

Digital Twin Technology and Its Application in Libraries: A Case Study of Xiong'an New Area Library Construction (Postprint)

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Abstract

[Objective/Significance] Digital twin helps advance the deep integration of physical and information systems in libraries, enabling “virtual-real mapping, virtual control of real, and coordinated interaction” between their physical entities and digital twin models. [Method/Process] Based on an analysis of the current research status of digital twin, this paper proposes the concept and model of digital twin library, analyzes its theoretical connotation and typical characteristics, and in conjunction with its technical features and application scenarios, puts forward a corresponding technical framework, operational mechanism, and policy recommendations, aiming to provide reference for future library construction and development. [Results/Conclusion] The digital twin library mainly comprises four elements: library physical entity, digital twin model, digital twin service system, and library twin big data; its typical characteristics include real-time full-element mapping, virtual-real fusion, from-real-to-virtual, virtual-control-of-real, twin big data-driven, software-defined, domain-wide intelligent management, and intelligent intervention.

Full Text

Preamble

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**Research on Digital Twin Technology and Its Application in Libraries:
A Case Study of Library Construction in Xiong'an New Area**

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Abstract:

[Purpose/Significance] Digital twin technology facilitates the deep integration of physical and information systems in libraries, enabling “virtual-real mapping, virtual control of reality, and coordinated interaction” between physical entities and their digital twin models. [Method/Process] Based on an analysis of the current state of digital twin research, this paper proposes the concept and model of a Digital Twin Library (DTL), analyzes its theoretical connotations and typical characteristics, and presents a corresponding technical framework, operational mechanism, and policy recommendations in conjunction with its technical features and application contexts, aiming to provide reference for future library construction and development. [Result/Conclusion] A Digital Twin Library primarily comprises four elements: library physical entity, digital twin model, digital twin service system, and library twin big data. Its main characteristics include real-time full-element mapping, virtual-real fusion, transformation from reality to virtuality, virtual control of reality, twin big data-driven operation, software definition, global intelligent management, and intelligent intervention.

Keywords: digital twin; digital twin library; digital twin city; future library; virtual-real mapping

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1. Problem Statement

In November 2019, China’s Ministry of Science and Technology launched the 6G technology research and development initiative [1]. Against the backdrop of comprehensive 5G deployment and early-stage 6G layout, technologies such as holographic communication, twin body area networks, intelligent production, and internet of senses have rapidly become focal topics in both industry and academia. Currently, as the fourth industrial revolution unfolds, driven by new technology waves including big data, IoT, artificial intelligence, and blockchain, next-generation information technologies represented by 6G and AI are beginning to guide future technological transformation and innovation-driven development. The real physical world and the future virtual world are forming two parallel development systems that interact with each other. The virtual world exists to serve the real world, while the real world becomes more efficient and orderly because of the virtual world. Digital twin theory and technology have emerged from this context and have been listed among Gartner’s top ten strategic technology trends for four consecutive years since 2016 [2], with applications gradually expanding from aerospace and military fields to intelligent manufacturing, smart cities, and knowledge management, potentially exerting significant influence on future economic and social development.

In April 2017, China established the Xiong’an New Area [3], and in January 2019, the State Council issued the “Master Plan for Xiong’an New Area in Hebei

(2018-2035)” (hereinafter referred to as the “Plan”) [4], which proposed “building a green and smart new city” and “establishing a complete public cultural service system” [5], explicitly calling for the synchronized planning of “digital city and physical city” and the construction of a “digital twin city” [6]. Consequently, digital twin city construction has attracted widespread attention from government, industry, and academia. However, there remains considerable confusion regarding how to plan and construct such cities, with urgent needs to clarify the corresponding theoretical systems, standards, technical methods, and implementation pathways. As an essential component of digital twin city construction, libraries face the important question of how to build a corresponding Digital Twin Library (DTL), making this a topic worthy of exploration.

In view of this, this paper attempts to analyze the application of digital twin technology in libraries from a theoretical perspective, examining its theoretical models, connotations, characteristics, and application contexts, with the aim of providing reference and guidance for future library construction and research.

2. Research Design

2.1 Main Research Methods

2.1.1 Literature Analysis Method This method comprises four aspects: (1) Comprehensive collection of online information resources on digital twins and Xiong’an New Area, including important documents issued by the State Council, Ministry of Science and Technology, and Ministry of Industry and Information Technology; relevant news from major media outlets such as government.cn, xinhuanet.com, and people.com.cn; and policy documents and news released by foreign governments. (2) Conducting title searches using “digital twin” and “Xiong’an New Area” as Chinese and English keywords in CNKI and Web of Science, selecting relevant and important references from 2017-2019 after comparison and screening. (3) In-depth analysis of 17 national strategic policy documents issued by the State Council and Ministry of Science and Technology over the past decade, including the “Master Plan for Xiong’an New Area in Hebei,” “New Generation Artificial Intelligence Development Plan,” and “Big Data Development Action Outline.” (4) Thorough analysis of all the above literature to provide theoretical support and a data foundation for this study.

2.1.2 Case Analysis Method This method includes three aspects: (1) Analysis of digital twin application cases in aerospace, military, and intelligent manufacturing fields. (2) Analysis of digital twin city practice cases such as Xiong’an New Area digital city, Virtual Singapore platform, 3D city of Rennes in France, and Toronto high-tech community. (3) For important concepts involved in this study, such as digital twin city and library, case analysis is employed to understand them from different perspectives.

2.2 Research Status

Based on searches limited to CSSCI and Chinese core journals in CNKI and Web of Science, this study identified 207 digital twin research papers (59 in Chinese and 148 in foreign languages), revealing a rapid growth trend since 2017, as shown in [Figure 1: see original paper].

Since Professor M. Grieves first proposed the digital twin concept in 2003 and NASA first applied it to aerospace in 2012, academia has described digital twins from perspectives such as lifecycle management, intelligent manufacturing, and smart design. However, due to the complexity and diversity of influencing factors, physical objects, and operating systems, no unified definition has been formed. NASA [7], G. Edward et al. [8], M. Grieves et al. [9], Zhuang Cunbo et al. [10], and Tao Fei et al. [11] have defined the concept from perspectives including aerospace vehicles, product lifecycle management, physical entity reconstruction and digital mapping, and virtual-real integration in product design. A basic consensus has emerged that digital twin refers to using digital technology to create a digital twin model of a physical entity, simulating the behavior and rules of the physical entity in the real world through this model, and adding or extending new capabilities to the physical entity through methods such as virtual-real interactive mapping, data fusion analysis, and decision iteration optimization [12].

Current research focuses on three main areas:

- (1) **Theoretical Models and System Construction:** Tao Fei et al. proposed a five-dimensional digital twin model and explored its application in ten fields [13], and introduced the concept and model of digital twin workshop [11]. Jiang Haifan et al. analyzed the evolution mechanism and operational rules of digital twin workshops from the perspectives of information flow, material flow, and control flow [14]. Zhao Haoran et al. proposed a 3D visualization monitoring model based on real-time information for digital twin real-time monitoring [15]. Zhuang Cunbo et al. analyzed the development background, technical connotation, architecture, and development trends of product digital twins [10]. B. Schleich [16], R. Soderberg [17], and U. Jumyung [18] studied digital twin models for product design, assembly, and manufacturing processes.
- (2) **Cyber-Physical Integration:** K. M. Alam et al. proposed a cloud-based CPS digital twin model [19]. J. W. Leng et al. proposed a CPS digital twin model based on large-scale personalization paradigm [20]. N. Elisa et al. analyzed the application of digital twin technology in CPS-based intelligent manufacturing systems [21]. Tao Fei et al. explored the theoretical system and key technologies of digital twin workshop CPS from four dimensions: physical, model, data, and service integration [22]. Ding Kai et al. proposed a multi-dimensional and multi-scale intelligent manufacturing space model based on CPS from a logical association perspective combined with digital twin implementation logic [23].

- (3) **Digital Twin City Construction:** Zhou Yu et al. conducted an in-depth analysis of the technical background, construction logic, practical requirements, and conceptual framework using Xiong'an New Area as an example [24]. J. On-Hyok proposed a digital twin smart city construction scheme against the background of the fourth industrial revolution [25]. Li Xin et al. argued that the rapid development of information technology has enabled society to build digital twin cities [26]. Tao Fei et al. believed that digital twin city construction will greatly change urban landscapes, reshape urban infrastructure, and achieve collaborative and intelligent urban management decisions [13].

In summary, on one hand, digital twin technology represents the development and integration of existing information technologies without a unified definition. On the other hand, related research mainly focuses on theoretical analysis, system construction, and application exploration, with relatively weak studies on operational mechanisms and applications. Moreover, digital twin technology has been widely applied and practiced in smart cities, knowledge management, and cyber-physical integration, which can certainly provide important reference for future library construction and development.

2.3 Research Framework

Based on digital twin theory and the digital twin city construction concept for Xiong'an New Area, combined with the actual needs of future library development, this study establishes a “demand analysis → application analysis → policy recommendations” research framework as an analytical tool for the deep integration and development of digital twin technology and future libraries, as shown in [Figure 2: see original paper].

3. Theoretical Analysis of DTL

3.1 Requirements for Library Construction in Future Digital Twin Cities

In April 2018, the State Council approved the “Plan,” which was issued in January 2019. The “Plan” outlines the digital twin city construction from ten aspects: overall requirements, spatial layout, urban style, ecological environment, high-end industries, public services, transportation network, green smart new city, urban safety, and safeguard measures [5], with the goal of basically “building a new-type city that is green, low-carbon, intelligent, efficient, environmentally friendly, livable, and equipped with high-quality public services” by 2035 [6].

Currently, Xiong'an New Area's digital twin city construction remains in the planning and initial implementation stage. As an important component of the digital twin city, libraries are expected to be basically completed by 2035. Their

construction will proceed from scratch, with strict requirements in service content, service environment, service facilities, service technology, and construction strategies. According to the “Plan,” library construction in future digital twin cities differs from traditional library construction in five main aspects:

3.1.1 Public Cultural Services There is a need to provide comprehensive, high-quality public cultural services, build multi-level public cultural service facilities, construct libraries to high standards, and promote the deep integration and high-quality development of cultural industries and public cultural services. The goal is to build world-class public cultural services, science and technology education infrastructure, and innovation service systems, create knowledge service areas with significant knowledge spillover effects, comprehensively integrate knowledge service resources, and construct a full-chain knowledge service system.

3.1.2 Service Environment The focus is on creating an ecologically beautiful natural environment, a harmonious space environment, a culturally integrated Chinese-Western environment, an intelligent and efficient urban environment, a high-end innovation environment, a high-tech industrial environment, a high-quality and comfortable living environment, and a safe and reliable network environment. High-standard environments bring high-standard demands, which in turn require library planning and construction to fully match the corresponding environmental design and high-standard service requirements.

3.1.3 Service Facilities The emphasis is on building a comprehensive digital identification system, constructing a unified and open IoT system, establishing multi-source and inclusive computing facilities, achieving real-time data exchange and early warning for libraries, and creating an all-accessible, multi-network collaborative ubiquitous network environment both above and below ground. The goal is to build a globally intelligent library environment, promote intelligent and digital planning and construction, and establish a fully digital personal credit system, a big data credit system, a data resource open sharing management system, and a comprehensive data resource catalog.

3.1.4 Service Technology Based on the digital twin city’s focus on developing 6G, IoT, big data, AI, and other information technology industries, as well as building a national new-generation AI innovation platform, the priority is to achieve breakthroughs in library unmanned system intelligence technology. By leveraging advanced technologies such as blockchain, terahertz, and cognitive computing, comprehensive construction and application in libraries will be integrated with modern services including finance, commerce, smart logistics, modern supply chains, smart education, and smart healthcare.

3.1.5 Construction Strategy The strategy involves achieving construction planning from zero to one, from nothing to something, insisting on synchronized

planning and construction of library physical entities and digital twin models, advancing the layout of intelligent infrastructure, promoting real-time controllable intelligent application services across the entire domain, establishing a sound big data resource management system, and creating digital cities and DTLs with deep learning capabilities. By 2035, this will establish a benchmark for future library construction and development worldwide, providing a Chinese solution for DTL construction.

3.2 Conceptual Model

Based on the above analysis, this paper defines DTL as: under the drive of new-generation information technology and service concepts, constructing a digital twin model that completely corresponds to the library entity. Through real-time bidirectional mapping and interaction between the library entity and its digital twin model, DTL achieves the fusion and interaction of full business, full process, and full element data resources among physical entities, digital twin models, and library service systems. Driven by library twin big data, it enables iterative optimization and operation of service element management, service process control, and service plan execution between the library entity, digital twin model, and digital twin service system, thereby achieving optimal library entity management and service under specific service requirements and rules. In short, a Digital Twin Library refers to the technology, methods, and models for constructing a digital twin model that completely corresponds to the library entity. It mainly includes four components: library entity, digital twin model, digital twin service system, and library twin big data. The basic conceptual model is shown in [Figure 3: see original paper].

The library entity includes physical space, service resources, human resources, service facilities, and other physical resources, as well as related behaviors, rules, and elements. The digital twin model primarily refers to the complete mapping of the entity in virtual information space, essentially a collection of digital models of all entities. The digital twin service system mainly involves intelligent control and coordination of the entire system's planning, design, implementation, deployment, evaluation, and monitoring, representing a functional integration of various data, services, applications, businesses, rules, modules, and strategies. Library twin big data mainly includes four parts: entity operation data, digital twin model operation data, digital twin service system operation data, and big data generated by the fusion of the three.

3.3 Connotation Analysis

Digital twin technology originated from big data, IoT, and AI, and flourished due to intelligent production, ubiquitous perception, and intelligent technologies. DTL is an emerging technical approach for constructing new future smart libraries, achieved when library data accumulation reaches a qualitative change from quantitative change, when information ubiquity evolves to intelligence ubiquity, and when breakthroughs occur in information technologies such as

6G, IoT, AI, and twin body area networks. It represents an advanced model for library operation intelligence and ubiquity and sustainable development, as well as a knowledge and service innovation system that adapts to social and urban innovation-driven and high-quality development, attracts comprehensive participation from high-end social and intellectual resources, and evolves from local application to global collaboration through continuous iterative optimization. Simultaneously, it represents a new form of future library construction and development where real-world library entities and virtual libraries in information space achieve global perception, virtual-real integration, and symbiotic coexistence.

The essence of DTL is a closed-loop data empowerment system for library knowledge and service innovation. It employs comprehensive domain-wide digital identification, precise intelligent IoT perception, real-time data interaction analysis, intelligent decision analysis, and efficient precise execution to achieve library situation awareness, simulation, monitoring, early warning, traceability, diagnosis, prediction, and control. This addresses uncertainties and complexities in the entire lifecycle management of library planning and design, resource construction, operation management, and knowledge services, thereby comprehensively improving the collaborative efficiency and operational status of library physical resources, space resources, document resources, information resources, intellectual resources, and service resources. It truly creates a user-centered, full-spatiotemporal intelligent service smart library.

DTL is an information technology system and digital space model based on global digital identification, intelligent IoT perception, contextual spatial communication, ubiquitous inclusive computing, holographic intelligent control, and real-time innovative services. It constructs a digital twin model in information space that completely maps and matches the physical entity, enabling holographic simulation, real-time monitoring and diagnosis, and precise prediction of the library entity's operation in the real world. This achieves real-time bidirectional mapping, iterative optimization, and autonomous evolution between the library entity and its digital twin model.

3.4 Typical Characteristics

DTL construction requires new information technologies such as big data, AI, IoT, and blockchain for comprehensive and full-element planning and design from digital processing, information display, resource interconnection to intelligent experience. It achieves synchronized planning and construction of library entities and digital twin models, virtualizing and digitizing all elements including people, machines, objects, environments, behaviors, rules, and processes to generate a holographic DTL. It has five main characteristics:

3.4.1 Real-Time Full-Element Mapping DTL constructs an intelligent perception system through IoT sensing devices at all levels of the external environment (streets, ground, buildings, airspace) and internal environment (physi-

cal buildings, spaces, doors, windows, air conditioning, bookshelves, documents, personnel, software and hardware infrastructure, environmental layout), as well as dynamic monitoring of management and service processes, behaviors, and rules. This creates a ubiquitous twin body area network, globally intelligent service environment, and full-spatiotemporal service system, forming real-time and precise mapping of library entities in virtual space.

3.4.2 Virtual-Real Fusion: From Reality to Virtuality, Virtual Control of Reality DTL's virtual-real fusion manifests in two aspects: (1) **From reality to virtuality**: The digital twin model accurately portrays and maps the entity's elements, rules, behaviors, and processes through big data, virtual/augmented/mixed reality, and simulation technologies, enabling complete correspondence and co-evolution. (2) **Virtual control of reality**: All entity data is transmitted in real-time to the digital twin model, which conducts in-depth analysis and optimization of the entity's operational status and performs real-time control of the entity based on optimization strategies.

3.4.3 Library Twin Big Data-Driven The essence is a closed-loop data empowerment system for library knowledge and service innovation. Data traces left during the operation of library infrastructure, service resources, spaces, culture, environment, and personnel, simulation processes of DTL, and service data from its intelligent sensing system converge into DTL big data, driving its development and operation.

3.4.4 Software Definition For the corresponding digital twin service system, application software is used to simulate the behaviors and activities of library people, machines, objects, and rules in the environment. Through intelligent sensing systems, twin body area networks, and edge computing, global real-time analysis of library entity physical facility operation, energy scheduling, service lifecycle management, and spatial environment is achieved, enabling intelligent allocation of public service resources.

3.4.5 Global Intelligent Management and Intelligent Intervention Through top-level planning, design, and simulation, DTL promotes intelligent and digital planning and construction of libraries, achieving global intelligent control and precise monitoring of corresponding resource flows, information flows, data flows, and service flows. Through its digital twin service system's security situation intelligent perception, early warning, traceability, and monitoring system, potential security warnings, harmful information, prominent issues, or potential dangers are intelligently alerted, providing optimal and scientific solutions in a timely manner. From the perspective of future library development, real-time intelligent intervention is implemented to optimize and guide planning and design, management services, resource allocation, and service provision.

4. DTL Technical Framework and Application Scenario Analysis

4.1 Application Value

The key value of DTL lies in constructing an intelligent IoT data closed-loop empowerment service system [27], building a corresponding globally virtual mapping digital model, and employing methods such as virtual simulation, virtual-real interaction, building block analysis, and intelligent coupling to construct a software-defined library, twin big data-driven decision optimization, and virtual-real fusion interactive library digital twin model. This enables library operation, management, and service to transform from reality to virtuality, simulating, intelligently evolving, real-time controlling, and virtually controlling reality in virtual information space to optimize and coordinate operational elements in library entities.

4.2 Technical Framework

From a technical perspective, DTL covers the four elements of “human-machine-object-environment,” relying on the “cloud-network-end” three-layer digital twin service system. The “cloud” layer achieves intelligent decision-making, precise prediction, and implementation control of libraries through multi-source inclusive computing systems such as cloud computing and edge computing, covering all elements comprehensively, multi-scalably, full-spatiotemporally, and intelligently. The “network” layer provides real-time bidirectional data transmission, builds a global intelligent environment, and establishes an intelligent sensor network system through ubiquitous intelligent sensor networks that are fully accessible above and below ground, internally and externally, and multi-network collaborative. The “end” layer builds a library global perception system and a comprehensive digital identification system, fully portraying and mapping the operational status of all library elements. The corresponding technical framework is shown in [Figure 4: see original paper].

4.3 Operating Mechanism

Similar to digital twin city and digital twin workshop construction models, DTL comprehensively integrates multi-source heterogeneous big data such as global intelligent perception, historical operation, and intelligent monitoring within specific scopes and contexts. It fuses multi-disciplinary, multi-domain, multi-scale, multi-probability, and multi-physical simulation processes, integrating intelligent coordination, precise monitoring, intelligent decision-making, inclusive precision, customized services, and full-spatiotemporal intelligent services to jointly construct a complex ecosystem that coexists, co-grows, and co-governs with library entities and integrates virtuality and reality.

The global digital identification system is the foundation and prerequisite for intelligent IoT perception, serving as the unique identifier for distinguishing

library entity elements in virtual information space. The intelligent IoT perception system is the interface and channel for achieving interconnectivity and intelligent perception between relevant entities, acting as the “nervous system” and “connector” for mapping library physical entities to their digital twin models. Global full-element data resources form the foundation for its deep learning, intelligent collaboration, and free optimization, providing data support for the AI system. The ubiquitous wireless network provides network environment guarantees, offering real-time data transmission, interaction, and fusion in a ubiquitous intelligent network environment. Collaborative cognitive computing capabilities provide capability and efficiency guarantees, offering computing power support for self-generation, self-growth, self-evolution, and self-optimization. The digital twin service system provides real-time decision-making and intelligent service guarantees, offering algorithm and strategy support. The digital twin model visually presents global intelligent IoT perception facilities, library operational status, decision execution status, and global full-element data resources, and performs intelligent control and decision optimization on entity operation status. The intelligent control application system is the “control room” and “command center” of DTL, comprehensively integrating and fusing the operational status of library resources, space, security, energy, human flow, logistics, information flow, management, and services. It integrates resource construction, safety monitoring, resource management, personnel management, service management, data management, process traceability, information release and display, and other businesses into a central command center. The basic operating mechanism of this technical framework is shown in [Figure 5: see original paper].

4.4 Application Scenarios

Xiong’an New Area’s goal of building a digital twin city, the Singapore government’s collaboration with Dassault to build a digital twin city [28], and Alibaba Cloud Research Center’s release of the “City Brain: Exploring Digital Twin City” white paper all indicate that digital twin technology has become an important trend for future social development and urban intelligent upgrading. As a new model, concept, and method for future library construction and development, DTL deserves attention and emphasis in the library field.

4.4.1 Integrated “Planning-Construction-Management-Operation” Collaborative Control Scenario In DTL mode, loading a global full-element virtual digital model becomes its most important data support and infrastructure. Its most typical application scenario is the integrated collaborative control of the entire lifecycle of “planning-construction-management-operation,” achieving simulation of planning and design, intelligent control of resource construction processes, intelligent coordination of management service resources, and precise prediction and optimization of operation management, thereby comprehensively improving the integrated collaborative management capability of library planning, construction, management, and operation.

In the planning and design phase, virtual digital models help understand the library's foundation and operational patterns. Through simulation and prediction, top-level planning and design can be promoted efficiently, quickly, and scientifically. By obtaining global full-element data resources related to space, personnel, resources, facilities, management, and services through the intelligent IoT perception system, corresponding planning and construction schemes are built in the digital twin model. Based on ensuring scientific validity and effectiveness, further simulation and visualization display are conducted to perform functional simulation, performance optimization, and digital delivery of planning schemes, improving planning quality and efficiency.

In the operation management phase, based on virtual digital models, global digital identification systems, intelligent perception systems, and corresponding intelligent infrastructure, real-time monitoring and visualization of infrastructure, service resources, space resources, energy systems, internal and external environments, business management, and service processes are achieved, enabling real-time interaction and decision optimization. Additionally, this system can qualitatively and quantitatively simulate library management and service scenarios, user flow and information flow evolution trends, and internal and external environment evolution, allowing managers and decision-makers to observe library operation management status in real-time, understand improvement effects, and evaluate construction effectiveness.

4.4.2 Virtual-Real Fusion and Virtual-Control-Reality Intelligent Operation Scenario DTL can display the full picture of library operation management in real-time, helping build an intelligent information management center. Based on intelligent perception, monitoring, management, analysis, decision-making, and optimization, it establishes a data mapping and visualization digital display system between the real world and virtual space, achieving cross-domain, cross-resource, cross-level, cross-institutional, and cross-business intelligent collaborative library operation. This forms an efficient, convenient, inclusive, precise, intelligent, proactive, and real-time online intelligent operation management model.

In service resource optimization and coordination, DTL can display in real-time the distribution and demand status of library users, document resource management and usage, facility resource distribution and usage, energy (water, electricity, air conditioning) consumption, and safety management status. Based on real-time calculation results, it intelligently decides resource coordination and optimization strategies. In abnormal situation intelligent control, through global full-element intelligent perception systems, real-time analysis, prediction, and display (energy environment, service resources, user demand, network security, emergencies, knowledge evolution, and management service optimization) are performed for abnormal and emergency situations. Through deep learning and real-time analysis, resource optimization and coordination are achieved. In intelligent infrastructure dynamic control, any person, object,

resource, or information entering DTL is intelligently perceived, recorded, and identified using technologies such as blockchain and IoT, ensuring irreversible trajectories, traceable history, and predictable development trends. All components, buildings, books, shelves, tables, chairs, computers, trash cans, faucets, plants, and personnel have unique digital identification, with their operational status monitored in real-time and managed centrally and dynamically.

4.4.3 Human-Centered Active Service Scenario with Integrated Contexts DTL will intelligently collect operational trajectory data of all elements, predict and analyze operation, management, and service patterns. In the digital twin model, it predicts the changing patterns of information resource structure and knowledge service demand, predicts future knowledge service trends, and evaluates the impact of operation management services. Through intelligent IoT perception, virtual human-computer interaction, and intelligent service recommendation, it achieves real-time and precise responses to inclusive, precise, and personalized customized services, forming a digital twin service system with strong innovation and intelligence.

In full-lifecycle intelligent services, a series of intelligent IoT perception devices are integrated to collect operation management and user behavior data, effectively associating user knowledge service needs with library operation management and global full elements. The entire lifecycle management process of knowledge services is simulated in the digital twin service system, and AI technology is used to predict and analyze its operation trajectory and development patterns. In user knowledge service demand analysis, each user's behavioral trajectory and service needs are accurately mapped, forming large datasets for individual users. Through data mining and real-time analysis, personalized knowledge service needs are calculated, enabling libraries to fully understand individual users' personalized needs and provide customized services. In inclusive and precise customized services, not only do entity operations coexist in virtual-real fusion, but knowledge service processes can also achieve virtual-real integration. All users can propose personalized needs for service content, form, and time according to actual requirements, and libraries can perform resource integration, virtual service design, and matching based on these needs, achieving inclusive, precise, customized, and personalized services.

5. Policy Recommendations for Promoting DTL Construction

Currently, digital twin technology is still in its infancy in smart city construction and has not yet appeared in smart library construction. The digital twin city construction in Xiong'an New Area provides important reference and guidance for the application research of digital twin technology in future libraries.

5.1 Strengthen Top-Level Design and Solve Problems Hierarchically

DTL top-level design is a guidance system for its planning, construction, development, operation management, and application practice. Top-level planning and design should be conducted from aspects such as construction vision, strategic goals, action programs, basic principles, construction planning, construction schemes, implementation strategies, and evaluation systems [29]. As a complex ecosystem, DTL lacks systematic basic theoretical and application practice research. Its construction integrates almost all current information technologies, representing an unprecedented technological integration innovation and comprehensive challenge. This requires not only accurately identifying and understanding library operation management patterns but also conducting global full-element simulation, intelligent perception, decision analysis, prediction optimization, and optimal control. The first level is simulation—constructing virtual digital models of entity objects. Given the operational complexity and element diversity of libraries, the digitalization and virtualization simulation technologies, rules, and standards for global full elements are not yet perfect and require in-depth research. The second level is intelligent perception—real-time mapping of physical entity changes in the digital twin model, which requires intelligent perception systems to obtain and perceive entity element data. Issues such as digital identification, coding, addressing, standards, and security need further research. The third level is decision analysis—during operation management, there will inevitably be many abnormal and emergency situations, requiring in-depth exploration of how to use AI technology for processing and analysis. The fourth level is prediction optimization—predicting library operation management, user knowledge service needs, and safety management risks based on existing twin big data, which places higher demands on the integration of multiple technologies. The fifth level is optimal control—optimizing and controlling library operation management through the constructed global intelligent software and hardware environment.

5.2 Strengthen Infrastructure Construction and Build by Fields Gradually

From the perspective of DTL technical characteristics and operating mechanisms, it will have greater impact in building intelligent perception systems, entity virtualization models, real-time bidirectional virtual-real mapping, and multi-dimensional intelligent decision-making systems [30]. Combined with practical realities, following the 思路 of local experimentation, pilot research, demonstration promotion, and gradual construction, DTL construction can prioritize four aspects: (1) **Intelligent planning and construction:** Through 3D visualization of digital twin models displaying spatial environment layout, temperature and humidity changes, document usage changes, and resource usage changes, providing decision-making basis for library operation management. Through simulation, dynamic evaluation, and deep learning of the impact of library planning and construction on future development, orderly

construction can be ensured. (2) **Intelligent building construction:** Promoting integrated “planning-construction-management-operation” of libraries, endowing every brick, tile, object, plant, and flower in library architectural space with data characteristics, synchronizing planning and construction with the entity. After completion, the digital twin model can display all aspects of the building in real-time, creating a global full-element digital identification system and achieving real-time bidirectional virtual-real mapping. (3) **Intelligent logistics system construction:** Through real-time monitoring and deep analysis of library human flow, resource flow, element flow, and information flow using digital twin models, AI and big data technologies are used to predict change patterns and achieve intelligent resource coordination and optimization. (4) **Intelligent energy system construction:** Digital twin models enable intelligent management of library water, electricity, air conditioning, sanitation, and other energy environments.

5.3 Coordinate Implementation and Promote Construction in Phases

Overall, DTL construction requires strengthening theoretical systems, key technologies, and application practice research. It needs to integrate multidisciplinary, multi-domain, and multi-institutional research entities for joint 攻关, focusing on key, difficult, and common technical issues in DTL, and coordinating theoretical research, technological 攻关, and application demonstrations. From the library perspective, DTL construction is a long-term process requiring comprehensive coordination and phased, step-by-step promotion: (1) **Intelligent infrastructure construction:** Synchronously construct intelligent IoT perception systems with library infrastructure, create a comprehensive digital identification system covering the entire domain, and build intelligent infrastructure capable of precise real-time perception and mapping. (2) **Digital twin model construction:** Utilize 3D digital modeling, virtual/augmented/mixed reality, and other technologies to build completely mapped digital twin models, achieving virtual-real fusion, from virtual to real, and virtual control of reality for integrated “planning-construction-management-operation.” (3) **Global application system construction:** Through intelligent IoT perception of library operation management status, achieve precise information expression and real-time mapping of library entities in information space dimensions, empower libraries through software, and gradually extend to all business areas, promoting the transformation of operation and service models toward context integration, virtual-real fusion, and intelligent personalization.

5.4 Combine with Actual Conditions and Construct by Types

5.4.1 Construction Approach for New Libraries Adhere to synchronized planning, construction, and deployment of “human-machine-object-environment” integrated intelligent IoT perception facilities and multi-network collaborative ubiquitous wireless networks. Then fully utilize cloud computing, big data, AI, and other information technologies to build corresponding digital

twin models, achieving digital, intelligent, and virtualized planning, construction, operation, management, and service of all elements, full processes, and all aspects. Construction should then proceed in stages according to library characteristics and development needs.

5.4.2 Construction Approach for Existing Libraries Based on existing IoT, internet, software and hardware infrastructure, and knowledge service platforms, coordinate to resolve issues such as information silos, software and hardware service facility compatibility, and business collaboration. First, further optimize and improve intelligent IoT perception facilities and service systems [31], then focus on information sharing and interconnectivity to build a unified virtual-real fusion digital twin model, promote global resource integration and open sharing, break existing information barriers and platform incompatibilities, achieve integrated “planning-construction-management-operation,” and gradually extend digital twin services to achieve comprehensive intelligent perception, intelligent monitoring, and dynamic supervision of library operation management.

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Digital Twin Technology and Its Application in Library —Taking the Library Construction of Xiong’an New Area as an Example

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Abstract: [Purpose/significance] Digital twin helps promote the deep integration of physical and information systems in libraries, realizing “virtual-real mapping, virtual control of reality, and coordinated interaction” between physical entities and their digital twin models. [Method/process] Based on analysis of the current research status of digital twin, this paper proposes the concept and model of digital twin library, analyzes its theoretical connotation and typical characteristics, and presents corresponding technical framework, operational mechanism, and policy recommendations combined with its technical features and application scenarios, in order to provide reference for future library construction and development. [Result/conclusion] Digital twin library mainly includes four elements: library physical entity, digital twin model, digital twin service system, and library twin big data. It mainly features real-time full-element mapping, virtual-real fusion, transformation from reality to virtuality, virtual control of reality, twin big data-driven operation, software definition,

global intelligent management, and intelligent intervention.

Keywords: digital twin; digital twin library; digital twin city; future library; virtual-real mapping

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

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