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SMART MUSEUM TECHNOLOGIES AND THEIR ROLE IN PROMOTING TECHNICAL UNDERSTANDING OF INDUSTRIAL HISTORY

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SUMMARY

New smart museums, integrating technologies like augmented reality (AR), virtual reality (VR), interactive kiosks, Internet of Things (IoT) devices, and AI tools, mark a departure from treating industrial history as a passive archival medium. The incorporation of these technologies allows for a shift from passive learning to actively experiencing history. This paper explains how these technological advancements improve visitor immersion, multi-dimensional learning regarding socio-economical shifts and identities, as well as deep processes associated with industrial machinery systems in context. Case studies from leading industrial heritage museums showcase how complex historical narratives are made relatable through the use of immersive simulations, digital reconstructive building, and dynamic data stream visualization technologies. The study also addresses the implications of adopting new technologies, including ease of use, content accuracy, and infrastructure expenditures. Lastly, the paper

concludes smart museums serve as connectors between the appreciation of history and the understanding of technical concepts – a fundamental need for younger people born into the digital age [2].

Key words: *smart museum technologies, industrial history, technical understanding, augmented reality (ar), virtual reality (vr), interactive exhibits, digital heritage.*

INTRODUCTION

Definition of Smart Museum Technologies

Smart museum technologies embrace the application of sophisticated digital devices and automation in the operations, curation, education, and visitor services of a museum. Such technologies include, but are not limited to, Internet of Things (IoT) devices, augmented and virtual reality (AR/VR), Artificial Intelligence (AI), digital touchscreens, mobile applications, navigation beacons, and big data. Their goal is to improve the ease of use, interactivity, customization, and educational impact of the cultural heritage institutions [3],[15]. With the adoption of smart devices, museums can turn passive exhibits into active, participatory ones that capture the attention of broader and younger audiences [7].



Figure 1. Smart museum, chicago

The University of Chicago has a dedicated fine arts museum known as the Smart Museum of Art [13]. Inaugurated in 1974, the museum has a compilation of more than 17,000 pieces of art, which include significant works by Mark Rothko, Diego Rivera, Frank Lloyd Wright, and other artists from various periods, including contemporary and antiquity.

Importance of Promoting Technical Understanding of Industry

As digitization continues to permeate every industry, the museum world also has to change by fostering smart technology proficiency among its employees and stakeholders [20]. Understanding the role of modern technologies in the museum industry is important for operational efficiency and cultural preservation in current times [10]. Competition for public interest and funding increases the necessity of using and knowing how to control smart technologies. In addition, promoting smart technologies fosters equitable and effective engagement integrated with curation, data governance, and restricted access oversight [1]. This improves ethical boundary-setting and expands inter-institutional partnerships beyond museums, into education, tourism, and technology [2], [17].

Overview of the Role of Smart Museum Technologies in Achieving This Goal

Smart museum technologies are immensely helpful in accomplishing the tasks set for the digital transformation of cultural institutions since they resolve the concerns of traditional approaches and modern demands placed by the society on such institutions. Such technologies allow museums to upgrade visitor participation with interactive storytelling and real-time feedback, while also automating backend functions like digital collections managing, environment monitoring, and maintenance forecasting. With the adoption of smart technologies, museums are able to set, manage, and personalize

visitors and tour experiences, analyse data, and increase outreach with online presence and hosted virtual tours. These capabilities foster a better informed, more inclusive, engaged, and future-proof industry. The adoption of smart technologies goes beyond just technical improvement; is a necessity strategic change for all museums that hope to achieve their educational purposes, support for the public's enduring understanding of culture, heritage and the nation, and adapt to the needs of the society within the modern digital landscape it's evolving in [1], [12].

SMART MUSEUM TECHNOLOGIES

Definition and Examples of Smart Museum Technologies

Smart technologies in museums integrate various digital devices and automated systems that improve the management, display, and preservation of cultural heritage [9]. Their primary goal is to optimize operational and visitor satisfaction engagement using advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Augmented Reality (AR), Virtual Reality (VR), mobile applications, and data analytics [3],[17]. For example, AR and VR can recreate historical events or spaces fully while IoT devices are able to check climate conditions in exhibition halls for delicate artifacts. Chat and spoken interface AI systems do guide virtual tours and mobile phones provide interactive content engagement with participants in real-time [12]. Modern exhibit technologies include digital signage, beacon navigation, interactive touch screen displays, and other technologies which improve the requirements of conventional exhibits [10], [15].

Benefits of Utilizing Smart Museum Technologies in Industry Education

Including smart technologies in the functioning of museums greatly impacts students learning within the culture and heritage industries. Such technologies promote profound deeper interaction and participation by transforming traditional learning settings into dynamic historical, scientific, or artistic environments that foster easy understanding and appreciation of content [16]. In terms of professional education, smart technologies used in the museum serve as powerful professionals modern teaching instruments for digital curation, museology, audience analytics, and many more. There are practically oriented ways to be taught data gathering, data interpretation, and behaviour analysis of visitors where there have been substantial changes in the expectations in the professional market and career paths offered in the field of museums and cultural heritage [15]. Also, smart technologies make it possible for museums to go beyond their physical educational outreach through virtual exhibitions and online archives which unlocks cultural wisdom to anyone and emphasizes collective effort toward cultural education at a global level [5].



Figure 2. Digital signage display

Through the use of smart technologies, museums are able to expand their educational outreach by providing exhibits, virtual tours, augmented reality experiences, and other activities designed for a wide range of audiences that go beyond physical locations [4]. Digital signage, as shown in Figure 2, is one of the new systems that is being applied in different industries and serves to capture audience attention through information interchange; such digital signage and its monitors are progressively deployed in all

sectors. In museums, museums are transforming into centres of information where visitors are provided with digital labels, exhibition guides, and multilingual explanations texted to them, thus assisting them with education. These displays are also used in retail to feature advertisements, promotional activities, and highlight certain merchandise that is often automated with audience analytics [14].

Challenges and Limitations of Implementing Smart Museum Technologies in Museums

There are a number of challenges associated with the smart technologies in museums that hinder their implementation, even though they offer a lot of possible advantages. The most apparent obstacle is the steep cost of investment and routine maintenance, which can be a challenge for smaller institutions or those situated in advanced developing regions [1]. Moreover, there are a digital divide in terms of visitor access and institutional capability: audience segmentation not only lacks equal access to mobile gadgets and the internet, but also some museum staff do not possess basic skills in operating digital systems [3]. Another troubling issue is the need for incessant upgrading and adaption to new world developments due to the pace of change in technology, commonly referred to as ‘technological’ or ‘the first world problem’. Ethically, there is concern for data protection policies together with the marketing of visitor information, which need proactive responsive policies on data management [5]. Finally, there is the risk of the distraction serving as the narrative or overtaking the primary focus, where digitally created attractions out of carefully planned teaching elements may serve to detract from education instead of promote it if added to the display stories without proper design principles.

TECHNICAL UNDERSTANDING OF INDUSTRY

Importance of Technical Understanding in Today’s Workforce

As with other sectors, the museum and cultural heritage sectors are impacted by the advancements in technology and require a form of technical literacy. In this context, museums and other cultural institutions are increasingly utilizing digital tools and working with data, meaning staff members must have at the very least some basic form of education along with expertise in specialized fields that relate to technology [15]. The integration of digital media into art, history, and science requires museum professionals be trained in digital curation, data analysis, user interface design, and content management systems. This is particularly important in the framing of employment actively changing skills, where interdisciplinary approaches dominate as the norm in solving issues within sophisticated technological ecosystems [7]. Without such competencies, cultural institutions stand to fall further behind in innovation, audience engagement, and accessibility [14].

Ways in Which Smart Museum Technologies Can Enhance Technical Understanding

Museum technologies have smartened up, offering practical, hands-on methods of developing competencies relevant to the industry and adjacent fields. As an example, VR and AR technologies allow students and trainees to meet digitally with artifacts through tours and recreations, which surfaces skills in spatial reasoning, digital design, and storytelling [16]. Touchscreen displays and mobile guides offer the ability to comprehend touch interfaces and imparted the underlying principles of UX design and human-computer interaction. Moreover, IoT sensors for environmental monitoring and digital asset management systems present learners with new issues dealing with cybersecurity, big data, and digital preservation. All these tools are redefining the museum as a place of learning, turning it into a dynamic setting for applied technical practice.

Additionally, the inclusion of data analytics tools for visitor behaviour monitoring empowers the students to study data science and machine learning in a different context. Direct interaction with intelligent systems develops learners’ critical thinking, adaptability, and digital fluency which are core competencies in the modern workplace [1].

Examples of Successful Integration of Smart Museum Technologies in Industry Education

All over the world, some institutions have integrated smart museum technologies into educational and professional training programs. One such example is the Smithsonian Institution in the United States, which has created the Smithsonian Learning Lab, a digital platform for educators, students, and museum

professionals that offers a wealth of interactive tools for working with digitized collections and devising personalized learning experiences [18]. The platform improves content access, as well as the ability to navigate through materials while boosting digital literacy and self-guided learning. In the UK, the Natural History Museum in London has applied immersive AR and AI technologies to bolster educational outreach and training programs targeted at curators and scientists. Their Digital Discovery Centre serves as a point of convergence where learners and professionals can work with technologies such as 3D scanning and digital modelling [17]. Another exemplary project is the Louvre Abu Dhabi's digital program, which uses interactive tablets and multilingual mobile guides to enhance visitor learning. Immersive galleries are also employed for docent training, enabling guides to learn how to use smart systems to customize content for different audience groups [16], [18].

The above examples illustrate that smart technologies applied in museums not only increase engagement with visitors, but also act as vehicles for training future professionals in the field of museums and heritage with essential skills.

ROLE OF SMART MUSEUM TECHNOLOGIES IN PROMOTING TECHNICAL UNDERSTANDING

Enhancing Visitor Engagement and Learning Experiences

Smart technologies in museums are encouraging visitors to actively engage with exhibits rather than passively observing. Moreover, learning styles of different visitors can be catered for using augmented reality (AR), virtual reality (VR), and interactive touch screens. Elementary school students for instance, learn better processes through hands-on activities. AR applications for example, allow users to view artifacts with digital contextual narratives, multilingual translations, and other sophisticated explanations, beyond still images and text. These technologies improve cognitive, emotional, and experiential engagement with content, which has a positive effect on knowledge retention. Visitors are now able to use mobile applications or AI-assisted gadgets, whose content is tailored according to the users interests or previous behaviour patterns. Such a high level of personalization makes it easier for users, including children, the elderly, and persons with disabilities foster an inclusive environment for complex subjects. Smart technologies such as these turn culture education from a boring, one-sided approach to a modern digital experience [15].

Providing Interactive and Immersive Educational Opportunities

Advanced museum technologies help educate learners by synthesizing real-life applications to subject areas, making the teaching of historical events and diverse concepts more concrete and easier to understand [6]. Virtual reality (VR) experiences allow learners to step into reconstructions of ancient cities or endangered ecosystems, providing spatial and experiential understanding of history and science that is not available in textbooks. Moreover, holography and 3D projection mapping can animate static objects, transforming museums from passive learning environments into interactive learning spaces where visitors can manipulate digital replicas, and partake in decision-making simulations [3].

In lesson plans, all of these technologies can be beneficial for training digital humanities specialists, archaeologists, designers, and conservators at different levels. For example, preservationists-in-training can walk through the processes and interact with digital twins, which are highly detailed models of the scanned objects in three dimensions. Educational smart technologies incentivize museums as places for 21st century skill development by not only enhancing learning through doing, but also fostering digital competencies like coding, UX design, data visualization, and content management. These skills, applicable across a multitude of industries, enable museums to serve as relevant training grounds [1].

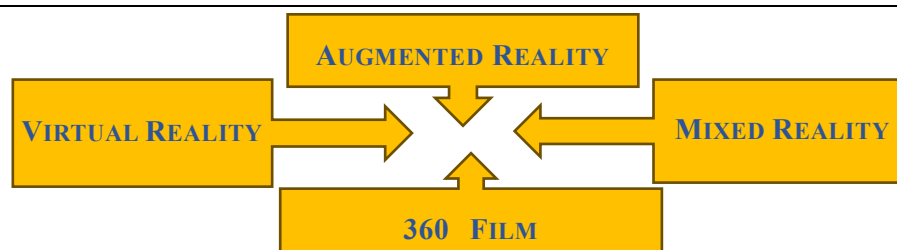


Figure 3. Immersive learning opportunities

As for immersive learning opportunities, refer to learning experiences that capture the attention of learners by fully engaging them in real world or simulated activities (Figure 3). The intention is to increase comprehension and retention of content while making learning participative instead of passive.

Fostering Collaboration Between Museums, Industry, and Educational Institutions

Integrating smart technologies in museums not only enhances their functionality, but also accelerates collaboration between different disciplines. More and more museums are partnering with technology and design companies and higher education institutions to develop educational materials that bridge the worlds of culture and technology. These partnerships are particularly important in developing context and culture-sensitive technological responses and allowing learners and practitioners to participate in various research, internship, and innovation activities.

Virtual access to museums and development of their online counterparts were facilitated through the European V-Must Project which offered a collaborative environment to museum curators, software developers, and academic researchers to enable best practice sharing across institutions. Similar initiatives are practiced at the Smithsonian Institution and Louvre Abu Dhabi where universities and tech startups are engaged in the development of digital instructional resources that serve research needs. This fosters a culture of developing for sustaining advancements in information technologies, facilitating the exchange of intellectual resources, and transforming cultural institutions into active sources of development-oriented education in the digital context.

CASE STUDIES

Case Study 1: Implementation of Smart Museum Technologies in a Specific Industry-Focused Museum

The German Museum of Technology (Deutsches Technikmuseum), Berlin

The German Museum of Technology in Berlin exemplifies the integration of innovative technologies into a museum focused on a specific industry. As a museum of the history and development of technology, it offers a wide array of digital interactives to explain sophisticated systems of manufacturing and engineering. For example, augmented reality (AR) applications let people digitally “dissect” the physical models of historical steam engines or early aircraft, revealing their inner components in an augmented reality layer.

Museum technology also includes RFID-based systems that tailor the content to individual visitors. Visitors receive smart cards that activate specific educational and entertaining multimedia presentations relevant to their age, interests, and prior engagements, thus making the museum more enjoyable. Such technological environments enhance the informal learning experience, especially for school-aged children or apprentices, and familiarize them with the digital technologies that pervade contemporary industrial settings. The museum’s practices demonstrate how smart technologies can aid in heritage conservation while simultaneously preparing a skilled workforce [8],[19].

Case Study 2: Impact of Smart Museum Technologies on Visitor Engagement and Technical Understanding

The Science Museum, London

London's Science Museum has been at the forefront of using immersive and interactive technology to foster engagement and promote technological literacy among its various audiences. One of the most transformational exhibits, Engineer Your Future, incorporates gamified learning experiences in which teenagers are able to solve real-time engineering problems at learning stations. Realistic scenarios in aerospace, civil, and environmental engineering are problem-solving and multi-faceted simulations aided with motion detection, touchscreens, and interactive interfaces [9].

The museum has since developed VR experiences including Space Descent VR that mimics an astronaut's re-entry into Earth from the International Space Station. These experiences enhance visitor engagement by offering emotional immersion coupled with high interactivity, which these visitors interact with as it influences their understanding of the material content in the exhibit, both temporally and contextually [16]. Surveys conducted after the visit indicated an increased interest in STEM fields among younger school-aged guests, showcasing the effectiveness of advanced technologies for illustrating complex engineering concepts in an accessible manner to the youth [11].

Case Study 3: Collaborative Efforts Between Museums and Industry Partners to Promote Technical Understanding

The Tech Interactive, San Jose, California

The Tech Interactive (previously known as The Tech Museum of Innovation) has pioneered a model for the collaboration of museums with technology companies and educational institutions in the promotion of technical literacy. In cooperation with Cisco, IBM, and Stanford University, The Tech Interactive has developed interactive exhibits and laboratories that teach coding, robotics, cybersecurity, and biotechnology through the application of modern technology.

One such Bio Tinkering Lab allows the visitors to play with modern biology by providing real laboratory equipment alongside digital microscopes for data editing. These programs are developed in conjunction with industry and educational partners to ensure relevancy to contemporary scientific work and professions. Also, the museum provides coding and design challenges that local technology companies have partnered with the museum to develop, which are incorporated into the educational outreach programs for students and teachers.

Such a model not only ensures that the content is relevant to the latest technological developments, but also enhances the understanding of digital skills application for the visitors and is aimed at bridging the gap between informal learning experiences and structured training in technology, thereby cultivating an informed public ready for employment in the industry.

FUTURE DIRECTIONS AND RECOMMENDATIONS

Artificial intelligence, extended reality (XR) and personalization through data will drive smart technologies in museums to further their impact on career-focused learning in the future. AI-based adaptive learning systems may vend exhibit materials in real-time depending on visitor monitor interactions, alongside XR habitats that replicate advanced industrial activities for practical training free from physical limitations. Moreover, smart wearables along with biomarkers could enhance learning pattern understanding, improving overall visitor experience and curriculum design. Aside from smart technology integration, these barriers need to be solved: high cost of implementation, deficient digital frameworks in smaller institutions, and lack of skills amongst museum workers. Addressing these issues requires deliberate steps to integration through investment, public-private partnerships, continuous staff training, and scalable strategies to ensure workable deployment.

Museums need to pay attention to emerging technologies and strive towards inclusivity through the use of flexible modular systems. School partners as well as other industry partners need to adjust their approach towards museums to co-creators instead of sponsors who only provide funding to develop educational materials and experiences that capture real-life vocational requirements. On the other hand, schools need to implement museum centred learning activities into course outlines which are centred around projects, mentorships, and transdisciplinary learning. Such collaborations have the potential to build a new ecosystem where museums offer hands-on training from major technical skills, creativity, innovation, and self-driven learning. With the collaboration of museums, businesses, and educators, the smart technologies incorporated in these museums are able to encourage people to reach a deep understanding and readiness to become active citizens in the future.

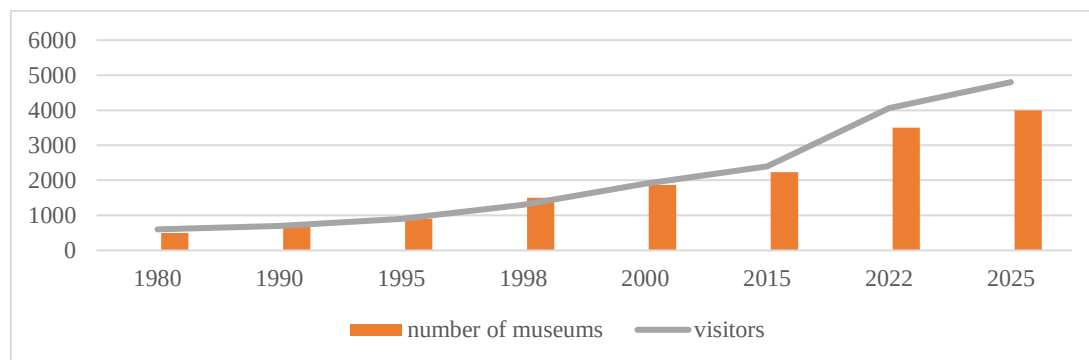


Figure 4. Impact of smart museum technologies on visitor

It can be clearly seen from figure 4 that the adoption of smart tools in museums is directly related to the growth in the number of visitors, as the digital tools integrate to improve overall experience for the visitors. The use of interactive screens, mobile application, AR/VR, and AI programs makes tours more interesting and helps customize them to each user's needs.

CONCLUSION

This paper analysed the impact of smart technologies in enhancing industry-related education and fostering technology skills in the digital world. Starting from a description of smart technologies in museums, such as augmented and virtual reality, IoT, and AI systems, the conversation emphasized how these aids enhance engagement in Museum Learning, transforming passive knowledge acquisition into participation, interactivity, personalization, and immersion. The importance of technical literacy for employment was highlighted as well, noting smart museum technologies as tools capable of fostering relevant competencies, especially when integrated into education and training programs.

The paper provided realistic case studies that reveal how museums across the globe leverage smart technologies to engage users, teach actual technical skills, and interact with industry and academic partners. While some problems like sponsorships, the state of existing systems, and the education and training available do pose some short-term difficulties, the cumulative impact on interactivity in teaching and cross disciplinary teaching and learning in the long term is promising. The functions of Smart Museum technologies go beyond providing new solutions; they allow to cultivate a digitally intelligent society. With the rapid growth of the digital skills gap in almost every industry, museums need to redefine their position as nonformal but significant centres of technology instruction. To achieve this, active collaboration among the museums, industry, and education is vital to augmenting funding and further research. Stakeholders are invited to actively participate in new confined and broader constructs that transform museums from simply custodians of culture to progressive educational facilities.

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