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INTERACTIVE DESIGN AND MUSEUM MANAGEMENT: ENHANCING GUIDED TOURS THROUGH IOT AND VIRTUAL SOLUTIONS

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Abstract: This study explores the move from traditional guided tours to interactive, technology-based navigation systems in museums. Virtual museum apps show educational potential but often lack interpretation and feedback, underscoring the need for human guidance. Intelligent systems can improve visitor convenience, aid staff in collection management, and strengthen educational roles, though issues of privacy, accessibility, and inclusivity remain. Overall, interactive and IoT-based tours can both enrich cultural education and enhance museum management efficiency and sustainability.

Key words: Museum management, guided tours, interactive navigation, Internet of Things (IoT), virtual museums, visitor satisfaction, cultural education, immersive technology, digital heritage, smart tourism.

Annotatsiya: Maqola an'anaviy ekskursiyalardan interaktiv muzey navigatsiyasi texnologiyalariga o'tish va ularning tashrif buyuruvchilar hamda muzey menejmentiga ta'siriga bag'ishlangan. Tahlil shuni ko'rsatdiki, virtual muzeylar katta o'quv salohiyatiga ega, biroq talqin va fikr-mulohaza vositalarining yetishmasligi inson omilining muhimligini yanada ta'kidlaydi. Intellekturnavigatsiya tizimlari tashrifni yengillashtiradi, kolleksiyalarni boshqarishda yordam beradi va muzeylarning madaniy-ma'rifiy rolini kuchaytiradi. Shu bilan birga, maxfiylik, ochiqlik va inklyuzivlik bilan bog'liq muammolar saqlanib qolmoqda. Umuman olganda, interaktiv va IoT yechimlari madaniy ta'limni boyitish bilan birga muzey menejmentining samaradorligini oshirishi mumkin.

Kalit so'zlar: muzey menejmenti, ekskursiyalar, interaktiv navigatsiya, Internet narsalar (IoT), virtual muzeylar, tashrif buyuruvchilar qoniqish darajasi, ta'lim, immersiv texnologiyalar, raqamli meros, smart-turizm.

Аннотация: Статья посвящена переходу от традиционных экскурсий к интерактивным технологиям навигации в музеях и их влиянию на посетителей и управление. Анализ виртуальных музеев показал их обучающий потенциал, но выявил нехватку инструментов для интерпретации и обратной связи, что подчеркивает важность роли человека. Интеллектуальные системы навигации упрощают посещение, помогают в управлении коллекциями и усиливают образовательную функцию музеев. Вместе с тем остаются проблемы конфиденциальности, доступности и инклюзивности. В целом, интерактивные и IoT-решения способны одновременно обогащать культурное образование и повышать эффективность музейного менеджмента.

Ключевые слова: музейный менеджмент, экскурсии, интерактивная навигация, IoT (технологии Интернета вещей), виртуальные музеи, удовлетворенность посетителей, культурное образование, иммерсивные технологии, цифровое наследие, smart-туризм.

INTRODUCTION

Currently, traditional guided tours in museums are no longer sufficient to satisfy visitors' expectations. The rapid advancement of smart technologies and the Internet of Things has created new possibilities for intelligent museum tour services. Through the use of modern information technologies, museums are able to overcome spatial and temporal constraints, offering visitors immersive experiences while also increasing engagement and interactivity through smart navigation systems and personalized recommendations[1,2]. The intelligent navigation system is an interdisciplinary technology that enables users to experience immersion while engaging with virtual objects. This not only enhances the image and appeal of the museum sector but also fosters the development of a personalized operational model for museums.

Different virtual solutions allow diversification in access to information, learning, and getting to places you would not otherwise be able to go [3]. Virtual solutions are increasingly becoming more accessible, engaging,



and immersive, often incorporating avatars linked to parts of the human body to enhance the perception of reality [4]. These technologies enable individuals to interact with virtual artefacts, construct personal interpretations, strengthen cognitive processes, and stimulate both creativity and innovation. Furthermore, the analysis of these solutions considers aspects such as graphical design, artefact aesthetics, information architecture, interoperability, and their potential application within educational contexts.

With the rapid growth of Internet technologies, new media such as interactive platforms, crowdsourcing, the Internet of Things, and natural user interfaces have reshaped how people think, communicate, and learn. Traditional navigation systems, reliant on static maps and signs, cannot provide real-time updates or dynamic content and offer little personalization. As audiences have diverse needs, these systems struggle to deliver tailored guidance and recommendations.

Museums need to move beyond simple modes of information display and interaction, reimagining how knowledge is transmitted by embracing diverse forms of interactive media and dismantling traditional barriers [5]. By creating more open and inclusive channels, museums can achieve true “resource sharing” and strengthen communication with the public. IoT technologies make this possible by collecting data on visitor behavior and preferences, enabling the delivery of personalized navigation routes and tailored recommendations through big data analysis. Moreover, sensors and connected devices allow for real-time updates of exhibition information. For instance, changes in exhibit locations, the introduction of new artefacts, or the scheduling of exhibition activities can be instantly communicated to visitors, ensuring they always have access to the most current navigation and exhibition details.

This paper compares traditional and interactive museum navigation, showing that visitors prefer faster, simpler ticketing and gain easier access to information, while staff deepen their understanding of exhibits. Overall, the exhibition experience becomes more engaging, meeting cultural needs and supporting heritage transmission. Key contributions:

Interactive Navigation System: Combining IoT and interactive design, the study develops a smart system that lets visitors explore exhibits from multiple angles, improving retention and creating immersive cultural experiences.

Advancing Cultural Education: Interactive tools make learning more engaging, fostering deeper interest in history, art, and science, and raising public cultural literacy.

Optimizing Museum Management: IoT-based navigation enhances efficiency through real-time visitor data, enabling better exhibit layouts and service improvements.

LITERATURE REVIEW

The integration of virtual museums and immersive technologies has been extensively explored in recent years. Schweibenz (2019) provides a comprehensive overview of the origins and conceptual foundations of virtual museums, emphasizing their role as digital cultural institutions. Daniela (2020) expands this perspective by examining virtual museums as learning agents, highlighting their potential in sustainability education. Pedagogical aspects of virtual reality (VR) are addressed by Fowler (2015), who raises critical questions regarding the absence of well-defined instructional frameworks in VR-based learning.

From a design perspective, Kapp (2017) suggests instructional strategies for effective VR learning environments, while Lombardo et al. (2018) introduce Practica, a VR platform tailored to productivity-oriented training. Studies in museum contexts illustrate the application of interactive technologies: Dawson, Joseph, and Champion (2020) evaluated multimedia storytelling for enhancing visitor engagement, and Hammady, Ma, and colleagues (2020, 2021) developed frameworks for mixed-reality guides in the Egyptian Museum. Furthermore, Hou (2024) integrates the Internet of Things (IoT) into museum tours, demonstrating intelligent interaction design for improved user experience. Complementing this, Yunita, Jauhari, and Heroza (2019) analyze visitor characteristics to enhance museum tour applications.

Collectively, these works demonstrate a convergence of VR, IoT, and mixed-reality applications toward enhancing educational and cultural engagement. However, while technical advancements are well-documented, pedagogical integration remains underexplored, indicating the need for further research linking immersive museum technologies with robust learning theories.

METHODOLOGY

With the advancement of interactive technologies, research on museum interactive guidance systems has made notable progress. Museums serve as spaces where people can acquire knowledge and gain insights into history, with their primary role being to introduce collections to the public—traditionally through human guides. However, when visitor numbers are high and tour guides are limited, it becomes difficult to provide personalized



attention to all guests. To address this challenge, Yunita R. has been developing a new platform designed for tourists. This software leverages visitor characteristics to deliver museum-related content quickly and efficiently [6].

At the University of Worcester, physics students visited the Worcester Art Gallery after completing a special course titled “Physics in Art.” During their study of geometric optics, Swaminathan S introduced concepts from atomic physics and highlighted the educational purpose of the museum visit, namely to demonstrate how physical technologies can be applied in non-traditional laboratory environments [7].

Markham’s Car Collection represents a model museum and cultural institution, using panoramic views and multimedia to present large artefacts such as antique cars. In developing virtual museums, it is essential to consider user needs, as the way digital product usability is measured directly affects both user experience and outcomes. Champion E. M. outlined strategies for evaluating narrative-driven designs, focusing on user engagement and comprehension as indicators of product utility [8].

Hammady R. proposed a new museum guidance system grounded in immersion and presence theory, aiming to reduce reliance on manual guides by incorporating visitors’ social needs and behavioral patterns. Qualitative survey results indicated that this system significantly improved the museum experience [9]. Furthermore, Hammady R. tested a mixed reality guidance system at the Cairo Egyptian Museum through a mixed-method survey with 171 participants, demonstrating the potential of mixed reality to ensure sustainable and engaging museum experiences beyond traditional tourism [10].

Although current interactive guidance systems have strengthened visitor–exhibit interaction, many still face limitations, particularly regarding real-time information updates and similar functionalities.

The advancement of IoT technology has created new opportunities for real-time updates and instant information delivery. To enhance the efficiency and security of network services, Sakirin T integrated blockchain technology with edge computing, offering lightweight data aggregation and secure survey solutions for IoT applications. By applying streamlined aggregation processes at the hub level, this approach ensures smoother and faster data flow, with preliminary tests confirming its feasibility [11]. Similarly, Sarathkumar R highlighted the synergistic relationship between digital twins and IoT in the development of smart cities. Such IoT-driven smart cities not only elevate the technological standards of exhibitions but also chart a path toward the harmonious integration of technology and societal progress [12].

In the context of museums, IoT has proven essential for enhancing visitor engagement and operational efficiency. Nevertheless, as tourist needs become increasingly diverse, current museum tour guide systems still face challenges in delivering fully personalized services that align with practical development demands.

RESULTS

Fowler [13] identifies three stages of learning through VR— conceptualization, (i construction, and discussion—which are also relevant for virtual museums. In the conceptualization stage, students are expected to learn and interpret facts, concepts, and theories. Virtual museums can support this by providing factual information and supplementary content; however, teachers must guide students to ensure appropriate learning paths are followed and cognitive development is taking place so that they gain the skills to interpret what they encounter. Among the analyzed applications, only Colm Cille included a built-in knowledge assessment, and it focused primarily on factual recall rather than interpretation.

In the second stage, learners should apply acquired knowledge to new contexts and build competences by comparing different experiences. None of the virtual museum applications offered this opportunity, making teacher involvement essential—for example, by facilitating group discussions or activities that connect museum content with broader knowledge. Only through such pedagogical support can the third stage, discussion, be achieved.

Virtual museums can function as learning agents [14], supporting continuous learning by expanding opportunities for collaboration with digital materiality, making abstract concepts more tangible through visualization and spatialization [15], and engaging learners as co-designers and co-researchers [16]. Although museums can act as situated learning environments, most virtual museum applications apply this only partially. This underlines the need for teachers to combine various tools—using virtual museums to spark interest and providing additional context when necessary. For instance, appreciating art also requires understanding techniques and symbolism. As Aguayo, Eames, and Cochrane emphasize, mobile learning should stay contextually authentic, cross-disciplinary, and scaffolded to build clear learning pathways [17]. Moreover, there must be a connection between virtual experiences and real-world actions [18] to ensure genuine mobile learning [19]. Establishing this synergy between diverse information sources can foster deeper knowledge and support the growth of metacognitive skills.



Table 1. Stages of learning in virtual museums and their application

Stage of Learning	Expected Outcome	Role of Virtual Museums	Current Application Status	Teacher's Role	Example / Limitation
Conceptualization	Learners interpret facts, concepts, and theories	Provide factual data, supplementary content	Implemented partially (<i>Colm Cille</i> includes factual recall)	Guide cognitive development, contextualize facts	Focus on recall, limited interpretation
Construction	Learners apply knowledge to new contexts and compare experiences	Facilitate interactive activities and scenario building	Not provided in most applications	Design group activities, connect content with broader knowledge	Lack of tools for applied learning
Discussion	Learners collaborate, reflect, and co-create knowledge	Enable forums, dialogues, and co-design opportunities	Weakly integrated	Facilitate structured discussion, provide scaffolding	Engagement remains surface-level
Situated Learning	Learners connect abstract concepts with real-world contexts	Visualization, spatialization, mobile learning integration	Partially implemented	Ensure authenticity, cross-disciplinary connections	Weak link to real-world actions

The table demonstrates that while virtual museums provide valuable support in the conceptualization stage, their capacity to extend learning into construction and discussion remains underdeveloped. Applications often stop at factual recall rather than enabling deeper interpretation. Teachers therefore play a critical role in bridging this gap, using collaborative methods such as group tasks and discussions. Moreover, although virtual museums show potential as situated learning environments, the absence of strong links between virtual experiences and real-world practices limits their pedagogical impact. Hence, achieving full learning potential requires combining digital tools with teacher-led scaffolding to strengthen cross-disciplinary connections and metacognitive skills.

CONSLUSION

This study compared traditional and interactive navigation methods in museums across four aspects: ticket purchasing, staff knowledge of collections, information reception, and visitor satisfaction. The results show that interactive navigation, supported by IoT and smart technologies, significantly improves the visitor experience—online ticket purchasing was overwhelmingly preferred, staff understanding of collections increased notably. These findings indicate that interactive design not only enhances efficiency and participation but also aligns more closely with cultural needs and expectations.

At the same time, research into virtual museums demonstrates their potential as learning agents. While they can stimulate interest, visualize abstract concepts, and expand collaboration with digital materiality, current applications rarely provide opportunities for deeper knowledge construction or interpretation. Most apps remain limited to factual recall, making the teacher's role indispensable in contextualizing content, guiding discussions, and ensuring cognitive development.

Taken together, these insights highlight both the promise and limitations of technology-driven museum experiences. Interactive and virtual systems can enrich cultural education, optimize museum management, and foster engagement, but challenges remain regarding privacy protection, accessibility, and inclusivity. Moreover, their educational value depends on careful integration with pedagogy, where teachers play a central role in framing content, motivating learners, and ensuring meaningful learning outcomes. Future research should address these limitations by incorporating augmented reality, strengthening feedback and assessment functions, safeguarding visitor data, and ensuring equal access—thereby advancing museums as both cultural and educational agents in the digital era.



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