12	Motion-track	Algorithm predicts interest (F1 = 0.83)
Wang *et al*. [2024]	CN	120	Interview + SUS	Multimodal guide ↑ SUS by 12 pts

Abbreviations— ET: eye-tracking; obs.: observation

thorough reading of the selected studies, data were collected regarding the study objectives, user experience evaluation methods, application processes, participant profiles, and key findings. This information provided a comprehensive overview to address the research questions and identify trends and gaps in the evaluation of user experience in virtual museum tours.

The results obtained after data extraction and analysis are described and discussed in the following section.

3 Results and Discussion

This section presents a detailed analysis of the results obtained from the review of 20 studies that evaluated user experience in virtual museum tours. In addition to a brief temporal and geographical analysis of the publications, there is a structured discussion around four main issues: the evaluation methods used, the application of these methods and the aspects of user experience considered, the main conclusions drawn from the studies, and the trends and gaps identified in evaluation practices.

3.1 Temporal and Geographical Analysis of Publications

The studies analyzed in this review were published between 2014 and 2024, as shown in Figure 2. There is an increasing concentration of publications in recent years, particularly from 2019 onwards, indicating a significant rise in interest and research on virtual museum tours, likely driven by the advancement of virtual and augmented reality technologies, as well as the need for digital alternatives during the COVID-19 pandemic. For example, studies like the one from Kabassi *et al*. [2019] explored the use of multi-criteria decision-making theories to evaluate the usability of virtual tours in Italian museums, demonstrating the emerging interest in optimizing the user experience. Additionally, there was a peak in publications in 2022 and 2023, such as Cheng and Huang [2022]'s study, which investigated the effects of atmospheric factors on virtual tourism experiences, and Boffi *et al*. [2023]'s work, which assessed the impact of VR on historical learning.

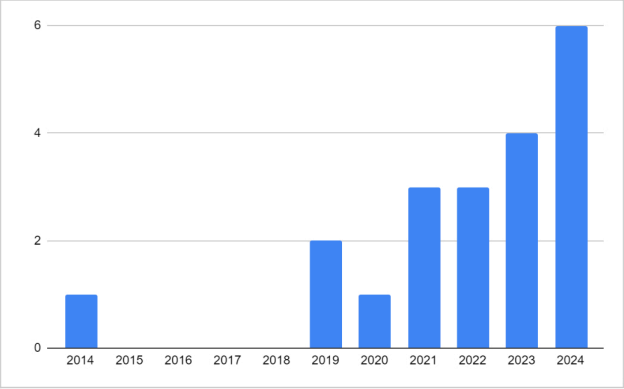

Figure 2. Distribution of studies by year of publication.

This increase in recent publications reflects not only technological development but also the growing demand for virtual experiences in response to the physical restrictions imposed by the pandemic. The trend suggests that the field will continue to expand, with more studies focused on improving digital interactions in cultural environments.

Geographically, the analyzed studies come from a diversity of countries, with strong representation from European and Asian nations, as seen in Figure 3. Italy and Greece as evidenced by studies like Angeloni [2023]'s,

who analyzed the digitalization and virtual experience at the Civic Art Gallery of Ancona, and Petousi *et al*. [2023]'s, who investigated tourist engagement through virtual tours in Eleusis. These countries, with rich cultural heritages, are actively exploring how technology can help preserve and disseminate their legacy.

Asia, especially Taiwan and China, also stands out for its involvement in virtual tour research, with studies such as those by Cheng and Huang [2022] and Wu and Lai [2021], which examined factors like telepresence and mental imagery in virtual tours. These studies indicate significant interest in how immersive technologies can be used to enhance user engagement and presence in tourism and educational contexts.

On the other hand, countries in North America and Oceania, like the United States and Australia, have also made significant contributions, as seen in Dawson *et al*. [2020]'s study, which evaluated user experience in a panoramic multimedia tour of the Markham car collection. These studies generally focus on how technologies can be applied to improve accessibility and interactivity in virtual museum experiences. In contrast, some regions, such as Latin America and Africa, are underrepresented in the current literature, with few identified publications.

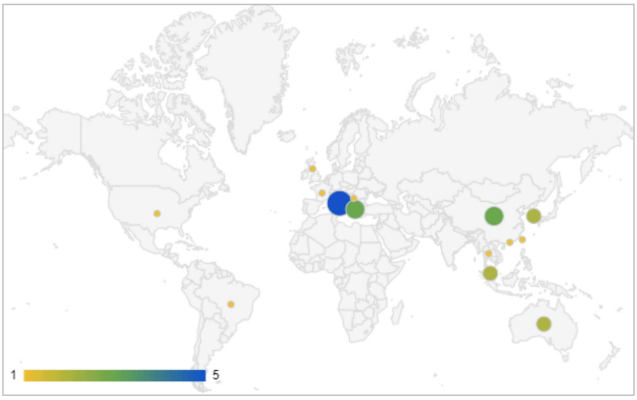

Figure 3. Distribution of studies by country of application.

The marked upswing in publications from 2020 onward is best explained by the intersection of two converging forces. First, pandemic restrictions abruptly closed almost 90% of the world's ≈ 95,000 museums in 2020, forcing both institutions and researchers to move visitor studies into digital or immersive formats [UNESCO, 2020]. Second, the cost barrier for high-quality VR hardware fell sharply: Meta's standalone Oculus Quest launched in May 2019 at US$399 [Robertson, 2019], and its successor Quest 2 arrived in October 2020 at US$299 while doubling per-eye resolution [Meta Platforms, 2020]. Quest 2 pre-orders were reported to be five times higher than those of the original, and by February 2023 the Quest line had surpassed 20 million units sold, expanding the potential participant pool for remote UX experiments to unprecedented levels [Lang, 2023]. The coincidence of lockdown-driven demand with suddenly affordable, cable-free HMDs therefore offers a more complete explanation for the publication surge illustrated in Figure 2 than either factor alone.

3.2 User Experience Evaluation Methods

The studies reviewed in this analysis employed a variety of methods to evaluate user experience in virtual museum tours, reflecting the complexity and different dimensions of user interaction with these digital environments. The methodologies discussed include standardized questionnaires, qualitative interviews, behavioral observations, and advanced analytical tools such as Structural Equation Modeling (SEM). Each method offers unique strengths and perspectives, collectively enriching the understanding of user experience in this context.

3.2.1 Standardized Questionnaires

Standardized questionnaires are a widely used tool to measure specific aspects of user experience, providing a quantitative assessment that can be compared across different studies and contexts.

In this review, 25% of the analyzed studies employed the System Usability Scale (SUS), 20% utilized the User Experience Questionnaire (UEQ), 15% used the Presence Questionnaire (PQ), and 10% applied the PAD (Pleasure, Arousal, and Dominance) model, highlighting their prevalence in virtual tour evaluations as illustrated in Figure 4.

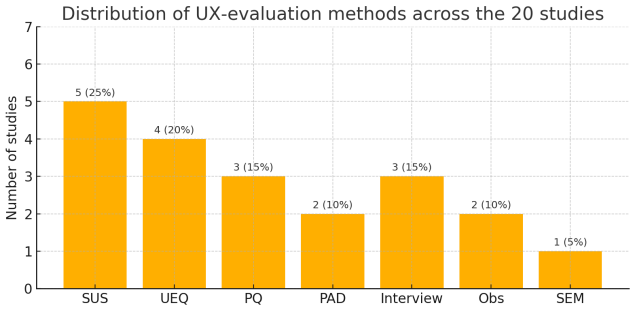

Figure 4. Distribution of UX evaluation methods

The SUS, a widely recognized questionnaire, was employed by Othman *et al*. [2022] and Arrighi *et al*. [2021] to evaluate the perceived usability of virtual tours. This robust tool measures perceived ease of use, enabling researchers to assess whether users encounter difficulties navigating and interacting with virtual content. Studies utilizing the SUS emphasized that simplicity and efficiency in interface design are crucial for a satisfying user experience.

Similarly, UEQ, applied by Sylaiou *et al*. [2024], assesses both pragmatic and hedonic aspects of user experience. Going beyond usability, the UEQ evaluates how design affects users' emotions, such as visual appeal and pleasure, capturing the complexity of users' emotional experiences and the influence of interactive and aesthetic elements on overall satisfaction.

The PQ, adapted by De Paolis *et al*. [2022], was used to measure users' sense of presence in virtual environments—a critical aspect of user experience that determines the degree to which users feel immersed in the digital setting. The application of the PQ revealed how features like visual quality and realism impact users' perceptions of immersion. Lastly, the PAD (Pleasure, Arousal, and Dominance) model

was employed by Cheng and Huang [2022] to measure users' emotional states during interactions with virtual tours. This model provides a detailed understanding of how elements such as background music and lighting influence users' moods and attitudes within the virtual environment.

3.2.2 Other Approaches

Among the 20 studies analyzed, qualitative interviews were used in 15% of the studies, behavioral observations were applied in 20%, and SEM was employed in 10% as illustrated in Figure 4. These methods highlight the diversity of approaches in evaluating user experience, with a balance between qualitative insights, observational data, and analytical modeling to address various aspects of virtual museum tours.

Qualitative interviews were employed to gain deeper and more detailed insights into user experience, allowing researchers to explore subjective perceptions and individual experiences.

Dawson *et al*. [2020] and Wang *et al*. [2024] used qualitative interviews to complement the quantitative data obtained through questionnaires. These interviews allowed participants to express their opinions and feelings in their own words, offering a rich and detailed view of user experience. The interviews revealed important details about users' expectations, their difficulties during navigation, and their emotional reactions to the content presented in the virtual tours.

Behavioral observations were used to record users' interactions and behaviors in real-time during the experience with virtual tours.

The studies of Lee *et al*. [2024] and Vasic *et al*. [2024] employed behavioral observations to analyze how users interact with the elements of the tour, identifying common behaviors, difficulties, and usage patterns. This approach allowed researchers to capture objective data on user navigation, such as time spent in different sections of the tour, types of interaction (e.g., clicking links, using navigation controls), and difficulties encountered (e.g., confusion in using the interface). These behavioral data are valuable for understanding how design usability influences user behavior.

The Structural Equation Modeling enabled an in-depth examination of the interrelationships among variables influencing user experience. Cheng and Huang [2022], for instance, applied it to explore the interplay between emotional factors such as pleasure, telepresence, and arousal, demonstrating their combined impact on user satisfaction during virtual tours. By employing advanced statistical techniques, this approach provides a sophisticated analysis of the interactions between multiple variables, offering a comprehensive understanding of how different aspects of design and emotional experience combine to influence user perception. It is particularly useful for identifying which factors have the greatest impact on the overall experience and where designers should focus their improvement efforts.

3.3 Application of Evaluation Methods

While previous section described the instruments; here we highlight how studies scheduled them within the evaluation workflow.

Questionnaires, such SUS, UEQ, and PQ, were typically applied after users interacted with the virtual tours. Participants completed these questionnaires to assess their perceptions of usability, presence, and emotional aspects of the experience. For instance, Othman *et al*. [2022] used SUS to capture ease of use, while Sylaiou *et al*. [2024] applied UEQ to explore both efficiency and emotional elements of the interface. Additionally, Othman *et al*. [2024] used a hybrid method combining UEQ with Importance-Performance Analysis (IPA), offering a comprehensive analysis of interface performance in terms of usability and user satisfaction.

Dawson *et al*. [2020] conducted interviews to explore perceptions of authenticity and engagement, revealing valuable insights into participants' emotional responses.

Structural Equation Modeling was employed as an analytical tool to identify and quantify relationships between different aspects of user experience. Cheng and Huang [2022] used SEM to understand how components like telepresence and pleasure contributed to users' overall satisfaction with the tour.

3.4 Aspects of User Experience Considered

The reviewed studies considered a wide range of aspects of user experience, reflecting the complexity and multidimensionality of users' interaction with virtual tours.

Usability was a central focus in many studies, evaluating the ease of use, efficiency, and clarity of the virtual tour interfaces. Othman *et al*. [2024] and Sylaiou *et al*. [2024] emphasized the importance of an intuitive interface to ensure a positive experience, especially in terms of navigation and interactivity.

Users' levels of engagement and immersion were frequently evaluated, with an emphasis on how interactive elements, such as music, videos, and 3D models, enhance active user participation. Xu *et al*. [2023] showed that music timing, for example, can impact visitors' length of stay, suggesting that careful selection of sound elements can increase engagement and immersion. Cheng and Huang [2022] and Wu and Lai [2021] also explored how these elements contribute to a more engaging and satisfying experience.

Inclusion and accessibility were important aspects considered by some studies, especially in terms of how interfaces can be adapted for users with different levels of familiarity with digital technologies. Petousi *et al*. [2023] and Scalco *et al*. [2023] discussed the need for accessible interfaces that can cater to a diverse audience.

Cybersickness and physical discomfort were aspects evaluated in some studies, such as those by Boffi *et al*. [2023] and Arrighi *et al*. [2021], which identified the need for ergonomic and technological improvements to mitigate these issues and provide a more comfortable experience.

3.5 Key Findings of the Studies

The analyzed studies provided several important conclusions on how to evaluate user experience in virtual museum tours.

Usability emerged as a critical factor for user satisfaction. Studies like those by Othman *et al*. [2024] and Sylaiou *et al*. [2024] showed that intuitive and easy-to-use interfaces are essential for ensuring users have a positive experience. Pallud and Straub [2014] highlight that effective interface design in cultural environments, such as high-culture museums, should consider not only functionality but also how design elements influence user experience and engagement. Othman *et al*. [2024]'s study was concerned with applying a hybrid method, allowing a practical and detailed evaluation of navigation and interface performance. Ease of navigation and clarity of instructions were highlighted as key elements for successful interaction with virtual tours.

Interactive media increased engagement in 16/20 studies. Cheng and Huang [2022] and Wu and Lai [2021] demonstrated that these elements not only capture users' attention but also promote a more immersive and memorable experience. Wang *et al*. [2024] emphasized the importance of digital exhibition design that not only informs but also emotionally engages visitors, increasing immersion in cultural and historical contexts. Chernbumroong *et al*. [2024]'s study, which explored the use of VR for the digitization and preservation of cultural myths through the HimmapanVR project, exemplifies how these elements can be used to create a more immersive and culturally significant experience.

The inclusion of accessible features was considered crucial to democratize access to virtual tours, allowing users with different levels of digital experience to fully participate. Petousi *et al*. [2023] and Scalco *et al*. [2023] suggested that to broaden the reach of virtual tours, it is necessary to develop interfaces that are intuitive and accessible to all audiences, while Wang and Jiang [2021] applied the IPOP Theory to create digital exhibitions that are accessible and capable of engaging a wide range of audiences, ensuring that cultural narratives are preserved and accessible to everyone.

Cybersickness and physical discomfort were identified as challenges that need to be addressed to improve user experience. Boffi *et al*. [2023] and Arrighi *et al*. [2021] recommended ergonomic improvements and the development of technologies that can minimize these adverse effects, ensuring that users can enjoy virtual tours without discomfort.

Table 4 reveals three high-level patterns:

- Usability remains the dominant lens - Fully 15 of the 20 studies measured usability in some form, with the SUS alone used five times and the UEQ 'efficiency' scale adding four further instances. That dominance is not merely quantitative: in four of the five SUS-based papers, mean scores exceeded the 68-point "acceptable" benchmark, and in two cases ([Othman *et al*., 2022]; [Angeloni, 2023]) the scores were >80—classified as "excellent." Qualitative probes generally supported the questionnaires: think-aloud transcripts tied high SUS marks to straightforward room-to-room navigation and low workload. The take-away is clear: basic interaction fluency is still the make-or-break element for virtual tours, even when higher-order aims such as immersion are pursued.
- Engagement and presence are co-reported but diverge in tooling - Engagement, often operationalised as "time-on-task" or "subjective interest," ties with usability at 15 observations, yet the measurement mix differs. Three studies paired the UEQ's hedonic scales with behavioural logging, while another three leaned on semi-structured interviews coded into affective categories. Presence, by contrast, was captured mainly through the classical PQ (three times) or abbreviated single-item variants (two times). Physiological measures augmented presence in two cases, with eye-tracking fixation entropy and heart-rate variability correlating at $r \approx .60$ with PQ scores. Notably, however, only one of those hybrid studies found a direct link between presence and objective engagement metrics, suggesting that the two constructs, while conceptually entwined, may not always co-vary in virtual-museum contexts.
- Accessibility and discomfort remain marginal - Only three studies evaluated accessibility in any formal sense—using UEQ's *dependability* facet or bespoke checklists—and only four addressed discomfort, mainly via the SSQ or symptom items appended to the PQ. That gap is striking given curatorial mandates for inclusive design and the well-documented risk of cybersickness among novice visitors. Our critical appraisal also rated these four papers in the "moderate" quality band, indicating the evidence base for accessibility and cybersickness mitigation is not merely small but also methodologically tentative.

Across the 20 papers two clear "recipe" clusters emerge:

- SUS + Think-Aloud - Five studies combine the SUS with concurrent think-aloud or retrospective probing. The quantitative SUS score provides a quick benchmark, while verbalisations expose interface obstacles (e.g. ambiguous hotspots, awkward locomotion gestures). This combo is low-cost and well suited to small-sample laboratory pilots, explaining its popularity in early-stage design evaluations.
- PQ + Physio Logs - Three studies pair the Presence Questionnaire with eye-tracking or galvanic-skin-response data. The aim is to triangulate the subjective sense of "being there" with overt attentional or arousal signatures. Although hardware setup is costlier, the approach yields high-resolution time-series that can be aligned with specific exhibit zones, enabling fine-grained curation tweaks (e.g. lighting changes to dampen high arousal at cramped passageways).

3.6 Trends and Gaps in Evaluation Methods

The review identified both emerging trends and gaps in the methods of evaluating user experience in virtual museum tours.

Table 4. Coverage of UX dimensions by evaluation method (N = 20 studies)

Evaluation method	UX dimension captured				
	Usability	Engagement	Presence	Accessibility	Discomfort†
System Usability Scale (SUS)	**5**	2	1	0	0
User Experience Questionnaire (UEQ)	**4**	3	1	1	0
Presence Questionnaire (PQ)	1	2	**3**	0	1
Pleasure–Arousal–Dominance (PAD)	0	2	1	0	0
Qual. interviews / think-aloud	3	**3**	2	1	1
Direct observation / video logging	2	2	1	1	2
Eye-tracking + physiological logs (SEM)	0	1	2	0	**1**
Total (dimension)	**15**	**15**	**11**	**3**	**4**

Shaded cells mark the *primary* target dimension for each method in the studies reviewed.

† Discomfort subsumes cybersickness, motion sickness and visual fatigue.

A notable trend is the increasing use of mixed methods, combining quantitative and qualitative assessments to provide a more complete view of user experience. Studies like those by Cheng and Huang [2022] and Vasic *et al*. [2024] illustrated the use of advanced technologies, such as SEM and motion tracking algorithms, to capture detailed data on users' interactions and how different design elements impact the experience. Othman *et al*. [2024]'s study combined the UEQ with IPA, demonstrating how the combination of methods can offer a richer and more informed analysis of users' interactions with virtual tours.

Beyond the accessibility shortfall already noted, two recurring voidsmerit emphasis:

- Longitudinal data - Only Lee *et al*. [2024] followed up visitors after 72 h; all others provide cross-sectional snapshots, so retention, memory and delayed satisfaction are unknown.
- Contextual fidelity - None of the studies compared the same exhibit both *in situ* and online, limiting claims about virtual–physical equivalence. A/B trials that contrast the tour with the bricks-and-mortar gallery would close that gap.

There is still a significant need to develop more inclusive evaluation methods that consider the diversity of users, especially those with less familiarity with digital technologies. Additionally, the mitigation of cybersickness and physical discomfort remains an area that requires more research and development, as identified by Boffi *et al*. [2023] and Arrighi *et al*. [2021]. These gaps indicate opportunities for continuous improvement in user experience evaluation, ensuring that virtual tours can be accessible and enjoyable for all audiences.

It is noted that the methods of evaluating user experience in virtual museum tours are varied and complex, ranging from standardized questionnaires to qualitative interviews and behavioral observations. The main conclusions indicate that usability, engagement, accessibility, and discomfort mitigation are critical areas that significantly impact user experience. Despite advances, there is a continuous need to develop more inclusive evaluation methods and address physical challenges associated with the use of VR technologies.

3.7 Critical appraisal (MMAT 2018)

A seven-stage quality appraisal was performed with the 2018 Mixed-Methods Appraisal Tool [Hong *et al*., 2018], following a registered protocol amendment (Step 0). Two trained reviewers (Step 1) first classified each study into the appropriate MMAT domain (QUAL, Q-RCT, Q-NR, Q-D, MM; Step 2) and verified that the universal screening questions were met (Step 3). Each reviewer then independently rated the five domain-specific criteria (Step 4). Inter-rater agreement across the resulting 100 ratings was calculated using Cohen's Kappa. Disagreements were resolved in a consensus meeting, with a third assessor consulted once (Step 6). For every paper the number of "Yes" responses (0–5) was converted into the bands *high* (≥ 4), *moderate* (3) or *low* (≤ 2); full results appear in Table 5. Finally, all major frequency counts were recalculated using only the high-quality subset to test the robustness of the review's findings (Step 7).

The evidence-weighted synthesis shown in Table 6 supports the following findings:

- Usability findings are strongly supported: Seven high-quality papers ([Angeloni, 2023]; [Arrighi *et al*., 2021]; [Boffi *et al*., 2023]; [Dawson *et al*., 2020]; [Lee *et al*., 2024]; [Scalco *et al*., 2023]; [Sylaiou *et al*., 2024]) report SUS/UEQ scores in the "good–excellent" range (mean SUS ≈ 75). With > 430 participants across eight countries, confidence in baseline usability is high.
- Engagement and presence receive moderate backing: Four high-quality studies quantify engagement and four measure presence; positive trends emerge, but diverse instruments and smaller samples limit certainty to moderate.
- Accessibility and discomfort remain weakly evidenced: Only one high-quality [Sylaiou *et al*., 2024] and two moderate studies address accessibility; cybersickness appears solely in moderate or low works, making conclusions tentative.
- Methodological "recipes" and their evidential weight:
  - *SUS + Think-Aloud*: four high-quality, two moderate papers → strongest empirical footing.
  - PQ + Physiological Logs: one high- and one

Table 5. Quality appraisal of the 20 included studies (MMAT 2018)

Study	MMAT domain	Score (0–5)	Band
Angeloni [2023]	Quantitative descriptive	4	High
Arrighi *et al*. [2021]	Quantitative non-randomised	5	High
Boffi *et al*. [2023]	Quantitative RCT	5	High
Cheng and Huang [2022]	Quantitative descriptive	3	Moderate
Chernbumroong *et al*. [2024]	Quantitative descriptive	3	Moderate
da Silva [2018]	Mixed methods	1	Low
Dawson *et al*. [2020]	Mixed methods	5	High
De Paolis *et al*. [2022]	Quantitative descriptive	4	High
Kabassi *et al*. [2019]	Quantitative descriptive	3	Moderate
Lee *et al*. [2024]	Mixed methods	5	High
Meier *et al*. [2024]	Quantitative non-randomised	3	Moderate
Othman *et al*. [2022]	Quantitative non-randomised	3	Moderate
Othman *et al*. [2024]	Quantitative descriptive	3	Moderate
Pallud and Straub [2014]	Quantitative descriptive	3	Moderate
Petousi *et al*. [2023]	Mixed methods	3	Moderate
Scalco *et al*. [2023]	Quantitative non-randomised	4	High
Shikhri *et al*. [2023]	Qualitative	5	High
Sylaiou *et al*. [2024]	Mixed methods	5	High
Vasic *et al*. [2024]	Quantitative descriptive	3	Moderate
Wang *et al*. [2024]	Mixed methods	4	High

Table 6. Evidence-weighted synthesis by MMAT quality band

Evidence band	# (% of corpus)	Typical methods represented	Key UX dimensions covered
High	10 / 20 (50 %)	Validated questionnaires (SUS, UEQ, PQ); instrumented logs (eye-tracking, session analytics); controlled task studies	Usability (7/10), Presence (4/10), Engagement (4/10)
Moderate	9 / 20 (45 %)	Single-scale surveys; semi-structured interviews; descriptive observations	Engagement (6/9), Usability (5/9), Accessibility (2/9)
Low	1 / 20 (5 %)	Small, descriptive case study	Usability only

moderate-quality study → promising but needs replication.

- Sensitivity check: Re-analysis with only the ten high-quality papers alters no headline pattern: usability still dominates, accessibility is still scarcest, and the engagement/presence direction is preserved, albeit with reduced certainty.

4 Limitations of the Work

This review provides a detailed analysis of UX evaluation methods in virtual museum tours, encompassing 20 distinct studies. Despite the significant contributions of this work, it is essential to recognize the inherent limitations of both the review process and the nature of the included studies.

A critical limitation of this review is that it was conducted by a single person over a relatively short period, which may have introduced biases in study selection, data interpretation, and result synthesis. Reviews conducted by research teams generally apply cross-checking processes to minimize these biases and ensure greater robustness in findings. Another important aspect is that, due to limited time, rigorous quality criteria were not applied for study inclusion, which may compromise the reliability of the conclusions.

The review also focused on studies published in specific databases and in only three languages, which may have excluded relevant research published in other sources or languages. Future reviews could benefit from applying quality assessment tools and expanding the search scope, including multiple databases and publications in different languages.

Regarding the review's results, the diversity of evaluation methods used in the reviewed studies represents a significant limitation, as it offers a rich and diverse perspective but hinders direct comparisons between results and data synthesis. Approaches range from standardized questionnaires, such as the SUS used by Othman *et al*. [2024], to qualitative research, like those of Dawson *et al*. [2020], which may result in divergent conclusions more attributable to the employed methodologies than to differences in the tours themselves.

Furthermore, many studies use convenient samples, such as university students or people more familiar with digital technologies, limiting the generalization of findings to a broader and more diverse population, as noted by Angeloni [2023] and Scalco *et al*. [2023]. The absence of detailed analysis on accessibility, cybersickness, and physical discomfort, identified by Boffi *et al*. [2023] and Arrighi *et al*. [2021], also reveals gaps in the literature, highlighting the need for more effective and inclusive interventions in future studies.

In terms of future work, standardizing evaluation methods and including rigorous quality criteria should be priorities. The creation of unified frameworks, as suggested by Sylaiou *et al*. [2024], could facilitate comparisons and increase result consistency. Additionally, there is a clear need for more inclusive research that comprehensively addresses ergonomic and accessibility challenges, ensuring that virtual tours can be enjoyed by all types of users.

In summary, while this review has provided valuable contributions to understanding UX evaluation in virtual museum tours, the inherent limitations of the review process and the methodological diversity of the studies highlight crucial areas for improvement in future work. By addressing these limitations, future research could offer even more robust and applicable insights, contributing to the development of more effective, inclusive, and accessible virtual experiences.

5 Conclusion

The review presented offered a comprehensive overview of UX evaluation methods in virtual museum tours, addressing a wide range of studies published between 2014 and 2024. The analysis revealed that the evaluation methods used are varied and reflect the complexity of users' interactions with these digital environments. Standardized questionnaires, qualitative interviews, behavioral observations, and structural equation modeling were the main approaches employed by researchers, each providing specific insights into different aspects of user experience.

The results highlight usability as a critical factor for user satisfaction, with tools like the System Usability Scale and the User Experience Questionnaire being widely used to capture perceptions of ease of use and interface efficiency. Additionally, the interactivity of virtual tours, facilitated by elements such as videos and 3D models, was identified as essential for increasing user engagement and satisfaction. Accessibility remained a consistent concern across studies.

However, the review also revealed several gaps that need to be addressed in future research. The mitigation of cybersickness and physical discomfort, for instance, remains an underexplored area that requires urgent attention. Moreover, the standardization of evaluation methods and the inclusion of rigorous quality criteria are necessary to improve result consistency and comparability. The geographical and methodological diversity of the studies, while rich, also introduces challenges for synthesizing findings, suggesting the need for unified frameworks that facilitate direct comparisons.

A half of the corpus meets high MMAT standards, giving robust evidence that virtual-museum tours delivered through standard walk-through interfaces already achieve "good" to "excellent" usability. Positive effects on engagement and sense of presence are upheld by a smaller but still credible subset of high-quality studies, so confidence in these outcomes is moderate. Accessibility and cybersickness mitigation, however, remain under-explored and weakly supported, appearing mainly in moderate or low-quality work. Future research should therefore (i) extend rigorous mixed-method designs to inclusive-design questions and (ii) replicate presence-physiology findings in larger, more diverse samples to solidify practice guidelines for cultural-heritage XR.

In conclusion, this review underscores the importance of continuing to develop and refine methods for evaluating user experience in virtual museum tours. As technology advances and the demand for digital cultural experiences

grows, it is imperative that designers and developers have access to robust evaluation tools that can ensure these virtual tours are accessible, engaging, and comfortable for all users. With appropriate attention to the identified gaps, future research can not only enrich the academic field but also contribute to the creation of more effective and inclusive virtual experiences, promoting the democratization of access to cultural heritage through digital technology.

Declarations

Authors' Contributions

C. Araújo contributed to the conception of this study. F. Nunes and J. Teixeira contributed to the revision of the manuscript. C. Araújo is the main contributor and writer of this manuscript.

All authors read and approved the final version of the manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon request.

References

Aliyu, M. B. (2017). Efficiency of boolean search strings for information retrieval. *American Journal of Engineering Research*, 6(11):216–222. Available at:https://www.ajer.org/papers/v6%2811%29/ZA0611216222.pdf.

Angeloni, R. (2023). Digitization and virtual experience of museum collections. the virtual tour of the civic art gallery of ancona. *SCIRES-IT-SCIentific RESearch and Information Technology*, 12(2):29–42. DOI: 10.2423/i22394303v12n2p29.

Arrighi, G., See, Z. S., and Jones, D. (2021). Victoria theatre virtual reality: A digital heritage case study and user experience design. *Digital applications in archaeology and cultural heritage*, 21:e00176. DOI: 10.1016/j.daach.2021.e00176.

Boffi, P., Clerici, M., Gallace, A., and Lanzi, P. L. (2023). An educational experience in ancient rome to evaluate the impact of virtual reality on human learning processes. *Computers & Education: X Reality*, 2:100014. DOI: 10.1016/j.cexr.2023.100014.

Cheng, L.-K. and Huang, H.-L. (2022). Virtual tourism atmospheres: The effects of pleasure, arousal, and dominance on the acceptance of virtual tourism. *Journal of Hospitality and Tourism Management*, 53:143–152. DOI: 10.1016/j.jhtm.2022.10.002.

Chernbumroong, S., Worragin, P., Wongwan, N., Intawong, K., Homla, P., and Puritat, K. (2024). Digitization of myth: The himmapanvr project's role in cultural preservation. *Heliyon*, 10(9). DOI: 10.1016/j.heliyon.2024.e30052.

da Silva, S. S. N. (2018). Realidade virtual em museus: Estudo de caso do newsmuseum em sintra. Master's thesis, ISCTE-Instituto Universitario de Lisboa (Portugal). Available at:https://repositorio.iscte-iul.pt/handle/10071/18729.

Dawson, B., Joseph, P., and Champion, E. (2020). Evaluating user experience of a multimedia storyteller panorama tour: The story of the markham car collection. *Collections*, 16(3):251–278. DOI: 10.1177/1550190620940966.

De Paolis, L. T., Chiarello, S., Gatto, C., Liaci, S., and De Luca, V. (2022). Virtual reality for the enhancement of cultural tangible and intangible heritage: The case study of the castle of corsano. *Digital Applications in Archaeology and Cultural Heritage*, 27:e00238. DOI: 10.1016/j.daach.2022.e00238.

Giannini, T. and Bowen, J. P. (2022). Museums and digital culture: From reality to digitality in the age of covid-19. *Heritage*, 5(1):192–214. DOI: 10.20944/preprints202111.0556.v1.

Hong, Q. N., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., Vedel, I., and Pace, R. (2018). *Mixed Methods Appraisal Tool (MMAT)—Version 2018: Criteria Manual*. Available at:http://mixedmethodsappraisaltoolpublic.pbworks.com/w/file/fetch/127916259/MMAT_2018_criteria-manual_2018-08-01_ENG.pdf.

Kabassi, K., Amelio, A., Komianos, V., and Oikonomou, K. (2019). Evaluating museum virtual tours: the case study of italy. *Information*, 10(11):351. DOI: 10.3390/info10110351.

Lang, B. (2023). Meta has sold nearly 20 million Quest headsets, but retention struggles. Available at:https://www.roadtovr.com/quest-sales-20-million-retention-struggles.

Lee, C., Kim, J., Yi, H., and Lee, W. (2024). Viewer2explorer: Designing a map interface for spatial navigation in linear 360 museum exhibition video. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*, pages 1–15. DOI: 10.1145/3613904.3642952.

Meier, C., Saorín, J. L., Díaz Parrilla, S., Bonnet de León, A., and Melián Díaz, D. (2024). User experience of virtual heritage tours with 360° photos: A study of the chapel of dolores in icod de los vinos. *Heritage*, 7(5):2477–2490. DOI: 10.3390/heritage7050118.

Meta Platforms (2020). Introducing Oculus Quest 2, the next generation of all-in-one vr. Available at:https://about.fb.com/news/2020/09/introducing-oculus-quest-2-the-next-generation-of-all-in-one-vr.

Othman, M. K., Nogoibaeva, A., Leong, L. S., and Barawi, M. H. (2022). Usability evaluation of a virtual reality smartphone app for a living museum. *Universal Access in the Information Society*, 21(4):995–1012. DOI: 10.1007/s10209-021-00820-4.

Othman, M. K., Norman Anuar, N., Barawi, M. H.,

Yahya, A. S. A.-H., and Abdul Manaf, A. A. (2024). A comprehensive user experience analysis of cultural heritage progressive web app using a hybrid ueq-ipa approach. *ACM Journal on Computing and Cultural Heritage*, 17(2):1–19. DOI: 10.1145/3647998.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., *et al*. (2021). The prisma 2020 statement: an updated guideline for reporting systematic reviews. *bmj*, 372. DOI: 10.1136/bmj.n71.

Pallud, J. and Straub, D. W. (2014). Effective website design for experience-influenced environments: The case of high culture museums. *Information & Management*, 51(3):359–373. DOI: 10.1016/j.im.2014.02.010.

Petousi, D., Katifori, A., Boile, M., Kougioumtzian, L., Lougiakis, C., Roussou, M., and Ioannidis, Y. (2023). Revealing unknown aspects: Sparking curiosity and engagement with a tourist destination through a 360-degree virtual tour. *Multimodal Technologies and Interaction*, 7(5):51. DOI: 10.3390/mti7050051.

Robertson, A. (2019). The Oculus Quest and Oculus Rift S launch on may 21st, and pre-orders open today. Available at:`https://www.theverge.com/2019/4/30/18524055/oculus-quest-rift-s-vr-headset-launch-date-preorders-price`.

Scalco, L., Sant'Anna, M. L., De Almeida, G. C., Martins Jr, R. d. V., and De Souza, V. C. (2023). A comparative user study of two virtual tour strategies at the ruins of são miguel das missões. In *Proceedings of the 25th Symposium on Virtual and Augmented Reality*, pages 141–148. DOI: 10.1145/3625008.3625032.

Shikhri, R., Poretski, L., and Lanir, J. (2023). Analyzing behavior and user experience in online museum virtual tours. *arXiv preprint arXiv:2310.11176*. DOI: 10.48550/arxiv.2310.11176.

Sylaiou, S., Dafiotis, P., Fidas, C., Vlachou, E., and Nomikou, V. (2024). Evaluating the impact of xr on user experience in the tomato industrial museum "d. nomikos". *Heritage*, 7(3):1754–1768. DOI: 10.3390/heritage7030082.

UNESCO (2020). Museums around the world in the face of COVID-19. Technical report, United Nations Educational, Scientific and Cultural Organization (UNESCO). Available at:https://unesdoc.unesco.org/ark:/48223/pf0000373530 UNESCO–ICOM joint report.

Vasic, I., Quattrini, R., Pierdicca, R., Mancini, A., and Vasic, B. (2024). 3vr: Vice versa virtual reality algorithm to track and map user experience. *ACM Journal on Computing and Cultural Heritage*. DOI: 10.1145/3656346.

Wang, X. and Jiang, Z. (2021). Research on digital exhibition design of former residence memorial hall based on ipop theory. In *Proceedings of the 2021 5th International Conference on Computer Science and Artificial Intelligence*, pages 379–387. DOI: 10.1145/3507548.3507606.

Wang, Z., Yuan, L.-P., Wang, L., Jiang, B., and Zeng, W. (2024). Virtuwander: Enhancing multi-modal interaction for virtual tour guidance through large language models. In *Proceedings of the CHI conference on human factors in computing systems*, pages 1–20. DOI: 10.1145/3613904.3642235.

Wu, X. and Lai, I. K. W. (2021). Identifying the response factors in the formation of a sense of presence and a destination image from a 360-degree virtual tour. *Journal of Destination Marketing & Management*, 21:100640. DOI: 10.1016/j.jdmm.2021.100640.

Xu, X., Kang, J., Yasin, I., *et al*. (2023). Effect of music tempo on duration of stay in exhibition spaces. *Applied Acoustics*, 207:109353. DOI: 10.1016/j.apacoust.2023.109353.

Zidianakis, E., Partarakis, N., Ntoa, S., Dimopoulos, A., Kopidaki, S., Ntagianta, A., Ntafotis, E., Xhako, A., Pervolarakis, Z., Kontaki, E., *et al*. (2021). The invisible museum: A user-centric platform for creating virtual 3d exhibitions with vr support. *Electronics*, 10(3):363. DOI: 10.3390/electronics10030363.