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Quantitative Analysis of the Impact of Digital Transformation on Museum Management: Examining Visitor Satisfaction and Engagement through Augmented Reality (AR) and Virtual Exhibitions in the UK Art Museums

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Abstract

Introduction: Digital technologies such as AR and Virtual exhibitions are changing the art and cultural industry such as museums by impacting visitor engagement and satisfaction. In the UK, the museum sector represents a broad landscape due to the vast number of museums, in which these technologies are implemented to address the challenges of declining visitors and enhancing visitor satisfaction. Objective: This study purported to investigate the impact of AR and Virtual Exhibitions on visitor engagement and satisfaction in UK art museums. Methodology: A cross-sectional research design was employed, collecting data from 155 respondents through a structured questionnaire based on the Technology Acceptance Model (TAM). Results: The results revealed that AR and Virtual exhibitions have a positive impact on visitor engagement and satisfaction though moderated by factors such as technical usability, visitor demographics and museum types. Here, larger museums have more resources which demonstrates greater capacity to adopt digital transformation, while smaller museums may have to face resource constraints. Conclusion: In a nutshell, it can be said that AR and Virtual Exhibitions can enhance museum experiences and foster long-term visitor behaviours such as repeat visits and positive word of mouth. Hence, the hybrid model of museums us critical for museums to combine all the digital and physical experiences for diverse audiences.

Introduction

In recent years digital technologies such as Augmented Reality and Virtual Exhibitions have provided innovative ways to engage audiences which reshaped the cultural and heritage sectors. With the rapid transformation of digital technologies, digital tools such as Augmented reality and virtual exhibitions have transformed the cultural industry by changing visitors' experience (Khalil et al., 2023). These technologies emerged as an innovative way to enhance the visitors' experience by delivering immersive and interactive experiences that go beyond traditional displays. Through mobile devices, AR enables visitors to interact with objects in museum in the real time to access additional information and historical and artistic content related to that object (Paliokas et al., 2020). On the other hand, Virtual exhibitions eliminate geographical inhibitions by creating digitalised museum experiences which enable users to explore the artworks and artefacts digitally (Zidianakis et al., 2021). This shift toward the digital experience of museums was accelerated during COVID-19 as the pandemic restricted the physical access of museums which created the long-term trend toward embracing digital technologies for visitors' engagement and experience in museums.

The UK has a rich museum sector with almost 2500 museums across the country and 1800 of these are accredited (Museum Association, 2024). These institutions range from large national museums such as the British Museum and the National Gallery, to smaller regional and independent galleries. Museums in the UK are central to the cultural and educational fabric of society, attracting millions of visitors each year. The heritage sector in the UK is also a significant contributor to the UK economy as contributed around £44.9 billion to the economy in 2022 (Historic England, 2023). This indicates that the museum sector contributes to the economy significantly with tourism, visitor expenditure, and also through educational outreach, community engagement, and cultural preservation. However, the museum industry in the UK faced several challenges such as increasing demand for digital experiences, rising operational costs, and the competition for visitors' attention. For example, visitor traffic registered 14% lower than in the pre-pandemic pandemic era between July to September despite 12 million visits in this time in 2024 (GOV.UK, 2024). As a result, to address these challenges imposed by the pandemic, digital technologies specifically virtual exhibitions and AR help museums enhance revenue and traffic by attracting new consumer segments offering

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immersive experiences. For instance, the Natural History Museum in London integrated AR in the museum while the Tate Museum offered free virtual tours of its exclusive collection (Har-Even, 2024; Waldek, 2020). Therefore, it can be said that these digital technologies help museums to provide a learning and immersive experience with personalised services.

This research can help to understand the direct impact of digital tools such as AR and Virtual Exhibitions on visitor engagement and satisfaction as a significant contribution. Xu et al. (2024) opined that the digitalisation of museums can help to enhance visitor expenditure on the museums which justifies the investment in digital technologies. Here, understanding the direct impact of these technologies on visitor engagement can help museums personalise their digitalisation strategy constructively to generate a competitive edge in the market.

The accelerated digitalisation and increasing impact of digital technologies on different cultural and tourism industries provide the rationale for this research. It means that increasing adoption of AR and Virtual tours can help the museums to identify and fulfil the needs of the new targeted audience and here, this research can help to understand the specific need of these technologies on the engagement and satisfaction of the visitors. In this context, this research aims to fill the gap in the literature by precisely analysing UK art museums utilising digital tools for visitor engagement and satisfaction.

Research Aims

This research aims to assess the impact of digital transformation such as the use of Augmented Reality and Virtual Exhibitions on visitor engagement and satisfaction in the UK art Museums.

Research Questions

- How does the use of Augmented Reality (AR) in exhibitions affect visitor engagement in UK art museums?
- What is the impact of virtual exhibitions on visitor satisfaction in UK art museums?
- Is there a significant relationship between the use of digital technologies (AR and virtual exhibitions) and overall visitor satisfaction?
- Do AR and virtual exhibitions influence visitors' likelihood to revisit museums or recommend them to others?
- How do different museum types (e.g., large national museums versus smaller regional museums) vary in their use of AR and virtual exhibitions, and how does this impact visitor engagement and satisfaction?

Research Objectives

- To examine the impact of the integration of AR and virtual exhibitions influences visitor engagement levels.
- To investigate the relationship between digital technologies and visitor satisfaction.
- To evaluate whether these digital innovations contribute to repeat visits and positive word-of-mouth among museum-goers.
- To explore variations in the impact of digital transformation across different types of art museums, including large national museums and smaller regional galleries.

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Literature Review

Digital Transformation in the Museum Sector

Concerning the vast adoption of digital tools and technologies such as Augmented Reality (AR) and Virtual Reality, digital transformation has become the key innovation in the museum industry. Wen and Ma (2024), summarised that digital transformation refers to the utilisation of digital technologies such as AR and Virtual reality by the museum to improve visitor engagement and enhance operational efficiency by managing collections and delivering educational content. In this context, the digital transformation of the museum can improve the accessibility of art and artefacts online through high-quality and multidimensional scans and records of the collections (Qi et al., 2024). Here the researchers, learners, educators, and visitors can explore the art collection of major museums beyond the physical, geographical, or financial constraints which is instrumental in improving visitor engagement with digital collections. According to Khalil et al. (2023), digital tools have revolutionised visitor experiences by offering interactive and immersive experiences to the audience that extend the impact of collections beyond traditional display in museums. Consequently, the digital technologies can help to improve visitor traffic in museums concerning the improved engagement with art collections.

H1: *The use of digital technologies such as AR and virtual exhibitions is positively associated with overall visitor satisfaction in UK art museums.*

Augmented Reality (AR) in Museum

The potential of AR to enhance traditional museum visits caters for its immersive experience due to overlaid digital content on physical objects. Paliokas et al. (2020), asserted that AR provides an immersive and interactive experience to the audience in museums which can help to enhance visitor engagement with art and artefacts. Consequently, the AR can help the audience to interact with the art collection to get a personalised and rich learning experience which is not possible in traditional museums and static displays. Research studies have shown that AR can help enhance visitor engagement through improved memorable and interactive moments for visitors which not only help to understand exhibits but also help to enhance visitor's satisfaction (Han et al., 2019). Consequently, through AR, Visitors can see additional information about the exhibits such as historical context, artisan techniques, and much more, which enhances the educational value of the exhibits for the visitors. However, despite the potential benefits, high technical costs, and lack of familiarity of visitors with technology can limit the adoption of AR. However, large museums are increasingly adopting AR to integrate into museums creates a necessity to understand the direct impact of AR on visitor engagement.

H2: *The integration of Augmented Reality (AR) in exhibitions positively impacts visitor engagement in UK art museums.*

Virtual Exhibitions in Museums

Virtual exhibitions have emerged as a transformative technology which helps museums enhance audience engagement by enabling them to experience art and culture remotely which not only eliminates geographical inhibitions but also enhances the accessibility of the art for the global audience (Resta et al., 2021). Here, the innovation of virtual reality helps users to engage with exhibits in the museum without being physically present in the museum which can help the audience with financial, physical, or logistical constraints to enjoy the art and culture. According to Resta et al. (2021), virtual exhibitions are beneficial for attracting a diverse audience segment, particularly those facing financial or geographical challenges and who are unable to visit museums in person in major cities. In this context, the interactive features in virtual exhibitions such as zooming on the art and artefacts, 3D models, and guided virtual tours help to improve audience experience and satisfaction (Zhang et al., 2024). However, there may be some gap in the ability of virtual reality to deliver the same level of emotional connection and satisfaction as physical visits, as Shehade and Stylianou-Lambert (2020) opined that virtual reality may lack the immersive experience of physical museum visits. Hence, Virtual reality enhances visitor satisfaction and engagement due to immersive experiences that extend beyond geographical boundaries for remote visitors and first-time visitors.

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H3: *Virtual exhibitions positively influence visitor satisfaction, particularly among remote or first-time museum audiences.*

Impact of Digital Technologies on Visitor Satisfaction

YiFei and Othman (2024) opined that visitor satisfaction in museum visits depends on emotional engagement, cognitive learning, convenience and value of experience. Digital technologies such as AR and virtual museum tours can influence these factors due to potential of providing immersive and interactive content which is easily accessible and provides emotional value to the visitors. Boboc et al. (2022) mentioned that the emotional factors can be driven by the integration of AR in the museum concerning the additional information about the artefacts. Virtual exhibitions can help to get a learning experience or cognitive stimuli by removing the physical barriers and enabling the visitors to explore the collections beyond geographical boundaries. Consequently, the digital transformation of museums is positively related to the visitor's engagement and satisfaction concerning its connection to the emotional and cognitive experience of the visitors. However, with the exceeding digital transformation of the museums, it is critical to understand the exact impact of AR and Virtual exhibitions on visitor satisfaction in the context of UK art museums.

H4: *Visitor satisfaction is positively correlated with the engagement provided by immersive experiences in UK art museums.*

Revisit intentions and Word of Mouth due to technical usability

With a positive experience provided by digital technologies such as AR and Virtual exhibitions, long-term behaviours such as repeat visits and positive publicity are correlated. According to Wu et al. (2022), digital technologies can help audiences create a deeper connection with art and artefacts due to enhanced engagement, personalised experiences, and convenience which exceeds the possibilities of physical visits to the museums. Here, the emotional engagement with art and exhibits due to AR is reinforced by virtual exhibitions which helps visitors to stay connected with the artefacts beyond the geographical constraints, however, depends on the familiarity of the technology for visitors. Consequently, the technical familiarity extends not only visitors' satisfaction, but also has the potential to impact long-term attitudes such as repeat visits, and recommending the virtual tours to the social circle of the visitors (Zeng et al., 2022). It creates a narrative that digital technologies have the potential to foster long-term behaviour in the context of visitors' loyalty and increased likelihood of recommendations. However, there may be limited empirical evidence to identify the clear impact of these technologies on visitors in UK art museums. Therefore, further research is needed to investigate the impact of these technologies on visitor revisit intentions and word-of-mouth promotion.

H5: *Technical Usability moderates the relationship between immersive experience and visitor satisfaction in museums.*

Variation in digital technology implementation according to the museum types

The adoption and implementation of digital technologies in museums are different depending on the types of museums such as large state-accredited museums, and smaller regional galleries. According to Lyu (2024), museums need lots of resources such as financial and technological sufficiency to invest in cutting-edge innovations such as AR and Virtual exhibitions to enhance visitor experience. Here, state-controlled or accredited museums have more traffic of visitors which enhances the overall turnover and helps these to be better equipped to provide high-quality interactive and immersive digital experiences of arts and artefacts to boost visitor engagement and satisfaction. For example, the digitalisation strategy of the British Museum is a large project for five years at a total cost of $ 12 million (Ho, 2023). Here, to follow the lead of the British Museum, the regional museums may have to face financial constraints. However, the smaller museums may have budget or infrastructure constraints which may limit their ability to implement cutting-edge tools with technical expertise in the context of visitor engagement. Consequently, the impact of AR and Virtual exhibitions can vary depending on the type and size of the museum. However, the UK Research and Innovation provided funds for the museums and galleries up to £50k to scale up and evaluate the innovation of digital technologies opted for during the pandemic (UKRI, 2020). Similarly following through with the plan of UKRI, a funding of £155 million for 10 years has been announced to digitise natural

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science collections led by Natural History Museum in the UK (NATsca, 2024). It means that the varying impact of digital technologies due to the size and types of museums may be different in the UK as it depends on the initiation for digitalisation and accessibility for grants and subsidy for integrating technology for immersive experience of the visitors.

H6: *Museum type moderates the relationship between digital technologies and visitor engagement in museums.*

Visitor Demographics and Digital Engagement

Visitor demographics such as age, educational background, geographic location, and familiarity with technologies impact the perception of technology and also interaction with digital tools such as AR and Virtual reality (Zhang, Papp-Vary, et al., 2024). Here, young visitors from the digital native generation can be more comfortable with technologies and more likely to engage with digital tools such as AR and Virtual tours and exhibitions. However, the older generation with less familiarity with technology may struggle to connect with technological tools due to a lack of technical literacy and perceived ease of use. Although, museums offer personalised digital experiences to meet the needs of different audience groups containing content in different languages, enhanced user engagement and satisfaction depend on the perceived usefulness and ease of use of the digital tools. Therefore, the connection of digital technologies with the audience demographic is important to identify the overall impact of AR and virtual exhibitions in art museums in the UK.

H7: *Visitor demographics moderate the relationship between AR and VR technologies and visitor engagement in museums.*

Theoretical Underpinnings

Considering the research topic on the impact of digital technologies in museums a suitable theoretical framework for this research can be the Technology Acceptance Model (TAM). TAM is the theoretical model that can help to assess the usability of the technological integration in museums with its elements namely Perceived Ease of Use and Perceived Usefulness in this research.

As opined by Alsyouf et al. (2023), TAM is the model that assesses the technologies on its parameters namely Perceived Ease of Use and Perceived Usefulness to know the ease of acceptance of the technology by the use. It means that technology can be easily accepted by the users due to perceived usability which means that the benefits can be earned by the technology. Here, users will easily accept the technology which has high potential to help the users to achieve high goals. Similarly, perceived ease of use is the degree to which a user believes that using the technology is easy or requires less effort. It means that users can easily accept a technology depending on the user-friendly nature of the technology. In the context of the undertaken research, TAM can provide a valuable lens for understanding the impact of AR and Virtual exhibitions on visitor engagement and satisfaction by examining the visitor's perception of the ease of use and usefulness of these technologies. Here, it will also help to investigate the varying impact of the integration of these technologies in different museums due to the ease of use and usefulness of the available technological tools in the museums.

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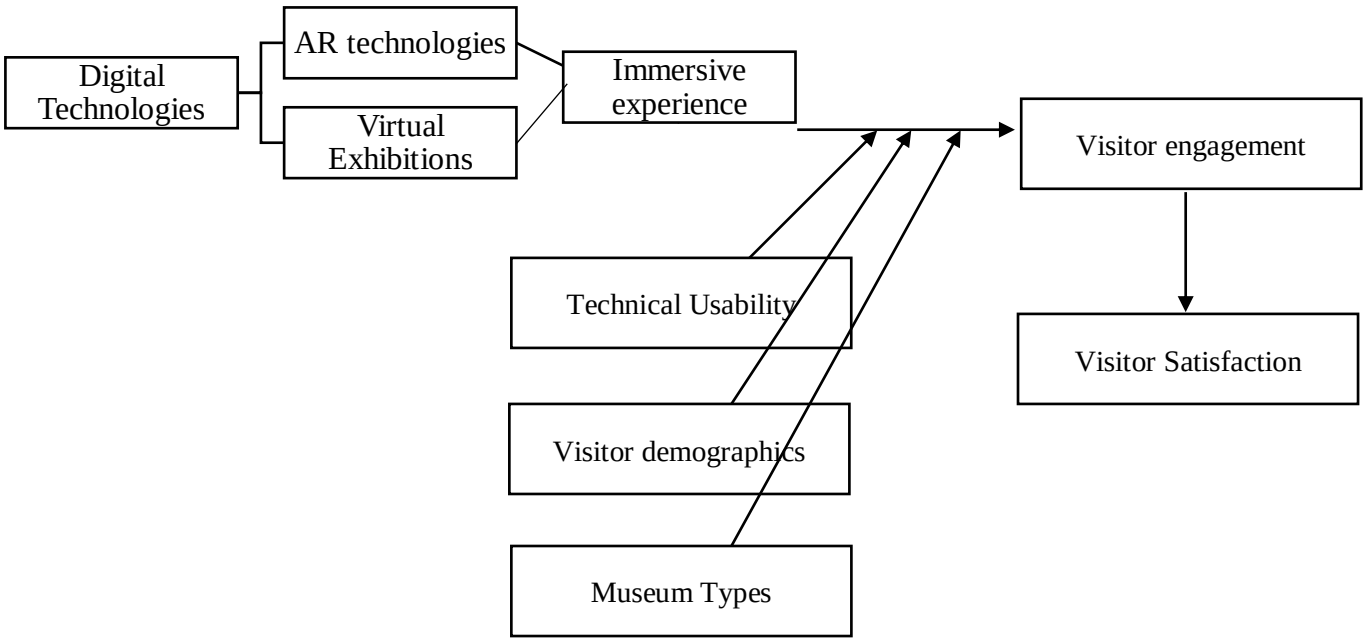
Conceptual Framework

The elements of TAM have been added to the following conceptual model:



Literature gaps

Despite the accelerated digitalisation of the art and artefacts in Museums, there have been some key gaps remaining in the literature. There is a dearth of studies highlighting the potential of digital technologies (Han et al., 2019), the research mostly focused on visitor satisfaction and engagement and lacks a deeper investigation of these digital technologies in the long-term behaviour of the visitors which includes repeat visits and word-of-mouth recommendations. Also, Boboc et al. (2022) explored the emotional connection in the digital technology context in the museums but lacked the cognitive benefit of these technologies for visitors which is a key driver for visitor satisfaction. Another significant gap exists regarding the influence of visitor demographics on digital engagement. Previous studies have touched on the role of age and technological familiarity in heritage tourism (Zhang, Papp-Vary, et al., 2024). However, there is a lack of comprehensive exploration of the impact of demographic factors such as education level, cultural background, and technological comfort influence satisfaction with digital tools like AR and virtual exhibitions in museums. Lastly, there is a gap in research exploring the integration of AR and virtual exhibitions in smaller regional museums compared to large national institutions in the UK context.

Methodology

Research Methodology

This study investigates the impact of digital transformation on visitor satisfaction and engagement, with a particular focus on AR and Virtual exhibitions in UK art museums. In this context, this study adopts a cross-sectional research design, which means that data has been collected at a single time to evaluate digital technologies' impact on museum experiences. A primary survey of art enthusiasts and museum visitors has been collected through a standardized questionnaire. This study is based on the Technology Acceptance model which includes the factors of technology adoption namely Perceived ease of use, perceived usefulness, and user satisfaction. Hence the constructs in this study are expanded to include specific

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dimensions of the museum experience such as digital technologies AR and Virtual exhibitions, immersive experience, technical usability, visitor engagement, and visitor satisfaction. These constructs were measured through structured questionnaire and adapted from previous papers to ensure reliability and validity. For instance, digital technologies are taken from Liu (2020), and AR exhibitions are taken from Yim et al. (2017), while, Virtual Exhibitions are based on Regenbrecht (2021). Similarly, Immersive experience and visitor satisfaction drew from Chen et al. (2024) and Hammady et al. (2020). Here, drawing on the factors of the Technology Acceptance Model these constructs helped to operationalize the Perceived use of digital technologies in museums and the perceived usefulness of digital technology in museums which can impact visitor engagement and satisfaction. Table 1 below has information on the scales and authors from which these are adopted. The questionnaire included self-developed items informed by relevant studies, ensuring comprehensive coverage of all constructs. All items were measured on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Table 1. Measurement Scales

Construct	Sample Questionnaire Items	Source
Digital Technologies	• I was pleased with the way digital technologies were used to enhance my overall museum experience. • The museum's use of digital technologies increased my knowledge and curiosity. • I find digital technologies in museums useful for learning and exploration of history and arts.	(Liu, 2020)
AR Exhibitions	• The AR features enhanced my understanding of the exhibits. • The augmented reality technology in the Museum was entertaining • The augmented reality technology enables me to acquire additional historical and artistic context for the exhibits.	(Yim et al., 2017)

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Virtual Exhibitions	• Was watching the virtual objects just as natural as watching the real world? • Did you have to make an effort to recognize the virtual objects as being three-dimensional? • Did you have the impression that you could have touched and grasped the virtual objects?	(Regenbrecht, 2021)
Immersive Experience	• I met my expectations through this experience. • I think that this kind of VR is suitable for learning about history in museums. • This VR journey has motivated me to find a different way to learn about cultural heritage.	(Chen et al., 2024) (Hammady et al., 2020)
Technical Usability	• Navigating through the digital content was straightforward and intuitive. • The AR/VR tools were user-friendly and easy to operate. • I encountered no technical difficulties while using the museum's digital tools.	(Liu, 2020) (Yim et al., 2017)
Visitor Engagement	• The digital features motivated me to interact more deeply with the exhibits. • The museum's digital features held my attention throughout the visit. • The digital tools encourage me to share my experience with others.	(Hammady et al., 2020)

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Visitor Satisfaction	• I am satisfied with the experience provided by the museum's digital offerings. • The museum met or exceeded my expectations in terms of digital engagement. • I am likely to visit this museum again due to its innovative use of digital technologies.	(Chen et al., 2024)
Visitor Demographics	• I can usually use new high-tech products and services without help from others. • Younger visitors might find these digital tools more engaging than older visitors. • My educational background helped me better understand and appreciate the digital tools provided by the museum.	(Hammady et al., 2020)
Museum Type	• The digital transformation of museums needs a lot of professional talents and financial support.	(Lyu, 2024)

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A Purposive sampling approach was used to select the participants with direct experience with digital technologies such as AR and Virtual Exhibitions in their museum visits. The completion of the survey resulted in 322 valid samples. As discussed by Ong and Puteh (2017), the high sample size can exceed the validity of the results by strengthening the statistical power of SPSS. Here, the factors with a load of more than 0.7 were accepted for construct validity, while internal consistency was evaluated with Cronbach's alpha with a measuring dimension of 0.7 for reliability. Descriptive statistics summarized the demographic characteristics of the respondents and their familiarity with digital technologies. Exploratory Factor Analysis was performed to identify underlying dimensions and validate the constructs' structure. Correlation analysis examined the relationships between TAM factors namely perceived ease of use and perceived usefulness, and dependent variables such as visitor satisfaction and engagement. Multiple regression analysis was conducted to test the hypotheses and identify the most significant predictors of visitor satisfaction and engagement. The model's goodness-of-fit was assessed using the R-squared value, and p-values below 0.05 were considered statistically significant.

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Result

Descriptive statistics

Table 1: Demographic

Category	Frequency	Percent
Age		
25–34	59	38.1%
35–44	58	37.4%
45–54	20	12.9%
55–64	9	5.8%
Gender		
Female	86	55.5%
Male	69	44.5%
Educational Background		
Doctoral degree	20	12.9%
High school or below	21	13.5%
Other	5	3.2%
Postgraduate degree	40	25.8%
Undergraduate degree	69	44.5%
Familiarity with Digital Technology (e.g., AR, VR)		

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Expert	21	13.5%
Moderately Familiar	23	14.8%
Not Familiar	15	9.7%
Slightly Familiar	13	8.4%
Very Familiar	83	53.5%

The sample of 155 respondents is balanced in terms of key demographic factors. Most of the respondents fall in the age group of 25–34 years (38.1%) and 35–44 years (37.4%), thus showing a predominantly younger audience. Gender representation is slightly skewed, with 55.5% female and 44.5% male participants. Educational background reveals a highly educated sample, with 70.3% holding undergraduate or postgraduate degrees. A total of 53.5% are very familiar and 13.5% reported being experts in digital technology (e.g., AR and VR), which suggests a technology-savvy audience, and this composition of demographic indicates that the respondents can effectively evaluate digital engagement in museums.

Table 2: Reliability

	Cronbach's alpha
Digital Technologies	0.985
AR Exhibitions	0.982
Virtual Exhibitions	0.991
Immersive Experience	0.985
Immersive Experience	0.979
Visitor Engagement	0.985
Visitor Satisfaction	0.984

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Visitor Satisfaction	0.978

The Cronbach's alpha values for all constructs range from 0.978 to 0.991, which indicates excellent internal consistency. This means that the survey items reliably measure their respective constructs, such as Digital Technologies, AR Exhibitions, Immersive Experience, Visitor Engagement, and Visitor Satisfaction, ensuring the validity of the study's findings.

Regression Analysis

Table 3:Single Linear Regression model summaries

Model	IV	DV	Beta	Sig	R2
1	Digital Technologies	Visitor Satisfaction	1.061	0.000	0.892
2	AR Exhibitions	Visitor Engagement	1.077	0.000	0.848
3	Virtual Exhibitions	Visitor Satisfaction	0.883	0.000	0.942
4	Immersive Experience	Visitor Satisfaction	1.06	0.000	0.886

The regression analysis supports all first four hypotheses with significant positive relationships between the independent and dependent variables. H1 is supported as Digital Technologies significantly predict Visitor Satisfaction ($\beta = 1.061$, $R^2 = 0.892$, $p = 0.000$), highlighting their influence. H2 is also proved, as AR Exhibitions significantly impact Visitor Engagement ($\beta = 1.077$, $R^2 = 0.848$, $p = 0.000$), underlining their contribution to interaction enhancement. H3 is verified to be true since Virtual Exhibitions play a considerable role in Visitor Satisfaction ($\beta = 0.883$, $R^2 = 0.942$, $p = 0.000$), especially for the distant audience. Lastly, H4 is valid since Immersive Experiences have a positive correlation with Visitor Satisfaction ($\beta = 1.06$, $R^2 = 0.886$, $p = 0.000$). Overall, the findings illustrate that digital technologies play an essential role in improving the experiences of visitors in UK art museums.

Moderation Analysis

Table 4: Moderation Effect I

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Model Coefficients

Variable	Coefficient	p-value	LLCI	ULCI	R-squared (R^2)
Constant	-1.813	0.000	-2.248	-1.379	
Immersive Experience (IE)	1.371	0.000	1.232	1.511	
Technical Usability (TU)	0.632	0.000	0.465	0.798	
Interaction (IE × TU)	-0.142	0.000	-0.191	-0.093	0.9228
Test(s) of highest order unconditional interaction(s):					
X*W	0.0167		0		

Conditional Effects of IE on VS at Different Levels of TU

Technical Usability (TU)	Effect of IE on VS	p-value	LLCI	ULCI
1	1.230	0.000	1.133	1.326
3	0.946	0.000	0.890	1.003
4.6667	0.710	0.000	0.597	0.824

The association between Immersive Experience (IE) and Visitor Satisfaction (VS) is moderated by Technical Usability, according to the investigation. As TU rises, the beneficial effect of IE on VS diminishes, according to the significant interaction term (β = -0.142, p = 0.000). The influence of IE is somewhat significant, with conditional effects showing that it is strongest at low TU (1.230) and weakest at high TU (0.710).

Table 5: Moderation Effect II

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Model Coefficients

Variable	Coefficient	p-value	LLCI	ULCI	R-squared (R^2)
Constant	0.000	1.000	-0.632	0.632	
Digital Technologies (DT)	0.802	0.000	0.563	1.041	
					0.9438
Museum Types (MT)	-0.147	0.158	-0.352	0.058	
Interaction (DT × MT)	0.085	0.027	0.010	0.161	

Test(s) of highest order unconditional interaction(s):

X*W	0.0036	0.0274	

Conditional Effects of IE on VS at Different Levels of TU

Museum Type (MT)	Effect of DT on VEG	p-value	LLCI	ULCI
3	1.057	0.000	0.996	1.119
4	1.143	0.000	1.048	1.237

The association between Immersive Experience (IE) and Visitor Satisfaction (VS) is moderated by Technical Usability, according to the analysis. As TU rises, the beneficial effect of IE on VS diminishes, according to the significant interaction term (β = -0.142, p = 0.000). The influence of IE is somewhat significant, with conditional effects showing that it is strongest at low TU (1.230) and weakest at high TU (0.710).

Table 6: Moderation Effect III

Model Coefficients

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Variable	Coefficient	p-value	LLCI	ULCI	R-squared (R^2)
Constant	-1.310	0.000	-1.715	-0.905	
AR/VR (Independent Variable)	1.296	0.000	1.161	1.432	
					0.9592
Visitor Demographics (VD)	0.482	0.000	0.325	0.640	
Interaction (AR/VR × VD)	-0.117	0.000	-0.164	-0.069	
Test(s) of highest order unconditional interaction(s):					
X*W	0.0126		0		

Conditional Effects of IE on VS at Different Levels of TU

Visitor Demographics (VD)	Effect of AR/VR on VEG	p-value	LLCI	ULCI
1	1.180	0.000	1.086	1.274
3	0.947	0.000	0.890	1.003
4.6667	0.752	0.000	0.643	0.862

The findings validate that the association between AR/VR and Visitor Engagement (VEG) is moderated by Visitor Demographics. The effect of AR/VR on VEG diminishes as VD rises, according to the interaction term (β = -0.117, p = 0.000). Conditional effects suggest considerable demographic effects on AR/VR engagement, with the biggest impact occurring at low VD (1.180) and the least at high VD (0.752).

Table 7: Summary

Hypotheses	Decision
H1: The use of digital technologies such as AR and virtual exhibitions is positively associated with overall visitor satisfaction in UK art museums.	Accept

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H2: The integration of Augmented Reality (AR) in exhibitions positively impacts visitor engagement in UK art museums.	Accept
H3: Virtual exhibitions positively influence visitor satisfaction, particularly among remote or first-time museum audiences.	Accept
H4: Visitor satisfaction is positively correlated with the engagement provided by immersive experiences in UK art museums.	Accept
H5: Technical usability moderates the relationship between immersive experience and visitor satisfaction in museums.	Accept
H6: Museum type moderates the relationship between digital technologies and visitor engagement in museums.	Accept
H7: Visitor demographics moderate the relationship between AR and VR technologies and visitor engagement in museums.	Accept

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Discussion

These findings imply the transformative impact of digital technologies namely AR and Virtual exhibitions for enhanced visitor engagement and satisfaction in the UK art museums. It has been underscored by the results that AR and virtual exhibitions are the technologies which can help museums address the changing expectations of the visitors and also address the geographical and logistical challenges for them.

The results effectively underscored that digital technologies such as AR and Virtual Exhibitions enhance visitor satisfaction and engagement supported by hypothesis 1 which encompassed the potential of modern technical tools to deliver immersive experiences to the visitors and enhance engagement. These findings aligned with the study of Khalil et al. (2023), who observed that AR and VR can provide personalised and interactive content to increase the emotional and cognitive connection of visitors with the artefacts. It means that museums need to invest in digital tools to stay competitive in the industry shaped by enhanced visitor engagement with technology-driven experiences.

Similarly, the findings supported Hypothesis 2, which demonstrates the positive relation between AR and visitor engagement and also reinforced the assertions made by Paliokas et al. (2020), that AR enhances visitor engagement by enabling meaningful interaction between visitors and artefacts. It implies that AR can deliver contextual information about the exhibits to visitors through dynamic visualisations to improve visitor experience. Here, the museums with AR integration can enable visitors to look into historical narratives, artisan techniques, and 3D reconstruction of the artefacts which increase interest in the art through educational experience. However, the results also indicated the challenges for smaller museums to implement digital technologies due to resource constraints as asserted by Lyu (2024). It means that despite the potential to enhance visitor satisfaction and engagement, AR adoption is subject to challenges due to high implementation costs and varying levels of technical familiarity among the users. To address this issue, museums can explore partnerships with technology companies or seek grants from organizations like UKRI to enhance their ability to implement AR technologies for enhanced visitor engagement. Moreover, training programs for staff and interactive tutorials for visitors should be implemented to enhance the accessibility and usability of AR technologies which moderate the relationship between visitor engagement and immersive experience provided by AR tools.

Furthermore, the results also supported Hypothesis 3 demonstrating that virtual exhibitions influence visitor satisfaction among remote and first-time audiences which also reinforced the assertions of Resta et al. (2021), which opined that virtual exhibitions can increase the accessibility to cultural heritage and attract diverse audiences in the art museums by removing geographical barriers. It implies that virtual exhibitions enable the audience to explore the artefacts beyond geographical boundaries and financial and logistical constraints. However, the limitations of virtual exhibitions are also been highlighted as virtual exhibitions may not completely replicate the emotional resonance of physical visits (Shehade Stylianou-Lambert, 2020). It means that virtual exhibitions can enhance accessibility and emotional connection with the cultural heritage which can complement the physical experience.

Also, the findings revealed a positive relation between immersive experiences and visitor satisfaction which supports Hypothesis 4 and is consistent with the study of Wu et al. (2022), which implies that immersive experiences through AR and virtual exhibitions can create long-term impact in the form of repeat visits, and positive word of mouth. This means that immersive experiences to visitors can help to create deeper connections with artefacts due to engaging communication, and interaction. Moderation analysis confirms that immersive experience through AR and Virtual exhibitions depends on familiarity with the technology which means that user-friendly interfaces and robust technical support can optimise visitor experiences. This implies that with the increase of technical usability, the marginal benefits of immersive experiences decrease which complies with the highly usable system aligned with the higher expectations of users to deliver satisfaction.

Apart from technical familiarity or user-friendly interfaces, the adoption and impact of digital technologies also depend on the museum types which validates Hypothesis 6. As implied by Lyu (2024), the digital transformation of museums requires a high level of financial resources and technical experts which impact

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the ability of smaller museums to implement effective digital tools. Although there are multiple organisations such as UKRI and others that fund the digital transformation initiatives of museums in the UK, there is a need for collaboration between small and larger museums for knowledge transfer and resource pooling to enhance the digital capabilities of regional museums.

The moderating impact of visitor demographics is another relationship which is confirmed by results concerning the validation of Hypothesis 7. This implies that the younger generation which is more familiar with technology and used to utilise technology is more likely to be engaged with digital tools in museums which also aligns with Zhang et al. (2024), as the authors asserted that generation differences can impact the adoption of digital technologies. Thus, it can be said that the digital technologies can enhance the visitor engagement and satisfaction in the art museums in the UK.

Conclusion

In a nutshell, it can be said that digital technologies such as AR and virtual exhibitions are enhancing visitor engagement and satisfaction in UK art museums due to immersive experiences and improved interaction between artefacts and visitors. This means that digital technologies may also have a long-term impact on visitor engagement and behaviour by encouraging repeat visits and spreading positive word-of-mouth which is critical for museums to stay competitive and generate revenue. Here, the strategic integration of AR and virtual reality for exhibitions can help museums in the UK generate more revenue and compete on a global level beyond geographical constraints.

In this regard, this research created actionable insights for museums and policymakers to implement digital technologies. Here, the museums need to prioritise investment in digital transformation and create user-friendly interfaces to enhance visitor engagement and satisfaction, while policymakers need to provide assistance to the smaller museum operators to implement digital technologies combating the resource challenges. Furthermore, this research provides the ground for future research such as a longitudinal study that can be conducted to identify the long-term impact of digital transformation on visitor behaviour. Here, it has been identified in this paper that AR and virtual exhibitions can improve visitor engagement and satisfaction in the art museums in the UK through considerable strategic implementation of AR and Virtual exhibitions.

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Appendix

SPSS Output

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Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.945[a]	.892	.891	.50351

a. Predictors: (Constant), Digital Technologies

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	320.977	1	320.977	1266.059	.000[b]
	Residual	38.789	153	.254		
	Total	359.766	154			

a. Dependent Variable: Visitor Satisfaction

b. Predictors: (Constant), Digital Technologies

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.437	.113		-3.858	.000
	Digital Technologies	1.061	.030	.945	35.582	.000

a. Dependent Variable: Visitor Satisfaction

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.921[a]	.848	.847	.60505

a. Predictors: (Constant), AR Exhibitions

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	311.939	1	311.939	852.101	.000[b]
	Residual	56.011	153	.366		
	Total	367.950	154			

a. Dependent Variable: Visitor Engagement

b. Predictors: (Constant), AR Exhibitions

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.417	.138		-3.015	.003
	AR Exhibitions	1.077	.037	.921	29.191	.000

a. Dependent Variable: Visitor Engagement

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Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.971[a]	.942	.942	.36844

a. Predictors: (Constant), Virtual Exhibitions

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	338.997	1	338.997	2497.230	.000[b]
	Residual	20.770	153	.136		
	Total	359.766	154			

a. Dependent Variable: Visitor Satisfaction

b. Predictors: (Constant), Virtual Exhibitions

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.277	.068		4.088	.000
	Virtual Exhibitions	.883	.018	.971	49.972	.000

a. Dependent Variable: Visitor Satisfaction

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.941[a]	.886	.885	.51820

a. Predictors: (Constant), Immersive Experience

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	318.680	1	318.680	1186.736	.000[b]
	Residual	41.086	153	.269		
	Total	359.766	154			

a. Dependent Variable: Visitor Satisfaction

b. Predictors: (Constant), Immersive Experience

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.431	.117		-3.693	.000
	Immersive Experience	1.060	.031	.941	34.449	.000

a. Dependent Variable: Visitor Satisfaction

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H6: Matrix

```
Run MATRIX procedure:

***************** PROCESS Procedure for SPSS Version 4.2 *****************

          Written by Andrew F. Hayes, Ph.D.       www.afhayes.com
    Documentation available in Hayes (2022). www.guilford.com/p/hayes3

**************************************************************************
Model  : 1
    Y  : VS
    X  : IE
    W  : TU

Sample
Size:  155

**************************************************************************
OUTCOME VARIABLE:
 VS

Model Summary
          R       R-sq        MSE          F        df1        df2          p
      .9606      .9228      .1839   601.6203     3.0000   151.0000      .0000

Model
              coeff         se          t          p       LLCI       ULCI
constant    -1.8132      .2198    -8.2483      .0000    -2.2475    -1.3789
IE           1.3712      .0707    19.3878      .0000     1.2315     1.5110
TU            .6315      .0845     7.4755      .0000      .4646      .7984
Int_1        -.1416      .0248    -5.7075      .0000     -.1907     -.0926

Product terms key:
 Int_1    :        IE       x        TU

Test(s) of highest order unconditional interaction(s):
       R2-chng          F        df1        df2          p
X*W      .0167    32.5756     1.0000   151.0000      .0000
----------
    Focal predict: IE       (X)
          Mod var: TU       (W)

Conditional effects of the focal predictor at values of the moderator(s):

        TU     Effect         se          t          p       LLCI       ULCI
    1.0000     1.2296      .0488    25.2117      .0000     1.1332     1.3260
    3.0000      .9464      .0287    32.9312      .0000      .8896     1.0031
    4.6667      .7103      .0574    12.3751      .0000      .5969      .8237

************************ ANALYSIS NOTES AND ERRORS ************************

Level of confidence for all confidence intervals in output:
  95.0000

W values in conditional tables are the 16th, 50th, and 84th percentiles.

------ END MATRIX -----
```

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H7: Matrix

```
Run MATRIX procedure:

***************** PROCESS Procedure for SPSS Version 4.2 *****************

          Written by Andrew F. Hayes, Ph.D.       www.afhayes.com
    Documentation available in Hayes (2022). www.guilford.com/p/hayes3

**************************************************************************
Model  : 1
    Y  : VEG
    X  : DT
    W  : MT

Sample
Size:  155

**************************************************************************
OUTCOME VARIABLE:
 VEG

Model Summary
          R       R-sq        MSE          F        df1        df2          p
      .9438      .8908      .2661   410.5067     3.0000   151.0000      .0000

Model
              coeff         se          t          p       LLCI       ULCI
constant      .0002      .3198      .0006      .9996     -.6318      .6321
DT            .8018      .1208     6.6361      .0000      .5631     1.0406
MT           -.1468      .1036    -1.4177      .1583     -.3515      .0578
Int_1         .0852      .0382     2.2267      .0274      .0096      .1607


Product terms key:
 Int_1    :        DT       x        MT

Test(s) of highest order unconditional interaction(s):
      R2-chng          F        df1        df2          p
X*W     .0036     4.9582     1.0000   151.0000      .0274
----------
    Focal predict: DT       (X)
          Mod var: MT       (W)

Conditional effects of the focal predictor at values of the moderator(s):

        MT     Effect         se          t          p       LLCI       ULCI
    3.0000     1.0573      .0310    34.1073      .0000      .9961     1.1186
    3.0000     1.0573      .0310    34.1073      .0000      .9961     1.1186
    4.0000     1.1425      .0476    24.0026      .0000     1.0484     1.2365

************************ ANALYSIS NOTES AND ERRORS ************************

Level of confidence for all confidence intervals in output:
  95.0000

W values in conditional tables are the 16th, 50th, and 84th percentiles.

------ END MATRIX -----
```

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H8: Matrix

```
Run MATRIX procedure:

***************** PROCESS Procedure for SPSS Version 4.2 *****************

          Written by Andrew F. Hayes, Ph.D.       www.afhayes.com
    Documentation available in Hayes (2022). www.guilford.com/p/hayes3

**************************************************************************
Model  : 1
    Y  : VEG
    X  : AR_VR
    W  : VD

Sample
Size:  155

**************************************************************************
OUTCOME VARIABLE:
 VEG

Model Summary
          R       R-sq        MSE          F        df1        df2          p
      .9592      .9200      .1949   578.8968     3.0000   151.0000      .0000

Model
              coeff         se          t          p       LLCI       ULCI
constant    -1.3098      .2051    -6.3857      .0000    -1.7150    -.9045
AR_VR        1.2964      .0687    18.8706      .0000     1.1607    1.4321
VD            .4823      .0795     6.0647      .0000      .3252     .6395
Int_1        -.1166      .0239    -4.8811      .0000     -.1638    -.0694

Product terms key:
 Int_1    :        AR_VR    x        VD

Test(s) of highest order unconditional interaction(s):
       R2-chng          F        df1        df2          p
X*W      .0126    23.8247     1.0000   151.0000      .0000
----------
    Focal predict: AR_VR    (X)
          Mod var: VD       (W)

Conditional effects of the focal predictor at values of the moderator(s):

         VD     Effect         se          t          p       LLCI       ULCI
     1.0000     1.1798      .0477    24.7277      .0000     1.0855     1.2741
     3.0000      .9466      .0285    33.1769      .0000      .8902     1.0030
     4.6667      .7523      .0555    13.5481      .0000      .6425      .8620

************************ ANALYSIS NOTES AND ERRORS ************************

Level of confidence for all confidence intervals in output:
  95.0000

W values in conditional tables are the 16th, 50th, and 84th percentiles.

------ END MATRIX -----
```

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