Metaverse Environment: Research on Smart Library Applications under Technology Empowerment

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Abstract

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Method/Process This paper investigates the relationship between the metaverse and smart libraries, and expounds upon the fundamental framework, technological applications, equipment and facilities, user application scenarios, standards and specifications, data resource management, and user management for smart library scenario construction within metaverse environments.

Results/Conclusion It presents implementation cases of technology-empowered smart scenarios and summarizes four essential characteristics for the innovative development of future smart libraries.

Full Text

Metaverse Environment: Research on Smart Library Applications Under Technology Empowerment

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Abstract

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[**Method/Process**] This paper explores the relationship between the metaverse and smart libraries, and elaborates on the basic framework, technical applications, equipment and facilities, user application scenarios, standard specifications, data resource management, and user management for smart library scenario construction in the metaverse environment.

[**Result/Conclusion**] It introduces implementation cases of smart scenarios under technology empowerment, and summarizes the four characteristics that future smart library innovation and development will possess.

Keywords: metaverse; smart library; smart scenario; technology empowerment
Chinese Library Classification: G250.7

1. Introduction

In 2021, the gaming company Roblox revived the concept "Metaverse" from the 1992 sci-fi novel *Snow Crash* in its prospectus, becoming the first metaverse concept stock. In the same year, Facebook CEO Mark Zuckerberg announced the renaming of "Facebook" to "Meta," expressing his vision for transformation and development toward the metaverse. Additionally, Microsoft, Apple Inc., Tencent, ByteDance, and others also began investing in the "metaverse" in 2021. Thus, 2021 became the breakout year for the metaverse.

In fact, the metaverse is not a new concept. It has evolved from its initial form in classical art and religion that sparked human imagination, gradually developing into a virtual-physical world construct carried by electronic games and sci-fi forms. People enter surreal digital spaces through "avatars" to experience the fusion of virtual and real. Today, the metaverse has transcended gaming and begun seeking integration with the real world, becoming one of the hottest concepts in technology, finance, and IT in 2021. The industry generally believes that the metaverse is an inevitable result of current technological development, the epitome of information technology, and a perfect combination of virtual and real technologies.

In summary, the metaverse is a virtual world constructed using technologies such as artificial intelligence, virtual reality, information communication, and the internet that mirrors the real world. From a technical perspective, the metaverse encompasses content systems, blockchain systems, display systems, and operating systems, manifested through 3D interfaces that transcend screen limitations, heralding the era of holographic digital platforms. Wikipedia defines the metaverse as: a collective virtual shared space created by the fusion of virtually enhanced physical reality and physically persistent virtual space, including the sum of all virtual worlds, augmented reality, and the internet.[1] The *2020-2021 Metaverse Development Research Report* compiled by Tsinghua University's New Media Research Center defines the metaverse as: a new form of internet application and social morphology that integrates virtual reality, blockchain, cloud computing, digital twins, and other new technologies, enabling close integration of virtual and real worlds in economic systems, social systems,

and identity systems, while allowing each user to produce content and edit worlds.[2]

In conclusion, the metaverse is a highly open, interactive, and integrated ultra-large virtual space where users, through digital identities, can fully experience immersive experiences, learning and training, entertainment and social interaction, and innovation and creation. The metaverse demonstrates excellent performance in network synchronization and interactivity, with its economic, legal, and service systems approaching those of the real world, thereby safeguarding users' virtual rights and interests in infrastructure, regulations, protocols, and processes. The basic characteristics of the metaverse are as follows: First, it provides a platform where digital users can publish their works and share creative experiences as knowledge creators. Users' identities in the metaverse platform can differ from reality, thus their creative and innovative skills can be fully explored. Second, the metaverse platform can establish digital currencies and transaction rules, allowing users to obtain economic benefits by sharing their creative content—that is, virtual digital currency. Third, compared to real identities, users' virtual identity experiences provide equally authentic feelings, giving users a strong willingness to immerse themselves in exploration, experience, creation, and sharing.

1.1 Smart Library

Research on smart libraries has recently reached an unprecedented boom, with the number of papers increasing annually and research content continuously expanding and broadening. In summary, the smart library is a new management model for libraries that integrates technology, equipment, librarians, and resources. Its main characteristics include precise grasp of user needs, collaborative implantation of intelligent technology, professional cultivation of smart librarians, intensive construction of library resources, cooperative establishment of industry standards, and personalized provision of smart services.[4] Smart libraries will change the traditional thinking and working models of libraries, establishing new models in space, resources, services, management, talent, and effectiveness.[5] Specifically, this involves using high-tech for intelligent management of physical library buildings; constructing online-offline, virtual-real integrated smart spaces to provide immersive service experiences; achieving intelligent processing, integration, analysis, and mining of collection resources and social resources to form smart data platforms; using intelligent technology to provide services and achieve scientific operation of economic and legal regulatory systems for smart services; realizing intelligent management of the entire library process; and achieving high-efficiency results with precise services.

Regarding the "element theory" of smart libraries, domestic library circles mainly propose "three-element," "four-element," "five-element," and "six-element" theories. See Table 1 for details.[6] Despite differing views and perspectives in the industry, all external and internal elements will become tools to promote the smart development of libraries during their transformation

toward smart libraries.

Table 1 Some Viewpoints on the "Element Theory" of Smart Libraries

Element Theory	Viewpoints
Three Elements	1. Intelligent technology, smart librarians, library business and management systems (Dong Yan's view)[9]2. Library building ontology, modern information technology, intelligent equipment, smart librarians (Kun Zhang et al.'s view)[10]
Four Elements	1. Library, IoT, cloud computing, smart equipment (Xianzhi Li, Bo Shao's view)[13]2. People, resources, space (Lixin Xia et al.'s view)[8]
Five Elements	Technology, resources, services, librarians, users (Jingli Chu, Meizhen Duan's view)[7]
Six Elements	User needs, library resources, smart librarians, intelligent technology, industry standards, smart services (Kun Zhang, Xianjin Zha's view)[14]

1.2 The Convergence Points Between Metaverse and Smart Library

Both provide a virtual platform connecting users and content. The service model of smart libraries primarily involves online-offline integration and fusion of virtual and real resources; the metaverse platform also provides experiential services to users through multiple methods, with extensively unrestricted content, offering products and services in a decentralized manner.

Both use digital means to provide users with diverse service experiences. Smart libraries enable readers to enjoy convenient and efficient cultural services through multiple methods and multi-dimensional experiences; the metaverse platform features basic characteristics such as high efficiency, interconnectivity, openness, integration, and economic systems.

Both benefit from increasing user stickiness and share the intention to continuously accumulate and expand digital users. Smart libraries expand their digital user base, social functions, and influence through high-tech; the metaverse platform is characterized by network externalities, large user bases, and strong attractiveness, with user activities generating considerable revenue for the platform.

At present, wireless communication networks, AR, VR, cloud computing, blockchain, digital twins, GIS, and other technologies provide technical guarantees for the intelligent construction of libraries. As a fusion of various new technologies and a concrete form of technical concepts, the metaverse represents a new model of current scientific and technological innovation development, leading the continuous development of technology, economy, culture, and other industries.[15] Therefore, from the perspective of the metaverse, it is hoped that it can provide new ideas and momentum for the construction and development of library intelligence, thereby expanding the field and boundaries of smart libraries. In the metaverse environment, libraries can achieve a new integrated entity of virtual-real fusion, with service models including online services, knowledge services, proactive services, diversified services, and personalized services, and service effectiveness characterized by high efficiency, real-time performance, and precision—precisely the new model of smart libraries.

2.1 Basic Framework of Smart Library Application Scenarios Under Technology Empowerment

In the metaverse environment, smart libraries utilize mobile devices, big data, sensors, positioning systems, and social networks to provide readers with virtual space services and create a sense of presence and experience.[16] Therefore, the basic framework of smart library application scenarios under technology empowerment mainly includes technology provision, facilities and equipment, user applications, standard specifications, data resource management, and user regulation and supervision. See Figure 1 [Figure 1: see original paper].

- **Technology Provision**: VR/AR/MR
- **Facilities and Equipment**: RFID chips, cloud computing centers
- **User Applications**: Virtual space experience, virtual knowledge provision, virtual reference consultation
- **Standard Specifications**: *(content not specified in original)*
- **Data Resources**: Digital resource rights confirmation
- **User Regulation**: *(content not specified in original)*

2.2.1 Technology Provision

Technology provision is the soul of smart library construction and the foundational technology required for conducting smart services and management. The metaverse environment converges diverse technical means, creating an innovative development model of virtual-real integrated immersive experiences that achieves high integration of the physically tangible real world and the interactively perceived virtual world.[17] It mainly includes technologies such as VR/AR/MR, cloud computing, artificial intelligence, blockchain, and digital twins.

Virtual simulation primarily uses computers, electronic information, and simulation technology to imitate a real system with a virtual system, enabling people to

immerse themselves in it.[18] It mainly includes virtual reality (VR), augmented reality (AR), mixed reality (MR), extended reality (XR), computer simulation, 3D modeling, digital twins, and holographic projection. VR uses computers to generate multi-sensory experiences such as 3D vision, hearing, and touch, allowing users to connect with the virtual world through appropriate equipment for experience and interaction. AR overlays virtual information onto live video to achieve reinforcement of reality by virtual information.[19] In the metaverse environment, libraries can create digital identities and virtual scenes for users, using virtual simulation technology to build experience spaces for free creation, learning, social interaction, and entertainment, enabling users to conduct learning, office work, socializing, entertainment, and creation without temporal or spatial limitations.

Cloud computing decomposes complex data processing procedures into several small programs through the "cloud," then processes and analyzes these programs through systems composed of multiple servers, and finally feeds the results back to users. Cloud computing technology can support massive data storage, analysis, and cloud backup for libraries, providing users with integrated retrieval of collection and network information resources and personalized reference consultation services.

Artificial intelligence is a technology that studies and develops theories, methods, and technologies for human intelligence. AI technology can build the entire process of library business, including collection digital resource integration, knowledge resource integration, smart retrieval, smart services, and smart library system analysis and management, through theories and technologies such as language recognition, image recognition, and natural language processing.

Blockchain technology is a serial transaction record that connects and protects content through encryption. It is a new application mode of computer technologies such as distributed data storage, peer-to-peer transmission, consensus mechanisms, and encryption algorithms.[20] It is a data storage architecture that cannot be forged. Libraries can build distributed collection resource storage, smart reading, independent creation, interactive experience, credit campus, and network education application systems based on blockchain. At the same time, blockchain technology can help libraries build shared learning platforms, open academic platforms, and 3D printing platforms under new copyright utilization forms such as MOOC, UGC, and 3D printing, achieving decentralization, intelligence, and transparency of library digital copyright management. Additionally, blockchain technology can better protect library users' personal information.

Digital twin technology constructs a twin space in virtual space that corresponds to real physical space, using sensing technology to upload various data to the twin virtual space in real time, thereby achieving extremely detailed and realistic library scene construction. Digital twin technology can achieve seamless connection between virtual and physical spaces, as well as holographic simulation and supervision of real physical spaces. Therefore, digital twin technology has broad application prospects in dynamic supervision of library facilities, energy-saving

construction of libraries, maker space services, user portrait analysis, online learning support, library virtual cultural heritage, and user information literacy education.

2.2.2 Equipment and Facilities

Equipment and facilities are necessary means for building smart libraries and the foundation for conducting smart services, including high-performance computers, user access devices, and 5G networks. User access devices enable users to achieve visual virtual interaction through VR equipment. VR equipment requires extremely high resolution and frame rates, which necessitates support from ultra-high-speed mobile communication technology.[21]

Mobile terminal devices are intelligent devices with multiple application functions, such as smartphones and tablets. With the rapid development of network technology and integrated circuit technology, mobile terminals possess powerful processing capabilities. Mobile intelligent terminals are key entry points for internet business and major innovation platforms, as well as important tools and hubs for libraries to conduct network information services, with their operating systems being critical to library automation management.

The main function of sensors is to receive various stimulus signals from humans and clarify the expressed content through signals. Sensors function similarly to human organs, possessing the capability to obtain external information.[22]

Cameras are digital devices used to collect video, divided into two categories: digital cameras and analog cameras. Digital cameras can convert analog video signals generated by video collection devices into digital signals for storage in computers. Analog cameras must have their captured video signals converted from analog to digital mode by specific video capture cards and compressed before they can be used on computers.

GPS is the English abbreviation for Global Positioning System, whose main function is to provide real-time positioning and navigation services.

RFID involves embedding chips into buildings, electronic products, or books. These chips can emit radio frequency signals and have transmission characteristics, enabling monitoring of library environments and items while reducing manual operations. These chips can respond promptly to received signals, completing management of books, electronic products, and buildings.

5G is communication equipment based on 5th-generation mobile communication technology, featuring high speed, low latency, and massive connectivity, mainly applied in smart library scenarios such as seamless borrowing, smart study rooms, intelligent facilities, library robot services, and cloud classrooms. High-performance computing equipment meets the supercomputing power required for 3D rendering and cloud computing, thereby achieving realistic visual rendering effects.

2.2.3 User Applications

User applications constitute the basic content of users' participation in smart library activities. In the metaverse environment, libraries must focus on building entirely new operational and service models while constructing digital and intelligent technology scenarios. Libraries include not only the functions of physical libraries such as services, education, preservation of human cultural heritage, entertainment and leisure, and think tanks, but also new functions such as virtual space experience, virtual knowledge service provision, virtual data, and innovation and creation.

(1) **Virtual Space Experience Services**
Libraries can use VR, AR, smart interaction, holography, sensory interconnection, and other technologies to create a virtual world for users, satisfying their integrated experience of the real and virtual worlds. It is mainly used for space navigation, guided reading, and virtual information resource retrieval, enabling people to achieve immersive experiential effects and view library environments, resources, and facilities panoramically and comprehensively.[23]

(2) **Virtual Collection Resource Retrieval Services**
Libraries can achieve literature resource construction on a unified cloud service platform, accurately providing knowledge information reorganized by AI according to readers' real needs. Libraries can use new technologies to conduct knowledge analysis, integration, and frontier dynamic forecasting to provide intelligence services for technological innovation and technology transfer, while also conducting interdisciplinary intelligence services.

Libraries' business processes such as literature acquisition, classification, cataloging, collection, and circulation can be realized through VR integration of multidisciplinary technologies and research results. Readers can access, browse, roam, retrieve, collect, and publish all library resources through computer VR technology, using digital and network technology to control super-spatiotemporal simulation scenarios. Additionally, libraries can digitize and process ancient books, special collections, and database resources, using VR and digital twin technology to build virtual simulation three-dimensional resource models for readers to retrieve and use.[24] This way, readers can not only obtain the original reading experience but also view precious ancient books and special collections that are normally inaccessible.

(3) **Virtual Reference Consultation Services**
Libraries can use VR to conduct virtual resource reference consultation services. Specifically, this involves allowing users to select service content on web pages and deducing derivative services that the user might need based on other users' needs. When user needs are not met, they can enter one-on-one virtual consultation, where users enter a simulated virtual library community and engage in real-time conversations with online librarians in this virtual space. Additionally, libraries can use VR

technology to provide remote retrieval services for users. When users encounter retrieval difficulties, they can enter virtual remote assistance for one-on-one guidance from librarians on how to retrieve information. They can also use remote space functions to help users quickly retrieve needed resources first, with follow-up feedback inquiries. Libraries can also use AR technology to push information resources that users might encounter problems with or be interested in at the library through big data analysis, conducting proactive services to optimize reference consultation service content and methods.

(4) **User Online Intelligent Learning**
Libraries can effectively integrate real-world physical spaces and personal learning spaces to create spatiotemporally fused online intelligent learning spaces that meet users' personalized needs. These spaces converge various digital learning resources, shortening and fusing the spatiotemporal distance of knowledge production, dissemination, and use, changing teaching relationships in the space, and forming open, decentralized, personalized, and diverse learning space formats. Additionally, users can use massive information resources for learning, forming personal knowledge accumulation and learning habits. By publishing personalized content such as research resources, course information, literature materials, and suggested viewpoints, they can achieve user-generated content functions, thereby effectively improving the quality of user-generated content.[26]

(5) **User Independent Knowledge Creation**
Libraries use virtual platforms to add reader creation modules, allowing readers to use open and shared knowledge resource spaces for AI creation, forming personal knowledge spaces. Readers can create and publish native digital knowledge through this virtual knowledge space, such as their own digital literary works. Digital works created by different readers form different personal knowledge spaces, which in turn generate high association with the library's digital knowledge resources in the metaverse environment, increasing user participation, enhancing users' enthusiasm for providing content, better improving public service effectiveness, and providing new momentum for library transformation.[27] In short, users are not only passive recipients of various information services but also creators of information resources. Everyone can modify, expand, and recreate stored information on the blockchain, and they are even initiators and organizers of library business and activities.

(6) **User Social Interaction**
Libraries can provide online virtual social interaction for users, allowing them to meet people with similar information needs while conducting information queries and receiving services.

2.2.4 Smart System Management Standards and Specifications

Libraries must issue standard specifications related to smart library systems, mainly including business, data, service, and product aspects. Some general basic specifications and industry standards for key technologies can be followed by libraries as they are. Libraries can add necessary domain terminology, explanations, application cases, or scenarios according to practical applications, and can also formulate application guidelines for their own fields. Specifically, these include basic specifications, technical specifications, business specifications, data specifications, service specifications, and product specifications. Basic specifications include terminology glossaries, privacy specifications, security specifications, and testing specifications. Technical specifications include natural language processing, biometric recognition, intelligent building management, user interfaces, and intelligent technologies. Business specifications include information exchange, smart space management, intelligent stacks, data standardization, and named entity recognition. Data specifications include linked data publishing, data quality control, data interfaces, data mining, and visualization specifications. Service specifications include intelligent navigation, information push, user information management, and evaluation management specifications. Product specifications include identity recognition, self-service borrowing and returning machines, robot management, digital reading devices, helmets, and smart screens.[28]

2.2.5 Digital Resource Management and User Management

Digital resource management and user management on the platform are the constraint mechanisms and organizational regulations required for libraries to implement activities in the metaverse environment.

(1) **Virtual Digital Resource Rights Confirmation**
Libraries can use technologies such as blockchain and non-fungible rights technology to confirm, protect, and manage the rights and interests of virtual digital resources on the platform.[29] Solving digital rights confirmation is a prerequisite for establishing a digital ecosystem. The metaverse, based on blockchain technology, manages digital resources and authenticates user digital works, while using encryption technology to establish the correspondence between digital works and producers. Users use private keys for electronic signatures and constrain them through consensus mechanisms to ensure that the electronic identity of digital products cannot be tampered with, completing digital resource rights confirmation on the blockchain.[30] Simultaneously, users' personal privacy can be fully protected.

(2) **Construction of Virtual Economic Systems**
Libraries can construct their own economic systems to manage user activities, which is the foundation for motivating users to create on virtual platforms and an important means to increase user stickiness. Libraries

can use a unified currency form to confirm rights for user activities in virtual digital spaces, supplemented by transaction rule management. The safe and stable operation of the economic system is the driving force for the steady development of smart libraries in the future. The virtual economy is also an effective supplement to the real economy and can stimulate the vitality of the real economy to a certain extent.[31]

3.1 Daxing International Airport Branch of Capital Library of China

The Daxing Airport Branch of Capital Library of China integrates multiple high-tech technologies, adopting a model of immersive fusion with smart technology. Using mobile internet, IoT, 5G, artificial intelligence, and other technologies, it provides services such as mobile borrowing, smart push, and smart navigation. Specifically, the branch breaks temporal and spatial constraints by providing readers with remote book return services; offers smart robot librarian guided tour services; provides flexible and varied display of cultural tourism-themed content through various special-shaped screens; features a virtual anchor at the library entrance providing real-time Q&A on weather, tourism, and other topics; offers free "audio-visual" services via mobile phone scanning; and provides touch-screen electronic newspaper and periodical systems. Additionally, the branch has joined the Beijing public library "One Card" service system, providing inter-library borrowing and returning services across 388 member libraries, as well as reservation borrowing services.

Readers can use the "Reading Beijing" mini-program in Alipay, bind their reader cards, scan the barcodes on books to borrow or reserve them, while also enjoying multiple online and offline book return modes.

The branch's main characteristics are reflected in: using new technology to integrate social resources and create smart spaces; focusing on the two major themes of "cultural tourism" and "Beijing" to promote effective and deep utilization of massive resources; advancing innovative applications of smart technology, allowing readers to fully enjoy and experience mobile borrowing, smart push, smart guidance, and other services through mobile internet, IoT, 5G, and artificial intelligence; providing flexible, personalized customized services and experiential activities for different travelers, readers, and airport staff, such as lectures, "intangible cultural heritage" handicraft making, concerts, reading clubs, and youth technology experiences; advancing the construction of the "Beijing Cultural Tourism Information Resource Center" to satisfy both public basic services and professional research needs; and integrating advanced service concepts with cutting-edge technology, organically fusing space design with service design, emphasizing insight into user experience and personalized service push, thereby improving service effectiveness.

Table 2 Innovative Application Scenarios of "Intelligence" in Daxing Airport Branch of Capital Library of China

Smart Function Name	Smart Function Description
Smart Library Management Platform	For the first time in the Daxing Airport Branch, it achieved interconnectivity between the library management system ALEPH500 and smart bookshelves, robots, self-service card registration and borrowing/returning machines, and other equipment.
City Study Room Management System	The City Study Room Management System is an integration of reader services built upon the smart library management platform. Within this system framework, the Daxing Airport Branch has implemented multiple reader service applications such as mobile literature borrowing, mobile remote book returning, intelligent collection management, and statistical reports according to the data and interface specifications of the smart library platform.
Smart Collection Management	Smart bookshelves are real-time management systems for books on shelves, using RFID technology to identify books on shelves. They can achieve functions such as collection inventory, query, and positioning, and can help librarians count mis-shelved books.
Librarian Mobile Services	Display brief reports of various business operation data of the Daxing Airport Branch on mobile terminals, allowing librarians to grasp overall operation status and quickly respond to reader inquiries based on the data.
Data Visualization Display	Can display literature borrowing/returning trend charts, reader card application trend charts, new book recommendations, book activity rankings, book borrowing rankings, announcements, and service data of various libraries within the Beijing public library service system on large screens.

Smart Function Name	Smart Function Description
Smart Bookshelves	On the first floor of the Daxing Airport Branch of Capital Library of China: literature positioning, searching, analysis, popular book push, and intelligent collection management. The smart bookshelf system features fast detection speed and accurate positioning, along with big data analysis and statistics of borrowing rates. It can help librarians automatically locate and know the status of literature in real time, obtain literature activity data, understand reading needs based on book borrowing situations, timely supplement books, and adjust collection construction accordingly.
Smart Robots	On the first floor of the Daxing Airport Branch of Capital Library of China: consultation, guidance, query, reading, and navigation. Smart robots are placed at the library entrance, actively greeting readers when they approach, prompting QR code temperature scanning, engaging in simple conversations, helping readers query collection information through voice dialogue, and guiding them to the bookshelves where books are located.

Smart Function Name	Smart Function Description
Mobile Inter-Library Book Return	The branch has joined the Beijing public library "One Card" service system. Borrowed books can be borrowed and returned across 388 member libraries with "One Card" inter-library return services. Books reserved from other libraries when searching the Beijing public library catalog OPAC can be selected for pickup at the Daxing Airport Branch, with unified delivery by logistics vehicles. Every reader's mobile phone can become a "self-service borrowing/returning machine." Using the "Reading Beijing" mini-program in Alipay, after binding their reader card, they can scan the barcode on the book's title page to borrow books. For returns, there are two methods: offline return by going to the nearest inter-library return point, or online return by filling in their pickup location and paying logistics fees for courier pickup, which is very suitable for out-of-town traveler readers. The reader end of the mobile inter-library book return function is integrated into the "Reading Beijing" mini-program, enabling book borrowing by scanning codes in the Alipay "Reading Beijing" mini-program, as well as online returns and nationwide cross-provincial logistics returns.
Book Reservation and Delivery	Readers can log in to the Capital Library of China official website to freely reserve on-shelf books from other libraries, which are then delivered by logistics to the Daxing Airport Branch for reader borrowing.

3.2 Beijing Sub-center Library

The Beijing Sub-center Library under construction, located in Tongzhou District, Beijing, is a "Forest Book Garden" style library that integrates "people-friendly, distinctive, and smart" features. Scheduled to open at the end of 2023 with a construction area of 75,000 square meters, it will further explore future smart library construction methods. On the first-floor public activity area,

approximately 600 square meters are designated as a “metaverse” experience space, using big data and artificial intelligence as core carriers and employing various display media such as screens and mirrors to construct offline metaverse experience scenarios, achieving connection between real and virtual reality and bridging online-offline immersive interactive reading experiences. It will showcase five core experience scenarios: “Capital Library Public Metaverse,” “Reader Personal Metaverse,” “Capital Library Public Digital Human,” “User Digital Human,” and “Data Sea.”

In terms of smart buildings, through highly automated and intelligent monitoring systems, it forms a visual operations and maintenance management system with automatic response systems, automatic linkage systems, and network alarm systems to achieve real-time management of all building spaces and equipment information, ensuring normal operation of various facilities. In terms of smart resource retrieval services, it mines collection resources through text analysis and entity recognition to build knowledge graphs, providing platforms for cultural knowledge popularization and professional knowledge services. In terms of smart services, it will also install smart seating system equipment, smart consultation, smart wristband system equipment, and others.

Additionally, the library will build three characteristic themed libraries: the “Intangible Cultural Heritage” Document Library will become the first specialized library in China to collect and display intangible cultural heritage digital resources, providing an immersive humanities experience with unique Beijing regional scene characteristics through media digital technology; the Art Document Library will mainly highlight audio-visual experience features, allowing readers to listen to and experience the joy of old vinyl records while enjoying wonderful music in HIFI appreciation rooms; the Ancient Books Document Library will comprehensively display collection, protection, and research activities of precious ancient books and documents for readers, serving as a public cultural space integrating research, education, exhibitions, and leisure. Another major feature of the Sub-center Library is the smart stack, covering approximately 3,400 square meters. It combines high-density storage shelves with automatic storage and retrieval systems, equipped with automatic storage and retrieval, sorting, and intelligent book delivery robots to achieve automatic book 出库, automatic sorting, and automatic 搬运, significantly improving retrieval efficiency and accuracy. With a collection capacity of no less than 7 million volumes, it will become the largest 立体 book stack in China upon completion. This smart library with panoramic ecology, cross-boundary integration, and full-element knowledge services will not only allow readers to experience the beautiful reading imagination of “reading among mountains, under trees, and with diligence” but also comprehensively use 5G, artificial intelligence, blockchain, cloud computing, and big data technologies to provide immersive reading and precise perception services.

New technologies have brought disruptive changes to library service models. From “information islands” to big data, library service models have evolved from

traditional models to digital library service models and then to smart libraries. The metaverse environment similarly represents another 冲击 on library service models, breaking the temporal and spatial boundaries between the digital and physical worlds, expanding the service boundaries of smart libraries, and bringing more possibilities for the future development of libraries. The innovative development of future smart libraries possesses the following characteristics.

4.1 Virtual-Real Integration

In the metaverse environment, technology-enabled smart libraries rely on virtual reality, digital twins, and multi-source data and algorithm models to achieve smart twin spaces with online-offline data circulation, providing virtual roaming, immersive reading, and VR navigation services. This constructs a virtual-real integrated environment for users, who can remotely roam the twin virtual library space as digital humans in the metaverse concept, freely browsing collection resources and easily achieving immersive reading.

4.2 Data Empowerment

In the metaverse environment, libraries use intelligent detection and data mining technologies to collect users' dynamic twin data resources. Through macro cognition and micro observation of users' operation trajectories, combined with algorithm models for automatic data analysis and pattern acquisition, they simulate patterns to deduce users' potential service needs, forming individual datasets mapped to the library's virtual space while embedding customized web page recommendation reminder functions matching user portraits to achieve intelligent coupling of resource services and user needs.

4.3 Intelligent Perception

Libraries use robots with visual, auditory, and tactile perception capabilities to communicate and interact with users in familiar ways. Relying on the trend of IoE (Internet of Everything), libraries build intelligent platforms to achieve comprehensive perception of resources, management, and services. In the metaverse environment, resources and data are diverse and massive. Smart libraries rely on artificial intelligence to build perception platforms, integrate scattered data, and use comprehensive computing power systems to analyze and process perceived data.

4.4 Cognitive Intelligence

Libraries introduce natural language understanding, IoT, and other technologies through cognitive intelligence technology to achieve human-robot interaction and symbiosis, using robotic technological wisdom to break barriers between human-computer interaction. With the proposal of the metaverse concept, brain-computer interaction will become the mainstream method of next-generation human-computer interaction. Brain-computer interaction collects

human brainwave signals to command virtual scenes, generating better experiences. Future smart libraries will use brain-computer interaction technology to provide users with an immersive experience and embodied interaction virtual reality deep fusion system, completely breaking the barriers between reality and virtuality, allowing users to truly experience the pinnacle of smart library immersive experience services.[32]

Of course, the metaverse is not the development of a single technology but a comprehensive body of technological innovation. Therefore, our consideration of the metaverse's development in smart libraries must always adopt a holistic approach.[33] The future may face issues such as technical bottlenecks, legal and regulatory development, intellectual property rights, and user privacy. Therefore, moving from concept, technology, architecture, management, and evaluation to actual implementation will require solving many problems. Technically, it will require support from numerous scientific systems; managerially, it will require the introduction of a series of standards and protocols; legally, it will require legislative research across various industries and fields.[34]

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Note: Figure translations are in progress. See original paper for figures.