Research on Smart Library Construction Based on the Smart-Native Philosophy

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Date: 2022-06-29T00:00:00+00:00

Abstract

[Purpose/Significance] In response to the strategic objectives of Digital China formulated in the 14th Five-Year Plan, this paper proposes a smart library construction pathway based on the smart-native concept. [Method/Process] Through a systematic review of the digitalization construction trajectory of libraries, it analyzes the deficiencies and bottlenecks in library smart construction under current development demands, and explores corresponding solutions from the smart-native perspective. [Results/Conclusion] The paper envisions the transformation of library service paradigms brought by the smart-native system, and proposes smart library construction strategies supported by new technologies, encompassing distributed data governance, platform-based knowledge management, zero-trust security architecture, and the cultivation of librarians' holistic intelligence.

Full Text

Preamble

Research on Smart Library Construction Based on the Smart-Native Concept

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Abstract

[**Purpose/Significance**] In response to the strategic goals of Digital China outlined in the 14th Five-Year Plan, this paper proposes a smart library construction approach based on the smart-native concept. [**Method/Process**] By reviewing the evolution of library digitalization, we analyze the deficiencies and bottlenecks in current smart library development and explore corresponding solutions from a smart-native perspective. [**Results/Conclusions**] We envision a paradigm shift in library services enabled by the smart-native architecture and propose construction strategies for smart libraries, including distributed data governance, centralized knowledge management, zero-trust security architecture, and the cultivation of librarians' holistic intelligence.

Keywords: Smart Library; Data Governance; Centralized Knowledge Management; Zero Trust Architecture; Smart Librarians
Classification Number: G250.7

The 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Long-Range Objectives Through the Year 2035, released in 2021, included "smart libraries" in the national five-year plan for the first time. Similarly, the Ministry of Culture and Tourism's 14th Five-Year Plan for Public Cultural Service System Construction explicitly proposed the development goal of "significant progress in smart library system construction," marking national and governmental endorsement of library smartification. Technologies such as IoT, big data, cloud computing, artificial intelligence, and 5G provide fast lanes for the evolution from "Internet of Everything" to "Intelligent Connection of Everything." The COVID-19 pandemic has profoundly impressed upon libraries the importance of comprehensive digital, networked, and intelligent service construction. It can be said that the digital era has assembled the "right timing, favorable conditions, and popular support" for libraries' intelligent transformation. Against this backdrop, libraries should seize this historical opportunity, explore construction and development paths for smart libraries in the digital age based on contemporary readers' new demands for information and knowledge services, enhance public cultural acquisition and happiness through high-quality services and technological innovation, and contribute to national cultural prosperity and the realization of a socialist cultural powerhouse.

1.1 Literature Review

This research is supported by the Chongqing Education Science Planning Project "Research on the Construction of an Ecological Smart Teaching Platform for Fragmented Learning" (Project No. 2019-GX-306) and the Fundamental Research Funds for Central Universities "Semantic Duplicate Checking Strategy for Book Selection" (Project No. SWU2009421).

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Since the 1990s, rapid internet development has sparked a global boom in digital library construction [?], gradually migrating more resources and services online. The network broke through temporal, spatial, and carrier limitations on information dissemination, enabling readers to access most needed services anytime, anywhere, without physically visiting the library. After decades of digital accumulation, library data volumes began expanding exponentially, ushering in the big data era around 2005 [?]. Libraries' primary functions evolved beyond merely preserving and disseminating information resources to helping readers filter needed content from massive data. Service innovation based on big data consequently became a hot topic. Libraries began using data mining, user profiling, and other technologies to discover intrinsic relationships among readers' basic information, behavioral data, and collection resources, inferring reader needs to provide personalized services [?], such as pushing potentially interesting resources [?] and optimizing search engine display schemes [?]. The digital era accelerated life rhythms, further raising readers' demands for information service efficiency and accuracy. Personalized services based on feature similarity could no longer help readers identify valuable content from extremely redundant data, necessitating more intelligent and efficient methods for providing accurate and effective information and knowledge services. Thus, the concept of smart libraries emerged. Starting around 2010, libraries embarked on smartification with AI technology assistance [?]. IoT and context-aware technologies built bridges between physical and digital libraries, while cloud computing and 5G opened high-speed channels for data processing and transmission. AI began empowering library intelligence under new infrastructure support. Technologies like facial recognition [?], voice recognition [?], and natural language processing [?] enabled library platforms to simulate human communication for interacting with readers. Practices such as machine learning-assisted book selection [?], neural network-based intelligent book-finding services [?], and knowledge graph-based intelligent retrieval services [?] demonstrated that library systems could provide decision support through logical reasoning. As more intelligent technologies joined, library service models gradually evolved beyond request-response based on keywords or links to acquire judgment and analytical feedback capabilities based on information.

1.2 New Challenges in Contemporary Library Digitalization

The rapid development of the digital era presents both opportunities for deep smartification and new challenges for libraries. This paper identifies the following main issues in contemporary library digitalization:

(1) Multi-modal Data Governance
After decades of digital accumulation, library data has grown exponentially in volume while diversifying in structural forms. Resources expanded from single books to images, audio, video, and even spatial data. Logs now include not only traditional circulation records but also more reader behavioral information such as entry, reservations, recommendations, searches, browsing, and downloads. Meanwhile, big data era tolerance for heterogeneous data makes it difficult to

ensure data integrity, standardization, and connectivity. Manual data collection and cleaning based on experience severely impacts decision-making efficiency and accuracy. Additionally, legacy systems create data silos, posing challenges for multi-modal data governance. Libraries need differentiated management capabilities for new and old data assets and horizontal recognition capabilities for structured and unstructured data to extract effective knowledge for both readers and libraries themselves.

(2) Knowledge Service Timeliness
Today' s knowledge dissemination audiences include not only individuals but also information exchanges between people, between people and machines, and between machines. As life rhythms accelerate, information generation and refresh rates increase, and people's knowledge demands continuously change. The service model shift from passive response to active push demands higher information identification and content adaptation capabilities from libraries. Smart libraries no longer need report summaries from traditional databases but require timely updated profile tags and reader demand insights through intelligent analysis of real-time dynamic data in information systems. Knowledge service timeliness requires libraries not only to respond promptly to current service expectations but also to anticipate future demand changes among reader groups and prepare accordingly. For example, subject services should provide more predictive analysis on frontier dynamic trends beyond traditional bibliometric statistics based on past achievements.

(3) Data and Information Security
The successive implementation of the Data Security Law and Personal Information Protection Law demonstrates national resolve in data and information security governance while exposing deficiencies in cybersecurity construction. To provide rich online services, libraries have built various information systems with different operating environments, platform architectures, data services, and management interfaces, creating significant pressure and burden for security maintenance. Additionally, many libraries provide remote access services to external users, and vulnerabilities in remote service products combined with insufficient account management awareness among some users further increase security risks. Current library security measures mainly consist of boundary security products like firewalls, VPNs, and WAFs, which can prevent external vulnerability attacks but lack effective threat monitoring and protection inside security zones, with insufficient coordination between security devices and incomplete security information analysis.

The 14th Five-Year Plan period imposes higher requirements on library digitalization. Libraries need more effective means to manage and develop growing data assets, correctly understand their strengths and weaknesses, and reasonably plan construction paths adapted to current technological levels, library status, and development needs.

2.1 Concept Definition

Continuous cloud technology development gave birth to the Cloud-Native concept, meaning product solutions no longer migrate from traditional architecture to cloud platforms but generate business applications directly from cloud platforms [?]. Inspired by this, this paper proposes reconstructing library smartification systems using the Smart-Native concept. In Chinese dictionaries, "原" means original or beginning, while "生"means development or growth. Therefore, Smart-Native signifies birth and development from intelligence, referring to considering intelligent technology application and wisdom capability 发挥 from the initial design stage. Smart-Native is not a specific technology but a methodology for achieving library smart transformation based on AI systems. Smart-native library construction is not about adding intelligent technology solutions to business processes and service models but generating library service functions on a full-stack smart architecture, realizing "coming from intelligence and returning to intelligence."

The core concept of Smart-Native is unboundedness: first, data unboundedness, where data can interact and be used seamlessly across different devices, systems, platforms, and network architectures; second, service unboundedness, eliminating service category divisions like paper resources, electronic resources, and reference consultation, with each smart service integrating all necessary elements from traditional businesses; and third, knowledge unboundedness, where knowledge production, processing, and application are not domain-limited, providing cross-disciplinary and cross-industry knowledge integration and consumption services. Therefore, Smart-Native is an ecological construction concept that breaks traditional technical, business, and environmental boundaries for information flow, extracting valuable knowledge through continuous generation, recombination, and application cycles, ultimately forming a dynamically updated intelligent ecosystem.

2.2 Reconstruction Strategies Based on Smart-Native

(1) Overall Architecture

Existing library frameworks can no longer meet smartification development needs and may even create obstacles, mainly manifested in: Current construction patterns primarily apply intelligent technology within traditional business processes, limiting intelligent effectiveness. For example, book information can usually only be queried in the catalog system, making it difficult to provide more effective resource discovery services beyond optimizing search results. Intelligent applications lack effective connectivity, resulting in insufficient timeliness of smart services. For instance, building library user profiles typically requires manual data collection from various systems before integration [?], inevitably causing delays in profile-based services. Lack of effective knowledge management strategies prevents automatic knowledge formation and dynamic updating. For example, existing intelligent Q&A systems mainly match preset answers through semantic analysis technology [?], making it difficult to provide knowledge-inspiring responses based on individual reader development needs.

To break through current dilemmas, libraries need more open platform architectures, shared intelligent strategies, ecological operation and maintenance systems, and reliable security mechanisms. Therefore, this paper designs a "1+3+3+N" smart-native library architecture. The entire architecture is based on AI technology, realizing all library intelligent functions through one cloud infrastructure, three management middle platforms providing intelligent capabilities, three comprehensive control centers providing resource and security management, and multiple business applications at the top level, as shown below.

[Figure 1: see original paper] Smart-Native Library Architecture

The control center dynamically schedules software and hardware resources of the infrastructure. The security center provides architecture- and policy-based security guarantees for data, information, networks, and privacy across the entire platform. The evaluation center manages evaluation indicators, strategies, and results for the whole system and feeds them back to various platforms in the intelligent layer to achieve adaptive dynamic optimization.

(2) Reconstructing Data Governance Solutions
Intelligent technology application relies on data support. To effectively integrate and utilize heterogeneous data from different sources, establishing unified metadata standards for different data resources has become a hot topic in library research. With deepening digitalization, library resources have become more diverse and complex, expanding from traditional paper books to electronic texts, images, audio, video, geospatial data, and other multimedia files with different structures. Resource content has expanded from traditional documents and archives to dynamic information in various forms such as web news, behavioral logs, and event memories. It becomes difficult for libraries to quickly establish metadata standards for continuously emerging new resource types, and even resources of the same type cannot be effectively revealed through completely consistent standards, such as metadata design for leisure versus professional books.

Microservices architecture provides complete and feasible solutions for integrating platforms with different business processes and has achieved success in new-generation library platform practices [?]. This paper argues that when facing diverse and constantly changing data resources, effective governance solutions may not lie in unified standards but in distributed management strategies. The key to data availability may not be consistent description languages but universal interfaces. Therefore, distributed data governance based on distributed thinking can adapt to flexible, variable, and continuously expanding data needs, providing a solid data foundation for smart-native platform knowledge system construction. Thoughtworks Chief Technology Advisor Zhamak Dehghani points out that distributed data governance will become the next-generation data platform architecture. She designed a domain-oriented distributed data mesh construction scheme with detailed implementation steps [?]. Referencing Data Mesh core concepts, this paper formulates a distributed data governance strategy for libraries, including:

Domain-Oriented Data Ownership: Divide data according to business domain contexts, with data producers owning their data. For example, datasets can be divided by library functional departments: the collection department manages resource-related data, the circulation department manages reader behavior data like borrowing and reservations, and the general affairs department manages daily work and financial data. Each department takes full responsibility for data generated from their business, enabling continuous support for data changes and extensions while localizing change impacts.

Data as a Product: Manage each domain' s dataset with product thinking. Data producers, also serving as data providers, must deliver data as products to external applications and define objective indicators for evaluating data quality and consumer satisfaction. Data products encapsulate structural components including metadata, APIs, access control policies, and infrastructure, providing complete service functions for external access, statistics, and analysis needs regarding the dataset.

Autonomous Data Infrastructure: In distributed data governance strategies, data no longer runs on unified big data platforms. Each owner has autonomy over infrastructure aspects like storage modes, encoding rules, description languages, and computing methods for their data. Therefore, only domain-specific metadata and universal standards need to be established, enhancing governance architecture stability and flexibility. Taking paper book data management as an example, based on distributed thinking, paper book collection business can be divided into one dataset. All attributes, operations, and platforms for book data are product-encapsulated, with the collection department implementing business domain autonomy. The external interface of this product mainly provides analytical data views, allowing the collection department, most familiar with book data, to provide more appropriate interface rule definitions.

(3) Reshaping Knowledge Lifecycle Management

[Figure 2: see original paper] Data Product Example for Paper Book Domain

Knowledge forms the foundation of library intelligence and serves as crucial basis for providing smart services and making reasonable decisions. Therefore, knowledge management is the core element for achieving Smart-Native. Libraries have provided excellent solutions for knowledge construction but rarely formulate strategies for knowledge management. For example, questions like how user profiles in personalized recommendations should be updated and how knowledge graphs in intelligent Q&A should be maintained often treat knowledge as disposable consumer goods, hindering the formation of overall library intelligence.

Unlike distributed data governance, knowledge management should be centralized because knowledge originates from information 归纳 and summarization, requiring sufficient samples extracted from multiple businesses to form accurate knowledge. Some high-tech companies have provided detailed solutions for knowledge management. For example, the 2020 Knowledge Middle Platform White Paper jointly released by Deloitte and Baidu demonstrates the necessity and feasibility of centralized knowledge management with detailed architecture and application strategies [?]. Based on this concept, this paper proposes a knowledge management solution based on a knowledge-sharing middle platform, managing library knowledge through a centralized platform. The knowledge-sharing middle platform, based on AI technologies like speech processing, visual processing, natural language processing, and knowledge graphs, provides generation, fusion, storage, updating, and visualization functions for various knowledge systems required by Smart-Native, including Q&A knowledge, full-text knowledge, tag knowledge, event knowledge, and causal knowledge. It also stores and maintains algorithm models for knowledge computing, reasoning, decision-making, and recommendation, thereby achieving full lifecycle management from knowledge production to aggregation to application. The knowledge-sharing middle platform is built between the data middle platform and the service & business middle platform, obtaining massive data from the data middle platform to train knowledge, and outputting knowledge to various service applications based on different strategies. All businesses are designed and operated based on knowledge and supported by knowledge decision-making, thus achieving Smart-Native-driven library business process reconstruction, as shown in Figure 3 [Figure 3: see original paper].

(4) Zero-Trust Network Security Architecture

[Figure 3: see original paper] Knowledge Middle Platform Architecture for Smart Libraries

As business expands, role permission definitions for various librarians, readers, and third-party partners become increasingly complex. Cloud computing and mobile technologies blur library security boundaries, and support for more online, mobile, and remote services forces libraries to expose more sensitive data. In the post-pandemic era, cybersecurity has become an issue libraries cannot ignore. Recent cybersecurity incidents show that boundary security based on firewalls, WAF, and IPS can no longer provide adequate protection for information and data security. Libraries need new cybersecurity architectures to adapt to complex infrastructure in new-generation libraries, address intensifying security attacks, and prevent data privacy leaks caused by conscious or unconscious actions.

Exploration of zero-trust network architecture has a long history. In 2010, Forrester research engineer Kindervag formally proposed the "Zero Trust" term [?]. Shortly after, Google published multiple papers based on its BeyondCorp project, elaborating on successful practices in building zero-trust architecture for internal employees. In January 2022, the White House's latest cybersecurity strategy proposed a vision for government agencies to transition to zero-trust architecture, demonstrating that zero trust has become the development trend for next-generation cybersecurity architecture. Zero-trust theory is premised on assumptions that "external or internal threats always exist in the network" and "network location cannot determine network trustworthiness," performing fine-grained permission definitions for devices, users, and systems based on context. Every end-to-end connection requires authentication and authorization, with terminals accessing needed resources only within minimum permission scopes. Dynamic security policies provide trusted security access control, effectively preventing data leaks and lateral movement of threat attacks. In library networks, zero-trust architecture can provide more reliable protection for various application scenarios like remote resource access services, interactions between main and branch libraries, and providing operational authorization to external system maintainers. Taking electronic resource remote access as an example, under zero-trust architecture, reader terminals and library resources are isolated by a zero-trust gateway. Readers must be authenticated and authorized by the zero-trust security control center to obtain authorization tickets, which must be verified by the zero-trust gateway before accessing resources within permission scopes. The architecture is shown below.

[Figure 4: see original paper] Zero-Trust SDP-Based Remote Resource Access Architecture

The above figure shows a zero-trust architecture approach based on SDP technology. SDP is currently one of the mainstream technical solutions in zero-trust practice, namely Software-Defined Perimeter, which replaces traditional boundary security devices with logical components running under service and resource owners' control, requiring authentication and verification of both user identity and user devices to achieve the zero-trust requirement of "never trust, always verify" [?]. Compared with traditional VPN architecture, the security advantages of building remote access services based on SDP technology include:
Using gateway policies to isolate users from internal network resources for resource concealment, protecting intellectual property rights of electronic resources, while zero-trust gateways only need to execute simple functional code, reducing their own vulnerability risks; The authentication control center responsible for authentication is not directly connected to the internal network, making it difficult for hackers to enter the internal network even if the control center is compromised, reducing leakage risks; SDP clients perform multiple audits on users, devices, and applications, reducing risks from account leaks, while identity-based authentication authorization achieves fine-grained access control, effectively shrinking exposure and attack surfaces.

In increasingly complex network environments, libraries should remain vigilant for all data interactions from both internal and external networks in any application scenario. Formulating different security-level permission management strategies for each end-to-end connection through zero-trust architecture can further enhance library network security guarantees and provide readers with more secure and reliable information service environments.

(5) Reorganizing the Smart Librarian Workforce

Librarians are the execution subjects of libraries. As library smartification deepens, librarians' responsibilities, functions, and capability requirements also change. Many scholars have discussed role positioning for smart library librarians, with some arguing that smart librarians should not only be familiar with library and information knowledge and skills but also understand information technology and intelligent equipment, possessing professional, open, and diverse smart service capabilities [?]. However, as scholars like Duan Meizhen point out, such requirements for integrated 多元 knowledge and capabilities are excessively high, easily causing ambiguous role positioning for smart librarians and affecting workforce construction [?]. This paper also believes that the goal of building smart libraries is to use technology to compensate for librarians' deficiencies in manpower, expertise, and skills, while what smart librarians should possess is the ability to apply data intelligence.

Under the smart-native vision, library services and business processes will be self-maintained, self-managed, self-scheduled, self-diagnosed, and self-healed by smart platforms. Are librarians still necessary? In fact, under the smart-native library architecture, librarians are even more indispensable. The open, shared, and ecological basic characteristics of smart-native blur service domain boundaries. The rapidly updated information, constantly changing demands, and ever-evolving technologies in the digital era impose higher requirements on smart iteration agility, and formulating efficient and feasible iteration strategies will become the main work of smart librarians. Smart-native librarians need to focus not on specific businesses but on constantly following social development to discover new reader needs, using data-driven decisions as basis and accumulated business experience as reference, thinking about tools and methods to respond to needs, optimize processes, and improve efficiency from a library-wide perspective. On the other hand, currently maturing low-code [?] and zero-code [?] technologies lower the threshold for library system construction, allowing librarians without coding capabilities to independently complete system development through visual programming interfaces. Successful practices in finance [?], transportation [?], education [?], and other industries have confirmed that this construction model can effectively avoid information gaps between libraries and third-party software companies, responding to personalized customization and agile delivery needs. Technology continuously provides basic business capabilities for libraries, so the cultivation focus for smart library talent teams should not be in-depth resource knowledge, personalized service capabilities, or professional data technology, but in cultivating librarians' ability to gain deep insights into reader needs based on data, systematic thinking ability to overview library-wide development, and service innovation ability to keep pace with the times.

3 Service Paradigm Shift in Smart-Native Systems

Mobile technology 普及 has changed readers' reading habits, and explosive information growth has made "micro-reading" and "shallow reading" the new normal.

In this fragmented era, as readers' demands for information acquisition content and methods change, library service models should correspondingly transform. On one hand, libraries need to meet readers' needs for quick access and provide more precise information content; on the other hand, libraries should guide readers toward deep reading, promoting knowledge system formation and public cultural literacy improvement. Under the smart-native concept, comprehensive and complete data and more advanced intelligent technologies can help libraries profoundly understand information meaning and embedded knowledge, achieving smart services that meet contemporary readers' reading and cultural needs.

3.1 From Providing Options to Precise Answers

Massive data volumes have enriched readers' information sources while creating obstacles to accurate information acquisition. Readers often get lost in data oceans due to inability to identify information value. Imagine searching a keyword in a catalog system with millions of collection records—how can readers filter desired content from dozens of pages of results? In the digital era, content display models based on keyword clustering are no longer optimal for information services. Smart libraries should be like wise experts proficient in business, capable of deeply understanding reader intentions and providing one or a few precise answers. Under the smart-native system, query systems are designed with access solutions for reader profiles, resource profiles, knowledge graphs, and other knowledge from the start, allowing readers to describe desired content like asking a librarian through voice recognition, semantic analysis, and knowledge reasoning technologies, then providing resource information that best meets their personalized needs.

3.2 From Service Personalization to Personalized Services

Personalized services are frequently discussed topics. Libraries analyze readers' interests and needs based on basic information and behavioral logs to achieve diversified service upgrades like personalized information search, personalized subject services, and personalized resource recommendations [**?**]. However, this personalization mainly optimizes content organization schemes for existing library businesses through data analysis, while the service items and content readers actually obtain remain essentially consistent. Smart-native will redefine library personalized service methods. Through all-element data-driven strategies, libraries can deeply understand demand differences between reader groups and individuals, customizing service strategies for each reader like personal trainers. For example, learners versus researchers, children versus adults, and general public versus special groups will see different service interfaces, guided service spaces, pushed service items, received service information, and obtained service experiences, allowing readers to truly have their own personal libraries—this is an embodiment of library intelligence.

3.3 From Meeting Needs to Creating Needs

Library construction and development have long aimed to discover and meet reader needs, such as building electronic resources to adapt to online reading needs and constructing mobile libraries based on readers' smart terminal usage habits. However, this passive demand-response model somewhat limits library service innovation capabilities. While focusing on readers' current explicit needs, libraries should also actively discover potential needs, transforming potential needs into future real needs through forward-looking service construction to enhance core competitiveness. The study room reservation service is a successful case of need creation. In 2008, Google successfully predicted flu outbreaks based on user search data [**?**], and big data' s insight and prediction capabilities have been repeatedly verified. Smart-native' s unbounded data capabilities will help libraries excavate and anticipate readers' future needs from broader perspectives, thereby guiding the construction of more valuable innovative services to create reader needs and gain dominance in disseminating public cultural knowledge and improving public cultural levels.

3.4 From Catering to Interests to Stimulating Interests

Guiding readers to cultivate reading interests and promoting universal reading development are important library functions. However, beyond personalized recommendations and reading promotion activities, libraries seem to have few effective means to motivate reading. The most common incentive method is catering to reader interests by providing interest-aligned content to promote reading, but this restricts readers to relatively single knowledge domains and makes it difficult to maintain long-term incentive mechanisms. In intelligently interconnected smart-native libraries, every service built on wisdom possesses in-depth understanding capabilities of readers and resources, enabling reading promotion to be embedded in various service details to subtly stimulate reading interests. For example, identifying mentioned popular knowledge in electronic reading content through hotspot mining and semantic analysis technologies with external link annotations, or randomly providing one or two "wrong" answers in information services based on knowledge association and reasoning technologies, may attract readers' attention to new domains, thereby expanding reading boundaries and stimulating reading enthusiasm.

4 Conclusion

Undeniably, libraries have achieved remarkable results in decades of digitalization construction, yet reconstruction may entail enormous costs. However, when appending functions to original architecture can no longer adapt to development needs, only reconstruction can bring new opportunities for sustainable library development. In the digital era, smartification demands from both readers and libraries themselves make reconstruction necessary. Therefore, this paper proposes a library system reconstruction scheme based on the smart-native concept, emphasizing that smart library construction is not simply adding intelligent elements to service models but generating library functions on a fully intelligent platform. This paper proposes smart-native construction strategies for key elements including data, knowledge, and personnel, such as distributed data governance, centralized knowledge management, and cultivating librarians' holistic perspectives, while envisioning service transformation directions brought by smart-native characteristics. Against the backdrop of Digital China construction, library smart transformation has attracted widespread thinking and discussion. Based on current deficiencies in library smart construction and combining new technology development trends, this paper explores a construction 思路 for smart transformation, hoping to provide some reference for libraries' future construction and development paths.

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