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The Impact of Augmented Reality Tourism on Tourist Experience and Behavior —A Case Study of the Mogao Caves Cultural Heritage

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Abstract

Background and Aim: The Mogao Caves, representing the pinnacle of Chinese cave art evolution, enjoy esteemed historical significance. With backing from the local government's "Belt and Road" initiative and the establishment of the "Dunhuang Cultural Tourism Economic Circle," Mogao Caves tourism is undergoing high-quality development. However, the surge in tourist numbers has compromised the visitor experience, posing challenges to heritage conservation and tourism development balance. To address this, the Dunhuang Academy has integrated AR technology, safeguarded the heritage while enriched visitor experiences. This study aims to understand tourists' experiences and intentions in virtual Mogao Caves exploration, investigating factors influencing AR tourism experiences. By examining AR's impact and proposing management enhancements, this research contributes to Mogao Caves' sustainable development.

Materials and Methods: This study utilizes a quantitative approach with two main stages: literature analysis and statistical analysis. Initially, it defines concepts and establishes the conceptual framework of AR technology by reviewing SOR theory, tourist experiences, behavioral intentions, and relevant studies. It then refines the SOR theory's origin, concept, characteristics, and application areas, analyzing variables such as stimulating factors, tourist experiences, and behavioral intentions. Research hypotheses are formulated, and a theoretical model is constructed. Offline questionnaires from 400 Mogao Caves AR tourists were collected, and data were analyzed using PLS-SEM. The study aims to understand the relationship between tourist experiences and behavioral intentions, analyze mediating effects, validate hypotheses, and confirm the structural model, offering reliable statistical support and a scientific basis for the findings.

Results: The results indicate that in AR tourism, content quality, system quality, and interaction quality have a positive impact on tourist experiences. AR tourism experiences significantly influence behavioral intentions. Particularly surprising is that the impact of tourism experiences on behavioral intentions exceeds expectations, demonstrating its importance in AR tourism. This finding highlights the potential of AR technology in enhancing tourist experiences and provides new development opportunities for tourism destinations.

Conclusion: AR technology holds immense promise for tourism development at the Mogao Caves heritage site. Factors like content, system, and interaction quality significantly enhance tourist experiences and behavioral intentions in AR tourism there. Quality content not only shapes a positive brand image but also opens up commercial and collaborative opportunities. System stability ensures smooth AR experiences, while interactive design boosts engagement and spending. However, the potential negative impacts of AR technology on tourism require further exploration in future research.

Keywords: AR Tourism; Tourist Experience; Behavior Intention; Mogao Caves

Introduction

With the rise of the digital age, the tourism industry is undergoing a significant transformation due to economic digitalization. The COVID-19 pandemic has severely impacted global tourism, prompting the emergence of new trends in utilizing digital technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR). AR technology, as a highly interactive and immersive technological tool, has rapidly grown in the tourism industry and has played an important role in enhancing the tourist experience, enriching tourism products and services, and expanding marketing channels.

AR offers innovative ways for tourists to explore unknown environments (Cranmer et al., 2018). AR applications help practitioners attract more tourists and enhance service experiences (Wei, 2019). AR allows tourism enterprises to unpredictably integrate computer-based digital worlds into the immersive

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realm of the physical world(Çeltek, 2020). AR applications are particularly valuable for the tourism industry as they provide travelers with opportunities to understand unknown environments and enhance the overall experience(Jingen Liang et al., 2021), emerging as a significant trend in digital transformation and experience innovation of tourism destinations (Qiji & Chensi, 2022). AR is increasingly utilized for marketing and enhancing experiences in the tourism industry(Cranmer et al., 2023).

The Mogao Caves, among China's earliest heritage conservation units, embarked on digital exploration in the 1980s, pioneering heritage protection methods. The Dunhuang Academy's three-decade-long research into digital technology led to comprehensive digitization of grotto cultural treasures and data findings. This effort ensures perpetual preservation and spares heritage from destruction(Yu et al., 2022). Digital initiatives extend beyond virtual tours, incorporating cutting-edge technologies like holographic projection and 3D screens to create immersive exhibitions and attract public interest. Digitization enhances public awareness of heritage preservation and facilitates academic research and education. AR tourism revitalizes Dunhuang culture, prompting a reevaluation of its impact by experts and tourism professionals. How does AR tourism enhance the tourist experience? What impacts does the AR tourism experience have on tourist behavioral intentions?

To fill research gaps, this study aims to expand the theoretical research on the influence mechanism of AR tourism on tourists' behavioral intentions through literature analysis and questionnaire surveys, improve the research outcomes of digital cultural heritage tourism, and offer empirical references for stakeholders in the tourism and cultural heritage sectors. This will help them enhance AR tourism projects, improve tourist experiences, and achieve a mutually beneficial scenario for cultural heritage conservation and sustainable tourism development.

Objectives

1. To study and understand tourists' AR tourism quality, tourist experience, and behavioral intentions while virtually exploring the Mogao Caves.
2. To analyze the stimulating factors that influence tourists' experiences and behavioral intentions of the AR tourism of Mogao Caves.

Literature review

1. SOR Theory

The SOR theory, or Stimulus-Organism-Response theory, is a psychological framework (Mehrabian & Russell, 1974) used to understand consumer behavior by examining how external stimuli (S) affect internal psychological processes (O), ultimately leading to behavioral responses (R)(Li, 2022). It defines human behavior as a "stimulus-perception-response" process, where stimuli prompt individuals to act, their internal psychological state mediates these stimuli, and various behaviors or intentions are the responses(Elaine et al., 1997).

This study employs the SOR theory to investigate the impact of AR tourism at the Mogao Caves on tourists' experiences and behavioral intentions. To achieve this, a conceptual model was constructed, categorizing relevant variables into three dimensions: AR tourism stimulation, internal psychological influence, and behavioral response. Within the AR tourism stimulation dimension, factors such as content quality, system quality, and interaction quality are examined. The internal psychological influence dimension focuses on tourists' emotional, recreational, and cultural states formed during the tourism process. Finally, the behavioral response dimension emphasizes tourists' intentions regarding stay, revisit, recommendation, and premium payment.

2. Stimulus Factor

The "stimuli" refers to environmental signals influencing an individual's mental state (Jung et al., 2021). In the context of tourist decision-making, a stimulus is an external factor propelling tourists to

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formulate travel intentions. AR provides unprecedented sensory stimulation for tourists through immersive and interactive experiences(Chunhui et al., 2022).

Previous studies have identified content quality as a key factor influencing stimuli in AR tourism(Liu et al., 2023). High-quality content leads to positive experiences, while low-quality content results in negative perceptions. In AR tourism, system quality is crucial for determining the effectiveness of user experience and their willingness to engage(Guo et al., 2024). Recent literature suggests that in the field of AR tourism, interaction quality is a key determinant of user satisfaction, making it a crucial stimulus variable in the SOR model(Bird et al., 2023).

This study recognizes the interdependence among these factors and categorizes the stimulation process into three distinct variables: content quality, system quality, and interactive quality.

2.1 Content Quality

Content quality is defined as information that adds value and is perceived as meaningful and useful by the target audience(Arif et al., 2020). In the tourism industry, content quality plays a crucial role in shaping the tourism experience. The Mogao Caves leverage high-quality smart tourism technology to enrich AR tourism content, thereby enhancing tourism efficiency(Su et al., 2023).

In this study, content quality refers to the information presented, visual effects, and the authenticity of perception within the AR tourism of Mogao Caves.

2.2 System Quality

The concept of system quality can be traced back to DeLone and McLean's Information System Success Model. Information and system quality are two crucial constructs. Scholars consider information quality as representative of the product or service, while system quality refers to the technical aspect. Both can be viewed as environmental stimuli(Yen et al., 2018). In cultural heritage museums, interactivity, as part of AR's unique attributes, is an important factor in how digital technology influences user experience perception(Nikhashemi et al., 2021).

In this study, system quality is defined as the technical performance of the Mogao Caves AR tourism system, including application stability, user-friendliness, and performance responsiveness, among others.

2.3 Interactive Quality

Interaction is the psychological state that users undergo during the entire process of engaging with a digital interface or system (Park et al., 2020). Interaction quality refers to the effectiveness and efficiency of user engagement with a digital interface or system, encompassing aspects such as responsiveness, intuitiveness, and satisfaction(Pelau et al., 2021). Interaction is a widely recognized factor in AR and VR tourism research(Jiang et al., 2023).

In this study, interactive quality refers to how effectively the AR tourism experience at Mogao Caves enables users to engage with its content and features. It includes the flexibility for users to customize their interactions in real time, enhancing personalization and involvement within the AR environment.

3. Tourist Experience

Tourism experience refers to the feelings of tourists affected by the environment, products, services, other tourists, or other factors(Zhang et al., 2023). AR technology has fundamentally transformed the way tourists experience tourism-related products and services(Roodposhti et al., 2024). AR tourism products encompass sensory experiences, cognitive experiences, operational experiences, and emotional experiences(Lv et al., 2020).

In this study, the tourism experience is defined as tourists' perceptions, emotions, and cognitive expressions during their visit to the Mogao Caves. This experience is divided into three dimensions: emotional experience, cultural experience, and leisure experience.

3.1 Emotional Experience

Emotional experience is defined as an individual's psychological response to meaningful events(Vishkin et al., 2023). When emotional experience occurs as a contextual response to value-related stimuli, core values can be seen as antecedents of emotional intensity(Conte et al., 2023). Increasingly, immersive technologies are being adopted in museum tourism to evoke visitors' emotional resonance and historical associations with the authenticity of exhibited artifacts(Bosman et al., 2023).

In this study, tourists' emotional experiences act in the mediating role of the SOR model. The emotional experience is defined as the emotions and feelings that tourists experience when participating in AR tourism activities in Mogao Caves.

3.2 Leisure Experience

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Leisure experience is defined as the subjective feelings and psychological states individuals acquire during leisure activities(Hosany et al., 2022). In leisure tourism, engaging in AR tourism destination experiences, such as scenes, cuisine, souvenirs, or festivals, enhances the leisure travel experience for online tourists by utilizing AR(Huang, 2021).

In this study, leisure experience is defined as the sensations and experiences tourists acquire while touring the Mogao Caves, particularly those obtained through interactions with tourist attractions and activities using AR technology during the travel process.

3.3 Cultural Experience

Cultural experience refers to tourists experiencing different cultures within the cultural connotations of tourist attractions or other elements to meet their cultural needs or obtain self-identity(Zhang et al., 2023). Tourists actively shape cultural experiences through "gazing," emphasizing their role as participants rather than passive observers(Shiqing et al., 2021).

In this study, cultural experience is defined as the process through which tourists, utilizing AR technology, perceive, engage, and immerse themselves in the unique culture and history of the Mogao Caves during their visits and explorations.

4. Behavior Intention

Behavioral intention refers to the degree of willingness or inclination of individuals to adopt specific behaviors in a given context(Siribowonphitak, 2024). In the literature on tourism destinations, behavioral intention is often described as the intention to revisit and recommend(Kaur et al., 2020). AR technology provides users with immersive interactive experiences, influencing user immersion and Premium payment(Tu et al., 2024). Smart tourism technologies such as AR and gamified sightseeing enhance tourist satisfaction and intention to revisit(Torabi et al., 2022).

In this study, behavioral intention is defined as the intentions or inclinations displayed by tourists after their AR tourism experience at the Mogao Caves, including their intentions to stay longer, revisit, recommend, and express a willingness to make premium payments.

4.1 Stay Intention

Staying intention refers to tourists' willingness to extend their stay or visit time at a specific destination, serving as a positive indicator of their satisfaction with the destination and their level of engagement with local attractions, culture, and experiences(Adruce et al., 2021). In Mogao Caves, AR technology enables tourists to clearly and thoroughly appreciate the caves and murals, enhancing their willingness to explore Dunhuang and extend their stay(Li et al., 2024).

In this study, stay intention is defined as the intention or desire of tourists to extend their stay at the destination after the conclusion of their AR tourism experience in the Mogao Caves.

4.2 Revisit Intention

Revisit intention refers to the likelihood of tourists engaging in repetitive activities or revisiting a destination(Purnama et al., 2023). It serves as a crucial indicator for measuring tourist loyalty. In the context of tourism, revisit intention reflects the degree of satisfaction and attachment that tourists have towards a destination(Rahmawati et al., 2024).

In this study, revisit intention is defined as tourists' positive intentions and expectations to revisit the Mogao Caves. This signifies that tourists wish to spend more time exploring, appreciating, and engaging in local culture and attractions at the Mogao Caves.

4.3 Recommendation Intention

Recommendation intention is defined as the inclination to encourage others to use services or products based on one's own positive experiences, reflecting satisfaction and loyalty(Prayag et al., 2017). When tourists experience richer and more immersive experiences through AR technology, they are more likely to recommend the destination or experience to others(Ahmad et al., 2023).

In this study, recommendation intention is defined as the extent to which tourists, after experiencing the Mogao Caves AR tourism, are willing to recommend this innovative way of touring to others.

4.4 Premium payment Intention

The premium payment intention, also known as "premium payment willingness," or "extra payment willingness," refers to the extent to which consumers are willing to pay an additional fee for a particular product or service(Kovacs et al., 2022). In the tourism industry, AR serves as a medium that provides tourists with a richer, more immersive experience. This experience extends from tourists' satisfaction to their willingness to pay a premium(Zhang et al., 2022).

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In this study, premium payment intention is defined as the extent to which tourists are willing to pay a higher price, following their experience of AR tourism at the Mogao Caves, to re-experience this innovative form of travel.

In summary, while existing literature sheds light on SOR theory, stimulus factors, tourism experiences, and behavioral intentions, certain gaps persist. Studies often narrowly focus on AR's application in tourism and overlook deeper investigations into AR tourism quality and behavioral intentions, particularly in the context of specific cultural heritage sites like the Mogao Caves. This study aims to bridge these gaps by thoroughly examining the influence of AR tourism quality on tourist experiences at the Mogao Caves and the subsequent impact on behavioral intentions. Analyzing stimulus factors affecting AR tourism experiences and intentions will provide valuable insights for developing AR tourism at cultural heritage destinations like the Mogao Caves, thus promoting their sustainable development and heritage conservation.

Conceptual Framework

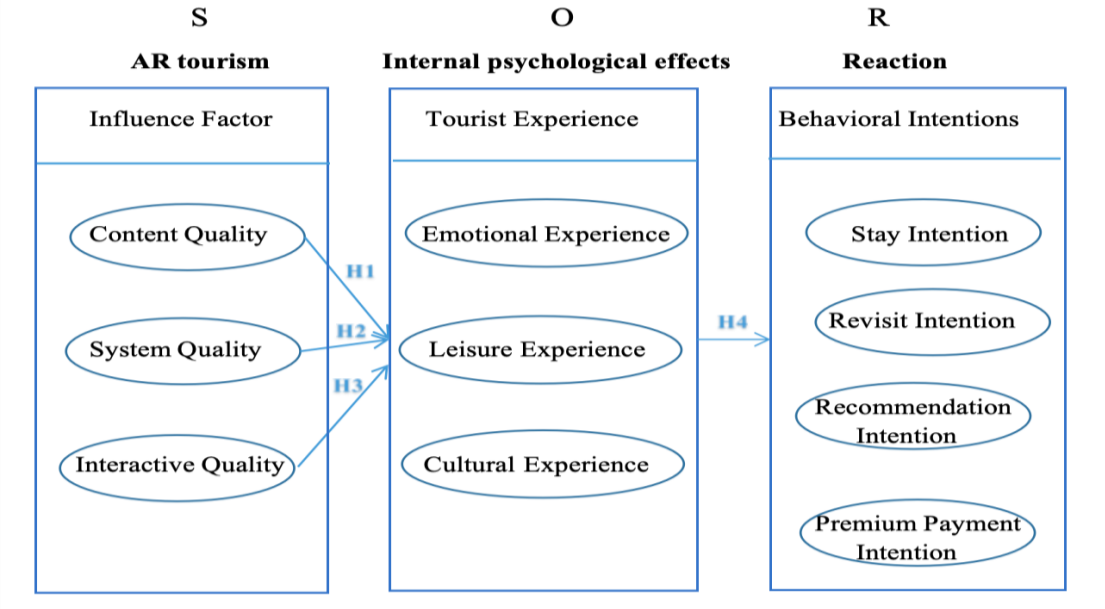

Figure 1 Conceptual Framework

This study utilizes the SOR theory to explore how tourists' AR experiences at the Mogao Caves influence their behavioral intentions. AR tourism serves as the stimulus (S), with its content quality, system quality, and interactive quality directly influencing tourists' perceptions and experiences (O). Ultimately leading to tourist behavioral intention (R). These experiences encompass psychological states and cognitive evaluations, such as emotions, cognitions, and attitudes. Positive emotional responses, relaxation, and cultural inspiration during AR tourism can positively influence tourists' intentions to stay, revisit, recommend, or pay a premium. High-quality AR content offers richer experiences, enhancing engagement and satisfaction (Agustini et al., 2023; Cheng et al., 2023). The stability and usability of AR technology are crucial for enhancing tourist experiences. Stable, user-friendly, and aesthetically pleasing system designs can increase tourists' willingness to use and satisfaction, thereby positively influencing tourism experiences(Anand et al., 2023; Jiang et al., 2023). Additionally, robust interactive features can facilitate the integration of tourists with the virtual environment, enhancing immersion and engagement, thus enhancing tourism experiences (Ahmad et al., 2023; Su et al., 2023). Based on these findings, this study adopts a quantitative assessment approach and proposes the following hypotheses:

H1: The content quality of AR tourism positively influences the tourist experience.

H2: The system quality of AR tourism positively influences the tourist experience.

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H3: The interactive quality of AR tourism positively influences the tourist experience.

H4: Tourist experience influences behavioral intentions.

These hypotheses are proposed to explore the complex relationship between various aspects of AR tourism quality and tourists' experiences and behavioral intentions. While the SOR framework provides a solid theoretical basis for understanding these relationships and proposes relevant hypotheses, attention should still be paid to potential limitations such as the availability of AR technology, homogeneity of tourist experiences, and the generalizability of the study results.

Methodology

This study aims to analyze of tourist experience and behavior intention of the AR tourism of Mogao Caves. The research methodology for the research is quantitative survey research. Because it is suitable for achieving the research objectives and effectively addressing the research questions and hypotheses. Quantitative survey research allows for the collection of standardized data from a large sample size, ensuring objectivity in data collection and analysis, as well as consistency in the measurement of variables across respondents. The quantitative nature of survey data enables hypothesis testing, pattern identification, and statistical inference about the relationships between variables, providing the potential to generalize study results to a broader population beyond the specific sample studied.

Population and sample

Population: Chinese tourists who have visited the Mogao Caves of Dunhuang, have prior experience with AR, and are at least 18 years old constitute the research population.

Sample: This study utilizes convenience sampling due to its efficiency in quickly gathering data from a representative subset of the research population. Given the high tourist volume and transient nature of visits at the Mogao Caves, convenience sampling allows for flexible data collection from diverse individuals without extensive pre-planning. However, it may lead to sample bias as participants are selected based on availability and willingness, potentially excluding certain demographics. Despite these limitations, convenience sampling was chosen for its practicality and feasibility. Compared to other sampling techniques like random or stratified sampling, which require more resources and time, convenience sampling can more effectively collect sufficient data to address the research questions.

According to the Taro Yamane's formula, the following steps were taken to calculate the sample size:

$$\text{Formula: } n = \frac{N}{1+N(e)^2}$$

Determine the total number of visitors with AR experience (5 million). Where "n" is the sample size. "N" is the population size, and " e " is the level of precision or sampling of error.

Substituting into the equation:

$$n \approx \frac{5000000}{1+5000000\times 0.05^2}$$

As a result, the sample size of this study is 400.

Research Instruments

1. Literature analysis. Definition of research concepts and questions from the perspectives of SOR theory, tourism experience, behavioral intention, Dunhuang AR tourism, and related studies. By reviewing the development trajectory of AR technology, its application in the tourism industry, and academic research related to AR in the tourism industry, explore the concept of AR tourism. Then, review the origin, concept, characteristics, and application fields of the SOR theory, provide an overview and in-depth analysis of variables such as stimulus factors, tourism experience, and behavioral intention, conceptualize the relationships between these variables, and guide questionnaire construction based on research objectives and theoretical frameworks.

2. Questionnaire Design. The questionnaire underwent validation by an advisor, who reviewed the initial draft to assess its structure, clarity, and alignment with research objectives and the theoretical framework. Items were revised to better capture intended constructs, ensuring clarity and comprehension. Ambiguous or confusing items were clarified, and adjustments were made to the questionnaire structure. It was divided into four sections, ensuring relevance to research objectives and the theoretical framework.

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The choice of a 5-point Likert scale was confirmed by the advisor. After multiple rounds of feedback and revisions, the questionnaire comprised four sections with 28 items, each rated on a 5-point Likert scale, covering various aspects related to research objectives and the theoretical framework.

3. The Index of Consistency (IOC) test. The research questionnaires underwent content validity examination by three experts. The first expert, a professor in tourism development management, ensured the precise alignment of questions with research themes and objectives. The second expert, a psychology professor, assessed the questionnaire's ability to capture psychological activities accurately, enhancing content validity and reliability. The third expert, specializing in tourism marketing and risk management, offered a unique perspective on questionnaire design. Following the experts' review, the questionnaire achieved an IOC>0.7, indicating strong alignment with the research content and objectives. Thus, the questionnaire is deemed suitable for data collection, providing reliable support for subsequent research.

4. Reliability test. To ensure the reliability of the questionnaire, internal consistency reliability was adopted. After the careful review and suggestions of three experts, the questionnaire underwent targeted modifications primarily focusing on enhancing the clarity of question expressions and logical coherence. Subsequently, a preliminary test of the survey questionnaire was conducted with 30 tourists outside the sample size of 400. The data was collected through on-site surveys at tourist attractions to ensure sample diversity and representativeness. The Cronbach's α coefficient was utilized as an indicator of the reliability of the scale. As shown in Table 1, the Cronbach's α coefficient was 0.974, exceeding 0.7. Therefore, the survey questionnaire was deemed reliable.

Table 1 Cronbach's Alpha for All Constructs

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.974	0.978	23

Data collection

This survey adopted an offline approach to ensure access to rich and comprehensive information. The survey form was distributed through face-to-face interactions on WeChat, a widely popular social media platform in China, with links to the digital Dunhuang website. This approach allowed users to provide feedback after experiencing "Cloud Tour Dunhuang" and "Digital Dunhuang Immersion Exhibition." Efforts were made to conduct the survey efficiently while allowing participants enough time to provide thoughtful responses. Throughout the data collection process, ethical principles were followed. Participants were provided with detailed explanations of the survey's purpose and assured of the strict confidentiality of their personal information and survey responses. Their full understanding and consent to participate in the survey were ensured. However, the face-to-face WeChat distribution method may introduce demographic biases among users, potentially limiting the diversity of the respondent pool. Therefore, surveys were conducted at different locations in this study to attract various participants, aiming to mitigate these limitations.

Data Analysis

The basic statistical data for this study includes mean values, percentages, frequencies, and standard deviations. All completed questionnaires were collected and analyzed using the SPSS software. The analysis process of data was as follows:

1. Personal Data. Frequency and percentage analysis were used to analyze Respondents' involvement in variables such as gender, age, occupation, education level, and region. To reduce the limitations of convenience sampling's lack of representativeness, it is necessary to ensure the diversity and comprehensiveness of the sampling process. This involved covering tourists from various age groups, genders, occupations, and education levels as much as possible.

2. Questionnaire Data. To calculate the tourists' experiences and behavioral intentions towards the AR tourism of the Mogao Caves in Dunhuang from the four sections of the questionnaire, the results were described using mean and standard deviation (S.D.). Calculate the average value of each question. Although

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questionnaire surveys are a commonly used research method, their results only reflect the viewpoints and attitudes of respondents at specific points in time, unable to capture their dynamic changes. To address this potential limitation, plans are in place for follow-up longitudinal surveys. Tracking changes in the viewpoints and attitudes of the same group of tourists multiple times to accurately assess the impact of AR tourism on tourists and its long-term effects.

3. Structural Model Evaluation. This study utilizes structural equation modeling (SEM) to analyze tourists' experiences and behavioral intentions in AR tourism at the Mogao Caves in Dunhuang. SEM enables the examination of mediating effects between variables and path analysis to test these effects, revealing both direct and indirect influences among variables. By validating research hypotheses and determining the model's structure, SEM offers a comprehensive evaluation of complex relationships among variables. SPSS software is employed for robust data analysis, capable of handling various data types and producing accurate statistical results. The combination of SEM and SPSS facilitates the evaluation of model fit and alleviates issues of multicollinearity between variables. Table 2 outlines the evaluation steps for the structural model.

Table 2 Structural Model Evaluation

Step	Evaluation Content	Evaluating Indicator	Evaluation Criterion
1	Structural Model Assessment	Outer Model Equation	To assess the reliability and validity of the measurement variables.
		Inner Model Equation	To test hypotheses about the relationships between latent variables.
2	Measurement model evaluation Formative Indicators	Convergent Validity	The larger the redundancy value, the higher the modulus. The better the overall predictive ability of the model.
		Multicollinearity	Variance Inflation Factor (VIF) >1.
		Item Significance	Bootstrapping. 5% level, T>1.96.
3	Measurement model evaluation Reflective Indicators	Indicator Reliability	Cronbach's alpha, CA>=0.7
		Convergent Validity	AVE>0.5
		Discriminant Validity	Fornell-Larcker criterion.
		Cross Loadings	The load factor must be lower than the observed variable and its corresponding latent variable.
4	Inner Model Evaluation	R^2	R^2>=0.67 is better, 0.33 Moderate, < 0.19 Poor.
		Q^2	Q^2>0, has a predictive correlation. Q^2<0, the model lacks predictive correlation. Q^2>=0.35 is relatively large, 0.15 is moderate, and <0.02 is very small.
		f^2	>=0.35 is relatively large, 0.15 is moderate, <0.02 is very small.
		Effect Analysis	The indirect impact is obtained by multiplying the coefficients of each path, Total effect= direct effect + indirect effect.
5	Interpret the results	Path Coefficients and Significance Levels	P<0.05, T-statistic>1.96.

Results

The main purpose of this study is to investigate the factors influencing tourists' travel experience and behavioral intentions in augmented reality tourism at the Mogao Caves Heritage. To achieve this, the study employed a comprehensive set of analytical tools. Descriptive statistics were used to assess the basic characteristics of variables, while structural equation modeling was utilized to explore the underlying relationships and pathways of influence among variables. Ultimately, these tests provided valuable insights

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and confirmed the importance of AR tourism stimulus factors in shaping tourist experiences and behavioral intentions.

Descriptive Statistics

The sample demographics exhibit a balanced gender distribution, with men comprising 49.75% and women 50.25%. The largest age group is 26-35 years old (32%), indicating heightened interest in emerging technologies like AR during this career and family development stage. Participants mostly hold associate or bachelor's degrees (32.5%, 29.5%), suggesting a deeper understanding of AR tourism. A significant portion is employed by private companies or in professional roles (31.25%, 23%), potentially indicating a willingness to invest in tourism experiences. Geographically, the northwest region has the highest representation (36%), It is crucial to consider the differences in regional culture, economic development level, and tourism resources when interpreting and summarizing research results.

Analysis reveals positive responses across all four questionnaire components, with average scores ranging from 3.915 to 4.282. This indicates excellence in design, stability, engagement, and emotional experience, fostering rich, seamless, and enjoyable AR tourism experiences at the Mogao Caves. Although slight variations exist in leisure and cultural experiences, tourists demonstrate a strong willingness to stay, revisit, recommend, and pay for AR tourism, with satisfaction scores exceeding 4 points. Despite outliers suggesting areas for improvement like technical issues or content appeal, overall feedback underscores tourists' positive attitudes toward AR tourism at the Mogao Caves, offering insights for further enhancement.

Table 3 Descriptive statistical analysis of various variable items

Variables		Items	N	Mean	Standard Deviations	Cronbach's α
SOR	Content Quality	A1	400	4.215	1.145	0.917
		A2	400	4.282	1.177	
		A3	400	4.058	1.092	
	System Quality	B1	400	4.235	1.17	0.922
		B2	400	4.157	1.209	
		B3	400	4.178	1.21	
	Interaction Quality	C1	400	4.018	1.166	0.896
		C2	400	4.067	1.201	
		C3	400	4.103	1.151	
Tourist Experience	Emotional Experience	D1	400	4.205	1.158	0.914
		D2	400	4.247	1.133	
		D3	400	4.053	1.128	
	Leisure Experience	E1	400	3.998	1.129	0.893
		E2	400	3.953	1.206	
		E3	400	3.985	1.117	
	Cultural Experience	F1	400	4.005	1.137	0.902
		F2	400	4.12	1.22	
		F3	400	4.095	1.174	
Tourist Behavioral Intention	Stay Intention	G1	400	4.005	1.128	
	Revisit Intention	G2	400	3.993	1.19	
	Recommendation	G3	400	4.043	1.115	
	Premium Payment Intention	G4	400	3.915	1.037	
Tourist satisfaction		Q1	400	4.152	1.026	0.912

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Reliability Analysis

The reliability of the questionnaire indicates the consistency of measurements. Cronbach'sα coefficient is commonly used as an indicator of the reliability of measurement scales. When the α coefficient is high, it indicates that the items in the questionnaire are strongly correlated when measuring the same concept, less susceptible to random errors, and accurately reflect the true situation of the respondents. This enhances the credibility of the study and provides strong support for subsequent analysis. As shown in Table 3, the Cronbach'sα coefficients are 0.917, 0.922, 0.896, 0.914, 0.893, 0.902, and 0.912, all of which exceed 0.7. This indicates that the scale has high reliability and can be used for subsequent analysis.

Validity Analysis

The questionnaire's validity reflects the accuracy and authenticity of the model. Higher validity is achieved when the measurement results are more consistent with the investigated content; otherwise, validity is lower. In this study, exploratory factor analysis (EFA) was employed to examine the validity of the questionnaire items. Through this approach, the inherent relationships between various questions in the questionnaire can be identified, and it can be determined whether they effectively measure the expected concepts or dimensions. The results of this study indicate a clear and reasonable factor structure of the questionnaire, with good discriminant validity between various factors.

Table 4 KMO and Bartlett sphere tests

KMO ·		0.943
Bartlett sphericity test	Approximate chi-squared value	7397.080
	df	231
	P Value	0.000

KMO and Bartlett's tests were conducted for each variable. The KMO result is 0.943, indicating good sample adequacy. Bartlett's test yielded a chi-squared value of 7397.080 with $p<0.001$, suggesting correlated factors among variables. The factor loadings are shown in Table 5.

Table 5 Table of factor load coefficients after rotation

Variables and Measurement Items			**Factor loading coefficient**						
			F1	F2	F3	F4	F5	F6	F7
S-O-R Theory	1. Content Quality	Q 1.1	0.208	0.827	0.158	0.177	0.152	0.200	0.178
		Q 1.2	0.197	0.765	0.259	0.186	0.220	0.181	0.244
		Q 1.3	0.215	0.789	0.209	0.189	0.212	0.167	0.148
	2. System Quality	Q 2.1	0.245	0.159	0.136	0.809	0.208	0.216	0.157
		Q 2.2	0.238	0.154	0.251	0.804	0.176	0.216	0.099
		Q 2.3	0.251	0.256	0.203	0.779	0.130	0.152	0.232
	3. Interactive Quality	Q 3.1	0.189	0.189	0.148	0.213	0.172	0.181	0.802
		Q 3.2	0.194	0.121	0.208	0.116	0.211	0.114	0.817
		Q 3.3	0.229	0.242	0.212	0.124	0.164	0.252	0.755
Tourist Experience	1. Emotional Experience	Q 1.1	0.198	0.224	0.196	0.193	0.767	0.258	0.209
		Q 1.2	0.206	0.206	0.220	0.156	0.790	0.165	0.228
		Q 1.3	0.222	0.148	0.134	0.159	0.832	0.161	0.145
	2. Leisure Experience	Q 2.1	0.256	0.143	0.173	0.216	0.173	0.781	0.180
		Q 2.2	0.175	0.201	0.160	0.141	0.173	0.811	0.136
		Q 2.3	0.239	0.174	0.125	0.205	0.203	0.772	0.212
		Q 3.1	0.205	0.199	0.791	0.190	0.201	0.134	0.190

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Variables and Measurement Items			Factor loading coefficient						
			F1	F2	F3	F4	F5	F6	F7
	3. Cultural Experience	Q 3.2	0.172	0.189	0.772	0.175	0.219	0.229	0.203
		Q 3.3	0.238	0.201	0.812	0.190	0.117	0.115	0.180
Behavioral Intentions	1. Stay Intention	Q 1.1	0.768	0.175	0.184	0.212	0.174	0.202	0.122
	2. Revisit	Q 2.1	0.780	0.162	0.167	0.238	0.197	0.158	0.194
	3.	Q 3.1	0.747	0.193	0.188	0.208	0.170	0.178	0.224
	4. Premium	Q 4.1	0.791	0.156	0.163	0.138	0.162	0.215	0.166
Eigenvalue (before rotation)			11.531	1.378	1.249	1.168	1.100	1.058	1.003
Explanation rate of variance% (before rotation)			52.415%	6.264%	5.675%	5.311%	5.000%	4.808%	4.558%
Cumulative variance interpretation rate% (before rotation)			52.415%	58.679%	64.354%	69.665%	74.666%	79.474%	84.031%
Eigenvalue (after rotation)			3.226	2.555	2.549	2.545	2.539	2.537	2.535
Explanation rate of variance% (after rotation)			14.666%	11.612%	11.588%	11.569%	11.542%	11.531%	11.525%
Accumulated variance interpretation rate% (after rotation)			14.666%	26.278%	37.865%	49.434%	60.976%	72.507%	84.031%
KMO value			0.943						
Bartlett sphericity value			7397.080						
df			231						
P value			0.000						

Factor analysis is employed to explore the underlying structure among variables. By rotating the factor loading matrix, this study categorizes the data into seven factors based on the magnitude of factor loading coefficients and the practical significance of variables. Factor 1 represents tourist behavioral intentions, encompassing four variables related to tourists' willingness and loyalty toward AR tourism experiences. Factor 2 signifies content quality, influencing tourists' overall evaluation of AR tourism experiences. Factor 3 represents cultural experience, focusing on tourists' cultural perceptions during AR tourism. Factor 4 denotes system quality, measuring the stability and reliability of AR tourism systems. Factor 5 represents emotional experience, encompassing feelings of pleasure and immersion. Factor 6 represents leisure experience, particularly significant for tourists seeking relaxation. Factor 7 represents interactive experience, evaluating the degree of interaction between tourists and AR tourism content. The cumulative variance is 84.031%, indicating a high explanatory power. It suggests that the extracted factors adequately represent the original data. Moreover, all factor loadings exceed 0.5, indicating good questionnaire validity and providing a solid foundation for subsequent analysis and discussion.

Structural Model Evaluation

This study utilizes the Partial Least Squares (PLS) method and Smart PLS software to evaluate the structural equation model. Figure 2 shows the Model of tourist experience and behavior intention of the AR tourism of Mogao Caves in China. The results of various indices indicate that the model adequately fits the data overall, capable of explaining the complex relationship between tourists' experiences and behavioral intentions.

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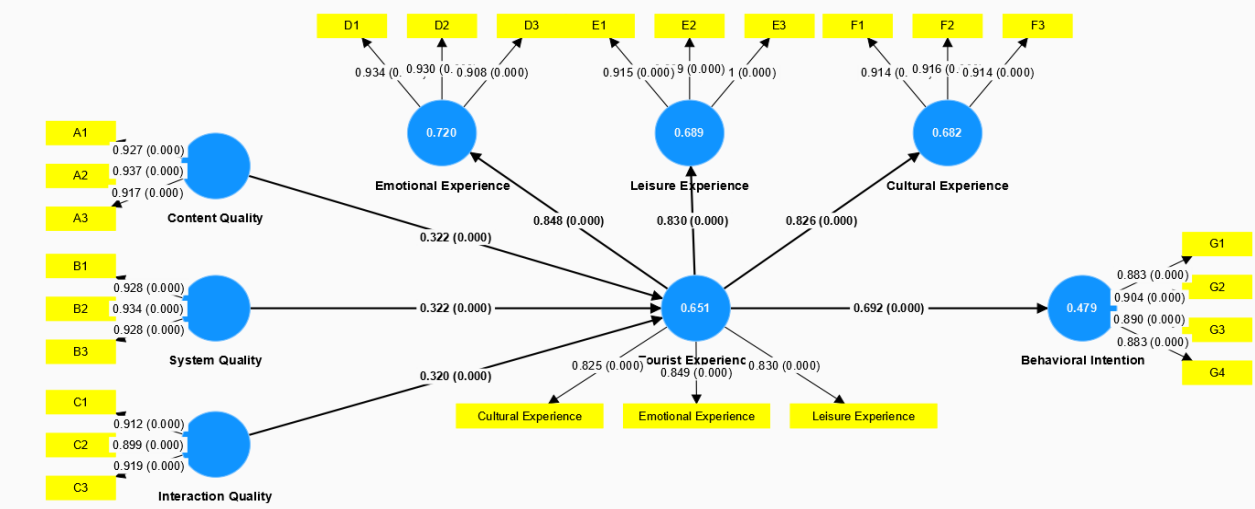

Figure 2 PLS-SEM Model of tourist experience and behavior intention of the AR tourism of Mogao Caves in China

Convergent Validity

When measuring relationships, the absolute values of standardized loadings are all greater than 0.6 and exhibit significance, indicating a strong measurement relationship. As shown in Table 6, from the perspective of AVE and CR values, it can be observed that the AVE of each factor is greater than 0.5, and the CR value is greater than 0.7, indicating high convergent validity.

Table 6 Measurement Model Summary

Variables	Factor Loading	Cronbach's α	CR	AVE
A1 <- A Content Quality	0.927	0.918	0.921	0.859
A2 <- A Content Quality	0.937			
A3 <- A Content Quality	0.917			
B1 <- B System Quality	0.928	0.922	0.922	0.865
B2 <- B System Quality	0.934			
B3 <- B System Quality	0.928			
C1 <- C Interaction Quality	0.912	0.896	0.900	0.828
C2 <- C Interaction Quality	0.899			
C3 <- C Interaction Quality	0.919			
D1 <- D Emotional Experience	0.934	0.914	0.917	0.854
D2 <- D Emotional Experience	0.93			
D3 <- D Emotional Experience	0.908			
E1 <- E Leisure Experience	0.915	0.894	0.895	0.825
E2 <- E Leisure Experience	0.899			
E3 <- E Leisure Experience	0.911			
F1 <- F Cultural Experience	0.914	0.902	0.904	0.837
F2 <- F Cultural Experience	0.916			
F3 <- F Cultural Experience	0.914			
D Emotional Experience <- G Tourist	0.849	0.782	0.782	0.697
E Leisure Experience <- G Tourist Experience	0.83			

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Variables	Factor Loading	Cronbach's α	CR	AVE
F Cultural Experience <- G Tourist Experience	0.825			
G1 <- H Behavioral Intention	0.883			
G2 <- H Behavioral Intention	0.904	0.913	0.913	0.793
G3 <- H Behavioral Intention	0.89			
G4 <- H Behavioral Intention	0.883			

Significance Analysis

The significance analysis via bootstrapping reveals that the path from tourist experience to behavioral intention is statistically significant ($p < 0.05$), supporting hypothesis H4. This suggests that tourists' experiences during AR tourism at the Mogao Caves positively impact their behavioral intentions, such as revisiting or recommending. This finding aligns with the SOR theory, highlighting the importance of providing high-quality AR tourism experiences to enhance behavioral intentions. The significance testing results offer theoretical insights and practical implications for destination management and tourism development, emphasizing the pivotal role of tourist experiences in driving favorable behavioral intentions in the context of AR tourism at the Mogao Caves.

Table 7 Structural equation model coefficients

Items	β	STDEV	T	P
A Content Quality -> G Tourist Experience	0.322	0.052	6.216	0.000
B System Quality -> G Tourist Experience	0.322	0.048	6.696	0.000
C Interaction Quality -> G Tourist Experience	0.320	0.044	7.344	0.000
G Tourist Experience -> D Emotional Experience	0.848	0.021	40.220	0.000
G Tourist Experience -> E Leisure Experience	0.830	0.024	34.874	0.000
G Tourist Experience -> F Cultural Experience	0.826	0.023	35.620	0.000
G Tourist Experience -> H Behavioral Intention	0.692	0.042	16.401	0.000

Discriminant Validity

According to the Fornell-Larcker criterion, if the square root of the AVE for each variable on the diagonal exceeds the correlation coefficients between the corresponding variables, it indicates good discriminant validity. In Table 8, the square root of the AVE scores on the diagonal exceeds the off-diagonal values, confirming discriminant validity. Similarly, other variables demonstrate sufficient differentiation. These results show that each variable effectively distinguishes from others, enhancing the reliability and validity of the research.

Table 8 Results of the discriminant validity test

Variables	A Content Quality	B System Quality	C Interaction Quality	D Emotional Quality	E Leisure Experience	F Cultural Experience	H Behavioral Intention
A	**0.927**						
B	0.567	**0.930**					
C	0.566	0.518	**0.910**				
D	0.578	0.542	0.564	**0.924**			
E	0.550	0.568	0.547	0.565	**0.908**		
F	0.589	0.568	0.564	0.556	0.515	**0.915**	
H	0.571	0.616	0.567	0.573	0.591	0.568	**0.890**

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Cross Loadings

The cross-loading matrix reveals how latent variables explain themselves and other measured variables. Bold letter combinations typically indicate a strong association between measured variables and their corresponding latent variables. Table 9 shows factors with high loadings are indeed correlated with their respective measured items, supporting discriminant validity.

Table 9 Cross-loading analysis scale

Items	A	B	C	D	E	F	H
A1	**0.927**	0.510	0.503	0.500	0.506	0.503	0.518
A2	**0.937**	0.543	0.572	0.567	0.526	0.592	0.542
A3	**0.917**	0.522	0.495	0.536	0.496	0.537	0.526
B1	0.505	**0.928**	0.470	0.517	0.538	0.488	0.569
B2	0.505	**0.934**	0.443	0.502	0.534	0.552	0.566
B3	0.573	**0.928**	0.532	0.492	0.513	0.545	0.585
C1	0.515	0.504	**0.912**	0.509	0.498	0.493	0.510
C2	0.460	0.428	**0.899**	0.505	0.436	0.501	0.486
C3	0.565	0.479	**0.919**	0.525	0.553	0.544	0.548
D1	0.571	0.535	0.549	**0.934**	0.576	0.540	0.547
D2	0.547	0.498	0.545	**0.930**	0.508	0.540	0.534
D3	0.479	0.465	0.465	**0.908**	0.477	0.456	0.506
E1	0.493	0.540	0.507	0.515	**0.915**	0.487	0.563
E2	0.494	0.473	0.456	0.490	**0.899**	0.450	0.491
E3	0.512	0.534	0.526	0.533	**0.911**	0.465	0.554
F1	0.541	0.523	0.517	0.518	0.457	**0.914**	0.520
F2	0.544	0.523	0.531	0.541	0.517	**0.916**	0.512
F3	0.530	0.513	0.499	0.463	0.436	**0.914**	0.527
G1	0.505	0.553	0.474	0.504	0.529	0.503	**0.883**
G2	0.512	0.576	0.519	0.529	0.519	0.510	**0.904**
G3	0.530	0.560	0.538	0.519	0.530	0.524	**0.890**
G4	0.487	0.505	0.486	0.487	0.525	0.485	**0.883**

Structural Model

To determine the importance of value and coefficient paths, the structural model is evaluated through R^2, Q^2, and f^2. The R^2 values for tourist experience and behavioral intention are 65.1% and 47.7%, respectively, indicating strong explanatory power. Q^2 values for tourist experience and behavioral intention are 0.446 and 0.373, suggesting the model explains 44.6% and 37.3% of the variance, with slightly higher predictive ability for tourist experience. Tourists' experience moderately influences quality factors, indicating a significant impact of behavioral intention on tourist experience.

Table 10 Structural model evaluation results

Variables	R^2	R^2 adjusted	SSO	SSE	Q^2 (=1-SSE/SSO)
G Tourist Experience	0.651	0.648	1200	664.897	0.446
H Behavioral Intention	0.479	0.477	1600	1003.265	0.373

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Table 11 Effect Size (f^2)

Variables	G Tourist Experience	H Behavioral Intention
A Content Quality	0.171	
B System Quality	0.185	
C Interaction Quality	0.183	
G Tourist Experience		0.919

Model Path Analysis

This study used bootstrapping and Smart PLS software to calculate path coefficients, T-values, and P-values, validating research hypotheses by assessing causal connections between variables in the research model. Through empirical analysis of the factors influencing the Dunhuang Mogao Caves AR tourism experience, the following three causal influence paths were identified:

Path 1: Content quality → Tourist experience → Tourist behavioral intention

Path 2: System quality → Tourist experience → Tourist behavioral intention

Path 3: Interaction quality → Tourist experience → Tourist behavioral intention

Table 12 Intermediary testing

Items	Direct	STDEV	T	P	Lower	Upper
A Content Quality -> G Tourist Experience -	0.223	0.039	5.744	0.000	0.154	0.307
B System Quality -> G Tourist Experience -	0.223	0.037	6.006	0.000	0.162	0.312
C Interaction Quality-> G Tourist Experience -	0.222	0.034	6.604	0.000	0.163	0.297

Table 12 presents results from the mediation analysis on the effects of tourism experience (G) and behavioral intention (H). The analysis highlights significant and positive impacts of content quality (A), system quality (B), and interaction quality (C) on both tourism experience and behavioral intention.

Table 13 Results of hypotheses test

Hypothesized Relationship	β	T	P	Test
H1: The content quality of augmented reality tourism positively	0.223	5.744	0.000	Valid
H2: The system quality of augmented reality tourism positively	0.223	6.006	0.000	Valid
H3: The interactive quality of augmented reality tourism	0.222	6.604	0.000	Valid
H4: Tourist experience influences behavioral intentions.	0.602	16.401	0.000	Valid

The statistical results provide support for all hypotheses proposed in the study. The analysis confirms that content quality, system quality, and interaction quality of AR tourism positively influence the tourist experience, which, in turn, influences behavioral intentions. These findings align with the research hypotheses, suggesting that improving these aspects of AR tourism can enhance both tourist experience and behavioral intentions.

Discussion

The study confirms Hypothesis 1 (β=0.223, $p<0.001$, T=5.744), indicating the significant impact of content quality, system quality, and interaction quality on tourist experiences and behavioral intentions. Quality content in AR tourism attracts and motivates tourists, enriching their experiences by offering deeper insights into destinations' historical and cultural significance. This aligns with existing research, emphasizing content quality's importance in AR tourism (Chen et al., 2022; Mohanty et al., 2020). Recent studies support this link, reinforcing our findings on content quality's pivotal role in AR tourism(Jiang et

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al., 2023). The study provides empirical support for applying the SOR theory in heritage tourism, expanding its relevance to emerging technologies.

The analysis results (β=0.223, p<0.001, T=6.006) confirm Hypothesis 2, indicating the significance of system stability in enhancing the user experience. High-quality AR systems, characterized by excellent performance and responsiveness, positively influence tourist experiences and increase their intention to revisit (Fan et al., 2022; Trunfio et al., 2022). Furthermore, (Cheng et al., 2023) utilized the Information Systems Success Model and Immersion Theory to underscore how AR quality enhances customer tourism experiences, reaffirming the positive impact of high-tech devices like AR or VR on tourism quality.

The analysis results (β=0.222, p<0.001, T=6.604) validate Hypothesis 3, affirming that interaction quality directly impacts user experience in AR applications. AR technology in the cultural heritage of the Mogao Caves not only offers rich visual experiences but also enhances visitor interaction through high-quality design. Previous research supports this perspective(Chen et al., 2021), emphasizing that engaging in virtual environments increases personal immersion. This is in line with assertions by (Arghashi et al., 2022), highlighting the importance of AR applications in enhancing immersion through interaction triggers. Recent studies further indicate that AR fosters immersion, engagement, and enjoyment, promoting interaction and creating holistic user experiences (Barhorst et al., 2021; Dağ et al., 2023).

The path analysis reveals similar standardized coefficients for tourism experience across content quality, system quality, and interaction quality, with values of 0.223, 0.223, and 0.222 respectively. The corresponding T-values are 5.744, 6.006, and 6.604. However, the impact of tourism experience on behavioral intentions is highly significant, with a coefficient (β) of 0.602, a T-value of 16.401, and a P-value of 0.000. This validates Hypothesis 3, emphasizing the significant influence of tourist experience on behavior. Literature supports the idea that AR tourism enhances engagement and interaction, prompting interest in on-site visits (Ercan, 2020). The experiential value of AR tourism may be an essential premise for tourists' perception of destinations and their future visitation behavior(Zeng et al., 2022).

Although the findings of this study align with existing literature, indicating significant effects of content quality, system quality, and interaction quality on tourist experience and behavioral intentions, unexpected and divergent findings were discovered during the research process, stemming from limitations such as sample selection and cultural factors. This study focused on the AR tourism experience at the specific heritage site of the Mogao Caves, providing an in-depth analysis of this particular case, but potentially limiting the generalizability of the research results. Future studies could expand the sample size, encompass broader demographics and regions, and uncover the underlying mechanisms of cultural factors' potential influence on AR tourism experience and behavioral intentions.

Conclusion

The Mogao Caves along the Silk Road hold profound historical and cultural significance. The AR technology not only offers tourists a novel way to explore but also opens up new possibilities for the protection and inheritance of cultural heritage by bridging the gap between historical heritage and modern technology. This study aims to explore the quality of AR tourism, tourist experiences, and behavioral intentions when tourists virtually explore the Mogao Caves. It analyzes the stimulating factors affecting the tourist experience and behavioral intentions of AR tourism at the Mogao Caves. The research findings indicate that the quality of content, system, and interaction significantly positively influence the tourist experience and behavioral intentions of AR tourism. While this study offers valuable insights into AR tourism at the Mogao Caves, its focus on this specific site may limit its broader applicability. Additionally, individual and cultural differences, pivotal in shaping tourist experiences, warrant further exploration.

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Future research endeavors could mitigate these limitations by broadening sample scopes and employing qualitative methods for deeper insights.

In conclusion, this study delved into the application of AR technology in Mogao Caves tourism and its impact on tourist experiences and behavioral intentions, revealing the crucial role of content quality, system quality, and interaction quality in shaping tourist experiences. The insights garnered contribute to the advancement of tourism in Dunhuang, fostering a deeper understanding and appreciation of the unique cultural heritage of the Mogao Caves along the Silk Road. More importantly, the research findings highlight the immense potential of AR technology in cultural heritage protection and tourism development. Through AR technology, tourists can explore world cultural heritage sites in new ways, experiencing their profound historical and cultural heritage.

Recommendation

1. **Enhancing Cultural Depth and Innovating Cultural Value.** The Mogao Caves' cultural heritage encompasses art, religion, and history. AR displays should delve into its artistic significance, religious connotations, and historical value. Encouraging collaborative value creation fosters cultural innovation. Providing more interactive experiences through role-playing, gamification, or emotional storytelling encourages collaborative value creation with visitors, promoting cultural innovation.
2. **Enriching and enhancing the cognitive experience of AR tourism.** Collaborate with local communities and Destination Marketing Organizations (DMOs) to provide richer, more locally distinctive content for AR tourism. Work with cultural historians and archaeologists to ensure the accuracy and authenticity of AR content presentation. Enhance the narrative and educational value of AR experiences.
3. **Meet the individual needs of tourists.** Emphasize digital inclusivity to cater to the preferences and needs of diverse tourist groups. Design user-friendly interfaces, multilingual content, audio descriptions, tactile elements, and other features for people with disabilities, elderly individuals, and non-English speakers. Provide low-cost or free access options for economically disadvantaged tourists to ensure accessibility to AR experiences for all.
4. **Develop sustainable development strategies.** Provide training programs on the use and maintenance of AR technology for employees and the local community to ensure sustainable and effective enhancement of the tourist experience through AR. Establish continuous assessment and feedback mechanisms to evaluate the effectiveness of AR experiences. Recommend tourism enterprises and planners develop long-term visions and strategies to ensure that AR applications can continuously meet tourist demands and provide high-quality experiences.

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