Research on the Essential Characteristics and Cognitive Model of Smart Libraries: Postprint

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Abstract

Purpose/Significance The conceptual definition and connotation deconstruction of smart libraries constitute the foundation for theoretical research and practical exploration in smart library studies. Method/Process This study employs content analysis to investigate representative concepts from domestic and international smart library research, extracting word frequency from these concepts to identify terms that represent key characteristics of smart libraries. Combined with an analysis of smart construction concepts such as smart cities, smart campuses, and smart museums, the common characteristics of smart construction concepts are identified. Subsequently, based on the above analytical results, the connotation characteristics and cognitive model of smart libraries are abstracted and defined. Results/Conclusion Starting from the essence of smart libraries, this paper scientifically defines their concept and proposes a PTP cognitive model for smart library system architecture, clarifying the objectives and pathways for smart library construction, thereby laying a theoretical foundation for further research and development of smart libraries.

Full Text

Preamble

Research on the Connotation, Characteristics, and Cognitive Model of Smart Libraries

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Abstract: [Purpose/Significance] The definition and deconstruction of the smart library concept constitute the foundation for theoretical research and practical exploration of smart libraries. [Method/Process] Using content analysis, this study examined representative concepts in domestic and international smart library research, extracted word frequencies from these concepts to identify key characteristics, and analyzed related smart construction concepts including smart cities, smart campuses, and smart museums to identify common features. Based on these analyses, the connotation, characteristics, and cognitive model of smart libraries were abstracted and defined. [Result/Conclusion] Starting from the essence of smart libraries, this study scientifically defined the concept and proposed a PTP cognitive model for smart library architecture, clarifying the goals and pathways for smart library construction and laying a theoretical foundation for further research and development.

Keywords: smart library; content analysis; concept; cognitive model
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With the continuous advancement of information technology, evolving societal development needs, and escalating user information demands, libraries have undergone transformative development from physical paper-based libraries to digital and mobile libraries, and further to intelligent and smart libraries. Smart libraries have become the new form of library development in the current environment, attracting widespread attention from both academia and practice [1]. However, there is currently no clear answer to the question of what constitutes a smart library, the relevant theoretical system remains incomplete, and research on smart libraries is still in a state of vibrant debate and diverse perspectives [2]. Based on this context, this paper analyzes fundamental theoretical issues such as the connotation, characteristics, and cognitive model of smart libraries, aiming to provide theoretical support for future research and practice.

2. Content Analysis of Smart Library and Related Concepts

2.1 Smart Library Concept Analysis

2.1.1 Content Analysis Method and Its Application Content analysis is a research method that provides objective, systematic, and quantitative description of relevant content [3]. Its essence lies in analyzing the information content and its changes across multiple research materials to make valid inferences based on the data [4]. This method can be used to extract essential facts and trends from research content, helping to overcome the subjectivity and uncertainty of qualitative research and enabling clearer understanding of different

thematic samples. As a method that converts qualitative materials into quantitative data, content analysis has numerous potential applications, including identifying the essence of research topics and constructing relevant standards and theoretical frameworks [5].

In this study, smart libraries have received widespread attention from domain researchers, resulting in numerous concepts without unified consensus. The applicability and conditions for content analysis are fully met in this research. Conducting "quantitative" analysis of existing typical smart library concepts to identify key content that reflects the essential characteristics of smart libraries can provide a basis for standardizing smart library concepts and constructing evaluation indicators. Moreover, no previous research has applied content analysis to the conceptual definition of smart libraries. Therefore, applying content analysis to define smart library concepts is both appropriate and innovative.

2.1.2 Data Collection and Organization To ensure scientific rigor and authority, this study followed principles of distinctiveness (selecting the earliest or most comprehensive concept when concepts were similar or repetitive), authority and representativeness (primarily selecting samples from core domestic journals with high download and citation rates), and timeliness (including samples from recent years) to extract 54 representative smart library concepts from existing literature and conference reports (see Table 1). Data collection was completed by December 2020. Among these, 44 concepts were extracted from journal articles, 5 from conference reports, 4 from newspapers, and 1 from a dissertation. The literature primarily came from the WoS Core Collection, Emerald, Ebsco, and CNKI databases. Conference reports were mainly sourced from domestic "smart library" themed academic forums and conferences, where speakers typically have substantial theoretical research and practical experience, making their perspectives highly representative and valuable for ensuring comprehensive and representative data.

Since no existing research has applied content analysis to smart library concepts, there was no ready-made category system. Therefore, this study designed its own category indicators. Based on principles of systematic completeness, independence of system elements, and reliability, the 54 smart library concepts were segmented to extract keywords. After manually filtering out meaningless words and merging synonyms, 17 categories were identified for smart library concept analysis (see Table 2).

To ensure reliability of the category results, this study used Holsti's reliability test [6] to examine inter-coder reliability by comparing agreement between different coders. Only when the inter-agreement ratio reached or exceeded 80% was the lead coder's result considered acceptable [7]. In this study, the first author served as the lead coder for the 54 smart library concept samples, while the fourth author was invited as a comparison coder to recode the samples for reliability testing. The results showed a composite reliability of 94%, far exceeding the 80% threshold, with reliability values for all categories also exceeding

80% (see Table 3), demonstrating high reliability of the research findings.

2.1.3 Statistical Results and Analysis Based on the reliability-tested coding results from the lead coder, concepts related to each indicator were extracted, and the frequency and percentage of each smart library concept analysis indicator across the 54 concepts were statistically analyzed (see Table 4).

The statistical results in Table 4 show significant variation in the frequency of indicators across smart library concepts, ranging from 0.87 to 0.09, indicating that researchers still have certain disagreements in defining smart library concepts. While different concepts share considerable common ground, they also exhibit dispersed characteristics. Among the 17 indicators, six had frequencies greater than 0.5: "new generation information technology," "service," "user," "intelligent," "resource," and "networked," with "new generation information technology" having the highest frequency. Additionally, "business and management" and "librarian" both exceeded 0.4, while other indicators such as "new type," "knowledge innovation," and "sustainable" appeared less frequently. Notably, "digitalization," with a frequency of only 0.39, is a prerequisite and foundation for high-frequency indicators like "networked" and "intelligent." Its relatively low frequency is mainly because many concepts implicitly assume digitalization without explicitly stating it, making it equally crucial for smart libraries.

In summary, "new generation information technology," "service," "user," "resource," "business and management," "librarian," "digitalization," "networked," and "intelligent" reflect common characteristics of smart library concepts. Among these, "new generation information technology" is an essential element and important driving force in smart library construction and development, while "digitalization," "networked," and "intelligent" represent key technological features. "Service," "user," "resource," "business and management," and "librarian" constitute the foundation and prerequisite for library operations—a status that remains unchanged across past, present, and future contexts. Other less frequent indicators such as "knowledge, innovation," "people-oriented," and "sustainable" should also be important directions for smart library development under the principles of "innovation, coordination, green development, openness, and sharing."

2.2 Analysis of Smart-Related Concepts

Smart libraries are an important component of the broader smart construction environment, sharing certain commonalities with smart cities, smart museums, and smart campuses in terms of concepts, connotations, construction philosophies, and practical implementation. Therefore, it is necessary and essential to consider the common features and characteristics of similar smart concepts when defining smart libraries.

2.2.1 On Smart Cities The State Administration for Market Regulation and the Standardization Administration of China have issued relevant stan-

dards defining smart cities as "innovative cities that use information and communication technology to effectively integrate various urban management systems, achieve information resource sharing and business coordination among urban systems, promote smart urban management and services, improve urban operation management and public service levels, enhance residents' happiness and satisfaction, and achieve sustainable development" [8]. Song Yi et al. analyzed smart city terminology and conceptual definitions in three major standards (ITU-T, ISO, and IEC), noting that smart city systems comprise inclusive human systems, transformative data/information systems, productive and competitive digital systems/digital technology/ICT, and resilient physical systems, with the goal of achieving urban sustainable development [9].

2.2.2 On Smart Campuses The State Administration for Market Regulation and the Standardization Administration of China defined smart campuses in the "Smart Campus Overall Framework" standard as the organic combination of information and physical spaces, representing a further upgrade of digital campuses and an advanced form of educational informatization. The ultimate goal is to enable anyone to access convenient resources and services anytime and anywhere [10].

2.2.3 On Smart Museums There is still no unified standard for smart museums domestically or internationally. Represented by Song Xinchao's research, smart museums are considered a museum form with "dynamic two-way multidirectional information transmission among people, objects, and data as the core" [11]. The construction subject, service subject, and service object of smart museums are all human; only by meeting public needs based on actual requirements can smart museums truly fulfill their smart service functions.

Based on the above conceptual definitions of smart cities, smart campuses, and smart museums, it is evident that "people," "technology," and "objects" are key elements requiring attention in smart construction processes. Coordinated integration among these elements is a necessary condition for efficient operation of smart entities, data serves as the core link throughout the entire smart operation system, being people-oriented and meeting user needs are essential requirements, and promoting innovation and achieving sustainable development are long-term goals.

3. Concept Definition and Connotation Characteristics of Smart Libraries

3.1 Concept Definition

Combining the analysis of existing smart library concept characteristics and the commonalities in current smart city and smart campus construction, this study defines the concept of smart libraries from their essence: "Smart libraries are advanced library forms dedicated to achieving deep-level, convenient services

through human-machine coupling." Characterized by the combination of human wisdom and artificial intelligence, with the integration of intelligent technology and wisdom investment as the pathway, and data throughout the entire operation process as the core link, smart libraries aim to achieve sustainable library development.

3.2 Connotation Analysis

Smart libraries inherit the excellent achievements and ideas from different library forms such as digital libraries, integrate new generation information technology and development concepts, represent a natural choice adapted to the current development environment, and embody people's aspirations for future library development. Following a people-oriented philosophy, smart libraries fully utilize and leverage human wisdom to comprehensively improve library operation, management, and service levels, create high-quality service content and capabilities, and strive to build an efficient, ubiquitous, intelligent, integrated, innovative, and sustainable knowledge and information access environment for society, thus possessing very rich connotations. Based on the above conceptual definition and the background of smart library emergence and development, this study analyzes its connotation from four perspectives:

First, smart libraries represent an advanced library form in the era of intelligent technology development, with sustainable development as the goal. The key points are reflected in three aspects: Era background: The emergence and development of smart libraries are marked by the development of intelligent technology in the information age. Development goals: Smart libraries aim to provide users with deep-level, convenient services and achieve sustainable library development. Form characteristics: Smart libraries represent a new form of library development, not merely a new form of library informatization. Therefore, smart libraries are not digital libraries; there are essential differences between them.

Second, smart libraries are characterized by the combination of human wisdom and artificial intelligence, with the integration of intelligent technology and wisdom investment as the pathway, operating through human-machine interactive coupling. The key points are reflected in three aspects: Basic characteristics: The feature of smart libraries is the combination of human wisdom and artificial intelligence. In operation and development, smart libraries must not only pool human wisdom and give full play to human roles in library management and services but also endow objects with intelligence, enabling intelligent equipment and technology to better serve library development. Development pathway: Smart library development relies on the organic combination of intelligent technology and equipment with wisdom investment. Smart library construction and development require not only full utilization of intelligent technology but also reliance on wise institutional norms and intellectual investment. Operation mode: Smart libraries operate through human-machine interactive coupling, with data as the core element connecting humans and machines. This opera-

tion mode can also be called a "human-machine coupling" approach, placing any "person" and any "machine" in the library operation process within the same closed-loop library system to improve overall library operation efficiency and service quality through "machine-assisted humans" and "human-assisted machines."

Third, smart libraries are systematic solutions proposed to address current social needs and library development problems. The key points are reflected in two aspects: Construction objectives: Smart library construction aims to solve problems in library development and meet user service needs. In different development stages and conditions, libraries face different problems that are constantly changing. Therefore, different libraries set different goals, development paths, and priorities in smart library construction, resulting in different final library forms. Construction scope: Systematic solutions require all library departments and personnel to actively participate, promoting overall development capacity improvement. This overall capacity enhancement requires comprehensive supporting facilities rather than focusing on a single aspect.

Finally, the concept of smart libraries is essentially the organic combination of "smart" and "library." The key to understanding smart libraries lies in understanding the "smart" and its generation process. This study's concept of smart libraries organically integrates the "intelligence" and "wisdom" of the new technology era into libraries that inherently possess social, systematic, technological, and cultural attributes. However, this integration does not change the fundamental attributes and nature of libraries but only transforms their development form.

3.3 Feature Analysis

3.3.1 High Perception Through perception devices and intelligent terminals, smart library operations are monitored and analyzed in real-time, enabling mutual perception between people and objects that need to be perceived. Human needs are identified quickly, and data and information are transmitted in real-time, often unconsciously.

3.3.2 Ubiquitous Connectivity By integrating different information networks, libraries are transformed into spaces combining virtual and physical realities, achieving connections between people, people and objects, and objects and objects. This enables anyone to interact with libraries barrier-free anytime and anywhere. This characteristic is mainly reflected in two aspects: First, ubiquitous connectivity within library management and operation, where all resources owned by libraries are described and stored digitally, and all data resources are managed through networks. The library system becomes a big data pool without access barriers between subsystems. Second, ubiquitous connectivity for users accessing library services, where libraries provide services through comprehensive, three-dimensional, and diversified channels, making user service

needs no longer limited by time and space. “To the side” and “to the terminal” have become the norm for library services.

3.3.3 Efficient Collaboration As individual entities, libraries need to strengthen integration of internal departmental and system resources and information sharing, transforming past multi-directional unilateral interactions between readers and libraries and within libraries into multi-directional network interactions. This enables efficient collaboration among all library elements and participants to achieve optimal operation of a single library system. As part of complex social systems, libraries need to strengthen integration with other libraries and different types of smart systems to achieve collaboration and mutual promotion between library systems and within and outside library systems [12].

3.3.4 Precise Services Through high perception and ubiquitous connectivity, user behavior data is collected for user profiling to identify user needs and personalized characteristics. Based on centralized, accurate analysis and processing of relevant information and data, precise information products and services are provided to users.

3.3.5 People-Oriented A library that cannot satisfy users cannot be called a good library. The strategic goal of smart library construction and development is to meet constantly changing user needs, improve service efficiency, and thereby promote sustainable library development. Therefore, the principle of “people-oriented” must be highlighted during smart library construction and development, emphasizing the “human” element. First, user orientation must be clarified in library operation and development, with users as the center and user needs as the goal. All work should anticipate user thoughts and needs, creating a better humanistic environment through personalized, precise, and ubiquitous services. Second, it must be recognized that humans are the builders and workers of smart libraries. Smart library construction cannot proceed without professional participation, and smart library services cannot be delivered without intelligent librarians.

3.3.6 Innovative Development By strengthening smart management and service platform construction, smart libraries promote innovation and development in library operation and management models, continuously exploring new service content and methods. This enables users to acquire new knowledge and develop independent innovation capabilities during their use of smart libraries, ultimately achieving sustainable development of national public cultural services, libraries, and users.

Smart libraries are neither digital libraries nor intelligent libraries but represent a further upgrade based on different library forms. They encompass the characteristics of digital and intelligent libraries such as “digitalization,” “networking,” and “intelligent” features, while also possessing attributes like “high

perception," "ubiquitous connectivity," "efficient collaboration," "precise services," "people-oriented," and "innovative development."

4. Cognitive Model of Smart Library Architecture

The emergence and development of smart libraries have their unique characteristics and complexities. As a new form and trend of library development in the new era, clarifying the connotation and characteristics of smart libraries becomes a necessary condition for sorting out their architecture and related elements, thereby promoting smooth construction practice and evaluation standard formulation. To further advance related research and practice, this chapter constructs a cognitive model of smart library architecture based on its connotation and characteristics.

4.1 Representation of Smart Library Architecture

"System" refers to a unified whole formed by interrelated things or concepts, with the arrangement of components called structure or architecture. Architecture focuses on the connotation, extension, hierarchical relationships, and the impact of related design and guiding principles on the research object at a high level of abstraction within its environment. Smart library architecture reflects the layout of smart library elements and functions according to certain theoretical logic and observation perspectives. Its characteristics should include four aspects:

4.1.1 Inheritance The existence and development of smart library architecture are usually based on existing system architectures, with its constituent elements and structural characteristics retaining features of previous library forms while continuously optimizing through sustained innovation, demonstrating diachronic inheritance and relevance.

4.1.2 Dynamism Smart library architecture results from the interaction between human activities and objective existence in specific social environments. As external environments and mechanisms change, the overall form of smart libraries and interconnections among elements will undergo dynamic changes.

4.1.3 Adaptability Smart library architecture comprises different elements with interrelated and mutually influential modules and components. When external environments and conditions change, the architecture spontaneously adjusts its form and element functions, while its form and functions also promote continuous architectural adjustment.

4.1.4 Integration The integration of smart libraries mainly refers to horizontal integration and consolidation of internal modules and elements, including micro and macro levels. The micro level involves integration of elements within

a module, such as library information resource integration. The macro level involves integration like that of services and business, typically involving different stakeholders.

4.2 PTP Cognitive Model of Smart Library Architecture

People and objects are basic elements of social systems. Their coordination can promote social development efficiency and quality improvement. As part of social systems, smart libraries' basic element composition follows general social system patterns. Based on the conceptual definition of smart libraries, their architecture construction and operation essentially combine human wisdom and artificial intelligence to conduct library business and services through human-object interaction (data flow) to solve library development problems. Therefore, this paper proposes a "People-Things-Problems" (PTP) cognitive model for smart library architecture, as shown in Figure 1 [Figure 1: see original paper].

In the PTP cognitive model, "People" typically includes librarians and users. Librarians' wisdom level has direct and decisive impact on library smart construction level, with their attributes and functions directly reflecting library smartness. Users are the service objects of libraries and external elements of the smart library system. However, as non-profit cultural service institutions, libraries serve users at different levels and scopes without strict user restrictions or distinctions, aiming to maximize service efficiency. Therefore, users are highly uncertain factors for smart library construction. In special cases, users may provide intellectual support for library construction and development, but such auxiliary support is neither mainstream nor decisive.

"Things" are the basic guarantee for smart library construction and development, representing another important support object in library systems besides "people." In the mid-to-late 20th century, scholars such as Liu Guojun [13], Wu Weici [14], and Huang Zongzhong [15] studied library constituent elements, generally considering "things" in libraries as mainly collections and building equipment. In the early 21st century, with era progress and information technology development, libraries have continuously evolved toward intelligence and smartness. Scholars such as Chu Jingli [1], Chen Jin [16], and Shao Bo [17] analyzed smart library constituent elements, generally considering that "things" in smart libraries mainly include information resources, space, and related technical equipment. Thus, regardless of era changes, information resources remain an essential material foundation for library existence and development—libraries without information resources are not real libraries. Physical space and technical equipment infrastructure are important carriers and means for library existence and operation. Smart infrastructure construction provides technical support and security guarantees for achieving thorough perception, extensive connectivity, and efficient operation of library infrastructure, as well as data integration and information sharing among different departments, groups, and subsystems within library systems. With scientific and technological development, library infrastructure will continuously update and change, but as a basic carrier for

library construction and development, infrastructure will remain an essential part of libraries for the foreseeable future. Therefore, this study considers that "Things" in the PTP cognitive model should include information resources and infrastructure.

The interaction process between people and objects is the process of conducting various library businesses and services, as well as the specific practice process of solving library development problems. From the perspective of interaction subjects, the interaction process in the PTP cognitive model typically includes three types: person-person, person-object, and object-object interactions within libraries. From the perspective of subject association, the interaction process between people and objects in the PTP cognitive model is the process of data flow generation, transmission, utilization, and reuse in library operations, forming a closed loop. From the perspective of interaction results, the interaction between people and objects in the PTP cognitive model produces machine-led businesses and services such as intelligent Q&A and librarian-led services such as decision support. Regarding library development problems, they involve a wide range of issues including libraries' role positioning in society and organizations, high-efficiency operation and sustainable development of libraries, and user services and satisfaction.

Through the above analysis, the PTP cognitive model, as an external representation and reflection of smart library form, outlines the architecture and constituent elements of smart libraries at the macro level, providing generalized explanations of elements involved in smart library construction and evaluation. This benefits the construction and further refinement of smart library architecture, thereby promoting the development of smart library construction practice and enhancing library smart capabilities.

4.3 Relationship Between Smart Library Connotation and PTP Cognitive Model

The PTP cognitive model is consistent with the connotation and characteristics of smart libraries. First, the PTP model follows the fundamental principle that smart libraries are people-oriented, endow objects with intelligence, and achieve optimal library services through interactive promotion between "people" and "objects." It proposes a system architecture approach that coordinates constituent elements with top-level design, pointing out the direction for smart library construction. Second, the connotation characteristics of smart libraries fully consider the use of intelligent technology and information networks, emphasizing full utilization of information and human resources to maximize library value. The smart library architecture and evaluation standards constructed based on the PTP model will reflect the foundation and core of the connotation through infrastructure and librarian team construction. Finally, the smart library connotation indicates that smart libraries should achieve different goals from three perspectives: society, libraries, and users. The library development problems pointed out in the PTP model also involve different stakeholders.

Conclusion

The definition and understanding of smart library concepts and connotation characteristics form the foundation for deepening smart library theoretical research and practical development. This study combined content analysis to abstract the smart library concept from its essence, thereby determining the connotation and characteristics of smart libraries. On this basis, it proposed the PTP cognitive model for smart library architecture, providing a macro-level analysis of the basic constituent elements of smart libraries. This not only deepens understanding of the core connotation and practical pathways of smart libraries but also lays a theoretical foundation for future research on smart library construction evaluation indicator systems.

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