Article

Empowering Museums with Artificial Intelligence: From Cultural Heritage to Sustainable Business Development

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Abstract: This article investigates the pivotal role of artificial intelligence (AI) in advancing museums from their traditional mission of cultural preservation towards a framework of sustainable commercial development. The findings suggest that AI, through refined user profiling, semantically enhanced knowledge graphs, and multimodal interactive experiences, is reshaping operational models and revenue systems within museums. Drawing on both domestic and international case studies, the paper proposes a tripartite model—Experience, Data, and Ecosystem—to articulate how AI fosters value creation. It further explores how AI enhances visitor satisfaction, stimulates cultural engagement, and sustains revenue through optimised membership services, expanded digital cultural products, and refined knowledge monetisation strategies. The article ultimately argues that AI is instrumental in enabling museums to undergo digital transformation and cultivate sustainable business value.

Keywords: artificial intelligence; museums; business models; cultural resonance; sustainable development

1. Introduction

In the context of accelerating digital economies, museums are undergoing a profound transformation from being collection-centric institutions to user-oriented cultural ecosystems. The

integration of artificial intelligence (AI) technologies has not only enhanced exhibition formats and operational workflows, but has also redefined how cultural content is organised and how commercial strategies are designed.

Academic Editor: Cindy CHOU

Received: 29th June, 2025
Revised: NA
Accepted: 1st July, 2025
Published: 5th July, 2025

Traditionally, museums relied heavily on static displays and unidirectional communication. The advent of AI has made possible a shift towards personalised recommendations, multimodal interactions, and semantically enriched content delivery. These capabilities contribute to more engaging and adaptive visitor experiences, while simultaneously opening up new avenues for knowledge dissemination and cultural consumption.

The strategic deployment of AI enables museums to fulfil their public mission more effectively whilst creating new forms of economic value. By embedding intelligent technologies in user profiling, content structuring, and sensory experience design, museums are increasingly able to operate as hybrid platforms—where heritage interpretation and audience engagement intersect with data-driven service innovation and sustainable revenue generation.

This paper proposes a three-layer model—experience, data, and ecosystem—as a conceptual framework to analyse the AI-enabled transformation of museums. Through a series of case studies from both domestic and international institutions, it explores how AI can simultaneously support cultural preservation and drive business sustainability.

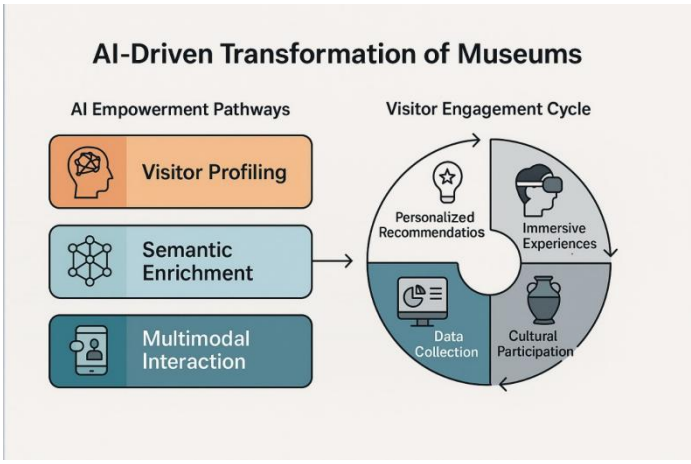

Figure 1. AI-empowered pathways and the user engagement feedback loop in museums

2. AI-Driven Pathways for Business Value Creation

Artificial intelligence contributes to value creation in museums across multiple dimensions. It not only enhances visitor experiences—thereby increasing appeal and retention—but also streamlines internal operations and paves the way for entirely new business models.

2.1. Integrating User Profiling with the Experience Economy

AI technologies enable museums to develop dynamic user profiles based on multimodal behavioural data—including voice input, gaze tracking, spatial movement, and emotional recognition. These data are used to deliver personalised tours and tailor content to individual interests. For instance, the Palace Museum in Beijing has employed a low-code platform that integrates RFID trajectory data with natural language processing to build a 12-dimensional tagging system, significantly improving the accuracy of predicting preferences among young visitors.

By analysing the interplay of semantic inclinations, cultural literacy levels, and interaction histories, the system is able to recommend differentiated outputs to diverse user groups. Children might receive gamified learning experiences and themed merchandise; older visitors may prefer voice-guided routes; while researchers might access academic resources. This facilitates diverse consumption paths embedded within the museum journey.

In memorial institutions such as the Chen Yun Memorial Hall, the hypothetical implementation of an AR-based treasure hunt could virtually reconstruct historical scenes and figures, enabling visitors to engage through role-play. Such immersive experiences can not only deepen understanding of historical narratives but also stimulate interest in related digital products. These interactive features may be further developed into paid mobile applications for educational markets, offering long-term monetisation potential.

2.2. Semantically Enhanced Knowledge Graphs and Ecosystem Designgrating User Profiling with the Experience Economy

Knowledge graphs have emerged as foundational infrastructure for linking museum collections with audiences through intelligent systems. Their construction has evolved beyond traditional subject–predicate–object triples towards multidimensional semantic

storytelling networks. By refining ontologies and leveraging AI-driven inference, museums are increasingly able to integrate artefact narratives across time periods and cultural contexts.

Such enriched structures offer content-as-a-service capabilities, enabling seamless collaboration with education platforms, e-commerce providers, and tourism operators. For example, constructing a four-dimensional semantic schema—spanning events, individuals, locations, and symbolic meanings—allows museums to co-develop narrative-based teaching materials or to coordinate with travel agencies to offer curated "knowledge-driven cultural itineraries".

A notable application is found at the Mausoleum of the First Qin Emperor, where knowledge graphs are being combined with blockchain technology to issue digital credentials for artefacts. This approach helps overcome data silos, facilitates secure data-sharing among partner institutions, and lays a trusted foundation for the commercialisation of knowledge graph services.

2.3. Multimodal Interaction Systems and the Rise of Immersive Consumption

Technologies such as AR, VR, and MR—when integrated with voice interfaces and emotional feedback mechanisms—are enabling museums to construct fully immersive "perceive–respond–transact" experiences. These multimodal environments offer visitors both cognitive enrichment and emotional engagement, while simultaneously unlocking new commercial opportunities.

For instance, the British Museum's podcast-guided tours have demonstrated that narrative-rich, trust-enhancing content can effectively drive user donations and convert casual visitors into paying members. Similarly, the use of explainable AI algorithms—such as SHAP and LIME—has increased transparency in personalised content recommendations, improving user trust and the likelihood of content monetisation.

Several museums have already incorporated such systems into their digital platforms. Voice navigation, virtual object try-on, and voice-triggered purchasing functions are being prototyped in museum apps. The Louvre's "My Louvre" initiative, for example, encourages users to generate content (UGC), which is then algorithmically recommended to others. This fosters a virtuous cycle connecting content creation, community participation, and commercial engagement.

3. System Architecture and Value Loop Design

The construction of personalised recommendation systems in museums now aims beyond mere functional implementation; its core objective lies in how to maximise commercial value through thoughtful system design. This implies that such systems must not only meet user needs, but also strategically incorporate revenue-generating touchpoints.

3.1. Segmented User Pathways: Children, Older Adults, and Researchers

In designing personalised recommendation systems for museums, it is essential to thoroughly understand and accurately deconstruct the needs of diverse user groups. The system must flexibly adapt to varying visitor goals and interaction preferences in order to maximise cultural experience and uncover potential commercial opportunities. To achieve this, user needs must be analysed contextually—translating abstract user characteristics into concrete interaction scenarios and monetisable functional requirements.

For children aged 6 to 12, their core needs centre around gamified learning and role-playing immersion. Traditional linear tour formats often fail to capture their interest; therefore, the system should integrate AR-based treasure hunts and animated knowledge graphs. AR treasure hunts can transform the museum space into an interactive learning environment, where children acquire knowledge about artefacts by completing tasks and solving puzzles. Animated knowledge graphs, meanwhile, use vivid, engaging visuals to translate abstract artefactual information into easily comprehensible content.

For example, the system could feature a “Time Travel Adventure” AR game, in which children take on the roles of historical figures and search for clues throughout the museum. As they complete missions, they simultaneously learn about the relevant historical context. This interactive approach not only boosts children's interest in learning, but also strengthens their memory of cultural heritage. Moreover, such game content can be commercialised through paid apps or bundled cultural products—such as role-play props—thereby generating direct revenue.

Older adults, on the other hand, often prefer voice-first interfaces and assistive technologies that account for accessibility needs. Features such as simplified interaction design, larger text displays, and audio narration can significantly improve their overall experience and increase their willingness to participate in additional services.

For academic users, the priority lies in access to high-fidelity digital artefacts and collaborative research tools. These may include 3D reconstructions, linked academic references, and cross-institutional knowledge graph integration.

Each of these user pathways opens the door to differentiated revenue streams: gamified content for children may support in-app purchases; inclusive services for older visitors may form the basis of subscription models; and research APIs for scholars may be offered as premium data services. A diversified strategy based on user segmentation enables the museum to extend its value chain and establish a multi-tiered income architecture.

3.2. Integrating Performance, Security, and Compliance

Designing a robust AI-enabled system within museums requires balancing high-performance delivery with rigorous data protection and legal compliance. A dual-architecture approach—combining edge computing with federated learning—can ensure responsive user interaction while safeguarding personal information.

From a regulatory perspective, systems must comply with international standards such as the General Data Protection Regulation (GDPR). This entails building end-to-end data lifecycle management mechanisms, from acquisition and processing to storage and deletion. The adoption of blockchain-based evidence protocols can further enhance transparency and user trust by securely logging all data operations.

Technically, modular architecture and load-balancing mechanisms contribute to system scalability and stability. Log auditing and real-time monitoring ensure that both front-end interactions and back-end processes are maintained at optimal efficiency. These infrastructural elements are crucial not only for operational reliability, but also for supporting sustainable business models based on AI services.

4. System Architecture and Value Loop Design

Although AI technologies have been applied in areas such as digital tours, content recommendation, and semantic structuring, many challenges remain. Lesser-known or non-mainstream artefacts often lack sufficient user interaction data or historical engagement records, making them difficult to identify and promote through algorithmic systems.

At the same time, issues such as cross-cultural misinterpretation and the limited explainability of recommendation mechanisms persist. One promising approach involves the use of generative AI to create visual narratives or virtual reconstructions, thereby drawing user attention to underrepresented collections. Cultural sensitivity, meanwhile, can be addressed through a hybrid approach combining algorithmic suggestions with expert review panels.

Furthermore, expanding cross-institutional collaboration and developing multilingual knowledge graphs will be essential for unlocking global commercial potential. Metrics of system success will also need to evolve—from conventional click-through rates to indicators of cultural resonance. Technologies such as eye-tracking, sentiment recognition, and biometric feedback may offer more meaningful insights into users' emotional engagement, enabling museums to better assess the impact and value of their digital offerings.

5. Conclusion: Toward a Convergent Model of Culture and Commerce

AI-driven museum systems are no longer mere integrations of technology and heritage; they are evolving into dynamic ecosystems of meaning, where people, objects, and narratives converge. At the heart of this evolution lies the concept of cultural resonance, which—when used as a key evaluation metric—can guide both algorithmic development and audience engagement strategies.

Future museum platforms are expected to move beyond operational efficiency, aiming instead to cultivate participation, co-create collective memory, and expand revenue in ethically grounded ways. In such systems, curators and users collaboratively contribute to content enrichment, forming a two-way value chain that reinforces both knowledge production and emotional connection.

Looking ahead, the benchmarks for AI systems will gradually shift from technical accuracy to metrics such as cultural relevance and affective impact. This transformation will require more transparent and interpretable recommendation engines, alongside new forms of evaluation incorporating eye movement, emotional tone, and tactile interaction.

Additionally, "cultural translation" and "intelligent co-creation" are emerging as key areas for research and development. These include the construction of cross-lingual knowledge graphs, adaptive semantic algorithms for diverse audiences, and curator-guided emotional design systems. Through such innovations, museums are set to become data-driven, value-led, and co-creation-oriented cultural hubs for the future.

6. Acknowledgements

This research was supported by the Key Research Project in the Field of Cultural Heritage and Museums, Sichuan Province(Grant Number: SCWW2023A04), titled *Design and Implementation of an AI-based Personalised Museum Visiting Experience System*.

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