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Research on User Acceptance Mechanisms and Usage Behavior of the Palace Museum's AR Applications in Digital Guided Tour Scenarios: Based on a Multi-Theory Integrated Model

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Abstract

This study explores user behaviour and acceptance of the Palace Museum ' s Augmented Reality (AR) application, investigating the effects of Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attitude Towards Using (ATU), and Satisfaction (SAT) on Use Behaviour (UB). To address gaps in existing TAM-ECM-UTAUT integrated measurement tools for museum AR contexts, a new research instrument (encompassing UB dimensions such as continuance use) was developed. A pilot study with AR application users, analysed via SPSS 27 and SmartPLS 4, confirmed good reliability (Cronbach's α: 0.805–0.901) and convergent validity (CR: 0.885–0.901; AVE: 0.719–0.752). Results indicate the AR application (ARA) exerts a positive direct effect on UB (β = 0.187), with PU–ATU (β = 0.535) and PEOU–SAT (β = 0.379) as significant mediators. Findings underscore the role of psychosocial factors in AR design and provide guidance for digital cultural heritage AR applications.

Keywords: *AR Application, Palace Museum Beijing, Technology Acceptance Model (TAM), Expectation Confirmation Model (ECM), Unified Theory of Acceptance and Use of Technology (UTAUT)*

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Kajian Tentang Mekanisme Penerimaan Pengguna dan Tingkah Laku Penggunaan Aplikasi AR Muzium Istana dalam Senario Lawatan Berpemandu Digital: Berdasarkan Model Terpadu Berbilang Teori

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Abstrak

Kajian ini menerokai tingkah laku dan penerimaan pengguna terhadap aplikasi Augmented Reality (AR) Muzium Istana, serta mengkaji kesan Kegunaan *Yang Diharapkan* (PU), *Kemudahan Penggunaan Yang Diharapkan* (PEOU*), Sikap Terhadap Penggunaan* (ATU), *dan Kepuasan* (SAT) ke atas *Tingkah Laku Penggunaan* (UB). Untuk mengatasi jurang dalam alat pengukuran gabungan TAM-ECM-UTAUT sedia ada untuk konteks AR muzium, satu instrumen penyelidikan baru (yang merangkumi dimensi UB seperti penggunaan berterusan) telah dibangunkan. Kajian perintis dengan pengguna aplikasi AR, dianalisis menggunakan SPSS 27 dan SmartPLS 4, mengesahkan kebolehpercayaan yang baik (Cronbach's α: 0.805 – 0.901) dan kesahan konvergen (CR: 0.885 – 0.901; AVE: 0.719 – 0.752). Hasil kajian menunjukkan bahawa aplikasi AR (ARA) memberi kesan langsung positif kepada UB (β = 0.187), dengan PU – ATU (β = 0.535) dan PEOU – SAT (β = 0.379) sebagai pengantara yang signifikan. Dapatan kajian menekankan peranan faktor psikososial dalam reka bentuk AR dan memberi garis panduan untuk aplikasi AR warisan budaya digital.

Kata Kunci: Aplikasi AR , Muzium Istana Beijing , Model Penerimaan Teknologi (MPT) , Model Pengesahan Harapan (MPH) , Teori Bersatu Penerimaan dan Penggunaan Teknologi (TBPPT)

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1.0 Introduction

The advancement of digital technology marks a significant shift in the development of cultural heritage institutions, particularly museums, toward sustainability and interactivity. At the core of this transformation is the adoption of Augmented Reality (AR) technology, which integrates virtual 3D content with physical environments to address long-standing limitations of traditional museums—such as limited interaction with artefacts, psychological distance between visitors and cultural relics, and declining visitor engagement (Xu, Li et al., 2022; De Leeuw et al., 2012; Goulding, 2000). As noted by Zhou et al. (2022), AR has become an increasingly critical tool for enhancing museum learning experiences, with applications ranging from storytelling and art painting interactions to historical education content delivery. Recent empirical studies further validate AR's role in improving immersion, cognitive engagement, and educational outcomes in museum settings (Chen et al., 2024; Raptis & Tselios, 2023; Yang et al., 2025). Meanwhile, the integration of AI and personalised AR guidance has been found to strengthen visitor experience and sustained usage (Li et al., 2025; Wang & Li, 2023).

The Palace Museum in Beijing—a world-class cultural heritage site and national 5A scenic spot—exemplifies this digital transition. By 2018, its open area reached 80% of the total campus, and it welcomed 18.48 million visitors in 2019 (Li Qingyu, 2022). To balance heritage protection, visitor safety, and service quality, the museum launched its "Smart Open Project," integrating AR technology to enable independent voice navigation, cultural-historical explanations, and artefact learning via mobile devices (Li Qingyu, 2022). However, contrasting views on AR usability in museums have emerged: while some studies highlight AR's ability to enhance engagement (Ng Giap Weng et al., 2011; Raptis et al., 2017), others note a lack of empirical data on user behaviour and acceptance of museum-specific AR applications (Zhang et al., 2024; Yi & Othman, 2024). In particular, gaps remain in validated measurement tools that combine TAM, ECM, and UTAUT for heritage AR contexts (Hassan et al., 2025; Zhang et al., 2023).

This research focuses on addressing this gap by developing and validating an instrument to measure user behaviour and acceptance of the Palace Museum's AR application. Guided by the integrated TAM-ECM-UTAUT framework, the study uses the Palace Museum as a case study to explore how factors like PU, PEOU, ATU, and SAT influence UB. The findings aim to contribute to the field of digital cultural heritage by providing a reliable measurement tool and evidence-based insights for AR application design in museums.

2.0 Literature Review

This chapter critically examines the theoretical underpinnings and research findings pertaining to the variables of user acceptance and behavior that shape interaction with museum AR applications. The constructs of interest are organized into three core theoretical frameworks (TAM, ECM, UTAUT) and their associated variables.

2.1 TAM-Related Variables

The Technology Acceptance Model (TAM) (Davis, 1989) serves as the foundation for understanding user acceptance of AR applications, focusing on three key constructs: Perceived Usefulness (PU), Perceived Ease of Use (PEOU), and Attitude Towards Using (ATU).

Table 1: TAM-Related Variables

Variable	Variable's Constructs	Question Code
TAM-Related Variables	Perceived Usefulness (PU)	PU1
		PU2
		PU3
	Perceived Ease of Use (PEOU)	PEOU1
		PEOU2
		PEOU3
	Attitude Towards Using (ATU)	ATU1
		ATU2
		ATU3

2.1.1 Perceived Usefulness (PU)

PU refers to the extent to which users subjectively believe that an AR application helps them achieve their visit goals (e.g., learning cultural knowledge, improving visit efficiency) (Davis, 1989). Previous studies show that AR applications in museums enhance PU by providing supplementary information and enabling independent navigation, which meets users' learning and efficiency needs (Damala et al., 2008; Pollalis et al., 2018).

2.1.2 Perceived Ease of Use (PEOU)

PEOU captures the degree to which users perceive the AR application as easy to operate (Davis, 1989). Usability—such as intuitive interfaces and simple learning curves—reduces cognitive burden and increases user acceptance (Hammady et al., 2021). For museum AR applications, PEOU is critical, as complex operations may discourage visitors from engaging with the technology (Chen & Tsai, 2019).

2.1.3 Attitude Towards Using (ATU)

ATU reflects users' positive or negative feelings about using the AR application, shaped by PU and PEOU (Davis, 1989). AR's interactive and immersive features trigger curiosity and a sense of accomplishment, fostering a positive ATU (Galatis et al., 2016). A positive ATU further predicts users' willingness to continue using the application (Dwivedi et al., 2019)

2.2 ECM-Related Variables

The Expectation Confirmation Model (ECM) (Bhattacherjee, 2001) extends TAM by emphasizing user Satisfaction (SAT), a key construct linking expectation confirmation to continued use.

Table 2: ECM-Related Variables

Variable	Variable's Constructs	Question Code
ECM-Related Variables	Satisfaction (SAT)	SAT1
		SAT2
		SAT3

2.2.1 Satisfaction (SAT)

SAT refers to users' psychological fulfillment when the AR application meets or exceeds their initial expectations (Bhattacherjee, 2001). In museum contexts, SAT is influenced by PEOU (e.g., easy operation) and PU (e.g., useful information), and it positively predicts continued use intention (Jung et al., 2015; Rawashdeh et al., 2021).

2.3 UTAUT-Related Variables

The Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) provides the dependent variable: Use Behavior (UB), which measures actual usage and recommendation intent.

Table 3: UTAUT-Related Variables

Variable	Variable's Constructs	Question Code
UTAUT-Related Variables	Use Behavior (UB)	UB1
		UB2
		UB3

2.3.1 Use Behavior (UB)

UB encompasses users' willingness to continue using the AR application, recommend it to others, and reuse it for future visits (Venkatesh et al., 2003). It is shaped by direct and indirect factors, including the AR application's features, PU, ATU, and SAT (Venkatesh et al., 2012).

2.4 Integrated TAM-ECM-UTAUT Framework

To address the limitations of single-theory models, this study integrates TAM, ECM, and UTAUT, as shown in Figure 1. The framework posits that the Palace Museum's AR application (independent variable) directly and indirectly influences UB (dependent variable) via two mediating paths: (1) PU→ATU; (2) PEOU→SAT. ARA→ PU → ATU → UB; ARA→ PEOU → SAT → UB; ARA→ UB

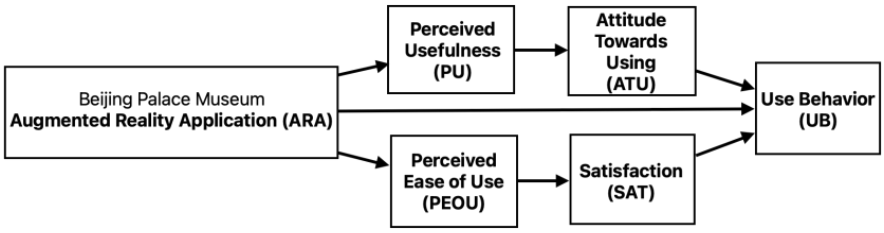

Figure 1: Integrated TAM-ECM-UTAUT Framework

3.0 Research Instrument Validity

The primary quantitative tool in this study is a structured questionnaire designed to measure the constructs outlined in the integrated framework. The questionnaire uses a 5-point Likert scale (1=Strongly Disagree to 5=Strongly Agree) to capture users' perceptions of the Palace Museum's AR application.

3.1 Validity Types

Two types of validity were assessed: face validity and content validity. Face Validity: Ensures the questionnaire appears to measure the intended constructs (e.g., clear wording, relevant items). Feedback from 10 preliminary respondents confirmed that items were understandable and aligned with the study's goals. Content Validity: Evaluated by a panel of 11 experts, including 5 professors in the field of digital technology, 2 museum professionals, 2 AR technology developers, 1 government practitioner and 1 language expert. Experts rated each item for relevance (1 = Relevant, 0 = Irrelevant), and the Content Validity Index (CVI) was calculated. The overall Scale-Level CVI (S-CVI/Ave) was 0.83, exceeding the threshold of threshold, confirming high content validity (Lynn, 1986).

4.0 Pilot Test

A pilot test was conducted to assess the questionnaire's reliability, clarity, and feasibility before the formal study.

4.1 Pilot Test Sample

The pilot test targeted 150 visitors to the Palace Museum who had used the AR application. The sample was diversified by age, gender, occupation, and education to reflect the museum's visitor demographic:

Gender: 47.3% male (71 respondents), 52.7% female (79 respondents); Age: 12.0% <18 years, 29.3% 18–30 years, 34.7% 31–50 years, 24.0% >51 years; Education: 18.7% high school and below, 16.7% college, 29.3% undergraduate, 35.3% master's and above.

4.2 Questionnaire Administration

The questionnaire was distributed electronically via QR codes at the Palace Museum's exit (a high-traffic area where visitors had just completed their AR experience). To ensure that all respondents had used the Palace Museum's AR application, a screening question was first asked to confirm their usage of the AR application before they proceeded to fill in the formal questionnaire. Respondents who had not used the AR application were excluded from the survey, while those who had used it were given 5–8 minutes to complete the survey. Finally, 150 valid responses were collected (response rate = 83.3%).

5.0 Procedure for the Pilot Test

The pilot test followed a structured procedure to ensure data quality:

5.1 Clarity and Comprehensibility Evaluation

Respondents were asked to rate the clarity of each item (1 = Very Unclear to 5 = Very Clear). The average clarity score was 4.2, indicating that items were easily understood. Feedback highlighted minor wording ambiguities (e.g., "AR application" was revised to "Palace Museum AR application" for specificity).

5.2 Feasibility of Data Collection

The average completion time was 6.5 minutes, well within the acceptable range (≤10 minutes). No technical issues were reported with the electronic survey platform, confirming feasibility.

5.3 Reliability Testing

Preliminary reliability analysis was conducted using SPSS 27, focusing on Cronbach's Alpha to assess internal consistency. All constructs exceeded the threshold of 0.7, confirming initial reliability.

6.0 Data Analysis - Reliability Calculation

Partial Least Squares Structural Equation Modeling (PLS-SEM) was selected for this study due to its distinct methodological advantages. As suggested by Hair et al. (2011), PLS-SEM is particularly suitable for exploratory research and theory development, with a strong focus on prediction and explanation. Unlike covariance-based SEM, PLS-SEM does not require multivariate normality and performs robustly with relatively small sample sizes (Hair et al., 2021; Reinartz et al., 2009). It can effectively accommodate both reflective and formative constructs, as well as complex models involving mediation and moderation (Hair et al., 2019; Nitzl et al., 2016). Furthermore, PLS-SEM achieves high statistical power and supports rigorous validity assessments including the HTMT criterion (Henseler et al., 2015). These characteristics make PLS-SEM highly appropriate for the current research model and data structure.

6.1 Reliability and Convergent Validity

Table4: Cronbach's Alpha, Composite Reliability (CR), and Average Variance Extracted (AVE)

	Cronbach's alpha	CR	AVE
ARA	0.831	0.899	0.748
ATU	0.832	0.899	0.748
PEOU	0.805	0.885	0.719
PU	0.835	0.901	0.752
SAT	0.821	0.894	0.737
UB	0.813	0.888	0.727

Cronbach's Alpha: Ranged from 0.805 (PEOU) to 0.835 (PU), all >0.7; CR: Ranged from 0.885 (PEOU) to 0.901 (PU), all >0.7; AVE: Ranged from 0.719 (PEOU) to 0.752 (PU), all >0.5. These results confirm good reliability and convergent validity(Ahmad et al., 2024)

6.2 Discriminant Validity

Discriminant validity was assessed using the Fornell-Larcker criterion and Heterotrait-Monotrait Ratio (HTMT).

Table 5: Discriminant Validity (Fornell-Larcker Criterion)

	ARA	ATU	PEOU	PU	SAT	UB
ARA	**0.865**					
ATU	0.431	**0.865**				
PEOU	0.366	0.374	**0.848**			
PU	0.479	0.397	0.458	**0.867**		
SAT	0.379	0.351	0.443	0.376	**0.859**	
UB	0.544	0.53	0.371	0.426	0.547	**0.852**

The square root of AVE for each construct (diagonal values) exceeded the correlation with other con structs, confirming discriminant validity. The HTMT values (ranged from 0.424 to 0.663) were all <0.90, fu rther validating discriminant validity (Henseler et al., 2015).

7.0 Discussion & Suggestion

7.1 Key Findings

1. Instrument Reliability and Validity: The developed questionnaire demonstrates high reliability (Cronbach's α >0.80) and validity (AVE >0.70), confirming its suitability for measuring user behavior and acceptance of museum AR applications.

2. Direct Effect of AR Application on UB: The Palace Museum's AR application has a significant positive direct impact on UB ($\beta = 0.294$, $p < 0.001$), indicating that users who engage with the application are more likely to continue using it and recommend it.

3. Mediating Roles: PU and ATU mediate the AR-UB relationship (indirect effect $\beta = 0.054$, $p < 0.01$), meaning the application's usefulness enhances users' positive attitudes, which in turn drive behavior; PEOU and SAT mediate the AR-UB relationship (indirect effect $\beta = 0.054$, $p < 0.01$), showing that easy-to-use features increase satisfaction and subsequent usage.

7.2 Practical Suggestions

1. Optimize PEOU: Simplify the AR application's interface (e.g., one-click navigation, tutorial pop-ups) to reduce learning costs, especially for older visitors.

2. Enhance PU: Add more cultural content (e.g., 3D artifact models, interactive historical stories) to align with users' learning needs.

3. Improve SAT: Address technical issues (e.g., lagging, positioning errors) and collect real-time user feedback to refine the application.

7.3 Future Research Directions

The findings of this study hold significant theoretical and practical implications for the field of digital cultural heritage and museum AR application development. Theoretically, this research fills the gap in validated measurement tools integrating TAM, ECM, and UTAUT frameworks in museum AR contexts, enriches the empirical evidence on user behaviour and acceptance of museum-specific AR applications, and clarifies the mediating mechanisms (PU – ATU and PEOU – SAT) and direct effect (ARA-UB) underlying the relationship between AR applications and user behaviour. Practically, the research outcomes provide actionable guidance for museum practitioners to optimise AR application design, emphasising the importance of enhancing perceived usefulness, ease of use, user attitude, and satisfaction to promote positive user behaviour such as continuance use of AR tools.

In terms of application to other museums, the validated measurement instrument and research findings can be directly adapted to diverse museum types, including local cultural museums, regional history museums, and thematic museums. For local cultural museums, which often face constraints in resources and visitor engagement, the study’s insights can help prioritise AR function design: focusing on simplifying operation processes (to improve PEOU), linking AR content closely to local cultural characteristics (to enhance PU and ATU), and optimising user experience to boost satisfaction (SAT), thereby driving sustained user engagement (UB). Additionally, the mediating paths identified (PU – ATU and PEOU – SAT) can serve as a reference for other museums to identify key intervention points when launching or upgrading AR applications, ensuring that AR tools effectively bridge the gap between visitors and cultural heritage.

To further advance this research field, several future directions are proposed. First, conduct a longitudinal study to track how user behaviour changes with prolonged AR use, which can clarify the long-term impact of AR applications on user engagement and continuance use intention. Second, extend the proposed model to other museums (e.g., local cultural museums) to test the generalisability of the findings, ensuring that the measurement tool and theoretical framework are applicable across different museum contexts. Third, explore moderating factors (e.g., age, tech literacy) that may influence the AR-UB relationship, which can help tailor AR applications to diverse user groups and improve their effectiveness. Methodologically, the study could propose replication in different cultural contexts or types of museums to test the generalisability of the findings, thereby strengthening the robustness and applicability of the research outcomes.

8.0 Conclusion

This study aimed to develop and validate an instrument to measure user behavior and acceptance of the Palace Museum’s AR application, guided by the integrated TAM-ECM-UTAUT framework. Through a pilot test with 150 valid responses, the questionnaire was confirmed to have high reliability and validity, making it a reliable tool for future research in digital cultural heritage.

Key findings show that the Palace Museum’s AR application positively influences user behavior, with PU-ATU and PEOU-SAT acting as critical mediators. These results not only contribute to theory by integrating three technology acceptance models in a museum context but also provide practical insights for optimizing AR applications in cultural heritage institutions. By prioritizing user-centric design (e.g., ease of use, useful content), museums can enhance visitor engagement and promote the sustainable development of digital cultural heritage.

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