

From digital libraries to future libraries: Reframing academic libraries as knowledge infrastructures in the age of artificial intelligence

Zihui Zhang[✉]^{1†}, Fei Xue^{1†}¹, Qinfeng Chen¹, Ping Lu²

¹ Zhejiang University Library, Hangzhou 310058, China

² Zhejiang University Museum of Art and Archaeology, Hangzhou 310058, China

[✉]Corresponding author. E-mail: zhangzihui@zju.edu.cn

Abstract: Generative artificial intelligence (AI) is reshaping the production, organization, dissemination, and use of knowledge. In this context, the traditional positioning of academic libraries as knowledge repositories is increasingly challenged by commercial AI platforms, while growing disintermediation raises questions about their role in contemporary knowledge ecosystems. Drawing on Infrastructure Studies and socio-technical systems theory, this study explores the conceptual transition of libraries from knowledge repositories to knowledge infrastructures. To support this argument, it proposes a “Four Pillars, Five Wings” framework, comprising four foundational capacities (AI model base, cross-media knowledge resources, full-chain knowledge services, and digital–physical integrated spaces) and five emerging capabilities

¹ [†] These authors contributed equally to this work and should be considered co-first authors.

(knowledge discovery, intelligent learning, collaborative creation, cultural activation, and research augmentation). Using Zhejiang University's Future Library initiative as an empirical case, the study examines implementation pathways and discusses key challenges encountered during the early stages of development. The findings contribute to ongoing discussions on the transformation of academic libraries from resource-centered institutions into knowledge infrastructures in the age of artificial intelligence.

Keywords: Future Library; Knowledge Infrastructure; Artificial Intelligence; Socio-Technical Systems; Multi-Agent Framework; Knowledge Services

1 Introduction

The development of libraries has long been intertwined with changes in the organization, preservation, and communication of knowledge. From manuscript and print collections to digital resources, and from classification catalogues to online retrieval systems, advances in information technology have continuously reshaped library resources, and institutional functions (McLuhan, 1964). More recently, the emergence of generative artificial intelligence, including large language models (LLMs), multimodal generative technologies, intelligent agents, and knowledge graphs, has introduced **unprecedented modes** of knowledge production, dissemination, and learning. **As commercial AI platforms increasingly assume traditional library functions, such as literature exploration, knowledge inquiry, and digital scholarship support, academic libraries are facing a profound "infrastructure rupture" (Edwards et al., 2007). This disruption extends beyond mere technological obsolescence; it poses a critical crisis of disintermediation, challenging the institutional legitimacy and intermediary roles historically performed by libraries in the knowledge ecosystem (Cox, 2023).**

In response to technological advancements, the digital transformation of libraries has evolved through several stages. Early digital library initiatives primarily aimed to expand information access through the digitization of physical collections and metadata standardization. Subsequently, smart library initiatives placed greater emphasis on service intelligence, utilizing the Internet of Things, big data analytics, and user-centered algorithms to optimize operational efficiency and personalized recommendations (Wang et al., 2023). More recently, the concept of the future library has gained traction, driven by the need to integrate AI into academic environments. Studies in this domain have heavily focused on spatial reconfiguration, such as the transition from collection-oriented spaces to interactive Future Learning Centers (Wu, J. Z., 2022; Zhao et al., 2026), and the shift from symbolic logic to vector-based semantic knowledge organization (Liu et al., 2026). Meanwhile, international discourse has increasingly emphasized the integration of digital scholarship (Padilla et al., 2019) and the necessity of establishing ethical frameworks for human-AI collaboration (Floridi et al., 2018).

Despite this comprehensive body of research, existing literature exhibits significant limitations in addressing the AI-driven paradigm shift within academic libraries. First, studies on digital and smart libraries have predominantly treated AI as a functional utility to optimize workflows and enhance service efficiency. This instrumental approach overlooks how generative AI fundamentally disrupts the underlying knowledge mediation mechanisms traditionally upheld by academic libraries. Second, while emerging scholarship on future libraries successfully highlights spatial and resource reconfigurations, it frequently neglects institutional and governance dimensions. Specifically, there is a paucity of research on how libraries, as authoritative institutions,

can navigate algorithmic bias and rebuild scholarly trust within an AI-mediated ecosystem. Third, although the theory of "knowledge infrastructures" has been extensively articulated at a macro-sociological level (Borgman, 2015; Karasti et al., 2016), there remains a critical dearth of operationalized, socio-technical frameworks capable of translating these broad theoretical tenets into the institutional-level architectural design of AI-enabled academic libraries.

To bridge these research gaps, a novel conceptual framework is imperative—one that shifts the analytical focus from mere technological deployment toward a comprehensive transformation of the knowledge ecosystem. Academic libraries must be conceptualized not simply as smart spaces or advanced retrieval engines, but as robust socio-technical systems grounded in governance structures, professional expertise, and ethical norms (Star & Ruhleder, 1996).

By reframing the AI-era academic library as a dynamic "knowledge infrastructure" rather than a static "knowledge repository," this study aims to share strategic pathways with the international LIS community. The paper makes three interconnected contributions. Theoretically, this reframing offers a critical lens to address the growing risk of institutional disintermediation. Building on this concept, we introduce the "Four Pillars, Five Wings" framework, which translates broad infrastructure theories into actionable components—specifically, foundational capacities and higher-order capabilities designed for AI environments. Finally, by drawing on early implementation evidence from the Zhejiang University Future Library initiative, we ground this framework in reality. This practical application provides the international community

with tested insights into the technical deployment, governance, and human-AI collaboration needed to successfully navigate library transformations.

2 Conceptual definitions and literature review

2.1 Knowledge repository: The traditional library paradigm

The concept of the library as a knowledge repository has long occupied a central position in library and information science. One of its early theoretical foundations can be traced to Ranganathan's (1988) Five Laws of Library Science. In particular, the principles that "Books are for use" and "A library is a growing organism" highlighted the relationships among collections, users, and library services, emphasizing the central role of resources within library practice. From the perspective of information retrieval, Mooers (1951) distinguished between information storage and information retrieval, arguing that the accumulation of information alone does not necessarily facilitate access to relevant knowledge. This distinction drew attention to a persistent challenge in library systems: the gap between information preservation and effective knowledge discovery.

With the development of digital technologies, knowledge repositories have gradually evolved into platforms for the storage, organization, and dissemination of knowledge. Buckland's (1991) influential conception of "information as thing" broadened the scope of information objects managed by libraries, extending beyond traditional documents to include a wide range of materials with evidential, cultural, or interpretive value. Within this context, institutional repositories emerged as an important form of digital infrastructure for collecting, preserving, managing, and disseminating institutional knowledge assets (Zeng, 2007).

In recent years, scholars have increasingly examined the limitations of repository-centered approaches in the context of digital-intelligence transformation. Wu, J. Z. (2022) argued for a transition from collection-centered to user-centered library development, while Liu et al. (2026) observed that library knowledge organization is shifting from symbolic logic toward vector-based semantic representation. Jin et al. (2025) further proposed a conceptual framework for the future library based on four dimensions—“big resources,” “big reading,” “big integration,” and “large models”—highlighting the growing importance of intelligent technologies in library transformation. Collectively, these studies suggest that the traditional repository paradigm, while remaining foundational, may no longer be sufficient for understanding the evolving functions of libraries in AI-enabled knowledge environments.

2.2 Knowledge infrastructure: A socio-technical perspective

The concept of knowledge infrastructure (KI) has its roots in broader discussions of the role of knowledge in social and economic development. The World Bank’s World Development Report 1998/99: Knowledge for Development highlighted the importance of knowledge systems for national development and promoted the construction of National Knowledge Infrastructures (NKI) to support knowledge creation, dissemination, and access (Mujumdar, 1999). Around the same period, Cao (2001) advanced a similar perspective in China, emphasizing the foundational role of knowledge engineering in innovation activities. In practice, the China National Knowledge Infrastructure (CNKI) has become one of the most influential examples of this concept, aiming to facilitate the organization, dissemination, and utilization of knowledge resources on a national scale. More recently, Wu, J. Z.(2025) explicitly characterized libraries as knowledge

infrastructures, arguing that their future development should be oriented toward openness, sharing, and knowledge creation.

To further examine the implications of this concept for library development, it is useful to situate knowledge infrastructure within the broader field of Infrastructure Studies. Edwards et al. (2007) defined knowledge infrastructures as robust networks of people, technologies, institutions, and practices that support the production, sharing, and use of knowledge. They further emphasized that infrastructures are not merely technical systems but socio-technical arrangements that develop over time through interaction between technological components and institutional contexts. Similarly, Star and Ruhleder (1996) argue that infrastructure is relational: it becomes meaningful only when it is embedded in the practices and communities that use it. Their discussion of embeddedness, transparency, reach, scope, and links with established practices provide a useful lens for understanding how library systems support scholarly and educational activities. Bowker and Star (1999) further demonstrated that classification systems, which constitute a core component of library knowledge organization, are shaped by social values and institutional choices rather than functioning as neutral technical mechanisms.

These perspectives offer several insights for understanding the **future library**. First, library infrastructure encompasses not only technological components but also organizational arrangements, governance structures, professional expertise, and user practices. Accordingly, the future library may be understood as a socio-technical network in which AI models, knowledge resources, service processes, physical environments, governance mechanisms, and professional values operate together. Second, the notion of an “installed base” suggests that library transformation is necessarily cumulative. Rather

than replacing existing systems, future libraries build upon established collections, metadata standards, institutional relationships, and professional competencies. Third, as infrastructures often become visible when they are disrupted (Edwards et al., 2007), current debates on AI-driven disintermediation have renewed attention to the roles of libraries within scholarly and knowledge ecosystems.

This perspective is consistent with Mattern's (2014) argument that libraries should be understood as intellectual and civic infrastructures that support the circulation of knowledge and the functioning of public knowledge systems. From this standpoint, the significance of the future library lies not only in the resources it holds, but also in what it enables. Its value depends on its capacity to connect resources, technologies, institutions, and users in support of knowledge access, interpretation, and use. This perspective provides an important conceptual foundation for examining the evolving role of libraries in AI-enabled knowledge environments.

2.3 Conceptual Differentiation and the Proposition of the New Framework

The transition from a knowledge repository to a knowledge infrastructure requires a fundamental conceptual differentiation. While a repository manages outputs (documents, datasets), an infrastructure facilitates the process of knowing. While a smart library optimizes service delivery (search efficiency, space management), an AI-driven knowledge infrastructure focuses on cognitive augmentation and collaborative creation.

Recognizing this critical shift, we propose the "Four Pillars, Five Wings" theoretical framework. To translate the abstract theory of knowledge infrastructure into library practice, the framework first establishes "Four Pillars" as the socio-technical base: AI models, cross-media resources, full-chain services, and integrated spaces. However,

infrastructure alone does not generate value; it requires human-AI mediation to achieve capability leaps. Thus, the framework derives "Five Wings" (Knowledge Discovery, Intelligent Learning, Collaborative Creation, Cultural Activation, and Research Augmentation) to represent the dynamic knowledge outcomes generated when institutional design and professional practice actively engage with the technological pillars.

3 The “Four Pillars, Five Wings” theoretical framework

3.1 Methodology of Framework Development

To ensure methodological transparency, the "Four Pillars, Five Wings" framework was developed through an integrated approach combining literature synthesis, empirical observation, and expert consultation. The process began by reviewing literature across Infrastructure Studies (Edwards et al., 2007; Star & Ruhleder, 1996), the Capability Approach (Sen, 1999), and AI in academic libraries (Cox, 2023) to establish a theoretical premise: a modern library system requires both structural foundations and human-centric capabilities. To ground these concepts in practice, we analyzed the planning and pilot deployment of the Zhejiang University Future Library (2024–2026). Observing real-world workflows and system requirements helped us identify the indispensable technical and spatial prerequisites for AI-driven services, which directly form the "Four Pillars" (Foundational Capacities). To understand how these structural capacities translate into tangible user value, we subsequently consulted with diverse stakeholders, including LIS practitioners, computer scientists, and faculty ambassadors. Their feedback helped us identify five core dimensions where AI meaningfully enhances academic work, which shaped the "Five Wings" (Capability Leaps). By uniting established theories with

frontline library practice and direct user input, this methodology ensures the framework is both conceptually sound and highly applicable to real-world library transformations.

3.2 Evolutionary Context and Conceptual Architecture

To understand the necessity of the "Four Pillars, Five Wings" framework, it is essential to contextualize the library's developmental trajectory. The evolution of library informatization can be broadly understood as a three-stage progression: the digital library, the smart library, and the future library (as summarized in Table 1). The digital library era focused primarily on resource digitization and networked access to expand information availability. Subsequently, the smart library introduced technologies such as the Internet of Things (IoT) and big data analytics to optimize service delivery through automation, contextual awareness, and personalized recommendations.

Currently, advances in generative AI necessitate the transition to the future library stage, where greater attention is given to knowledge processing, semantic understanding, and human-AI collaboration. In this context, library development extends beyond resource management and service automation toward actively supporting knowledge discovery, interpretation, creation, and use. This comparison highlights that the shift to the future library is not merely a technological upgrade, but a fundamental transformation in how libraries mediate the production and organization of knowledge.

Table 1. Comparison of three generations of library development

Dimension	Digital Library	Smart Library	Future Library
Core Logic	Resource digitization	Service intelligence	Knowledge intelligence
Technological	Databases, digital	IoT, big data,	LLMs, RAG, knowledge

Dimension	Digital Library	Smart Library	Future Library
Foundation	collections, web retrieval	mobile internet	graphs, multi-agent systems
Core Resource Form	Digital text and structured data	Digital resources + sensory data	Cross-media, multimodal knowledge resources
Knowledge Organization	Metadata and catalog systems	Automatic tagging and intelligent recommendation	Semantic association and dynamic knowledge graphs
Service Model	Passive retrieval	Personalized recommendation	Proactive cognitive enhancement
User Interaction	Keyword search and web access	Mobile and contextualized services	Conversational AI, multimodal interaction, human-AI collaboration
Spatial Form	Digital reading spaces	Smart learning spaces	Digital-physical integrated creation spaces
Institutional Role	Information resource center	Smart service platform	AI-driven knowledge infrastructure
Value Objective	Improve resource accessibility	Enhance service efficiency and experience	Activate knowledge ecosystems and innovation capacity

This comparison highlights important differences among the three stages. Digital libraries mainly address resource accessibility. Smart libraries emphasized service optimization. Future libraries, by contrast, are characterized by the integration of AI technologies into knowledge-related activities. The transformation from the smart library to the future library should therefore not be viewed only as a technological progress. It also represents a shift in how libraries support the production, organization, and use of knowledge.

While Table 1 outlines the historical evolution and defining characteristics of this paradigm shift, translating these broad concepts into institutional practice requires a robust architectural model. To illustrate how this transition is operationalized, we propose the "Four Pillars, Five Wings" theoretical framework. As shown in Figure 1, the framework employs a hierarchical, bottom-up architecture to demonstrate how infrastructural investments generate expected knowledge outcomes.

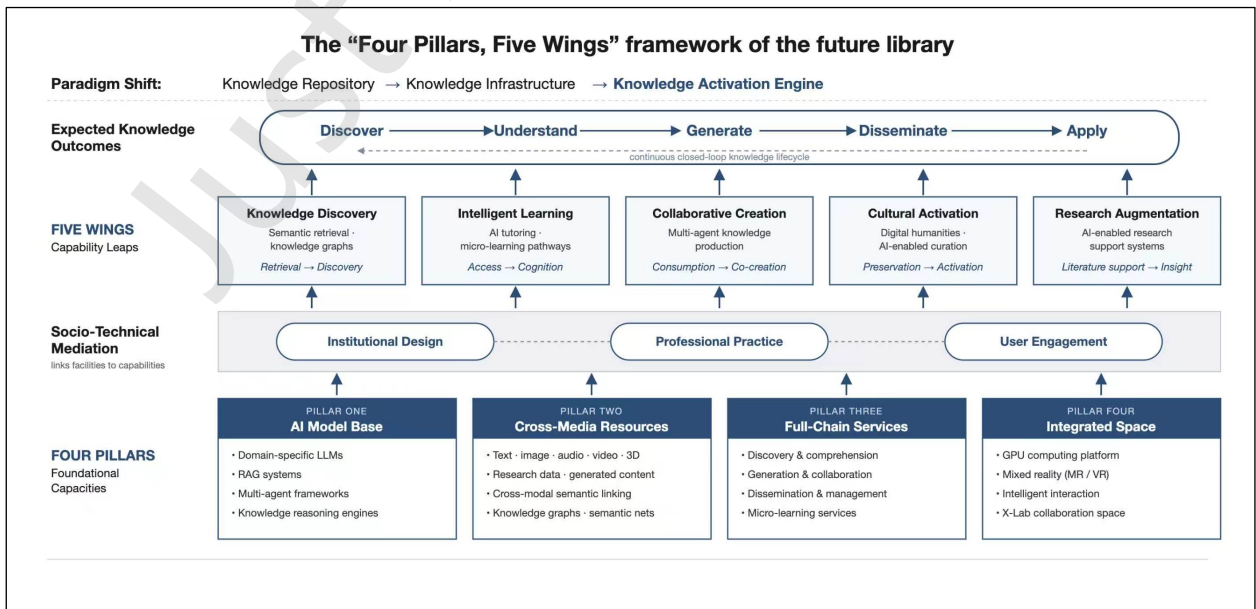


Fig. 1 The “Four Pillars, Five Wings” theoretical framework of the future library

The architecture is structured across four interconnected layers:

- (1) **Foundational Capacities (The Four Pillars):** At the base are the "Four Pillars," representing the essential technological and spatial investments required for AI-driven transformation. These encompass the AI Model Base, Cross-Media Resources, Full-Chain Services, and Integrated Space. However, drawing on infrastructure studies (Star & Ruhleder, 1996), the framework posits that these underlying facilities are merely structural prerequisites; they do not automatically generate higher-order service value in isolation.
- (2) **Socio-Technical Mediation (The Gears):** To transform raw infrastructural facilities into tangible capabilities, the framework introduces "Socio-Technical Mediation" as the critical middle layer. Functioning as a set of dynamic gears, this layer bridges the bottom facilities with the top capabilities. It demonstrates that the four pillars must be actively orchestrated through Institutional Design, Professional Practice, and User Engagement. It is through this continuous socio-technical coordination that the static infrastructure is successfully activated.
- (3) **Capability Leaps (The Five Wings):** Empowered by this mediation, the infrastructure enables distinct "Capability Leaps," conceptualized as the "Five Wings". These represent transformative, user-facing service dimensions: Knowledge Discovery, Intelligent Learning, Collaborative Creation, Cultural Activation, and Research Augmentation. Each wing signifies a qualitative evolution from traditional library functions, shifting from passive resource consumption to dynamic human-AI co-creation.

(4) Expected Outcomes and Paradigm Shift: At the pinnacle of the hierarchy, these capability leaps collectively support a continuous, closed-loop knowledge lifecycle: Discover, Understand, Generate, Disseminate, and Apply. By sustaining this dynamic knowledge flow, the academic library successfully realizes its ultimate paradigm shift. It evolves from a traditional, static "Knowledge Repository" into an enabling "Knowledge Infrastructure," ultimately serving as a powerful "Knowledge Activation Engine" for the contemporary academic community.

3.3 The Four Pillars: Foundational Capacities

As conceptualized in the lowest layer of the framework (Figure 1), the "Four Pillars" constitute the essential infrastructural bedrock of the future library. Rather than operating as isolated technical upgrades, these four pillars must be integrated as a cohesive foundation to support the library's paradigm shift.

3.3.1 Pillar one: AI model base

The AI model base serves as the cognitive engine of the future library. While general-purpose large language models (LLMs) possess robust natural language processing capabilities, their generalized knowledge structures and potential for factual hallucinations often fall short of the rigorous standards required in academic services. Therefore, the future library must construct a domain-oriented AI ecosystem. By integrating specialized models with Graph Retrieval-Augmented Generation (RAG) (Edge et al., 2024) and multi-agent architectures, libraries can ground AI outputs in verifiable knowledge sources. This pillar ensures that algorithmic services uphold core LIS principles: source traceability, citation verification, and explainability.

3.3.2 Pillar two: Cross-media knowledge resources

To fuel the AI model base, the traditional digital collection must evolve into a comprehensive "Cross-Media Knowledge Resource" system. This pillar extends beyond structured texts to encompass images, audio, video, 3D models, research data, and AI-generated content. Consequently, resource organization is shifting from static, metadata-centered cataloging toward dynamic semantic representation. Relying heavily on knowledge graphs and semantic networks, this pillar ensures that distributed resources are computationally processable and highly interoperable, aligning with global efforts such as the International Image Interoperability Framework (IIIF) (Snydman et al., 2015).

3.3.3 Pillar three: Full-chain knowledge services

Unlike traditional libraries that primarily facilitate passive access to information, this third pillar actively embeds the library into the entire academic workflow. Full-chain knowledge services encompass the continuous cycle of discovery, learning, collaborative creation, dissemination, and long-term knowledge management. For instance, emerging micro-learning services can modularize complex educational content into accessible units, while multi-agent systems can facilitate scholarly generation. This structural capacity ensures the library remains relevant across diverse educational and research scenarios.

3.3.4 Pillar four: Digital-physical integrated space

The proliferation of AI does not diminish the value of physical library spaces; rather, it necessitates their reinvention. The fourth pillar visualizes the library space as a socio-technical hub optimized for human-AI interaction, immersive learning, and digital experimentation. By embedding computational infrastructure (such as GPU computing

platforms and mixed reality interfaces) into the physical environment, the library transforms its reading rooms into dynamic, integrated collaborative spaces.

3.4 Five wings: Higher-order capabilities enabling innovative services

While the "Four Pillars" provide the structural prerequisites, infrastructural capacity alone does not automatically generate user value. It is through the critical gears of Socio-Technical Mediation—institutional design, professional practice, and user engagement (Star & Ruhleder, 1996)—that these foundations are activated into higher-order "Capability Leaps," metaphorically termed the "Five Wings." These wings represent the transformative service dimensions where the future library creates tangible academic impact.

3.4.1 Wing one: Knowledge discovery.

Moving beyond conventional keyword-based information retrieval, this capability leap leverages semantic networks and cross-modal association technologies. It empowers users to uncover hidden conceptual relationships, interdisciplinary patterns, and deep semantic connections that were previously obscured in traditional cataloging systems.

3.4.2 Wing two: Intelligent learning.

By harnessing the full-chain service pillar and cross-media resources, the library becomes an active participant in the educational process. This wing manifests through AI-supported tutoring environments, adaptive micro-learning pathways, and personalized cognitive assistance, allowing the library to tailor learning processes to individual user needs rather than merely supplying static materials.

3.4.3 Wing three: Collaborative creation.

Through the integration of multi-agent knowledge production systems and AI-assisted authoring tools, this capability transforms the user's role from a passive consumer to an active co-creator. The library facilitates a collaborative ecosystem where human intellect and machine intelligence jointly produce, refine, and publish new academic content.

3.4.4 Wing four: Cultural activation.

Rather than limiting cultural heritage to preservation and display, this wing actively revives it. Utilizing computational cultural analysis, immersive exhibitions, and digital humanities applications, the library transforms static historical archives into dynamic resources for modern interpretation, public engagement, and innovative reuse.

3.4.5 Wing five: Research augmentation.

Representing the pinnacle of academic support, AI-enabled research systems move beyond mere literature delivery. This capability leap assists scholars in identifying emerging topics, generating alternative hypotheses, and mapping cross-disciplinary frontiers. Crucially, this wing is designed to augment and stimulate human scholarly judgment, not replace it.

Ultimately, the emergence of these "Five Wings" is not a deterministic technological outcome. They are the direct result of socio-technical orchestration. By successfully translating the Four Pillars into these Five Wings, the academic library effectively drives the knowledge closed loop—Discover, Understand, Generate, Disseminate, and Apply—cementing its newly reframed position as a proactive knowledge infrastructure in the AI era.

4 Zhejiang University Future Library: An empirical case study

The Zhejiang University Future Library initiative was launched in May 2024 (Zhejiang University Library, 2024), followed by the release of Future Library 1.0 in April 2026 after a period of planning, development, and iterative refinement (Zhejiang University Library, 2026). As an institutional initiative associated with the university's broader digital transformation agenda, it provides a useful case for examining the conceptual framework proposed in this study. This section uses the initiative as an empirical case to explore its development process, operational arrangements, and emerging implementation practices.

4.1 Research design and data sources

This study adopts an exploratory single-case design (Yin, 2018) to examine how the Future Library concept is implemented within a specific institutional context. The Zhejiang University Future Library initiative was selected for two reasons. First, it represents a relatively early and comprehensive effort in Chinese higher education to develop an AI-enabled knowledge infrastructure in an academic library setting. Second, the authors' involvement in the initiative provided access to planning documents, governance materials, and operational records that would not otherwise be publicly

available, allowing for a more detailed examination of implementation processes and organizational practices.

The case analysis draws on multiple sources of evidence, including institutional planning documents and strategic reports (2024–2026), governance meeting records, platform usage statistics, project progress reports, and participant observations conducted by the authors as members of the technical and planning teams. The analysis is primarily qualitative, focusing on understanding implementation processes, identifying emerging patterns, and examining challenges encountered during the course of development rather than testing predetermined hypotheses.

Several limitations should be acknowledged. As the authors have participated in the initiative while simultaneously studying it, interpretive bias cannot be entirely excluded. To address this concern, the analysis reports both achievements and challenges. It also distinguishes between empirically observed outcomes and developmental objectives. In addition, the initiative remains at an early stage of implementation, and some components continue to evolve. Consequently, the findings should be regarded as preliminary and exploratory. Further research based on longer-term observation, independent evaluation, and comparative case analysis is needed to assess the broader applicability of the patterns identified in this study.

4.2 Strategic objectives and overall architecture

The “Four Pillars, Five Wings” framework provides a conceptual lens for understanding how future libraries may be developed as knowledge infrastructures. The Zhejiang University Future Library initiative offers an opportunity to examine how such ideas are translated into institutional practice. Its early conceptual design and overall framework

have been discussed in detail by [Jin et al. \(2025\)](#). Building on this foundation, the present analysis examines the relationship between the proposed theoretical framework and its practical implementation.

The initiative was developed around three broad objectives: the creation of a future learning center of more than 2,000 square meters as a digitally integrated learning environment; the establishment of local AI computing infrastructure, including GPU-based inference and testing platforms; and the development of large-scale digital learning resources, including digital courses and multimedia collections. Together, these objectives reflect an effort to combine technological infrastructure, knowledge resources, and learning services within a unified development framework.

Within the university's broader digital transformation strategy, the Future Library is positioned as a supporting component of a lifelong learning ecosystem. One example is the "Zheda Xiansheng" (Mr. ZJU) AI assistant, which was integrated into the university's DingTalk platform in October 2024. Institutional records indicate substantial user adoption during the early deployment period, and the system has subsequently attracted attention from other higher education institutions. At the same time, indicators such as long-term engagement, patterns of use, user satisfaction, and educational impact have not yet been systematically evaluated. Consequently, the effectiveness and scalability of the platform remain topics for further empirical investigation.

From an architectural perspective, Future Library 1.0 is organized around four interacting components: AI models, knowledge resources, service scenarios, and physical-digital spaces. This configuration reflects an approach in which the library is integrated more closely with the university's broader digital infrastructure. Within this

arrangement, the library extends its traditional role in resource provision by supporting knowledge organization, AI-enabled learning services, and emerging forms of digital innovation and cultural engagement. Rather than representing a complete transformation, these developments may be understood as an ongoing process through which the library explores new institutional functions in an AI-enabled environment.

4.3 AI digital infrastructure

The implementation of the Future Library is supported by the development of AI-related digital infrastructure. At Zhejiang University, this infrastructure includes GPU-based computing resources, a localized model development and testing environment, a multimodal knowledge repository, and Retrieval-Augmented Generation (RAG) **systems designed for library applications. The computing** platform supports a range of functions, including model inference, digital course production, multimodal resource processing, cultural heritage digitization, and AI-enabled user services. These capabilities provide the technical foundation for integrating AI into library operations and knowledge services. Compared with fully cloud-based AI solutions, the initiative places greater emphasis on localized deployment and institutional governance. This approach is intended to address concerns related to data management, system control, and the adaptation of AI technologies to domain-specific library contexts.

At the application level, the initiative is exploring AI agent-based service architectures that can support multiple tasks and service scenarios. To this end, the Future Library has established collaborations with external LLM providers, including Tongyi Qianwen (Qwen) and Panshi (Bedrock). It has also incorporated supporting components such as the Model Context Protocol (MCP) Center and a Skills Marketplace. At the same

time, reliance on externally developed foundation models presents a number of strategic considerations. These include technological autonomy, long-term sustainability, and potential vendor dependence.

Balancing the advantages of external AI ecosystems with the need for institutional control remains an ongoing issue in implementation. Initial operational data from the development and pilot environment (as of July 2026) provide exploratory evidence of this infrastructure's deployment. The platform has successfully exposed five active AI agents and 42 enabled skills, including 34 scenario-based and 8 tool-based applications. Within the pilot cohort of 330 active accounts, the infrastructure processed 1,451 AI interaction sessions, generating 3,552 complete question-and-answer turns. These preliminary figures operationalize Pillar One (AI Model Base) and Pillar Three (Full-Chain Services) of the proposed framework. These preliminary data suggest that the library's AI infrastructure is not merely a passive repository of computational power, but an active socio-technical network. By mediating thousands of structured scholarly queries through specific algorithmic skills, these foundational capacities are beginning to be translated into tangible service interactions.

4.4 Future learning center

An important aspect of the Future Library initiative concerns the reconfiguration of library space and its relationship to learning activities. Zhejiang University is planning a Future Learning Center of more than 2,000 square meters, conceived not simply as an expansion of learning facilities but as an environment that integrates AI technologies, digital resources, and collaborative learning practices. The project reflects broader efforts

to explore how library spaces may support emerging forms of human–AI interaction, knowledge creation, and lifelong learning.

One component of this initiative is the proposed Micro-learning Center, which seeks to address tensions between fragmented patterns of digital learning and the need for sustained and systematic knowledge acquisition. Its underlying approach uses AI technologies to identify key concepts within extended learning materials. It then generates condensed learning units and supports flexible movement between summary-level and detailed content. From a service perspective, this model represents an attempt to develop new forms of learning support within the library environment. At the same time, the educational effectiveness of AI-generated learning units remains insufficiently understood. In particular, questions remain regarding whether algorithmically condensed content can adequately support the depth, contextual understanding, and exploratory learning processes that are often associated with higher education. Continued evaluation, ideally involving collaboration with educational researchers, will be important for assessing these issues.

The initiative also reflects broader changes in the spatial organization of library services. Zhejiang University is exploring the introduction of small-scale GPU computing infrastructure, including devices such as NVIDIA DGX Spark. It is also developing dedicated spaces for AI experimentation and digital research, including the proposed X-Lab Research Collaboration Space. These developments indicate a shift toward spaces that support computational scholarship and human–AI collaboration. However, experiences from comparable initiatives suggest that the provision of advanced technologies does not automatically lead to meaningful use. The effectiveness of such

spaces depends not only on technological infrastructure but also on user communities, faculty participation, training opportunities, and integration with teaching and research activities.

These considerations highlight the socio-technical character of future library spaces and reinforce the importance of organizational and educational dimensions alongside technological development. To bridge this digital-physical divide, the Future Library Learning Center has launched an initial matrix of seven AI-enhanced courses, totaling approximately 120 minutes of instructional content. Covering five distinct disciplinary categories—including management, archaeology, literature, philosophy, and computer science—these courses are systematically linked with 79 library collection resources. This arrangement allows users to transition seamlessly from micro-learning modules to deep reading. Such evidence provides preliminary support for Wing Two (Intelligent Learning) and Pillar Four (Integrated Space). Rather than simply providing physical seating or static video playback, the library acts as an intelligent mediator. By integrating multidisciplinary curricula with specific knowledge resources, the learning center illustrates the access-to-cognition capability leap and the framework's objective of curating adaptive and personalized educational pathways.

4.5 Multi-agent knowledge production system

The increasing application of generative AI has expanded the potential role of libraries in knowledge production and educational content development. As part of the Future Library initiative, Zhejiang University is exploring a digital course production system based on a multi-agent architecture. The proposed workflow consists of five functional components: (1) a Course Planning Agent responsible for instructional design and course

structuring; (2) a Content Generation Agent that produces draft content and formative assessments with support from Retrieval-Augmented Generation (RAG) mechanisms; (3) a Multimedia Integration Agent that assists in identifying opportunities for visual and interactive enhancement; (4) a Quality Assurance Agent that performs validation and consistency checks; and (5) a Formatting and Publishing Agent that supports processes such as document formatting, metadata generation, and version management. The design of this system draws on the multi-agent standard operating procedure (SOP) paradigm and adapts it to educational content production scenarios (Qian et al., 2024). From the perspective of the “Four Pillars, Five Wings” framework, the system illustrates how AI infrastructure and knowledge resources can be combined to support emerging forms of collaborative knowledge creation.

At the current stage of development, several challenges remain. First, although the quality assurance process incorporates source verification and cross-referencing with authoritative resources, the reliability of AI-generated content remains uneven. Internal testing indicates that substantial human review is still required for some generated materials, particularly in domains involving complex interpretation, disciplinary nuance, or limited availability of authoritative reference sources. Second, system performance varies across disciplinary contexts. Structured domains with relatively standardized knowledge representations appear more amenable to AI-assisted content generation than fields characterized by interpretive, contextual, or contested forms of knowledge. Third, legal and ethical questions concerning intellectual property, authorship, and copyright in AI-generated educational materials remain unresolved in many jurisdictions and continue to present challenges for large-scale implementation.

These observations suggest that AI in educational content production is currently best understood as augmentative rather than fully autonomous. While multi-agent systems may improve efficiency and support new forms of knowledge production, their effectiveness continues to depend on human expertise, institutional governance, and disciplinary oversight.

Exploratory data from the pilot system highlights the practical viability of this AI-assisted knowledge production. The system currently hosts 5,946 active file records, with 5,551 files successfully processed by the AI parsing pipeline, achieving a 93.36% processing success rate. Empowered by these parsed resources, users have generated 270 discrete knowledge outputs, including 70 conceptual mind maps, 31 structured reports, and 20 presentation decks. Furthermore, the platform supports an initial pilot of 18 collaborative teams, demonstrating workflows where team knowledge files are shared only after AI-assisted pre-review. These metrics provide preliminary support for Wing Three (Collaborative Creation). The substantial volume of user-uploaded files, combined with the generation of structured scholarly outputs, suggests that the AI-enabled library can shift user engagement from the passive consumption of literature to the proactive co-creation of knowledge.

4.6 Digital humanities and cultural activation

Digital humanities and cultural heritage digitization constitute an important area of exploration within the Future Library initiative. The increasing application of AI technologies has created new possibilities for moving beyond the preservation and digitization of cultural resources toward broader forms of analysis, interpretation, and

public engagement. Within this context, Zhejiang University has undertaken a range of projects involving stele rubbings, historical texts, and traditional painting collections.

One representative example is the university's stele rubbing collection, which comprises approximately 16,000 items. The digitization workflow integrates multiple AI-based techniques, including ensemble OCR approaches, variant character recognition, historical entity extraction, spatiotemporal relationship analysis, knowledge graph construction, and visualization services. Similar efforts have been reported internationally in the field of historical Chinese text processing (Sturgeon, 2018), and experience from this project likewise suggests that domain-specific models can provide substantial improvements over general-purpose OCR systems when applied to historical documents. Nevertheless, significant challenges remain. Recognition accuracy for weathered or heavily damaged materials is often insufficient for fully automated processing.

Expert review, therefore, continues to play an important role in quality assurance. To further expand its digital humanities portfolio, the library is constructing a comprehensive Taoist academic resource database. Moving beyond simple digitization, this project involves high-resolution imaging and OCR processing of classical texts such as the Zhengtong Daozang, intentionally preserving original visual elements like talismans and cloud scripts. The initiative integrates tens of thousands of firsthand field materials—including stele rubbings and local historical records—and audiovisual archives through partnerships with music conservatories and religious associations. Embedded within the Zhejiang University Digital Humanities Platform, this resource ensures governed access for specialized researchers. The development of this database provides an empirical illustration of Wing Four (Cultural Activation) and Pillar Two

(Cross-Media Resources). By integrating texts, images, and audio-visual materials into a searchable, access-controlled academic platform, the library transcends traditional preservation. It suggests that cultural heritage, when subjected to socio-technical mediation through institutional partnerships and advanced parsing technologies, is actively transformed into a dynamic digital asset for contemporary scholarly inquiry.

4.7 Preliminary Operational Evidence

Although the Zhejiang University Future Library remains in a development and pilot stage, preliminary system records provide an initial indication of implementation scale and technical use. As of 11 July 2026, the development and pilot database contained 330 active accounts. Using a conservative definition that required both a user-visible question and a non-empty answer, 3,552 complete question-answer turns were recorded. Between 2 and 11 July 2026, skill instrumentation recorded 911 events, comprising 564 chat executions and 347 clicks by 39 users. In addition, two expert suites containing 15 packaged skills had recorded eight successful executions.

Table 2. Preliminary operational indicators (as of 11 July 2026)

Indicator	Current status	Definition / Scope
Active accounts	330	Valid, non-deleted accounts
AI interaction sessions	1,451	Covering 195 user identifiers
Complete Q&A turns	3,552	Both visible question and answer present

Indicator	Current status	Definition / Scope
Active agents / enabled skills	5 / 42	34 scenario skills and 8 tool skills
Active file records	5,946	5,941 original uploads
Successfully parsed files	5,551	93.36% of active file records
Knowledge-output records	270	250 downloadable, including 70 mind maps, 31 reports, 20 PPTs
Personal-team pilot	18 teams	20 memberships; 16 distinct members; 3 AI-approved files

Note: Data derived from the development and pilot environment. These figures are exploratory operational indicators and include testing and validation records. They are reported to demonstrate implementation progress rather than to establish institution-wide adoption or long-term educational outcomes.

4.8 Governance mechanisms and ecosystem development

The development of the Future Library involves not only technological infrastructure but also organizational coordination and institutional adaptation. Early implementation experiences suggest that while technological resources provide important enabling conditions, their effective utilization depends on governance arrangements, leadership support, and collaboration across organizational boundaries.

At the strategic level, the Future Library Academic Committee serves as an advisory and coordination body. It is responsible for guiding planning priorities and development directions. Its cross-sector composition is intended to incorporate perspectives from different institutional stakeholders and facilitate communication across organizational units. At the operational level, implementation activities are coordinated through a cross-

functional team that employs regular stand-up meetings inspired by agile development practices. This mechanism supports information sharing and iterative problem-solving across multiple stakeholders. At the same time, maintaining frequent coordination requires sustained participation and may generate additional organizational costs, highlighting the trade-offs involved in collaborative governance arrangements.

At the ecosystem level, the initiative is exploring a platform-oriented development model that seeks to connect faculty communities, technology partners, library networks, and broader knowledge-sharing activities. This approach reflects an understanding of the library not as an isolated service unit but as a node within a larger knowledge ecosystem. The initiative also employs a diversified funding structure combining institutional support, externally funded research projects, and strategic partnerships in an effort to enhance long-term sustainability and reduce dependence on any single funding source.

An additional governance mechanism is the Faculty Ambassador Program, through which faculty members from different disciplinary backgrounds participate in the development and evaluation of emerging services. These participants serve both as early adopters and as sources of critical feedback. They help bridge the gap between technological development and academic practice. However, maintaining faculty engagement beyond the initial stages of innovation remains a challenge. Experience to date suggests that long-term participation depends not only on individual enthusiasm but also on the establishment of appropriate incentive structures, institutional recognition, and sustained alignment with teaching and research needs.

From the perspective of socio-technical systems theory, these governance arrangements can be viewed as an essential complement to technological infrastructure.

The effectiveness of the Future Library depends not only on the availability of AI technologies and digital resources but also on the institutional mechanisms through which diverse actors coordinate, negotiate, and collectively shape the evolution of the knowledge infrastructure.

4.9 Implementation roadmap

To guide the long-term development of the Future Library initiative, Zhejiang University has formulated a phased implementation roadmap covering the period from 2026 to 2030. The roadmap reflects a gradual and iterative approach in which technological infrastructure, organizational arrangements, and service innovation are expected to evolve in parallel.

(1) Phase 1: Infrastructure development (2026–2027).

The first phase focuses on establishing the technical and organizational foundations of the initiative. Planned activities include the deployment of GPU-based computing infrastructure, the development of large-scale storage environments for cross-media resources, and the completion of the architectural design of the Future Learning Center. In parallel, governance mechanisms, operational procedures, and technical management frameworks are expected to be refined through coordination with relevant university-level committees and administrative units.

(2) Phase 2: Domain integration and model development (2027–2029).

The second phase emphasizes the integration of data resources, AI models, and institutional systems. Planned efforts include domain-specific model adaptation based on distinctive university collections and disciplinary resources, as well as the development of secure data exchange mechanisms connecting library services with learning platforms,

research information systems, and institutional authentication services. This phase is intended to strengthen the alignment between AI capabilities and disciplinary knowledge contexts while improving interoperability across institutional platforms.

(3) Phase 3: System integration and service expansion (2029–2030).

The third phase aims to extend intelligent knowledge services across a broader range of university activities. Proposed developments include integrating multi-agent content production tools into educational workflows. They also include establishing monitoring and evaluation mechanisms to support continuous service improvement. The collection of anonymized operational data is expected to provide evidence for assessing use patterns, identifying areas for optimization, and informing subsequent system iterations.

It should be emphasized that this roadmap represents a planning framework rather than a predetermined outcome. As with many large-scale digital transformation initiatives, implementation is likely to be influenced by technological developments, resource availability, institutional priorities, and user adoption patterns. The roadmap should therefore be understood as a flexible developmental trajectory that may be adjusted in response to emerging opportunities and challenges. From the perspective of knowledge infrastructure development, the phased approach recognizes that technological capacity, organizational governance, and service innovation must co-evolve over time. The roadmap therefore, illustrates not only a sequence of technical milestones but also a process through which socio-technical infrastructures are progressively assembled, tested, and institutionalized.

5 Discussion

5.1 Future Libraries as Knowledge Infrastructures

The Zhejiang University case illustrates both the opportunities and the challenges associated with the development of libraries as AI-enabled knowledge infrastructures. While the initiative remains at an early stage, several broader implications emerge from the analysis that may be relevant to libraries, funding bodies, and policymakers seeking to explore similar transformations.

5.2 Infrastructure investment as a prerequisite for AI-enabled services

The case highlights the substantial computational and data infrastructure required for AI-enabled library services. Zhejiang University has benefited from significant institutional investment, but such levels of support are unlikely to be available to all libraries. This raises important questions regarding how smaller institutions can participate in AI-driven transformation. One possible approach is to develop shared infrastructure models through library consortia or regional collaborations, allowing institutions to distribute costs and access resources collectively. For instance, the rapid accumulation of 5,551 active file records during the initial pilot phase at Zhejiang University underscores the necessity of robust local computing and storage infrastructures. Such substantial infrastructural investment is critical not merely for processing power, but for maintaining institutional sovereignty and data governance over scholarly assets.

5.3 Evolving competency requirements for library professionals

The implementation of AI technologies requires competencies beyond traditional library skill sets. In addition to expertise in information organization, reference services, and collection management, future library professionals may require greater familiarity with

data governance, AI applications, digital scholarship, and interdisciplinary collaboration. This observation is consistent with the IFLA Trend Report (2024), which emphasizes the need to strengthen digital and AI-related capabilities across the global library workforce.

5.4 The importance of standards and interoperability

The case demonstrates the growing importance of interoperable knowledge infrastructures capable of integrating heterogeneous resources, systems, and services. Two issues appear particularly significant: the development of standards for multimodal knowledge representation and the establishment of evaluation frameworks for Retrieval-Augmented Generation (RAG) systems in library contexts. Greater participation by libraries in standards development may help ensure that emerging infrastructures reflect professional values relating to openness, transparency, and trustworthiness.

5.5 Governance and collaboration in complex socio-technical systems

The complexity of AI-enabled library systems extends beyond the capacity of most individual institutions. The Zhejiang University experience suggests that effective implementation depends on coordination among technical teams, academic communities, institutional leadership, and external partners. Collaborative governance arrangements may therefore help distribute expertise and reduce duplication of effort. They may also support the broader diffusion of innovation across the library sector. International organizations and professional associations can further contribute by facilitating knowledge exchange and cross-institutional cooperation.

5.6 The need for continuous evaluation

The case shows that many anticipated benefits of AI-enabled services remain provisional and require empirical validation. Questions concerning learning outcomes,

user engagement, service quality, cultural impact, and organizational sustainability cannot be resolved through technological deployment alone. For example, while the pilot system demonstrated a high technical parsing success rate (93.36%) for AI file processing, this infrastructural efficiency must now be rigorously evaluated against actual pedagogical effectiveness and student learning outcomes. Systematic assessment should therefore be integrated into the design and operation of future library initiatives. Equally important is the transparent reporting of both successes and limitations, enabling cumulative learning across institutions and contributing to a more evidence-based understanding of library transformation.

Taken together, these observations suggest that the future library development involves not only technological innovation but also sustained investment in organizational capacity, professional expertise, governance mechanisms, and evaluation practices. The transition from vision to implementation is therefore best understood as a long-term socio-technical process rather than a purely technological undertaking.

6 Conclusions

6.1 Summary of findings

The emergence of artificial intelligence is reshaping the ways in which knowledge is created, organized, and accessed, prompting a reconsideration of the role of libraries in knowledge societies. From the perspective of Infrastructure Studies and socio-technical systems theory, the future library can be understood as an evolving form of knowledge infrastructure rather than a repository of information resources. The “Four Pillars, Five Wings” framework developed in this study provides a conceptual representation of this transition. The Zhejiang University Future Library initiative further illustrates how AI technologies, knowledge resources, service systems, and learning spaces may be integrated within a **shared infrastructural framework**. By disseminating the Zhejiang University experience through international exchange, this study offers a tested, socio-technical reference for the global LIS community as it navigates the complexities of AI integration.

6.2 Limitations and future research

The exploratory nature of this study inevitably imposes certain limitations. The proposed framework has yet to be examined across a wider range of institutional settings, and findings derived from a single case cannot fully capture the diversity of library contexts. Future research may benefit from comparative and longitudinal approaches that explore how knowledge infrastructures are developed, adapted, and sustained under different organizational, technological, and cultural conditions.

Declarations

Data availability statement

This study is based on an ongoing institutional initiative and represents an early-stage empirical investigation. The findings draw upon institutional planning documents, governance records, platform usage statistics, project reports, and participant observations by the authors. As the initiative continues to evolve, additional empirical data are being accumulated and may support future analyses.

Competing interests

The authors declare that they have no competing interests.

Funding

This research was supported by the National Science and Technology Major Project "Artificial Intelligence for Mineral Resource Prediction and Evaluation Software Platform Integration" (Grant No. 2025ZD1008103) and the General Research Project of the Department of Education of Zhejiang Province "Research on AI-empowered Embedded Service Paths in University Libraries" (Grant No. Y202557854). The funders had no role in the study design, data collection, analysis, interpretation, or manuscript writing.

Author contributions:

Zihui Zhang: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

Fei Xue: Conceptualization (Theoretical framework development), Methodology, Investigation (Literature review, Case analysis), Writing – original draft, Writing – review & editing.

Qinfeng Chen: Resources, Project administration, Funding acquisition, Visualization.

Ping Lu: Resources, Validation, Project administration (Museum collaboration).

Acknowledgments: The authors would like to thank colleagues at Zhejiang University Library, the National Library of China Research Institute, Shanghai Library, and collaborating institutions for valuable discussions and professional exchanges. The authors are also grateful to members of the Future Library implementation team for sharing insights into the planning, governance, and operational development of the initiative.

AI Use Statement: During the preparation of this work, the authors used Qwen & Qoder for language polishing and manuscript editing. After using this tool, the authors reviewed and revised the content and take full responsibility for the final manuscript.

References

- Borgman, C. L. 2015. *Big Data, Little Data, No Data: Scholarship in the Networked World*. Cambridge, MA: MIT Press.
- Bowker, G. C.; Star, S. L. 1999. *Sorting Things Out: Classification and Its Consequences*. Cambridge, MA: MIT Press.
- Buckland, M. K. 1991. Information as thing. *Journal of the American Society for Information Science* Vol. 42, No. 5, 351–360.
- Cao, C. G. 2001. The significance of national knowledge infrastructure. *Bulletin of Chinese Academy of Sciences* Vol. 16, No. 4, 255–259.
- Cox, A. M. 2023. How artificial intelligence might change academic library work: Applying the competencies literature and the theory of the professions. *Journal of the Association for Information Science and Technology* Vol. 74, No. 3, 367-380.

Edge, D.; Trinh, H.; Cheng, N.; et al. 2024. From local to global: A Graph RAG approach to query-focused summarization. *arXiv Preprint* arXiv:2404.16130.

Edwards, P. N.; Jackson, S. J.; Bowker, G. C.; Knobel, C. P. 2007. *Understanding Infrastructure: Dynamics, Tensions, and Design*. Ann Arbor, MI: University of Michigan.

Floridi, L.; Cowls, J.; Beltrametti, M.; et al. 2018. AI4People—An ethical framework for a good AI society: Opportunities, risks, principles, and recommendations. *Minds and Machines* Vol. 28, No. 4, 689-707.

IFLA. 2024. *IFLA Trend Report 2024: Facing the Future of Information with Confidence*. The Hague: International Federation of Library Associations and Institutions.

Jin, J. L.; Pan, J.; Zhang, Z. H.; Huang, C. 2025. AI-driven paradigm shift and innovation pathways for the future library. *Journal of Library Science in China* Vol. 51, No. 5, 67–78.

Karasti, H.; Millerand, F.; Hine, C. M.; Bowker, G. C. 2016. Knowledge infrastructures: Part I. *Science & Technology Studies* Vol. 29, No. 1, 2-12.

Liu, W.; Jin, J. Q.; Zhang, N.; Wang, L. H. 2026. From classification and subjects to semantic spaces: Transformation and development of library knowledge organization systems driven by artificial intelligence. *Journal of Library Science in China*. Advance online publication. Available at:

<https://link.cnki.net/urlid/11.2746.g2.20260409.1750.002>.

Mattern, S. 2014. Library as infrastructure. *Places Journal*. DOI:10.22269/140609.

McLuhan, M. 1964. *Understanding Media: The Extensions of Man*. New York: McGraw-Hill.

Mooers, C. N. 1951. *Making Information Retrieval Pay*. Cambridge, MA: Zator Company.

Mujumdar, N. A. 1999. World Development Report 1998–99: Knowledge for development. *Indian Journal of Agricultural Economics* Vol. 54, No. 4, 592.

Qian, C.; Liu, W.; Liu, H.; et al. 2024. ChatDev: Communicative agents for software development. In: *Proceedings of the 62nd Annual Meeting of the Association for Computational Linguistics* Vol. 1, 15174–15186.

Padilla, T.; Allen, L.; Frost, H.; et al. 2019. *Always Already Computational: Collections as Data. Final Report*. Available at: <https://osf.io/zqhnn/> (accessed 2026-07-25).

Ranganathan, S. R. 1988. *Five Laws of Library Science*. Translated by Yuan Pei. Beijing: Shumu Wenxian Press. (Original work published 1931).

Sen, A. 1999. *Development as Freedom*. Oxford: Oxford University Press.

Snydman, S.; Sanderson, R.; Cramer, T. 2015. The International Image Interoperability Framework (IIIF): A community and technology approach for web-based images. In: *Archiving Conference* Vol. 12, 16–21.

Star, S. L.; Ruhleder, K. 1996. Steps toward an ecology of infrastructure: Design and access for large information spaces. *Information Systems Research* Vol. 7, No. 1, 111–134.

Sturgeon, D. 2018. Large-scale optical character recognition of pre-modern Chinese texts. *International Journal of Buddhist Thought and Culture* Vol. 28, No. 2, 11–44.

Wang, X. W.; Wu, J. S. G. L.; Liu, Y. T.; et al. 2023. AI human-computer interaction for intelligent recommendation: Research hotspots and future opportunities. *Journal of the China Society for Scientific and Technical Information* Vol. 42, No. 4, 495–509.

Wu, J. Z. 2022. From space reengineering to business model reshaping: Creating a new generation shared knowledge repository driven by digital transformation. *Journal of Library Science in China* Vol. 48, No. 4, 15–19.

Wu, J. Z. 2025. *New Perspectives on Libraries in the 21st Century*. 4th ed. Shanghai: Shanghai Scientific and Technological Literature Press.

Wu, Y. 2022. Accelerating the modernization of academic library construction to support high-quality development of higher education. *Journal of Academic Libraries* Vol. 40, No. 1, 7–8.

Yin, R. K. 2018. *Case Study Research and Applications: Design and Methods*. 6th ed. Thousand Oaks, CA: SAGE.

Zeng, Y. Z. 2007. Theoretical exploration of the attributes and functions of institutional repositories. *Modern Information* Vol. 27, No. 10, 16–18, 21.

Zhao, J. R.; Chen, F.; Zhang, Y. J.; et al. 2026. Reflections and practices on spatial reconstruction of future learning centers in academic libraries: A case study of the Data Reading Hall at Peking University Library. *Journal of Academic Libraries* Vol. 44, No. 1, 120–128.

Zhejiang University Library. 2024. Zhejiang University Future Library unveiling ceremony held. Available at:
<http://www.news.zju.edu.cn/2024/0529/c23434a2924809/pagem.htm> (accessed 2026-04-20).

Zhejiang University Library. 2026. Digital-intelligence empowered new ecosystem of knowledge services: Zhejiang University Future Library 1.0 officially released. Available at: <https://libweb.zju.edu.cn/2026/0417/c39582a3153000/page.htm> (accessed 2026-04-20).

Author Biographies



Zihui Zhang is the Deputy Director of Zhejiang University Library. He joined Zhejiang University in 2018 as Chief Information Officer and led the development of Online ZJU, a next-generation smart campus platform. He was responsible for the top-level design of major digital platforms supporting teaching and research, including ZJU DingTalk, ZJU Cloud Computing, Study at ZJU, Zhiyun Classroom, and ZJU Scholar. His current work focuses on future library development and digital transformation in higher education.



Fei Xue received her M.S. in Library and Information Science from the University of Illinois at Urbana-Champaign (UIUC). She worked in the United States for three years before joining Zhejiang University Library in 2013. She also serves professional organizations including IFLA, CALA, and ZPSLS. Her research focuses on smart library services, generative AI applications, strategic intelligence analysis, and decision-support systems.



Qinfeng Chen is a librarian at Zhejiang University Library. She oversees information technology development and data services, including library systems, digital services, and IT infrastructure planning. Her work focuses on the strategic development of digital libraries and technology-enabled library services.



Ping Lu is Deputy Director of the Zhejiang University Museum of Art and Archaeology, where she oversees public education, visitor services, and smart museum initiatives. She previously served as Deputy Director of Zhejiang University Library,

responsible for Library Access Department. Her research interests include museum & library services, and educational space innovation.

Graphical abstract

