A Literature Review on Enhancing Exhibition Services in Smart Museums Based on Emerging Information Technologies

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Abstract: Smart exhibitions are audience-centered, interactive display services within smart museums. This paper investigates the primary technological applications and development trends that enhance exhibition services in smart museums. Through a literature review, the paper analyzes the concept and structure of smart museums, the application of exhibition technologies in smart museums, the major existing issues in traditional museums, as well as exhibition technologies and their future trends in smart museums. The study summarizes the characteristics of smart exhibition services, including personalized and precise services, multidimensional visitor experiences, flexible display methods, enriched viewing experiences, intelligent optimization of exhibition hall management, and the smart generation of exhibition content. It further elucidates the development trends of innovative exhibition forms, diverse expressive means, and the provision of intelligent and personalized services in smart exhibitions. The research aims to offer a reference for the application of new technologies in the advancement of museum exhibitions.

Keywords: Smart Museum; Exhibition; Information Technology; Efficiency Enhancement Services; Personalized; Intelligent

1. Introduction

With the advancement of the information age, various emerging technologies such as AI, big data, the IoT, and virtual reality are playing increasingly significant roles in the preservation and innovative dissemination of traditional culture. Museums undertake the tasks of researching, collecting, protecting, interpreting, and displaying both tangible and intangible heritage, providing a range of experiences for education, appreciation, reflection, and knowledge sharing. In China, traditional museums have progressed from informatization to digitization and are now evolving towards smart museums. The National Cultural Heritage Administration has emphasized that strengthening technological support, enhancing the quality of exhibitions, and optimizing communication services are key tasks for improving the service efficiency of museums in the country, advocating for the vigorous development of smart museums. Exhibitions are the primary service of museums; however, traditional museum exhibitions are limited by their singular exhibition methods, which lack appeal to audiences and hinder the growth of museum services. The integration of new information technologies provides fresh concepts for the construction of smart museum exhibitions, and the active introduction of these technologies is of great significance for the enhanced development of museum services.

This paper posits that the efficiency enhancement of exhibition services refers to the improvement of museum exhibition service effectiveness through curatorial content that better aligns with public demand, more precise and personalized audience services, presentation methods that facilitate quicker audience comprehension, real-time bidirectional interaction between exhibitions and visitors, more comprehensive and in-depth exhibition content, and more efficient exhibition management. Centered around the theme of enhancing exhibition service efficiency in smart museums within the context of new information technologies, this paper explores the key technologies applied in smart museum exhibitions and their characteristics, identifies the issues present in traditional museum exhibitions and the technologies that can address them, and examines the development trends of smart

museum exhibitions.

From addressing the challenges of traditional exhibitions through new technologies and driving the evolution of exhibitions, to forecasting future trends, this paper delves into the efficiency enhancement of smart museum exhibition services based on new information technologies. It does so by analyzing and discussing the concepts and structures of smart museums and their exhibitions, the application of exhibition technologies in smart museums, the primary issues in traditional museums, the analysis of smart museum exhibition technologies, and the development trends. This study, conducted through a comprehensive literature review, aims to provide a reference for the technological application in the development and construction of smart museum exhibitions.

2. Concepts and Structures of Smart Museums and Their Exhibitions: Evolution of Museums through Advanced Technological Systems

A smart museum represents an intelligent ecosystem where museums leverage new information technologies. Smart exhibitions, within this system, are audience-centered, interactive display services. By focusing on the interaction between visitors, collections, and data, smart museums have iteratively upgraded the traditional forms of museum exhibition services. The new information technologies discussed in this paper primarily include the IoT, big data, cloud computing, AI, virtual reality, augmented reality, intelligent robotics, and mobile communications. These technologies center around the interaction of objects, people, and data within the museum, driving the development and construction of smart museums and their exhibitions.

2.1 Definition of Smart Museums and Their Exhibitions

From the perspectives of intelligent systems, new information technologies, and museum forms, Chinese cultural heritage experts have defined the concept of the smart museum. The term “smart museum” originates from concepts like “smart earth” and is closely related to the construction of smart cities. Song (2015) posited that, in a narrow sense, a smart museum is an intelligent system based on the core business needs of a museum. Broadly speaking, it is a complete intelligent ecosystem constructed across one or more physical museums (museum clusters), and even at different scales, such as artifacts, architecture, sites, cities, and beyond. [1] Chen (2016) viewed the smart museum as a new museum form based on the digital museum, fully utilizing new technologies like the IoT and cloud computing, characterized by comprehensive and in-depth perception, ubiquitous broadband connectivity, and intelligent integrated applications. [2] Duan (2021) defined it as a new model and form of museum development, leveraging next-generation information technologies such as cloud computing, the IoT, mobile communications, and big data, to perceive, compute, and analyze people, objects, activities, and data related to museum operations. This enables the intelligentization of museum activities, including collection, protection, exhibition, dissemination, research, and management, thereby enhancing the museum’s capabilities in service, protection, and management. [3] Jin (2016) believed that the smart museum is a new concept and entity developed on the foundation of museum informatics and digital museum research and practice. [4] In summary, the smart museum represents a new museum form based on the integration of multiple new information technology systems.

Exhibition is one of the core functions of a museum, and Chinese experts have also defined smart museum exhibitions in terms of their service functions and characteristics. Chen (2016) proposed that smart museums achieve intelligent interactive display services through informatization, enabling the public to interact with online platforms, collections, exhibition halls, and related equipment and facilities. [2] Song (2017) suggested that smart museum exhibitions differ from digital museums by featuring cloud computing and big data platforms for intelligent services, and personalized smart guide platforms for visitors. [5] Chen (2016) [2], Duan (2021) [5], and Feng (2017) [6] emphasized that the primary characteristic of smart museum exhibitions is their audience-centered approach, utilizing technologies such as cloud computing and big data platforms to provide personalized services, and employing sound, light, electricity, and digital technologies to enhance visitors’

understanding and appreciation of historical and cultural content. In summary, smart museum exhibitions represent intelligent display services centered on the audience and enabled by various information technologies.

Therefore, this paper posits that a smart museum is an intelligent ecological system created by integrating museum informatization, digital museum frameworks, and the application of intelligent technologies. These intelligent technologies include next-generation information technologies such as the IoT and the Internet, high-speed communication, big data analytics, and AI. Traditional museums, which are primarily physical entities, have evolved into digital museums through informatization and digitization upgrades. Based on the foundation of digital museums, smart museums employ intelligent technologies to automatically collect and intelligently analyze information about people, objects, and activities at any time and place, providing real-time feedback and creating a smart museum ecosystem. Smart museum operations are centered on human interaction, using dynamic, bidirectional, and diverse exchanges of information among objects, people, and data to achieve intelligent protection, management, and service functions. Smart exhibitions, a key component of smart museums, are intelligent, interactive display services focused on the audience. These exhibitions can provide curatorial suggestions by mining social information, intelligently generate exhibition content, and smartly manage exhibition halls and equipment. They also have the capability to perceive changes in the needs of individual visitors and groups anytime and anywhere through the network, and, by using data analysis and intelligent feedback, offer personalized content recommendations for physical, digital, or online exhibitions.

2.2 Architectural Framework and Exhibition Design of Smart Museums

Based on informatization and digitization, Chinese experts have employed new information technologies to propose an overall framework, standards, and system architecture for the construction of smart museums, defining within this framework the work attributes, technical standards, and construction plans for exhibitions. Song (2015) introduced a smart museum characteristic model based on four dimensions: Roles, Objects, Activities, and Data (referred to as the ROAD model) [3]. Yang (2016) proposed a standardized framework for smart museums, which includes three major categories: top-level design standards, standards for collection, transmission, and management, and application service standards [7]. Chen (2016) put forward the “4+2” system architecture for smart museums [4]. Zhang (2016, 2018) identified the core systems of smart museums as the building/equipment system, business system, audience system, data communication system, and decision support system [8]. Based on these core systems, he proposed the “Perception-Judgment-Execution” construction plan for smart museums [9]. Shen (2016) proposed a comprehensive technical architecture for smart museum informatization platforms, encompassing five layers: the infrastructure layer, data resource layer, application support layer, application service layer, and presentation layer [10]. In conclusion, smart museums utilize systems, organizations, standards, and methodologies of information technology, integrating them to form their foundational architecture, which lays the technological groundwork for the construction of smart exhibitions.

Chinese experts have studied audience-centered exhibition design and technological development in smart museums, focusing on the interaction between audiences, collections, and data. Qiu (2016) proposed that museums should intelligently analyze basic audience information, behavioral data, and query and interaction details to comprehensively perceive and accurately predict needs, guiding the service system’s operations. [11] Shao (2015) suggested using data mining to understand audience preferences regarding exhibitions, thus providing data support for museum exhibitions. [12] Yang (2019) advocated for the application of AI in exhibition guidance to meet the personalized and differentiated needs of visitors. [13] Peng (2018) emphasized that museum application design should be user-centric, analyzing offline visit positioning services and in-museum interactive design. [14] Liu (2019) proposed the use of knowledge graphs to analyze, display, and utilize vast amounts of cultural relics data, supporting smart museum exhibition development through

semantic search, recommendation, and Q&A systems. [15] Wang (2019) believed that the "Smart National Museum" project fully leverages data centered on collection information and achieves information sharing among application systems [16]. In summary, China's smart museums are audience-centric, utilizing information technology to develop personalized smart exhibition services based on the interaction between audiences, collections, and data.

Smart museums have upgraded from traditional museums upgraded to digital museums by employing new information technologies to iterate on museum architecture and enhance exhibition design. In recent years, traditional museums in China have gradually progressed towards becoming digital museums. With the development of new information technologies, since 2014, the State Administration of Cultural Heritage has designated seven museums as pilot projects for the construction of smart museums. These smart museums integrate new information technologies such as big data, the IoT, mobile internet, AI, and cloud computing into the digital museum framework, gradually establishing the technical architecture of smart museums. The construction of smart museum exhibitions represents the iterative development of museums through the application of various new technologies. For instance, the use of cloud computing, big data, and virtual reality technologies enables the creation of cloud museums, providing viewers with a hybrid online and offline viewing experience. There is a significant distinction between smart museums and digital museums. Digital museums establish a foundation for data-related work, allowing for data processing, storage, analysis, and the recording of relevant operations. Smart museums, on the other hand, utilize IoT and the internet to gather information for exhibition-related tasks. They analyze information from various systems through AI, integrating and feeding back the acquired information using dynamic forms, thereby enhancing the museum's intelligent service capabilities. Zhang (2022) pointed out that smart museums fully integrate internet, IoT, big data, and AI technologies, creating intelligent perception and interaction, offering visitors different application experiences, and embodying the core feature of smart integration as the hallmark of smart museum [17].

In conclusion, the transition from traditional museums and digital museums to the construction of smart museums through the application of new information technologies is an inevitable trend. Exhibition design will inevitably iterate and upgrade to smart exhibitions in line with technological advancements. Smart exhibitions can provide visitors with personalized, interactive, immersive, and hybrid online-offline viewing experiences.

Therefore, smart exhibitions are intelligent interactive display services within the smart museum ecosystem. They center around the audience, enabling deep interaction among visitors, collections, and data, thereby enhancing the viewing and experience of museum visitors. Next, this paper will specifically analyze the main technological foundations used in smart museum exhibitions to improve service efficiency.

3. Key Technological Applications in Smart Museum Exhibitions: Laying the Foundation for Intelligent Management and Audience-centered Services

By applying new information technologies, smart museums have achieved intelligentization in exhibition, dissemination, and management functions within museum informatics and digital museums. This paper provides a comprehensive analysis of the key technological foundations of smart museum exhibitions, focusing on four main aspects: intelligent exhibition management systems, the adaption of RFID technology in exhibition areas, the application of big data analysis technology, and the integration of IoT technologies.

3.1 Intelligent Exhibition Management Systems

The intelligent management system is a framework that leverages big data and AI to manage exhibitions and related operations within museums. This system forms the technological backbone for the intelligent management of museum exhibition activities. Shen (2016) pointed out that the smart museum's information platform system utilizes components from the service layer and presentation layer, enabling bidirectional

information interaction through intelligent analysis of visitor data [10]. Zhang and Zhang (2020) argued that data visualization platforms can facilitate the transformation of museum operations, provide a basis for exhibition decision-making, and better serve the public [18]. Guo (2022) [19] noted that the intelligent information management system is a distinctive feature of smart museums. It collects basic data on exhibits, processes it digitally, and integrates it using 3D virtual technology for exhibition, management, and research purposes, while also updating the database content [20]. Traditional electronic software in museums often involves cumbersome operations; however, the intelligent information management system simplifies these processes. It allows for the timely collection of information, the storage of artifact data using cloud data technology, and the real-time updating of collection data. Therefore, the intelligent exhibition management systems enhance the efficiency of museum management and lay the foundation for the management of smart exhibition services.

3.2 Adoption of RFID Technology in Exhibition Areas

RFID technology is a wireless communication method that identifies specific targets within an exhibition and reads or writes related data via radio signals. This technology enables museums to automatically identify both visitors and exhibits. Tian (2020) [20] and Zhong (2020) [21] noted that this technology can be employed in smart museums to recognize visitors or exhibits, transmitting the identified information to the management for real-time processing. When visitors use RFID-equipped devices during their museum visits, the museum can enhance their personalized experience through identification, positioning, and push notification technologies. Wang (2022) suggested that the adoption of RFID technology in exhibition areas addresses the lack of personalized services in traditional museum exhibitions and provides a new technological platform for the dissemination of historical and cultural content [22]. Thus, RFID technology efficiently identifies exhibits and visitors, laying the foundation for a personalized viewing experience.

3.3 Application of Big Data Analysis Technology

Big data analysis technology involves the collection, processing, and analysis of vast amounts of data by museums, using algorithms to derive insights and judgments. The application of this technology can enhance the efficiency of curatorial planning, exhibition dissemination, and management in museums. Song (2015) [1], Wei (2018) [23], Yang (2019) [13], Zhang (2020) [18], and Wang (2022) [24] have analyzed various aspects of big data analysis, including its technical framework, applications in exhibition planning and management, and practical exhibition applications. They highlight the use of knowledge graphs to interlink diverse data and information, forming the foundation for AI services. Thus, the application of big data analysis technology lays the groundwork for intelligent exhibition services, providing personalized, demand-based services to museum visitors and enhancing exhibition hall management through the integration of smart devices.

3.4 Application of IoT Technology

IoT technology in museums involves connecting physical objects related to exhibitions to the internet via information sensing devices, allowing these objects to exchange data with other devices and systems through the internet. IoT technology serves as the sensory foundation of a smart museum, acting as the “eyes” and “ears” that perceive visitors, collections, and the environment. Shao (2015) suggested using IoT to establish a two-way information exchange between people and objects, objects and objects, and people and people, to achieve intelligent control of objects within the museum [12]. Wang (2020) [25], Liu (2017) [26], Li (2022) [27], and Yao (2022) [28] analyzed the information service models of IoT technology, the integration of “people—collections—education”, and the statistics and management of collections. They pointed out that smart museum data collection can utilize different systems for information interaction and management, while IoT enables information exchange between objects, allowing for real-time data exchange. Therefore, the application of IoT technology lays the technical foundation for museums to sense visitors and

exhibits, providing data sources for interactions among visitors, collections, and data, thereby enhancing exhibition management and services.

In summary, the use of smart management technologies, such as RFID, big data analysis, and IoT in smart museum exhibitions, lays the foundation for intelligent museum management and visitor-centered services, enhancing the effectiveness and experience of exhibitions while offering methods and pathways for the development of traditional museum exhibitions.

4. Issues in Traditional Museum Exhibitions: Lack of Diverse, In-depth, and Personalized Services

Under the guidance of national policies aimed at "enhancing service efficiency", the improvement of exhibition services in traditional museums must evolve in step with advancements in information technology. Exhibitions are a core service through which museums engage with society and serve as a primary medium for public communication. The form of exhibitions significantly impacts the audience's experience and understanding. However, traditional museum exhibitions face several issues, including a lack of diversity in exhibition methods, insufficient depth in showcasing the features of exhibits, and inadequate personalized services. There is considerable room for improvement in enhancing the effectiveness of exhibition services. The specific issues are analyzed as follows:

First, the exhibition methods are overly simplistic. He and Yang (2018) pointed out that traditional museums have long relied on a monotonous "object-oriented" exhibition method, lacking diverse and dynamic ways to present knowledge related to collections. This results in a limited and static exhibition format that fails to fully engage audiences, making it difficult to meet their expectations for exploring traditional culture and their growing demand for new cultural services and experiences [29]. Shen Jiang and Lu (2013) argued that this issue negatively impacts the audience's experience with exhibits, reduces their enthusiasm for visiting, and hampers their ability to deeply appreciate the historical and cultural significance of the objects on display [30]. In the information age, the public is frequently exposed to a variety of engaging and diverse presentation forms. Visitors often come to museums with high expectations for the exhibition style. However, if the exhibition methods remain simplistic, the visitor experience may fall short of these expectations, leaving them with a sense of disappointment. This not only hinders the understanding and appreciation of cultural knowledge but also diminishes the museum's appeal to the public.

Second, the exhibitions do not thoroughly or comprehensively showcase the unique characteristics of the exhibits. The collections displayed in museums each have their distinctive features, and a variety of presentation techniques should be employed to highlight these characteristics. Yao (2018) noted that the content and form of traditional museum exhibitions are limited, often merely showcasing the external features of the artifacts, while failing to convey the rich knowledge embedded within them, which is detrimental to the dissemination of cultural content [31]. Li and Zheng (2022) emphasized the need to use multiple intelligent technologies to highlight the unique attributes of exhibits [32]. When exhibitions do not comprehensively and deeply portray the features of the exhibits, it reduces the audience's understanding and the effectiveness of the exhibition's narrative.

Third, the level of personalized services in exhibitions needs improvement. Personalized services tailor the exhibition experience to the needs of different audience groups, such as through customized guided tours. Traditional museum exhibitions are typically centered around objects and lack the means to accurately and promptly grasp and anticipate the needs of the audience, resulting in insufficient personalized services for segmented audience groups. Zheng (2019) observed that most traditional museums rely on either textual explanation on signage or guided tours, which often do not fully satisfy the cultural needs of visitors [33]. Qiu (2014) noted that audience research in traditional museums is constrained by factors such as visitor demographics, visit times, and personality traits, leading to limited information on audience preferences [34]. Therefore, Chen (2020) suggested using more precise service technologies to enhance the effectiveness of exhibitions and provide a

better viewing experience for different audience groups [35]. The lack of personalized services in exhibitions reduces service accuracy and the overall visitor experience.

In conclusion, the lack of diverse, in-depth, and personalized services in traditional museum exhibitions is a major issue affecting the visitor experience and the effectiveness of these exhibitions. Smart museums urgently need to provide traditional museums with new technological solutions to "strengthen technological support, improve exhibition quality, and optimize communication services", thereby enhancing exhibition services.

5. Technological Analysis of Smart Exhibitions: Innovating Exhibition Forms, Enriching Presentation Methods, and Enhancing Intelligent and Personalized Services

In response to the issues present in traditional museum exhibitions, this paper advocates for the proactive use of advanced technologies in smart museums to innovate exhibition forms, enrich presentation methods, and enhance intelligent and personalized services. The new information technologies that can be utilized to improve the effectiveness of exhibitions in smart museums include virtual reality, 3D printing, screens and projections, intelligent motion theaters, AI, and more.

5.1 Virtual Reality

Zhao (2016) defined virtual reality as a technology centered on computer systems that generates a digitized environment closely resembling a real-world setting in terms of visual, auditory, and tactile experiences. [36] The key features of this technology are interactivity, imagination, and a sense of immersion, enabling audiences to simulate and experience exhibition content or environments as if they were physically present, thereby deepening their understanding of the knowledge being presented. Wang (2019) highlighted that virtual reality technology facilitates the "living" display of museum culture through immersive experiences [37]. Miao (2018) discussed the narrative design of virtual reality in museum exhibitions, which provides audiences with a more impactful sensory and psychological experience, along with greater freedom in choice and imagination [38]. Zhang and Yang (2020) suggested that the application of this technology in museums allows cultural heritage content to be symbolically regenerated within the networked society, connecting distributed cognition and collectively constructing the "super-presence" of cultural heritage memory [39]. By creating virtual museums on the internet, this technology enables the public to visit cloud exhibitions online. Huang (2020) categorized cloud exhibitions into real-scene 3D exhibitions and 3D virtual exhibitions, noting that this mode of dissemination fosters interaction among museums, exhibitions, and audiences [40]. The Palace Museum began exploring the application of virtual reality technology in 2000 and, by 2018, had created seven virtual reality programs based on theater environments, including The Forbidden City: The Emperor's Palace, The Three Halls, The Hall of Mental Cultivation, The Studio of Exhaustion from Diligent Service, The Pavilion of Prolonged Vitality, The Corner Tower, and The Imperial Garden. Wu et al. (2018) analyzed that virtual reality technology enhances the experiential and diverse aspects of exhibitions, revitalizing the display of cultural relics and improving the overall viewing experience [41]. In summary, virtual reality technology enriches the exhibition experience through virtual means, facilitating a more comprehensive and in-depth understanding of the exhibits by the audience.

5.2 3D Printing

Yu (2013) noted that, in a narrow sense, 3D printing technology is a process of rapid prototyping and, in a broader sense, is known as additive manufacturing [42]. 3D printing can be used for replicating and restoring artifacts, displaying replicas, and creating personalized cultural and creative products. Chen (2020) suggested that in the future, museums will increasingly utilize 3D printing technology to enhance the efficiency of artifact preservation and restoration, allowing some precious artifacts to be replicated for display [36]. Yang (2019) argued that this technology can better protect artifacts during touring exhibitions [13]. Wang (2022) proposed the use of this technology to replicate artifacts for the development of personalized cultural and creative products [43]. Ning and Gu (2018) analyzed the method of full-scale 3D printing

replication and virtual display of the Yungang Grottoes' Cave No. 3, realizing the smart museum's goal of exhibiting immovable cultural relics in different locations, thus bringing the artifacts to life and enabling them to reach a broader audience [44]. In summary, 3D printing technology offers more flexible means to display and interpret cultural heritage.

5.3 Screens and Projections

Museum screen technology primarily includes television screens, touchscreens, LED screens, and advertising displays, while projection technology encompasses projectors, holographic projections, and cinema projections. Screens and projections are essential tools for presenting digital visual content in museum exhibitions, playing a crucial role in content display, atmosphere creation, and audience interaction. Giuliana and Liu (2016) proposed that the modern museum has transformed into a new type of space: a multiscreen theater of memory, an intimate public screen. Screens and projection devices trace the paths of audience imagination, etched into the cinematic montage and the journey of viewing [45]. Huang (2016) analyzed the Palace Museum's Duan men Digital Exhibition Hall project, emphasizing that the design of screens and projection equipment in exhibition spaces is vital to the audience experience [46]. Qi (2021) [47], Fang (2018) [48], and Li (2015) [49] concluded that holographic projection and phantom imaging technologies represent new directions in exhibition content display. In summary, screens and projection technology provide audiences with a multidimensional exhibition experience, enriching their understanding and knowledge.

5.4 Smart Motion Theaters

Smart motion theaters are specialized cinemas that synchronize projected content with on-site sound effects, lighting effects, motion-enabled seats, and simulated experiences such as smoke, fog, rain, or lightning. This technology is crucial for enhancing the visual, auditory, tactile, and kinesthetic experiences of museum visitors. Chen (2020) asserted that smart motion theaters have become standard features in large museums and science centers, serving as memorable experiences for visitors [35]. Fan and Chen (2016) analyzed the Mogao Grottoes Digital Center's dome cinema and considered smart motion theaters as a technological revolution in film history, improving traditional viewing methods from a user experience perspective and increasing interactivity [50]. In summary, smart motion theater technology offers visitors a multidimensional experience encompassing sight, sound, touch, motion, and smell, thereby enhancing the overall exhibition experience.

5.5 AI

AI involves training computers to develop systematic thinking capabilities, enabling them to perform certain intellectual tasks and simulate human cognitive behaviors. In museums, AI is primarily utilized for smart guides, facial recognition, image recognition, and more [13]. AI technology enables smart museums to automatically process and analyze various data, thereby generating knowledge content for exhibitions, managing exhibition halls, and offering personalized guides and navigation. Brendan (2018) suggested that this technology can autonomously generate knowledge about museum collections, allowing museums to innovate and optimize the development of knowledge areas previously considered too costly or resource-intensive [51]. Zhao et al. (2022) provided a review and analysis of knowledge graphs built through the integration of big data and AI, elucidating how smart museums employ semantic web technologies to associate and manage cultural and museum knowledge [52]. Xu (2021) posited that AI can, through audience profiling, emotion analysis, and affective computing, comprehend audience habits and emotional characteristics, providing personalized services [53]. Duan (2020) analyzed AI and robotic guides at the Hunan Provincial Museum, noting that AI offers new opportunities for museum development, with robotic guides enhancing visitor interaction with the museum [54]. In conclusion, AI technology assists museums in delivering personalized, precise services to visitors, and aids in optimizing exhibition hall management and intelligently generating exhibition content.

Therefore, by employing technologies such as virtual reality, 3D printing, screens and projections, smart motion theaters, and AI, smart museums are able to address the limitations of traditional museums in terms of

visitor experience, exhibition impact, and management efficiency. Through innovative display forms, diverse modes of presentation, and audience-centered intelligent and personalized services, these technologies not only provide solutions but also shape the future trends in museum exhibitions.

6. Analysis of Efficiency-enhancing Trends in Smart Exhibitions: Human-centered, Intelligent, and Diverse Innovative Services

Through the comprehensive use of new technologies, smart museums provide traditional museum exhibitions with directions and pathways for efficiency enhancement, contributing to a more audience-centered approach and improved exhibition service effectiveness. This paper analyzes the trends in enhancing exhibition services in smart museums from four perspectives: dynamic exhibition activation, user-centric guided tours, innovative exhibition content experiences using various technologies, and the optimization of exhibition services through AI.

6.1 Dynamic Exhibition Activation

Dynamic exhibition refers to an exhibition method that integrates multiple media to disseminate multimodal information and employs various artistic forms to present exhibition content. It allows audiences to engage with exhibits through sight, sound, touch, and movement, and interact with exhibition information to understand the content from different perspectives. This trend is characterized by more diverse, interactive, and engaging exhibition forms, addressing the limitations of traditional static exhibitions, which often have simplistic exhibition forms, lack spatial vitality and fail to enhance visitor engagement.

Dynamic exhibition represents the smart museum's application of new information technologies in exhibition design and services, deeply integrating technology with artistic expression to attract audiences to understand knowledge through experience and interaction, thereby enhancing exhibition outcomes. For example, the "Inscriptions of the Forbidden City—Immersive Digital Experience Exhibition", hosted by the Palace Museum and Tencent in December 2021, utilized immersive rendering, image search, and surround sound technologies to showcase patterns in ancient architecture and cultural relics, allowing audiences to immerse themselves in the beauty and wisdom within. By employing symbols in various forms such as language, images, sound, space, and physical movement [55], this exhibition used glasses-free 3D and immersive projection among other media to convey multimodal information to visitors, presenting the art of patterns and historical knowledge from different angles. The "Love of the River" digital immersive exhibition at the China Grand Canal Museum in Yangzhou merged sound, light, electricity, and digital technologies with artistic forms like visuals, space, imagery, and music, enabling visitors to comprehend exhibition content through multidimensional information. This exhibition format is diverse, interactive, and engaging, enhancing visitors' understanding of the Grand Canal's knowledge through immersive experiences and interaction.

Dynamic exhibition activation reflects the shift from traditional museum displays centered on objects to smart museum exhibitions fundamentally based on audience understanding and experience, advancing the development trend of enhancing visitor exhibition experiences and outcomes.

6.2 User-centric Guided Tour Design

User-centric guided tour design refers to the provision of personalized tour services in smart museums tailored to the needs of different audience groups. This approach is based on analyzing audience data and profiles to maintain two-way information interaction between the museum and its visitors, ultimately achieving the goal of offering more precise and personalized services according to the specific needs of various user groups. The design of user-centric guided tours involves developing software and related hardware capable of delivering personalized services. Software development includes creating user-end applications that offer guided tours, software that collects visitor data from in-museum or online activities, and software that intelligently analyzes visitors' dynamic interests and tendencies. Hardware development involves creating tour terminal devices, indoor wireless positioning hardware, and more. The trend in user-centric guided tour design is characterized by a museum's focus on the audience, utilizing technologies like AI,

cloud computing, and big data to provide personalized services. Compared to traditional museums' manual guided tours, smart museum guided tours are more cost-effective, flexible in form, and personalized, while also enabling real-time collection of visitor data to provide feedback for museum exhibitions

More specifically, user-centric guided tour design integrates multiple technologies to establish a smart, personalized museum tour service system. This system includes services such as intelligent recommendation of personalized tour routes, image-based rapid and barrier-free artifact retrieval, personalized generation of tour content, augmented reality (AR) tour displays, and personalized visit records. The Shanxi Museum's smart personalized guided tour service system consists of five subsystems: 1. Audience Interest Trend Analysis System: This system processes, integrates, and analyzes visitor data to infer their interest trends. 2. Intelligent Recommendation and Tour Path Planning Service: Based on an analysis of the visitor's interests, the system intelligently recommends exhibits and tour routes. 3. Image-Based Rapid Artifact Retrieval Service: Visitors can quickly retrieve information about artifacts by photographing them. 4. Personalized Tour Content Generation Service: The system personalizes the recommended exhibit content based on the visitor's interests. 5. Personalized Visit Record Service: The system records tour routes and photos, allowing visitors to add their favorite artifacts to a digital keepsake menu, forming a personalized travelogue. [56] The Xiamen Museum, aiming for "high experience, high cognition, and high cost-effectiveness", has optimized its AR-enhanced intelligent guided tour design, improving user cognitive efficiency [57]. Developing a smart, personalized guided tour service system in museums requires the integration of various software and hardware technologies. For example, the Suzhou Museum's intelligent tour guide system integrates GIS technology, WIFI indoor positioning technology, iBeacon positioning technology, and visitor behavior analysis technology, along with sensors in the smart guide devices such as direction sensors, gravity sensors, gyroscopes, accelerometers, and GPS. [56] The Changsha Museum employs multiple technologies to create an integrated tour guide system, including smart guide machines, smart pens, and interactive touch screens. By utilizing short-range wireless universal technology, visitors can simply click on exhibits with the smart pen to access detailed voice information. [58]

User-centric guided tour design reflects the important development trend of smart museums in creating tailored services centered on the visitor, making exhibitions more accessible and easier for audiences to understand quickly.

6.3 Innovating Exhibition Content Experience Forms through Multiple Technologies

This approach involves museums using a variety of technologies to simulate artifacts and their associated knowledge, allowing visitors to engage with and understand the exhibition through these simulated experiences. The advantage of these technological applications is that they can replace the exhibition of original artifacts through simulation, facilitating the presentation of content in a digital or networked format, or offering visitors a multi-sensory experience that includes sight, sound, touch, motion, smell, or taste. These technologies encompass 3D printing, virtual reality, and intelligent motion theaters. The trend in innovating exhibition content experience through multiple technologies is characterized by the museum's focus on visitor experience, utilizing a range of information technologies to shift from merely displaying physical objects to providing immersive content experiences. By enriching the exhibition forms with diverse technologies, smart museums can address the limitations of traditional museums in fully and deeply showcasing artifacts, resulting in a more comprehensive and profound representation of the exhibition content.

Firstly, 3D printing technology can create models of movable or immovable cultural relics, allowing printed replicas to replace the original artifacts in exhibitions. This approach protects the original artifacts, enables the exhibition of immovable relics in different locations, and allows visitors to view the artifacts in a more flexible manner. For instance, in the 2021 special exhibition "Witnessing the Marvelous: The Protection and Inheritance of Yongle Palace" at the Shanxi Museum, 3D printing technology was

used to recreate the murals on the east and west walls of the Sanqing Hall in Yongle Palace. The replicas were identical in scale and form to the originals, faithfully restoring the colors and details, and allowing visitors to closely observe the murals.

Secondly, virtual reality technology can immerse visitors in the exhibition content by utilizing virtual models, environments, sounds, and dynamic effects, allowing them to engage through sight, sound, touch, or motion. Museums leverage the internet to disseminate exhibition content via virtual reality, enabling audiences to transcend the constraints of time and physical space to gain a deeper understanding and appreciation of the exhibits. For instance, the virtual reality design for the stone sarcophagus line engravings in the Tang Qianling Mausoleum at the Qianling Museum simulates the carvings on the inner and outer walls of the sarcophagus. This VR presentation overcomes challenges such as the erosion of the stone engravings over time, the limited space and dim lighting in the underground mausoleum, and the difficulty visitors face in directly viewing the carvings on the sarcophagus's inner walls, allowing them to perceive and comprehend the engravings more clearly and completely. [37] Additionally, cloud exhibitions have become a significant development trend in museum exhibitions. "In 2021, more than 3,000 online exhibitions and over 10,000 online educational activities were organized by museums across the country, with a total of over 4.1 billion online visits [37]". Virtual reality cloud exhibitions offer audiences an immersive viewing experience, as seen in institutions like the Palace Museum and the Guangdong Museum, where VR technology is widely used to provide cloud exhibitions, integrating online and offline exhibition services.

Thirdly, smart motion theaters utilize sound, light, electricity, and digital technology to provide visitors with a multi-sensory experience that includes sight, sound, touch, motion, smell, and taste. This approach enhances the audience's understanding and appreciation of the exhibits and their associated knowledge. The strength of smart motion theaters lies in their ability to deliver a more immersive and comprehensive experience, leaving a lasting impression on visitors. For example, the 4D theater at the Museum of Chinese Characters adds various environmental effects such as vibrations, fog, rain, wind, lightning, and bubbles to traditional 3D films. These effects are synchronized with the film's narrative, thereby intensifying the sensory experience for the audience. Currently, several museums in China, including the Jinsha Site Museum, the National Museum of Zoology, the new Tianjin Natural History Museum, the China Maritime Museum, and the Yanbian Museum, have implemented motion theaters to enhance visitor engagement. Innovating exhibition content and experience forms through various technologies reflects the trend of smart museums prioritizing the enhancement of visitor experience. This allows audiences to engage with the exhibits in a more flexible and dynamic manner.

6.4 Utilizing AI to Optimize Exhibition Services

This refers to employing AI to provide more personalized and effective services for museum visitors and to enhance exhibition management. Firstly, AI can offer comprehensive services throughout the entire visitor experience—from pre-visit to during the visit and post-visit—by collecting and analyzing visitor characteristics and needs, providing personalized and precise services, analyzing visitor behavior and facial expressions, observing in real-time, and dynamically adjusting exhibition workflows. It can also facilitate intelligent retrieval of exhibition content, provide guided tours through smart avatars and robots, and manage visitor flow in exhibition halls. Secondly, AI supports museum curation, design, and management by offering intelligent mining of social information, predicting trends and providing curation suggestions, generating exhibition content intelligently, managing exhibits and equipment efficiently, and integrating online and offline exhibition efforts, as well as blending exhibitions with cultural tourism. Optimization refers to the iterative improvement of traditional museum exhibition services through AI, focusing on user-centric innovation, efficient resource utilization, and enhancing the connection between exhibitions and society. The key characteristics of this trend include, firstly, providing a smart and comprehensive service process for visitors, delivering a personalized and humanized

experience throughout the stages of service - "before, during, and after the visit [53]". This approach allows for precise, customized exhibition services for different visitor groups. Thirdly, it optimizes the planning, design, and management of exhibitions with intelligent technologies, thereby increasing the efficiency of exhibition operations and enhancing the impact of exhibition communication. AI can address the limitations of traditional museums in offering personalized services, thereby enhancing the efficiency and effectiveness of exhibition dissemination.

Utilizing AI to optimize exhibition services is a hallmark of smart museums, which employ "comprehensive and thorough perception, ubiquitous broadband interconnectivity, and intelligent integrated applications [2]" through algorithms and big data analysis. This approach provides human-centered intelligent services for visitors and efficient, intelligent services for exhibition management. For example, in enhancing visitor services, the Guangdong Museum's intelligent service platform integrates indoor positioning, geographic information, and mobile connectivity technologies to create a smart mobile app that empowers visitors to actively discover, understand, and interpret exhibitions and their cultural significance. [56] The Nanjing Museum, in the special exhibition "World Masters—The Three Giants of the Italian Renaissance", utilized data visualization technology, employing devices such as crowd flow cameras, facial recognition cameras, crowd density cameras, advanced graphical computing systems, and customized statistical software to collect and analyze data. These technologies enabled the museum to manage visitor flow through facial recognition, measure visitor satisfaction, and use visitor behavior analysis systems to optimize the layout and route design for star exhibits. [19] In terms of supporting exhibition work, the Shanghai Museum's Dong Qichang Digital Humanities Project used machine annotation, data correlation, and quantitative analysis to make the knowledge content explicit and intelligently generate exhibition content, showcasing the connections between time, place, people, and events related to Dong Qichang. [59] The Nanjing Museum, through comprehensive comparison and intelligent analysis of real-time data from cultural relic environment monitoring, visitor behavior analysis, and management operations, provided detailed decision-making support for the protection, management, and utilization of cultural relics and exhibits. [18]

The optimization of exhibition services through AI reflects a trend in museum exhibitions that places the audience at the center, fostering the development of intelligent and interactive display services that offer more personalized and efficient exhibition dissemination.

Thus, the future of smart museum exhibitions lies in the integrated use of various information technologies, centered on serving the audience. By employing intelligent and diverse methods, smart museums enhance visitors' understanding of exhibition content and enrich their experience. Through curating content that better aligns with public needs, they provide more precise and personalized exhibition services, offering a more comprehensive and in-depth presentation of exhibits. This allows visitors to grasp the content more easily and quickly, efficiently manage exhibitions, and establish more immediate, bidirectional interactions between the exhibitions and the audience, thereby improving the effectiveness of exhibition services.

7. Conclusions

In the context of emerging information technologies, smart museum exhibitions are centered on serving the audience, with the goal of enhancing exhibition services. These exhibitions integrate the application of AI, big data, cloud computing, the IoT, virtual reality, and mobile communications to develop personalized and precise services, offer multidimensional visitor experiences, employ flexible display methods, enrich viewing options, intelligently optimize exhibition hall management, and generate exhibition content through intelligent processes. This paper's literature review yields the following conclusions:

First, by leveraging user profiling and intelligent interaction technologies to serve visitors, personalized and precise services are enhanced. Smart museums use big data collection, audience data mining, and intelligent analysis techniques to create visitor profiles, providing tailored viewing recommendations through smart guides for

different audience groups. This approach addresses the traditional museum's lack of personalized services, emphasizing human-centered technology applications in smart museum exhibitions, strengthening bidirectional interaction between exhibitions and visitors, and providing personalized services to audiences.

Second, by employing technologies such as projections, screens, and motion theaters, the multidimensional experience of visitors is enhanced. Smart museums utilize sound, light, electricity, and digital technologies combined with various artistic expressions, allowing visitors to perceive exhibition content through multiple senses—sight, sound, touch, motion, smell, or taste—thus enhancing their experience. This approach overcomes the traditional museum's single-dimensional display methods, which often fail to fully and deeply express the characteristics of exhibits and lack appeal to visitors, forming a characteristic of smart museums that enhances visitor experiences through diverse technologies.

Third, through the use of virtual reality, 3D printing, and other technologies, display methods become more flexible, and viewing options are enriched. Simulation technologies are used to present exhibits and exhibition content, allowing visitors to understand the exhibition by viewing virtual or physical models. By integrating virtual reality with network technologies, online and offline displays are combined. This approach enriches traditional museum exhibition methods, provides a more comprehensive expression of exhibit characteristics, and offers visitors more flexible viewing options, establishing a characteristic of smart museums where the forms of exhibition content viewing and experience services are diversified.

Fourth, by utilizing visitor identification, behavior analysis, and crowd analysis technologies, exhibition hall management is intelligently optimized. Visitor facial recognition and behavior analysis technologies, combined with data visualization and intelligent analysis, assist in managing crowd flow and security in exhibition halls. This approach enhances the efficiency of traditional museum exhibition management and optimizes security services, establishing a characteristic of smart museums in delivering efficient, refined exhibition hall management services.

Fifth, by using knowledge graphs and generative technologies, exhibition content is intelligently generated. Semantic networks, data correlation, machine recognition, and AI technologies are used to extensively link museum database content, automatically discovering and generating related knowledge, creating new methods for museum exhibition knowledge production, broadening knowledge sources, and establishing new ways to construct the knowledge value of exhibits. This approach innovates traditional museum exhibition knowledge construction methods and enhances curatorial standards, establishing a characteristic of smart museums where exhibition knowledge content is intelligently generated.

As the core business of the smart museum ecosystem, smart exhibitions will continue to develop along the trends of innovating exhibition forms, enriching expression methods, and providing intelligent and personalized services, contributing more diverse experiential methods for museum education, appreciation, reflection, and knowledge sharing. As new technologies continue to evolve, future research on smart museum exhibition technology applications will increasingly integrate with the detailed interpretation of exhibits and knowledge content, providing visitors with a deeper understanding and experience of exhibitions.

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