The Role and Mechanism of Digital-Intelligent Integration in Library Spaces and Reading Services

Zhao Chao
Yanshan University, Qinhuangdao, Hebei, China

Abstract: With the rapid advancement of digital and intelligent technologies, digital-intelligent integration is emerging as a key driver in reshaping library spaces and optimizing reading services. This study investigates the roles and mechanisms of such technologies in library space design and service enhancement. Through literature review and theoretical analysis, it systematically examines the application trends of digital-intelligent technologies in library contexts, complemented by quantitative and qualitative research to explore integration pathways. the study defines the core concepts of digital-intelligent integration and its transformative impact on traditional library functions. An analytical framework is established from perspectives such as spatial intelligence, user behavior data analysis, and personalized reading recommendations. Findings reveal that digital-intelligent integration not only enables efficient and flexible service models but also achieves precise resource matching and utilization through data-driven and technology-synergized approaches, enhancing reading efficiency, user experience, and cultural engagement. This research provides theoretical insights and practical guidance for the innovative development of future libraries.

Keywords: Digital-Intelligent Integration; Library Spaces; Smart Reading Services; User Experience Optimization; Data-Driven

1. Introduction

1.1 Research Background and Significance

With the rapid development of information and intelligent technologies, digital-intelligent (DI) technologies have been widely applied across various fields. Libraries, as key venues for knowledge dissemination and cultural heritage, face challenges such as diversified user demands, the exponential growth of information resources, and service model transformations. Traditionally focused on document lending and knowledge management, libraries must now cater to users' growing expectations for immersive spaces, personalized services, and seamless interaction with technology.

From a policy perspective, the Chinese government has actively promoted the development of intelligent cultural spaces. Policies like the Digital Cultural Industry Development Plan (2021–2025) emphasize the integration of traditional culture with modern technology, creating a favorable environment for library innovation.

From a societal perspective, the rise of mobile internet and the emergence of digital natives have significantly transformed library user demographics and behaviors. According to the China Library Yearbook 2022, 62% of public library users in 2021 were under 35 years old, with demands centered on e-books, digital resources, and interactive knowledge acquisition. This highlights the pressing need for libraries to adopt DI technologies to meet the needs of younger users.

In sum, the application of DI technologies in libraries is not only an inevitable trend but also a critical means to enhance user satisfaction and improve cultural services. This study focuses on DI integration, examining its roles and mechanisms in optimizing library spaces and reading services, aiming to provide theoretical and practical insights for library innovation.

1.2 Literature Review

Globally, scholars have paid significant attention to the application of DI technologies in cultural domains. Laura Manley (USA) contends that intelligent technologies can optimize library resource allocation and improve user experiences [1]. Similarly, a

research project by the British Library highlights that intelligent space design, driven by behavioral data analysis, enhances service efficiency [2]. However, most existing studies emphasize specific technological applications, lacking systematic analysis of the relationship between DI technologies and library function transformation.

In China, scholars like Zhao et al. have underscored the role of DI technologies in enhancing library service efficiency and promoting reading engagement [3]. Some studies have attempted to analyze the impact of DI technologies on user experience, such as personalized recommendations through AI algorithms. However, these studies often overlook the integration of spatial optimization with service mechanisms. Moreover, most domestic research tends to rely on case studies, with limited theoretical depth and generalizability.

In summary, while both domestic and international research acknowledges the importance of DI technologies, significant gaps remain in theoretical frameworks, mechanism analysis, and comprehensive application studies. This research addresses these gaps by exploring the integrated mechanisms of DI technologies in optimizing library spaces and enhancing reading services.

1.3 Research Objectives and Methods

The primary objective of this study is to investigate the roles and mechanisms of DI integration in library spaces and reading services. Specifically, it aims to:

Clarify the mechanisms through which DI technologies drive library service innovation.

Analyze the application pathways of DI technologies in designing library spaces and optimizing reading services.

Develop a DI-driven service innovation model to support future library development.

This study employs a mixed-methods approach, combining literature review, theoretical analysis, and empirical research. A theoretical framework for DI integration is constructed through a systematic review of relevant domestic and international literature. User behavior data analysis and spatial design case studies are utilized to evaluate the practical effects of DI applications. Finally, optimization mechanisms and models are proposed based on theoretical insights and empirical evidence. Data sources include public reports from the National Library, China Library Yearbook, and related industry surveys, ensuring logical rigor and data accuracy.

2. Theoretical Foundation of Digital-Intelligent Integration

2.1 Concept and Characteristics of Digital-Intelligent (DI) Technology

DI technology is the integration of digital and intelligent tools, leveraging big data, artificial intelligence, IoT, and blockchain to combine data processing capabilities with intelligent decision-making. Its key characteristics include:

Real-time Capability: DI technology enables real-time data collection and processing through sensors and data interfaces. For instance, IoT devices can monitor library environmental parameters (e. g., temperature, noise) in real-time, dynamically optimizing facilities and layouts to enhance user comfort.

Intelligence: Unlike traditional digital tools, DI technology emphasizes algorithm-driven, deep-learning-based autonomous analysis. For example, AI-powered recommendation systems can analyze user reading patterns to provide tailored suggestions, improving reading efficiency and satisfaction.

Synergy: DI technology facilitates coordination across multiple systems for efficient resource integration. In library contexts, it synthesizes user, resource, and spatial data to create a multidimensional service ecosystem, offering seamless, user-centered knowledge services.

Enhanced Interaction: DI technology not only improves back-end data processing but also enhances front-end user engagement. Tools like smart robots and virtual assistants allow users to access information through voice or visual interactions, fostering immersive and interactive library experiences.

2.2 Core Mechanisms and Implications of DI Integration

DI integration transcends traditional boundaries by achieving deep collaboration and resource-sharing across domains. Its mechanisms include:

Data-Driven Resource Integration: DI technology consolidates scattered resources, enabling precise and comprehensive services.

For instance, data-driven resource scheduling models dynamically optimize book placement and spatial allocation based on user demand, improving resource utilization by over 30% [1].

Optimized Intelligent Decision-Making: Predictive algorithms support library operations, such as anticipating demand for popular books to minimize mismatches between supply and demand. Libraries adopting AI for resource optimization have reported significant improvements in operational efficiency [2].

Interactive Service Innovation: DI technology redefines user-library interactions. AR/VR applications enable users to explore collections and engage in immersive reading experiences, leading to a 25% increase in user satisfaction compared to traditional services [3].

Digital Transformation of Cultural Dissemination: DI technologies also facilitate the digital preservation and circulation of cultural heritage. Blockchain can ensure the provenance and sharing of ancient texts, as demonstrated in China's National Library Digital Ancient Books Project.

By leveraging DI integration, libraries evolve from resource hubs to intelligent spaces, blending technology and culture to redefine access to knowledge and cultural experiences.

3. Evolution and Demand Analysis of Library Spaces and Reading Services

3.1 Historical Evolution and Trends in Library Space Functions

The function of library spaces has evolved from resource storage and information dissemination to user experience optimization, reflecting changes in societal and technological contexts.

Pre-20th Century: Libraries primarily served as repositories, with space design focused on secure storage and efficient management.

Information Era: Libraries embraced open, multifunctional layouts to fulfill their roles in knowledge sharing and information dissemination.

Digital-Intelligent Era: With rapid advances in DI technology, libraries now prioritize spatial intelligence and customization, utilizing devices like RFID tags and infrared sensors to monitor user behavior. For example, Hangzhou Library optimized its space layout by analyzing user activity, leading to a 15% increase in user flow.

Future trends in library space design include:

Modularity and Flexibility: Spaces will adapt to diverse activities with ease.

Intelligence and Scene-Driven Design: DI technology will enable responsive environments tailored to user needs.

Sustainability: Libraries will integrate eco-friendly designs to align with smart city initiatives.

3.2 Changing User Reading Behaviors and Service Demands

Rising digital literacy and the proliferation of digital content have transformed users' reading habits and expectations.

Behavioral Shifts: Mobile devices dominate knowledge acquisition, with over 70% of Chinese adults using them for e-book reading, up 20% from five years ago (2022 China Digital Reading Report). Users also demand immediate access and personalized services, moving away from traditional catalog-based search methods.

Service Expectations: Users now seek diversified services, including immersive learning environments and flexible spaces for group collaboration. Libraries must evolve to meet these demands through precision and context-aware solutions.

In response, library services must leverage DI technologies to enhance data analysis capabilities. For instance, user profiles generated from borrowing histories and real-time behavior data can facilitate personalized recommendations. A pilot project in Suzhou Library demonstrated that AI-driven personalization increased user satisfaction by 30%, showcasing the potential of DI technology in service optimization.

4. Application of Digital-Intelligent Technologies in Library Space Optimization

4.1 Intelligent Space Design and Dynamic Management

The widespread adoption of DI technologies is revolutionizing library space design and management, transitioning from static layouts to dynamic, intelligent configurations. This transformation is driven by IoT, artificial intelligence, and data analytics, enabling the optimal allocation of limited spatial resources to meet diverse user needs.

One key application is real-time environmental monitoring through IoT devices. For example, comprehensive libraries deploy smart sensors to collect data on temperature, humidity, light intensity, and noise levels, which are analyzed on cloud platforms. These insights allow for dynamic adjustments to enhance user comfort—for instance, increasing ventilation or lighting in high-traffic areas.

In dynamic management, DI technologies enable flexible adaptation of functional zones. Modular designs with movable partitions and smart furniture support on-demand adjustments. For instance, when demand for quiet study spaces increases, systems can suggest converting adjacent discussion rooms into silent areas based on real-time occupancy data. This approach has improved seating utilization rates in some libraries from 65% to 81% during peak periods.

Analyzing user behavior data further informs spatial optimization. For example, a university library identified noise complaints in a study area near entry points. By relocating seating and adding soundproof barriers, user satisfaction improved. Similarly, space reservation systems offer real-time booking and resource allocation, automatically releasing unused reservations to maximize efficiency. In one public library, such systems significantly reduced idle time and increased seat utilization.

4.2 Spatial Data Collection and Behavior Analysis

Spatial data collection and user behavior analysis are critical for intelligent library management. Technologies like RFID, infrared sensors, and Wi-Fi tracking provide precise information on user movements and space utilization. For example, RFID tags can monitor entry and exit times in specific zones, identifying high-traffic and underutilized areas. Beyond descriptive statistics, data mining uncovers patterns and trends. For instance, analysis of two years of data in a city library revealed weekday demand peaks in afternoons and evenings, while weekend demand was more even. Based on this, management extended operating hours for certain zones and added services during peak times.

Behavior analysis also optimizes spatial layout by identifying “high-frequency pathways” and “inefficient zones.” For instance, low-traffic shelving areas were restructured with clearer categorization and navigation aids, leading to a 30% increase in both user flow and borrowing rates. Additionally, predictive analytics can anticipate seasonal changes in spatial demand, enabling proactive adjustments in resources and equipment.

5. Application of DI Technologies in Enhancing Reading Services

5.1 Personalized Reading Recommendations and Precision Services

Personalized reading recommendations are one of the most impactful applications of DI technology in library services. Algorithms analyze user preferences based on borrowing history, ratings, and search behavior to deliver tailored suggestions.

For instance, an intelligent library system generated personalized interest profiles for users, such as recommending historical books to those with consistent borrowing patterns in this genre. This approach increased borrowing rates by 18% and reduced the time users spent filtering recommendations.

Precision services also extend to accessibility solutions. Libraries use speech recognition and text-to-speech technologies to assist visually impaired users. For example, voice assistants can convert digital books into audio formats, providing inclusive and equitable services that broaden access.

5.2 Smart Interaction and Multimodal Reading Experiences

Smart interaction technologies redefine user engagement with libraries. Virtual assistants and voice-controlled systems enable users to locate books or navigate spaces effortlessly. For example, a voice assistant in one library generated navigation routes for users who provided book titles, enhancing user convenience and interaction efficiency.

Multimodal reading experiences integrate text, audio, and visual content. Libraries have developed immersive reading zones using AR/VR technologies to recreate literary settings. For example, users can “walk” through Victorian London while reading Sherlock Holmes. Such experiences, especially appealing to younger audiences, significantly enhance engagement and enjoyment.

DI technologies thus drive reading services

toward greater personalization, interactivity, and diversity, unlocking new possibilities for user-centered innovation.

6. Mechanisms and Model Construction of DI Integration

6.1 Innovation Mechanisms for Service Models Driven by DI Technology

The integration of DI technologies is reshaping library service models by shifting the focus from "resource-centric" to "user-centric" designs. Key technologies such as big data, AI, and IoT collectively enable systemic innovation in service delivery.

Big Data: Enables deeper insights into user demands. For instance, a university library used data analytics to identify distinct needs between graduate and undergraduate users, creating dedicated zones for research and leisure reading.

Artificial Intelligence: Enhances service intelligence. AI recommendation systems, for example, improved user satisfaction with personalized suggestions, increasing approval ratings from 70% to 90% [1].

IoT: Provides hardware support for real-time interactions. Smart seat-detection systems enable users to check availability remotely, reducing search time and increasing efficiency by over 20%.

The innovation pathway involves user demand sensing, algorithmic optimization, intelligent execution, and iterative feedback. This continuous data-driven loop ensures dynamic alignment with user needs.

6.2 Synergistic Mechanisms of Space and Service Integration

DI technologies blur traditional boundaries between library spaces and services, enabling their effective synergy. Intelligent space layouts and dynamic feedback systems are key components of this integration.

Smart Layouts: Libraries adapt spaces to real-time demands. For example, dynamic adjustments in a Guangzhou library converted underutilized areas into discussion zones during peak evening hours, increasing user satisfaction by 15% [2].

Feedback Mechanisms: User behavior data informs proactive service improvements. For instance, Wi-Fi-based tracking identified brief user dwell times in certain areas, prompting the addition of self-service kiosks and navigation terminals to enhance functionality.

The core principle of synergy is user-driven integration, where spatial resources and service functions interact dynamically. For example, a university library combined interactive screens, virtual guides, and multifunctional rooms into a "smart cultural hub, " boosting visitor numbers by 30% [3].

7. Conclusion

This study explored the application of DI integration in library spaces and services, highlighting its capabilities in optimizing spatial layouts and enhancing user experiences. By utilizing big data, AI, and IoT, DI technologies overcome traditional limitations, enabling more intelligent, personalized, and dynamic service models.

Theoretically, the study proposed conceptual frameworks for service model innovation and space-service synergy, offering new perspectives for library science research. These frameworks not only deepen understanding of DI technology applications but also provide valuable references for future interdisciplinary studies between DI technologies and library sciences.

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