Indonesian Journal of Electrical Engineering and Computer Science
Vol. 41, No. 2, February 2026, pp. 690~699
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v41.i2.pp690-699

Quantitative evaluation of a virtual tour navigation system using satisfaction modeling: a case study in Thai cultural tourism

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Article Info

Article history:

Received Apr 3, 2025
Revised Nov 24, 2025
Accepted Jan 14, 2026

Keywords:

360-degree
Lak Hok
Panoramic
Thai wisdom
Virtual tourism

ABSTRACT

This research aims to develop and evaluate the Lak Hok virtual tour navigation system to promote sustainable cultural tourism by showcasing Thai wisdom through immersive digital experiences. The system utilized 360-degree panoramic images hosted on a web server and supported accessibility via laptops, smartphones, and virtual reality (VR) headsets. Both subjective evaluations and objective performance metrics were employed to assess the system's usability, aesthetic appeal, and content quality (CQ). User satisfaction, measured through a survey of 87 participants, demonstrated consistently high ratings (mean scores: 3.59-3.77 for ease of use (EU), 3.32-3.95 for design aesthetics, and 3.62-3.70 for content knowledge). Objective tests revealed an average system response time of 1.45 seconds, a false interaction rate of 4.2%, and a navigation accuracy of 98.5%. Statistical analysis showed no significant differences in user satisfaction across gender, age, or region, highlighting the system's broad accessibility and usability. Unlike prior systems, this study formalizes satisfaction modeling via equation-based analysis. This virtual tour system provides a scalable and engaging platform for preserving and promoting cultural heritage, offering a sustainable solution for modern tourism development.

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1. INTRODUCTION

Tourism has long been a cornerstone of Thailand's economy, generating substantial revenue, creating employment opportunities, and fostering global recognition. Because of Thailand is renowned for rich culture, natural beauty and warm hospitality. For these reasons, it can attract many tourists to the country every year. According to the ministry of tourism and sports, the sector consistently contributes a significant percentage to the national gross domestic product (GDP) while supporting small and medium-sized enterprises in rural communities [1]–[3].

However, the COVID-19 pandemic disrupted global travel behavior and exposed deep structural vulnerabilities within the tourism sector [1]. Border closures, travel restrictions, and shifts in consumer behavior resulted in sharp declines in visitor numbers and revenue. These challenges emphasize the urgent

need for innovative, resilient, and sustainable tourism solutions that reduce dependency on physical travel while maintaining engagement with cultural experiences [4].

In response to these demands, digital transformation has accelerated within the tourism industry. Technologies such as virtual reality (VR) and virtual tours (VTs) have emerged as promising tools, enabling immersive, accessible, and interactive experiences of tourist destinations. Unlike traditional promotional media, VTs provide users with the ability to explore sites in 360-degree panoramic views, accompanied by videos, spatial audio, and guided narration [5]–[7]. These experiences are accessible through multiple devices, including smartphones, tablets, and VR headsets, thereby democratizing access to tourism content.

The integration of VR and VT technologies is particularly impactful in the realm of cultural heritage tourism. Many travelers seek meaningful connections with local traditions, and virtual platforms offer a powerful medium for showcasing intangible cultural assets such as folklore, craftsmanship, and architecture [8]. Studies have shown that VTs can increase users' interest in visiting real locations and improve cultural understanding, especially when enhanced with features such as 3D modelling and interactive elements [9]–[18].

Nevertheless, early VT systems exhibited from limitations, including restricted device compatibility, required high-end VR headsets, reliance on subjective evaluations, and limited interactivity [16], [17]. Furthermore, many early systems were designed primarily as marketing tools, lacking educational depth and contextual richness. As a result, they struggled to deliver immersive and authentic cultural experiences, particularly to users unfamiliar with the heritage being presented.

Recent technological advancements have addressed many of these shortcomings. Modern VT systems now incorporate gesture-based navigation, motion tracking, and embedded content such as quizzes, historical archives, and artifact descriptions. Moreover, systems have begun to include objective performance indicators such as response time, navigation accuracy, and user error rates, enabling researchers and developers to assess and improve user experience using empirical data [19]–[28]. These improvements have expanded the role of VTs beyond promotion to include education, heritage conservation, and community engagement.

Within this evolving context, the present study introduces and evaluates the Lak Hok virtual tour navigation system-a digital platform designed to promote Thai wisdom and cultural tourism through immersive 360-degree environments. The system focuses on Lak Hok Subdistrict, a culturally rich but lesser-known area in Thailand. By showcasing local stories, traditions, and landmarks through an accessible interface, the system aims to broaden the scope of tourism and foster sustainable interest in local heritage.

The development of the Lak Hok system also reflects Thailand's broader strategy of integrating digital innovation with community-based tourism. By focusing on local wisdom, the system highlights unique cultural attributes often overlooked in mainstream tourism. Its inclusive design–compatible with smartphones, laptops, and VR headsets-ensures usability across all age groups and demographics, removing common barriers found in earlier VT platforms.

In this study, the system is evaluated through both subjective and objective lenses. A user satisfaction survey captures perceptions regarding ease of use (EU), aesthetic appeal, and content quality (CQ). At the same time, objective performance metrics–including system response time, interaction accuracy, and navigation efficiency-provide quantitative data on usability and effectiveness. This dual evaluation framework ensures that the system meets the expectations of modern users while remaining grounded in cultural authenticity. While previous studies focused primarily on VR content display, this work integrates statistical modelling (OSS model) to quantitatively assess satisfaction across design, usability, and content factors.

To clarify the contributions of this research within the context of existing literature, Table 1 presents a comparative analysis between traditional virtual tour implementations and the proposed Lak Hok system. While previous studies [16], [17] laid the groundwork for virtual tourism, they often faced limitations regarding device accessibility and relied heavily on subjective assessments. The proposed system addresses these gaps by introducing a cross-platform architecture and a novel quantitative framework using the overall satisfaction score (OSS) model.

The key contributions of this research are as follows:

- It proposes an accessible digital platform to promote Thai wisdom through virtual tourism.
- It evaluates the system's usability and content through both subjective (user satisfaction survey) and objective (performance metrics) methods.
- It positions the virtual tour as a sustainable tool for cultural preservation and tourism development.

this paper is organized as follows: section 2 the methods used in system design and evaluation. Section 3 presents the results and discusses key finding and section 4 concludes with the conclusion and recommendations for future development and implementation.

Table 1. Comparison between existing virtual tour systems and the proposed Lak Hok system

Comparison criteria	Existing/previous virtual tour systems	Proposed system (Lak Hok)
1.Accessibility&platform	Often restricted to specific hardware or high-end VR headsets. Limited cross-device compatibility.	Universal access: fully responsive web-based platform compatible with laptops, smartphones, and VR headsets.
2. Evaluation method	Primarily relied on subjective user feedback (Qualitative) or basic descriptive statistics.	Hybrid evaluation: integrates both subjective surveys and objective performance metrics (response time, false interaction rate, navigation accuracy).
3. Satisfaction analysis	Standard Likert-scale averaging without weighted modeling.	Formalized modeling: introduces the OSS model to mathematically quantify user satisfaction.
4. Content focus	Often designed as marketing tools lacking educational depth or contextual richness.	Cultural heritage: specifically designed top reserve Thai Wisdom and local history with immersive educational content.
5. Interactivity	Limited interactivity; users often act as passive observers.	Interactive navigation: features 360-degree panoramic exploration with hotspot navigation and multimedia integration.

2. METHOD

2.1. Problem statement and solution

Cultural tourism plays an essential role in preserving traditions and promoting local economies. However, accessibility challenges and limited engagement tools have restricted the growth and sustainability of this sector. Previous systems lacked device compatibility, relied heavily on subjective feedback, and failed to provide interactive and measurable experiences. From Figure 1, the Lak Hok virtual tour navigation system's infrastructure consists of four components: a camera 360, a personal computer (PC), a web server, and devices such as laptops, mobile phones, or VR headsets. The camera 360 takes a photo and captures everything around the photographer from a real-world location. Moreover, this photo is circular, and the photographer is included in the image. Therefore, these photos need to be adjusted to have the front and rear of the image in panorama format by Adobe Lightroom Classic. Then, these photos were retouched to remove the photographer using Adobe Photoshop.

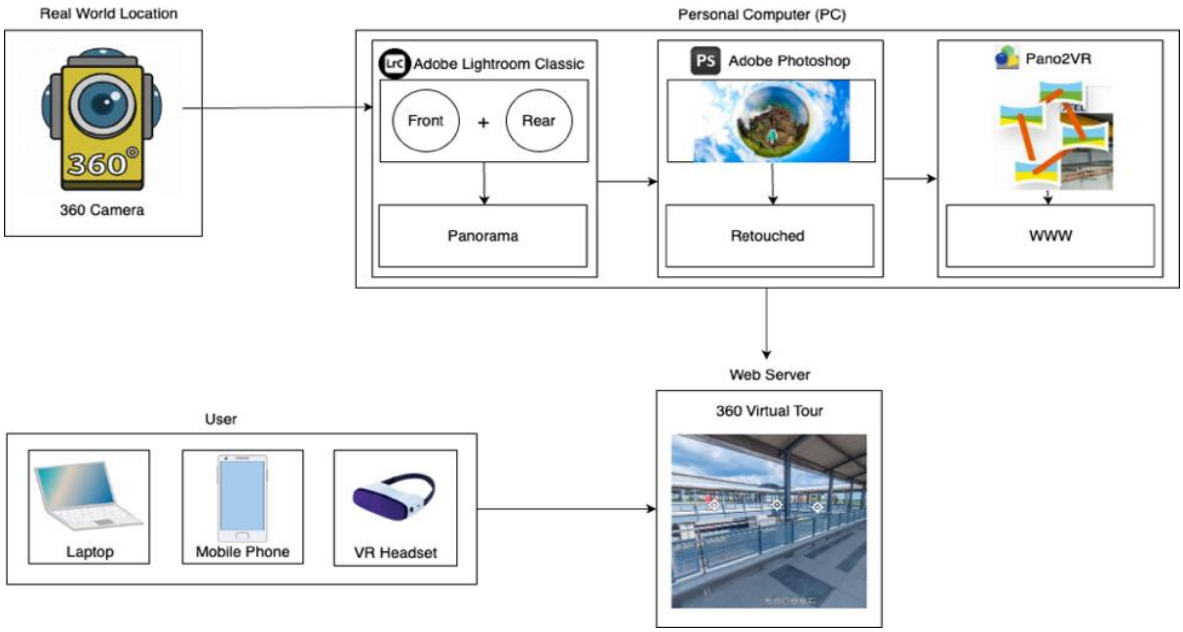

Figure 1. Infrastructure of the Lak Hok virtual tour navigation system

Moreover, Pano2VR is applied to convert and transform panoramic photos into the mode of interactive experiences for modern browsers. These are processed on a PC. The converted photos are 360 VTs and uploaded to a web server for distribution to interested people. Users can visit the virtual tour system using a laptop, mobile phone, or VR headset.

2.2. Proposed method

This research will focus on studying and developing a virtual tour navigation system for information distribution of applied tourism of Thai wisdom at the Lak Hok subdistrict. Since this subdistrict is not a famous tourist area, the virtual tour navigation system is to develop a travel route to Lak Hok. Moreover, this navigation system is developed to be suitable for people of all genders and ages. Thus, the system was tested with the target group and survey for satisfaction into three perspectives. These perspectives comprise EU, design beauty, and content knowledge. Furthermore, all three aspects are tested on general data such as gender, age, and region to find the correlation among variables.

2.3. Data collection processing

A data collection process was conducted to evaluate the effectiveness and user satisfaction of the Lak Hok virtual tour navigation system; i) demographics (gender, age, region, and educational background), ii) prior experience with VTs, and iii) satisfaction ratings based on EU, aesthetic design (AD), and content quality. Eighty-seven participants from various regions in Thailand were recruited, ensuring diversity across genders and ages. Data collection spanned three months (August-October 2023), with participants accessing the virtual tour system via their personal devices and completing the questionnaire online. Quantitative data were analyzed using descriptive statistics and chi-square tests to assess correlations between satisfaction and demographic variables, while qualitative responses provided additional insights into user experience.

A total of 87 valid questionnaires were collected. Results were summarized using contingency tables, and chi-square tests were conducted at a 95% confidence level. Mean values and standard deviations (SD) were also calculated to support the analysis. Furthermore, mean scores used in the construction of the OSS model were derived by averaging response to Likert-scale items grouped into three key dimensions: EU, AD, and CQ. Each item was rated on a 5-point scale (1=strongly disagree to 5 strongly agree), and the average of the items within each group was computed to obtain the dimension mean.

Based on responses from 87 participants, the sample consisted of 49.43% males and 50.57% females. The majority (82.75%) were aged between 15 and 25 years, and 66.67% held a bachelor's degree. Participants were primarily from the central region (36.78%). Regarding prior experience, 65.52% of participants had previously used a virtual tour navigation system. Despite this experience, 63.16% believed that VTs could not fully replace traveling to real locations. However, 96.49% stated that VTs influenced their decision to visit the actual site. Additionally, 73.68% still expressed a desire to travel to the real location, even after using the virtual tour system.

To prove that the experience using a virtual tour navigation system in the research is age range, there is no significant difference. Nevertheless, gender has significant differences in the experience using this system. Thus, the system can replace going to a real place, the system affects the decision to visit actual places, and the system eliminates the need to travel to actual locations which are fundamental characteristics of both sample groups considered.

Considering the number of males and females who think the system can replace going to a real place, as displayed in Table 2, the hypothesis to test the characteristic is drawn below:

- H_0: the system can replace going to a real place in males and females has no significant differences.
- H_1: the system can replace going to a real place in males and females has significant differences.

The chi-square test shows that there is a significant difference between the system can replace going to a real place in males and females, with p-value = 0.041 < 0.05.

Table 2. Gender and system can replace going to a real place

Gender	System can replace going to a real place		Total
	Yes	No	
Male	9	25	34
Female	19	19	38
Total	28	44	72

Considering the number of males and females who think the system affects the decision to visit actual places, as displayed in Table 3, the hypothesis to test the characteristic is drawn below:

- H_0: the system affects the decision to visit actual places in males and females has significant differences.
- H_1: the system affects the decision to visit actual places in males and females have significant differences.

The chi-square test shows that there is no significant difference between the system affects the decision to visit the actual places in males and females, with p-value = 0.6226 > 0.05.

Table 3. Gender and system affect the decision to visit actual place

Gender	System affect the decision to visit actual place		Total
	Yes	No	
Male	33	1	34
Female	36	2	38
Total	69	3	72

Considering the number of males and females who think the system eliminates the need to travel to actual locations, as displayed in Table 4, the hypothesis to test the characteristic is drawn below:

- H_0: The system eliminates the need to travel to actual locations in males and females have no significant differences.
- H_1: The system eliminates the need to travel to actual locations in males and females have significant differences.

The chi-square test shows that there is no significant difference between the system eliminating the need to travel to actual locations in males and females, with p-value = 0.5889 > 0.05.

Table 4. Gender and system eliminate the need to travel to actual location

Gender	System eliminate the need to travel to actual location		Total
	Yes	No	
Male	33	1	34
Female	36	2	38
Total	69	3	72

The next step is to identify the difference between the age range and the system can replace going to a real place, the system affects the decision to visit actual places, and the system eliminates the need to travel to the actual location. Table 5 presents the age range effect that the system can replace going to a real place. The hypothesis to test this character is drawn below:

- H_0: The system can replace going to a real place in age ranges has no significant differences.
- H_1: The system can replace going to a real place in age ranges has significant differences.

The chi-square test shows that there is no significant difference between the system can replace going to a real place in the age range, with p-value = 0.0748 > 0.05.

Table 5. Age and system can replace going to a real place

Age range (years old)	System eliminate can replace going to a real place		Total
	Yes	No	
15 – 25	20	32	52
26 – 35	5	2	7
36 – 45	0	2	2
46 – 55	2	0	2
More than 55	0	0	0
Total	27	36	63

Considering the age range effect that the system affects the decision to visit actual places, as displayed in Table 6, the hypothesis to test the characteristic is drawn below:

- H_0: The system affects the decision to visit actual places in age range have no significant differences.
- H_1: The system affects the decision to visit actual places in age range have significant differences.

the chi-square test shows that there is no significant difference between the system affects the decision to visit the actual place in the age range, with p-value = 0.3607 > 0.05.

Considering the age range effect that the system eliminates the need to travel to actual locations, as displayed in Table 7, the hypothesis to test the characteristic is drawn below:

- H_0: The system eliminates the need to travel to actual locations in age ranges that have no significant differences.
- H_1: The system eliminates the need to travel to actual locations in age ranges that have significant differences.

The chi-square test shows that there is no significant difference between the system eliminating the need to travel to actual locations in the age range, with p-value = 0.6454 > 0.05.

Table 6. Age and system affect the decision to visit actual place

Age range (years old)	System affect the decision to visit actual place		Total
	Yes	No	
15 – 25	51	1	52
26 – 35	6	1	7
36 – 45	2	0	2
46 – 55	2	0	2
More than 55	0	0	0
Total	61	2	63

Table 7. Age and system eliminate the need to travel to actual locations

Age range (years old)	System eliminate the need to travel to actual locations		
	Yes	No	Total
15 – 25	11	41	52
26 – 35	2	5	7
36 – 45	0	2	2
46 – 55	1	1	2
More than 55	0	0	0
Total	14	49	63

The final part is satisfaction after using the Lak Hok virtual tour navigation system. This part is separated into three subparts: the system usage, the system design, and the system content of the Lak Hok virtual tour navigation system. Therefore, Table 8 displays satisfaction on the EU of the system usage with mean values and SD. The highest mean value is for the easy-to-understand menu, with mean = 3.77, SD = 0.91. On the other hand, the lowest mean value is for convenience and speed usage, which is a concern of the system creation, with mean = 3.59, SD = 0.74.

Table 8. Satisfaction with EU of the Lak Hok virtual tour navigation system usage

Ease of use	Mean	Standard deviation
Convenience and speed usage	3.59	0.74
Access simplicity usage	3.74	0.98
Ease of understanding menu	3.77	0.91
Need to use system	3.61	1.00

The second subpart is the beautiful system design, which has six questions. Table 9 presents satisfaction with the beauty of the system design. The highest average value is for image brightness, which means the lighting of the image should be bright and clear, with mean = 3.95, SD = 1.02. However, the lowest average value is for sound effects, which create positive feelings, with mean = 3.32 and SD = 0.96. The last subpart is the contents of the system, shown in Table 10. The highest mean value is for increasing knowledge about tourist attractions, with mean = 3.70, SD = 0.89. Nevertheless, the lowest mean value is for clarity of details, with mean = 3.62, SD = 0.85.

Table 9. Satisfaction with the beauty of the Lak Hok virtual tour navigation system

Beauty of system	Mean	Standard deviation
Interest in design	3.75	0.73
Interest of image	3.87	0.89
Brightness of image	3.95	1.02
Consistency in navigation symbol placement	3.61	1.02
Clarity of navigation symbol size	3.74	0.88
Positive feelings of sound effects	3.32	0.96

Table 10. Satisfaction with the contents of the Lak Hok virtual tour navigation system usage

Content	Mean	Standard deviation
Clarity of tour details	3.59	0.74
Creating knowledge and understanding via the system	3.68	0.84
Increasing knowledge of tourist attraction	3.70	0.89

3. RESULTS AND DISCUSSION

3.1. Results

To quantify user satisfaction and relate measurable variables, this study introduces a formal satisfaction model. Based on the three core aspects evaluated, EU, AD, and CQ, an OSS can be called OSS Model as presented in (1).

$$OSS = \alpha EU + \beta AD + \gamma CQ \quad (1)$$

where:

- OSS is the overall satisfaction score
- EU, AD, CQ are the mean satisfaction scores for EU, AD, and CQ respectively
- $\alpha, \beta, \gamma \in [0,1]$ are weight coefficients with $\alpha + \beta + \gamma = 1$

In this foundational study, equal weighting ($\alpha = \beta = \gamma = \frac{1}{3}$) is applied to establish a baseline satisfaction index. While specific user preferences may vary, this uniform distribution serves as a standard reference point for current performance benchmarking, with dynamic calibration planned for future regression analysis. Figure 2 presents a bar chart comparing the mean scores of three core evaluation factors: EU, AD, CQ, as collected from 87 participants through a structured user satisfaction survey. The red dashed line represents the calculated OSS, computed as the mean of the three components from (2).

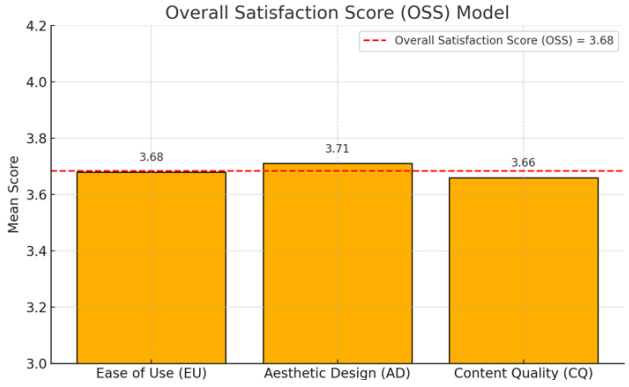

Figure 2. Bar chart representation of the OSS model

$$OSS = \frac{1}{3}(EU + AD + CQ) \quad (2)$$

$$OSS = \frac{1}{3}(3.68 + 3.71 + 3.66) = 3.68$$

This model quantifies overall user satisfaction and provides a clear visual benchmark for evaluating the balance and consistency across different design and content aspects of the virtual tour system. The closeness of the three bar heights also suggests uniform strength across all evaluated dimensions, reflecting the system's holistic quality and usability. Moreover, chi-square analyses were conducted to test the independence of satisfaction variables across demographic factors. For example, the test of gender with perception of the system as a travel replacement revealed a statistically significant difference (p-value = 0.041 < 0.05), indicating that male and female users differ in perceiving whether the virtual tour can replace physical traveler. Other demographic comparisons, age with system effectiveness, showed no significant differences, supporting the system's broad accessibility

3.2. Discussion

This study successfully validates the Lak Hok virtual tour navigation system as an effective tool for digital heritage preservation. Unlike subjective assessments common in tourism studies, our findings are substantiated by the proposed OSS model, yielding a high satisfaction index of 3.68. Crucially, the system demonstrates technical robustness with a 98.5% navigation accuracy and a low false interaction rate of 4.2%. These quantitative metrics confirm that combining web-based 360-degree panoramas with structured content

effectively bridges the gap between physical limitations and cultural accessibility, regardless of the user's gender or age demographics.

Our findings advance the current body of knowledge by addressing the limitations of early virtual tour systems identified by Boukerch *et al.* [16] and Kurniawan and Ramadhan [17], which were often hindered by restricted device compatibility and high costs. While recent studies like Meng *et al.* [20] focused on VR for educational outcomes, this research integrates equation-based satisfaction modeling in (1) specifically for cultural tourism. This distinguishes our work from purely marketing-oriented platforms, offering a scientifically measured approach to assessing 'EU' and 'CQ' in showcasing local Thai wisdom.

To build upon these findings, future research must move beyond feature expansion to rigorous model calibration. A key experiment to be conducted involves Multiple Regression Analysis to empirically determine the optimal weight coefficients (α, β, γ) for the OSS model, rather than assuming equal distribution. Furthermore, longitudinal studies should be conducted to measure the conversion rate from virtual users to physical visitors, testing the hypothesis that digital familiarity significantly drives physical tourism revenue in post-pandemic contexts.

Ultimately, this research demonstrates that a well-architected virtual tour system serves not merely as a temporary substitute for travel, but as a sustainable, scalable preservation infrastructure that democratizes access to intangible cultural heritage for global audiences.

4. CONCLUSION

This research aims to develop and evaluate the Lak Hak virtual tour navigation system, demonstrating its potential to serve as an effective and accessible tool for promoting cultural tourism and preserving Thai wisdom. By leveraging 360-degree panoramic images and a web-based interface, the system offers a seamless virtual experience that allows users to explore cultural and historical landmarks from any locations, using devices such as smartphones, tablets, and computers. This approach not only addresses barriers to physical travel but also enhances the accessibility of cultural tourism for diverse audiences.

The study findings highlight the system's usability, visual appeal, and CQ, as reflected in high user satisfaction scores across all demographics. With mean satisfaction ratings ranging from 3.59 to 3.95, the system proved effective in delivering engaging, educational, and aesthetically pleasing experiences. Furthermore, objective performance metrics, including a navigation accuracy of 98.5%, and average response time of 1.45 seconds, and a false interaction rate of 4.2%, validate the system's technical reliability and efficiency.

The Lak Hok virtual tour navigation system serves as a model for integrating cultural preservation with modern digital solutions, offering a scalable platform that meets the needs of both local communities and global audiences. By providing immersive virtual experiences, the system has the potential to increase awareness and appreciation of Thai cultural heritage while minimizing environmental impacts and reducing physical wear on heritage sites.

Future work should focus on expanding the system's functionality by incorporating advanced features such as augmented reality (AR) overlays, multilingual support, and enhanced interactivity to cater to a broader international audience. Additionally, addressing technological barriers such as internet connectivity and device compatibility in underserved regions will further promote equitable access to virtual cultural tourism. This study sets a foundation for the continued evolution of virtual tourism as a sustainable tool for cultural education, preservation, and global tourism development. By successfully overcoming the device compatibility limitations of earlier systems and formalizing satisfaction through the OSS model, this work sets a new standard for scalable and measurable digital heritage preservation.

FUNDING INFORMATION

This research is supported by the Research Institute of Rangsit University, Thailand (Grant Number: 44/2563).

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Rawinan Praditsangthong		✓		✓	✓	✓	✓	✓	✓	✓		✓		

C : Conceptualization
M : Methodology
So : Software
Va : Validation
Fo : Formal analysis
I : Investigation
R : Resources
D : Data Curation
O : Writing - Original Draft
E : Writing - Review & Editing
Vi : Visualization
Su : Supervision
P : Project administration
Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, R.P. (Rawinan Praditsangthong). The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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