AUTOMATION, TRANSPARENCY, AND EFFICIENCY IN LIBRARY MANAGEMENT THROUGH BLOCKCHAIN AND IOT TECHNOLOGIES

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Abstract
The purpose of this paper is to examine the literature on the applications of Blockchain and the Internet of Things (IoT) and to understand how libraries are engaging with this technology to enable users to feel more involved in the present and to share information about Library resources and services.
Based on the existing literature, the fundamental models of Blockchain and its combination with IoT are extracted, documented, and illustrated, focusing on performance, implementation ability, and the layers discussed for both.
The findings could also provide an empirical platform for comprehension of the technological and behavioural factors that drive adoption of blockchain and IoT to improve automation of services, transparency in records, and overall workplace efficiencies within libraries. The current study is a valuable addition to the body of library and information science literature in that it merges cutting-edge digital technologies with a widely accepted technology acceptance model, and its findings are of practical interest for librarians, system developers, and policy makers involved in smart library initiatives.
The recent applications and current uses of blockchain and IoT in libraries are presented with the hope that they will help build up future work across various sectors.
Keywords: Smart Libraries; Blockchain Technology; Internet of Things (IoT); Library Management; Digital Transformation.

Introduction

Libraries, historically revered as repositories of knowledge, are currently navigating a profound paradigm shift from traditional, centralized service models towards dynamic, technology-driven ecosystems. This transformation is inextricably linked to the advent of Industry 4.0 (I4.0) technologies, particularly Blockchain Technology (BCT) and the Internet of Things (IoT), which collectively promise to redefine the boundaries of automation, transparency, and operational efficiency in library management (Haque et al., 2024).

Blockchain, fundamentally a decentralized and immutable distributed ledger, offers unparalleled capabilities for secure, transparent, and tamper-proof record-keeping. These attributes are critically relevant for libraries, which manage sensitive circulation data, digital content with complex rights management, and shared cataloguing systems that require a high degree of trust and integrity (Research on the construction scheme of smart library based on blockchain technology, 2024). Complementing this, IoT provides a ubiquitous network of interconnected physical devices, such as RFID-tagged books, smart shelves, occupancy sensors, and environmental monitors, that enable real-time data capture and automated control, thereby streamlining inventory management and enhancing the physical library experience (Rouf & Raja, 2023).

Recent scholarly work has increasingly focused on the synergistic integration of BCT and IoT in distributed environments to address pervasive issues of trust, security, and efficiency. As highlighted by

Almarri and Aljughaiman (2024) and Haque et al. (2024), blockchain's decentralized consensus mechanisms can effectively secure the vast streams of data generated by IoT devices, creating a trusted environment for automated decision-making. While this integrated approach has been explored in sectors like transportation and supply chain, its application within the library context remains nascent and fragmented. This paper addresses this gap by systematically reviewing the literature to provide a consolidated understanding of how the BCT-IoT nexus can be harnessed to forge the intelligent, user-centric libraries of the future.

2. Objectives of the Study

The primary aim of this systematic review is to synthesize and critically evaluate the existing body of knowledge on the application of Blockchain and IoT technologies in library management. The specific objectives are:

1. To explore the fundamental theoretical constructs and architectural principles of BCT and IoT as they pertain to the library context.
2. To identify and categorize existing and proposed applications of BCT and IoT in libraries, focusing on automation, security, transparency, and service delivery.
3. To investigate the key technological, organizational, and behavioural determinants influencing the adoption of BCT and IoT in libraries.
4. To critically evaluate the potential of these integrated technologies to enhance user engagement, operational transparency, and efficiency.
5. To delineate the primary challenges and future opportunities for scaling BCT-IoT-enabled smart libraries, thereby proposing a roadmap for future research and practice.

3. Methodology

This study employs a systematic literature review approach to synthesize and critically evaluate existing research on the integration of Blockchain and IoT technologies in library management. The methodology follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure rigor, transparency, and replicability (Page et al., 2021).

3.1 Search Strategy

A comprehensive literature search was conducted across multiple academic databases and digital libraries to identify relevant peer-reviewed sources. The databases searched included: Scopus, IEEE Xplore, Google Scholar, Web of Science, and ACM Digital Library.

Additionally, library-specific repositories and journals were hand-searched to ensure depth of coverage, including Library Hi Tech, Journal of Librarianship and Information Science, Library Philosophy and Practice, and College & Research Libraries.

The search was limited to publications between January 2017 and March 2025 to capture the most recent developments in this rapidly evolving technological field. The following keyword combinations and Boolean operators were employed:

- ("Blockchain" OR "Distributed Ledger Technology" OR "DLT") AND ("library management" OR "academic library" OR "public library")
- ("Internet of Things" OR "IoT") AND ("library automation" OR "smart library" OR "library services")
- ("Blockchain" AND "IoT") AND ("library" OR "information management" OR "digital transformation")
- ("transparency" OR "efficiency" OR "automation" OR "security") AND ("library technology")

3.2 Inclusion and Exclusion Criteria

Articles were included in this review if they met the following criteria:

Inclusion Criteria:
- Written in English
- Published in peer-reviewed journals, conference proceedings, or authoritative technical reports
- Focused on the application of Blockchain and/or IoT technologies in library or information science settings
- Presented empirical research, theoretical frameworks, conceptual models, or detailed case studies

- Published between January 2017 and March 2025

Exclusion Criteria:

- Editorials, book reviews, opinion pieces, or blog posts without substantive academic contribution
- Publications not available in full text
- Studies focused exclusively on non-library domains without transferable implications
- Duplicate publications of the same research

3.3 Study Selection Process

The study selection process followed the PRISMA guidelines and proceeded through four phases: identification, screening, eligibility assessment, and final inclusion.

Phase 1: Identification. The initial database searches yielded 78 records. After removing 23 duplicate records, 55 unique articles remained for screening.
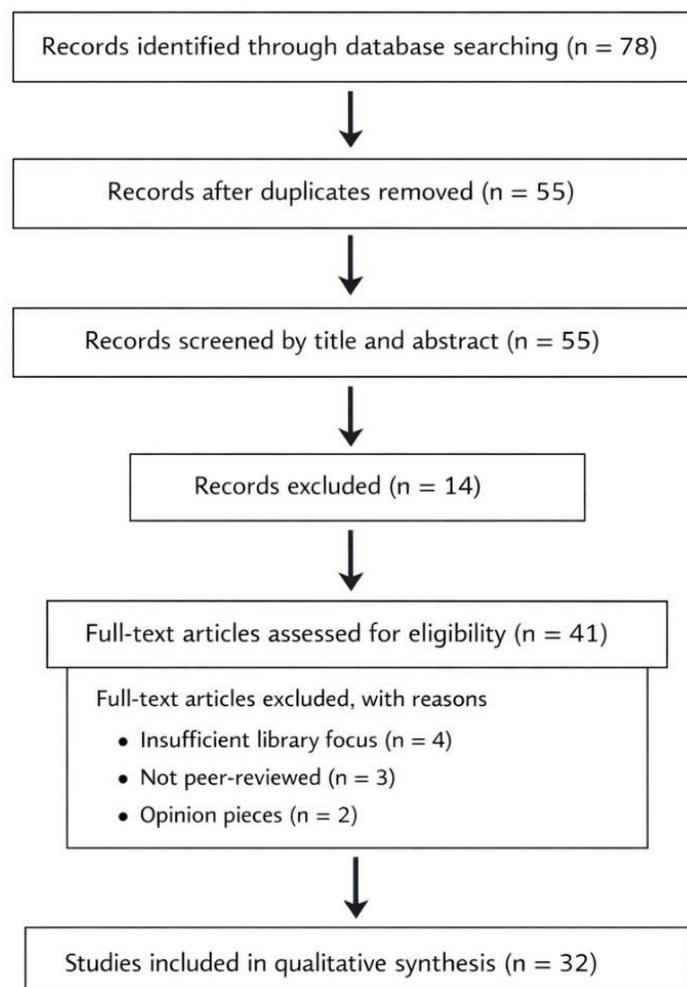
Phase 2: Screening. Titles and abstracts of the 55 articles were screened against the inclusion criteria. Articles clearly irrelevant to the research objectives were excluded, leaving 41 articles for full-text retrieval.

Phase 3: Eligibility Assessment. Full texts of the 41 articles were obtained and thoroughly assessed for eligibility. Nine articles were excluded during this phase for reasons including: insufficient focus on library applications (n=4), lack of peer review (n=3), and being opinion pieces without substantive evidence (n=2).

Phase 4: Final Inclusion. A total of 32 studies met all inclusion criteria and were included in the final qualitative synthesis.

Figure 1

PRISMA Flow Diagram of Study Selection Process

Records identified through database searching (n = 78)

Records after duplicates removed (n = 55)

Records screened by title and abstract (n = 55)

Records excluded (n = 14)

Full-text articles assessed for eligibility (n = 41)

Full-text articles excluded, with reasons
- Insufficient library focus (n = 4)
- Not peer-reviewed (n = 3)
- Opinion pieces (n = 2)

Studies included in qualitative synthesis (n = 32)

3.4 Data Extraction and Analysis

A standardized data extraction form was developed to systematically capture relevant information from each included study. Extracted data elements included:

- Author(s), year, and publication source
- Research objectives and questions
- Theoretical or conceptual framework employed
- Methodology (if empirical)
- Key findings related to BCT and/or IoT applications in libraries
- Identified benefits, challenges, and implementation factors
- Future research directions suggested by authors

The extracted data were analysed using thematic analysis, following the six-phase framework proposed by Braun and Clarke (2021). This involved: (1) familiarization with the data, (2) generating initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the final synthesis. The themes were subsequently mapped onto the UTAUT2 theoretical framework to provide a structured interpretation of the findings.

3.5 Quality Assessment

To ensure the quality and rigor of the included studies, each article was assessed using criteria adapted from the Critical Appraisal Skills Programme (CASP) checklists. Studies were evaluated based on clarity of research aims, appropriateness of methodology, rigor of analysis, and contribution to the field. No studies were excluded based on quality assessment alone, but methodological strengths and limitations were noted and considered during synthesis.

4. Literature Review and Synthesis

4.1 Theoretical Underpinnings of Blockchain and IoT in Libraries

The integration of BCT and IoT in libraries can be understood through the lens of several theoretical frameworks. From a socio-technical perspective, the shift towards "Library 4.0" embodies the convergence of physical and digital infrastructures. BCT addresses the need for a trusted, decentralized layer for managing transactions and records, directly tackling issues of data integrity and security that are paramount in public institutions (Khan, 2025). Its key features, decentralization, immutability, transparency, and smart contracts, offer a new paradigm for library operations, moving away from reliance on central authorities for functions like cataloguing and DRM (Laboso et al., 2026).

IoT, conversely, extends the library's digital reach into the physical world. By embedding sensors and connectivity into physical objects (books, shelves, rooms), IoT enables the creation of a "living library" that can sense, monitor, and respond to user actions and environmental conditions in real-time (Khan & Ullah, 2024). This capability aligns with principles of ubiquitous computing and ambient intelligence, where technology recedes into the background, providing seamless and context-aware services.

Table 1

Core Technological Features and Library Applications

Technology	Core Features	Library Applications
Blockchain	Decentralization, Immutability, Transparency, Smart Contracts, Cryptographic Security	Secure circulation logs, tamper-proof interlibrary loan records, decentralized digital rights management (DRM), transparent acquisition tracking, verified user credentials.
Internet of Things (IoT)	Real-time sensing, RFID/NFC, Connectivity, Data Analytics, Automation	Automated inventory with smart shelves, real-time book location tracking, occupancy monitoring for study spaces, environmental monitoring for preservation, personalized push notifications.

Figure 1
The proposed IoT-Blockchain integrated Architecture (Kharche et al., 2024)
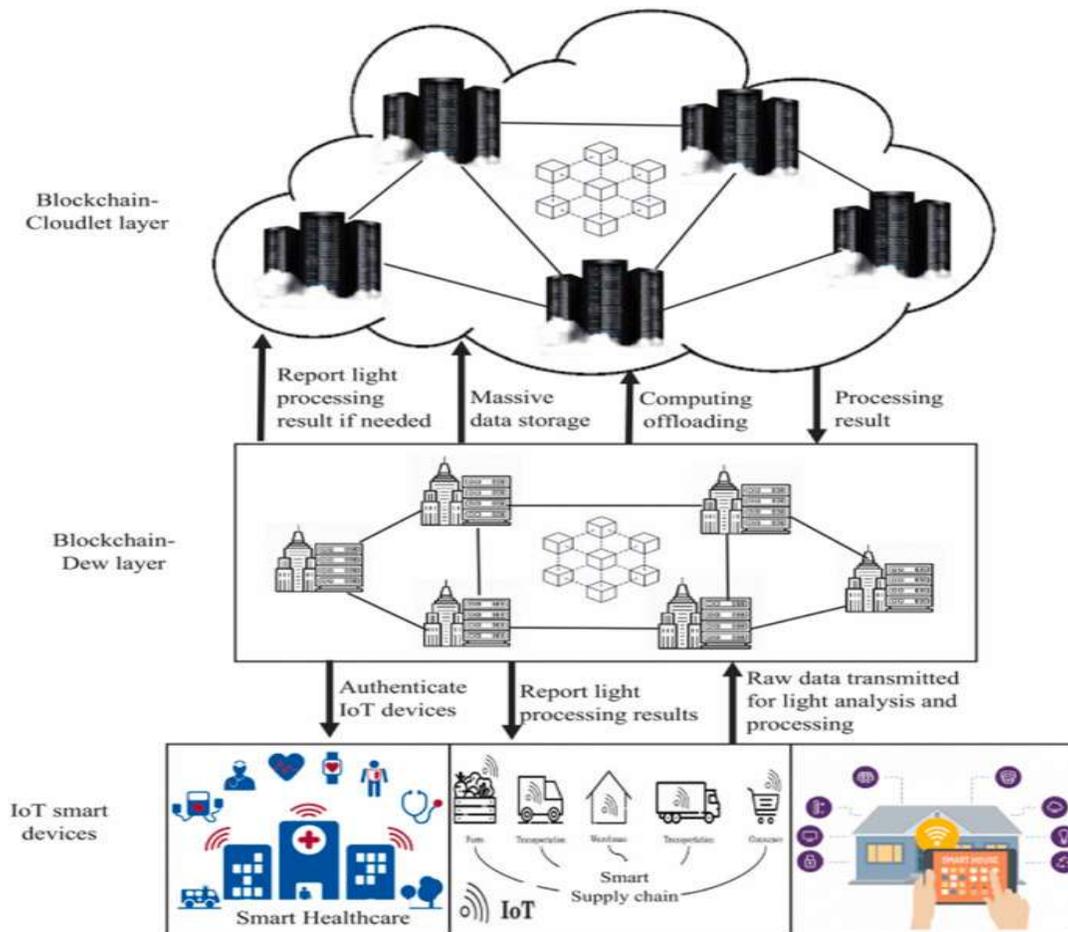
4.2 Blockchain Applications in Library Management Systems

The literature reveals a growing consensus on the transformative potential of blockchain for core library functions. Research on the construction scheme of smart library based on blockchain technology (2024) proposes a multi-layered architecture that leverages blockchain to create a decentralized and trustworthy cataloguing and circulation system. This model reduces the risk of a single point of failure and enhances data resilience. Similarly, the experimental framework by Laboso et al. (2026) demonstrates a blockchain-based LMS that effectively manages DRM, ensuring that digital content usage rights are enforced transparently and automatically through smart contracts, thereby enhancing both privacy and security for users and publishers.

Khan (2025) metaphorically describes the growing attraction to blockchain in libraries as a form of "technological amorousness," driven by its promise to revolutionize operations from centralized, opaque systems to decentralized, transparent, and user-trusting models. This perspective is echoed in reviews of I4.0 technologies in libraries, which consistently identify blockchain as a key enabler for building trusted service models and ensuring the long-term preservation and authenticity of digital assets (Innovative technologies in libraries under industry 4.0, n.d.).

Figure 2

The blockchain-based library management system (LMS) architecture used in the controlled experiment (Labosa et al., 2026)
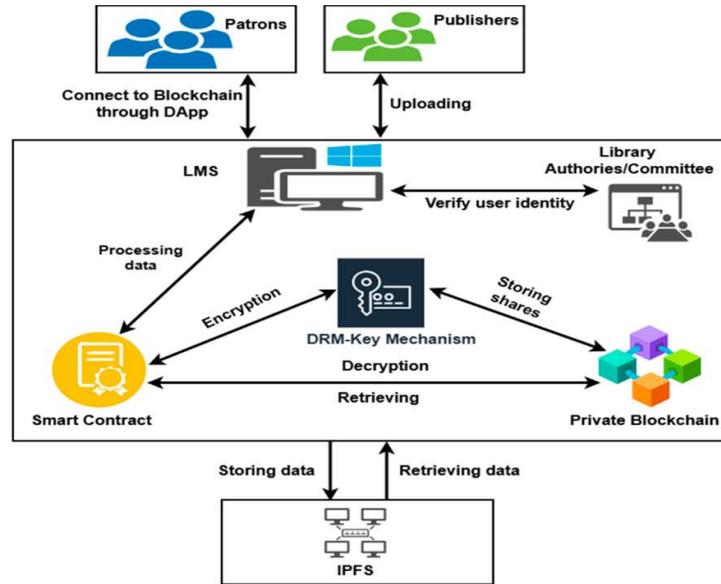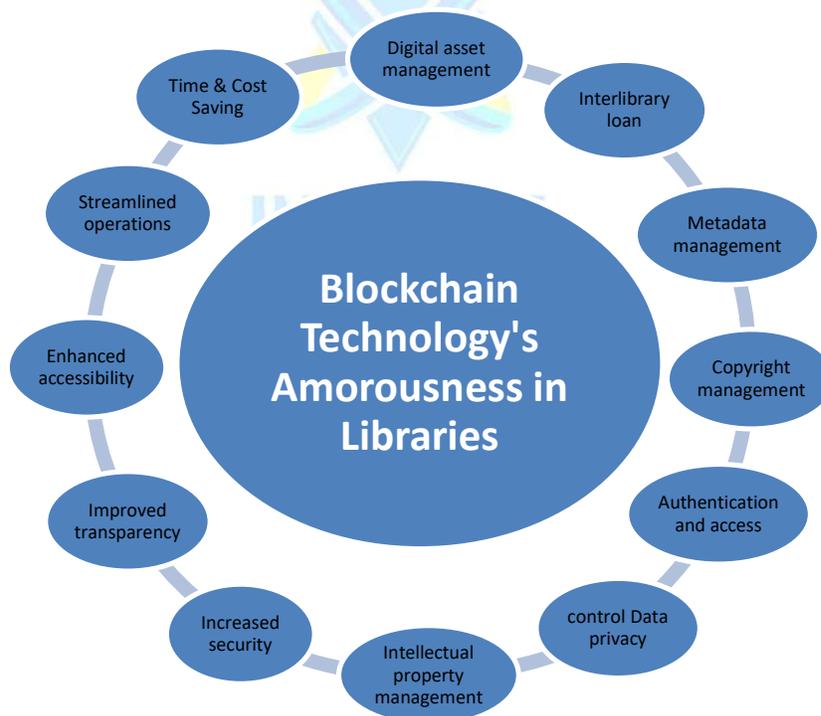

Figure 3

*Blockchain Technology's Amorousness in Libraries (Khan, 2024)*

4.3 Library operations through Blockchain Technology

Blockchain has fascinating library potential. This technique secures data such that it is hard to tamper with. Moreover, it could become easier for libraries to aggregate, preserve, and disseminate credible information. All in all, libraries could definitely benefit from blockchain to make them more secure, efficient, and transparent. Libraries should be cautious about adopting it, with data security and user privacy being concern number one for adoption (Khan, 2024).

Figure 4
Library operations through Blockchain technology (Khan, 2024)
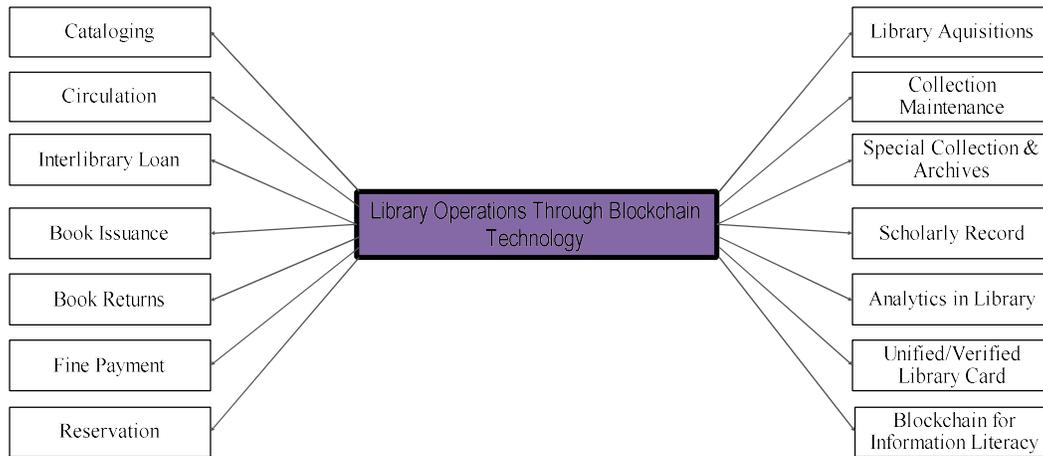
4.4 Uses of IoT in various areas of the library

In libraries, tasks are generally technical. "It is recognized in rare terms as housekeeping points for the library, which means all the work that goes into and everything that is done before an ebook ever gets to the library and gets into a reader's hands. Therefore, it is convenient to state that the e-book rental, inventory, tagging, and access manipulation are all stages of a smart library management system (Rouf & Raja, 2023). As we can see in the image below:

Figure 5
Uses of IoT in various areas of the library (Rouf & Raja, 2023)


4.5 Infrastructure of IoT-based library

Libraries are using IoT technology in their sections by smart setup technology, use of RFID Inventory management, Library classes, and Counters, as people (Khan et al., 2021; Khan, 2024) have been introduced. The two images below provide statistics on the adoption of IoT in a library. More specifically, the layered IoT architecture for libraries and software is displayed below.

Figure 6
Application areas for IoT in libraries (Khan et al., 2021)
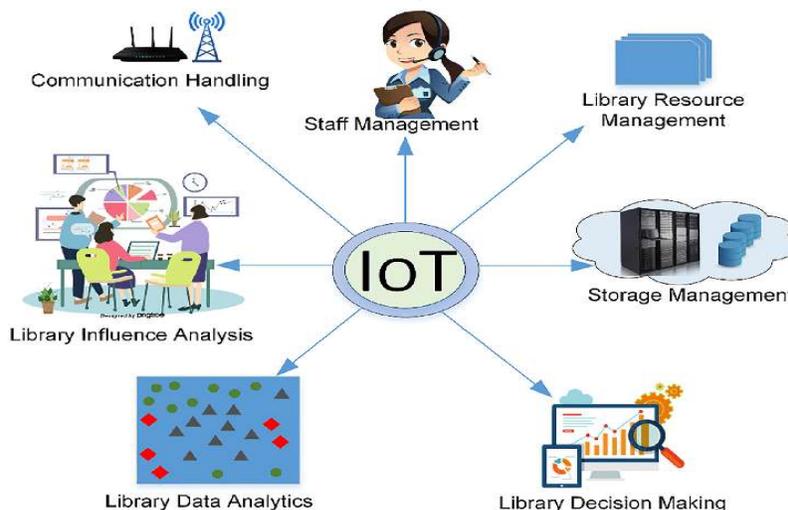
5. Thematic Synthesis of Findings

The thematic analysis of the 32 included studies revealed four overarching themes that characterize the current state of knowledge regarding Blockchain and IoT integration in libraries. These themes are summarized in Table 2 and subsequently discussed in detail.

Table 2
Thematic Synthesis of BCT and IoT Applications in Libraries

Theme	Description	Key Sources	UTAUT2 Construct
Decentralized Trust and Transparency	Using blockchain's immutable ledger for secure circulation records, tamper-proof interlibrary loan systems, and transparent digital rights management to reduce reliance on centralized authorities.	Research on construction... (2024); Laboso et al. (2026); Khan (2025)	Performance Expectancy; Trust (emergent)
Real-Time Resource Management	Employing IoT technologies including RFID, smart shelves, and environmental sensors for automated inventory, space utilization monitoring, and collection preservation.	Rouf & Raja (2023); Khan et al. (2021); Khan & Ullah (2024)	Performance Expectancy; Effort Expectancy
Synergistic BCT-IoT Security Integration	Leveraging blockchain's decentralized consensus mechanisms to secure and validate data streams generated by IoT devices, creating verifiable audit trails for physical asset movements.	Almarri & Aljughaiman (2024); Haque et al. (2024); Kharche et al. (2024)	Facilitating Conditions; Trust
Enhanced User Experience and Engagement	Combining IoT-generated behavioural data (with appropriate consent) and blockchain-secured user identities to deliver personalized recommendations, seamless access, and interactive library experiences.	Khan et al. (2021); Ennajeh & Najjar (2024)	Hedonic Motivation; Social Influence

5.1 Decentralized Trust and Transparency

The literature consistently identifies blockchain's capacity to establish decentralized trust as its most significant contribution to library operations. Research on the construction scheme of smart library based on

blockchain technology (2024) proposes a multi-layered architectural model wherein circulation records, acquisition logs, and cataloguing data are stored across a distributed network, eliminating single points of failure and unauthorized tampering. This decentralized approach fundamentally transforms the trust relationship between libraries and their patrons by making operational data transparent and verifiable.

Laboso et al. (2026) extend this application to digital rights management (DRM), demonstrating through controlled experimentation how smart contracts can automate licensing agreements and usage permissions. Their blockchain-based LMS architecture ensures that content access rights are enforced transparently without compromising user privacy, a persistent concern in traditional DRM systems. Khan (2025) metaphorically characterizes this growing professional attraction as "technological amorousness," reflecting the enthusiasm with which library professionals anticipate blockchain's potential to revolutionize information management. From a UTAUT2 perspective, these applications directly address Performance Expectancy by promising more secure, efficient, and trustworthy library operations. Moreover, the transparency afforded by blockchain systems may cultivate a dimension of institutional Trust that, while not explicitly named in the original UTAUT2 model, emerges as a critical mediating variable in the public sector context.

5.2 Real-Time Resource Management through IoT

The application of IoT in libraries represents the most empirically documented theme in the literature. Rouf and Raja (2023) provide a comprehensive taxonomy of IoT implementations, categorizing applications across technical services, circulation, inventory management, and access control. Their analysis demonstrates how IoT transforms traditional "housekeeping" functions, acquisition, cataloguing, and physical processing, into automated, data-driven workflows that operate with minimal human intervention.

Khan et al. (2021) advance this understanding by empirically investigating success factors for IoT services in academic libraries. Grounded in the Information Systems Success Model, their research identifies system quality, information quality, and service quality as critical determinants of user satisfaction. Smart shelves with RFID capabilities (system quality) generate accurate, real-time inventory data (information quality), which enables staff to respond promptly to user queries and collection gaps (service quality). This cascading relationship illustrates how technological infrastructure ultimately shapes user experience.

Khan and Ullah (2024) further elaborate on the layered architecture required for effective IoT implementation, emphasizing the integration of sensing layers, network layers, and application layers. Their work highlights that successful IoT adoption depends not merely on deploying devices but on establishing robust data processing and analytics capabilities.

Applying the UTAUT2 lens, these IoT applications strongly resonate with Performance Expectancy (improved efficiency and accuracy) and Effort Expectancy (automation reducing staff workload). The quality dimensions identified by Khan et al. (2021) align closely with Facilitating Conditions, underscoring the importance of technical infrastructure and organizational support.

5.3 Synergistic Integration of Blockchain and IoT

A significant contribution of this review is the synthesis of literature addressing the integration of blockchain and IoT, rather than treating them as discrete technologies. Almarri and Aljughaiman (2024) systematically review how blockchain enhances IoT security and trust, concluding that distributed ledger technology provides the governance layer necessary to secure the vast, heterogeneous data streams generated by IoT sensors. Their analysis demonstrates that blockchain's immutability and consensus mechanisms can prevent data tampering and establish verifiable data provenance—capabilities urgently needed as libraries deploy increasingly numerous connected devices.

Haque et al. (2024) propose a scalable blockchain-based framework for IoT data management that employs lightweight consensus mechanisms to balance security with performance. While their framework is domain-agnostic, its principles are directly transferable to library environments where numerous IoT endpoints (RFID gates, smart shelves, occupancy sensors) generate continuous data requiring secure handling without excessive computational overhead.

Kharche et al. (2024) provide a concrete architectural model through their work on intelligent transportation systems. Figure 1 illustrates how IoT sensors at the edge collect real-time data, which is then

secured and validated by a blockchain layer before being made accessible to authorized applications. Adapting this architecture to libraries would enable scenarios where, for example, IoT sensors track an interlibrary loan book's journey, while blockchain immutably records each transfer, automatically triggering smart contracts for insurance or fines based on verified delivery.

This integrated approach addresses multiple UTAUT2 constructs simultaneously. The secure, reliable infrastructure addresses Facilitating Conditions, while the automated, trustworthy processes enhance Performance Expectancy. Most significantly, the combination of real-time visibility (IoT) and immutable verification (blockchain) fundamentally addresses the Trust imperative that underpins patron confidence in automated library systems.

5.4 Enhanced User Experience and Engagement

The fourth theme emerging from the literature concerns the potential of BCT and IoT to transform user experience. While less empirically developed than the operational themes, several studies point toward personalized, engaging library services enabled by these technologies.

Khan et al. (2021) identify service quality as a key success factor for IoT implementations, suggesting that the ultimate value of smart technologies lies in their capacity to enhance patron interactions with the library. Real-time occupancy data enables users to find available study spaces; personalized notifications alert users to returned books or new acquisitions matching their interests; seamless self-checkout reduces waiting times. These enhancements contribute to what UTAUT2 terms Hedonic Motivation—the enjoyment and satisfaction derived from using the technology.

Ennajeh and Najjar (2024) explore blockchain adoption through the UTAUT model, identifying the mediating role of trust in shaping user intentions. Their findings suggest that when patrons understand how blockchain protects their privacy and secures their transaction data, their willingness to engage with smart library services increases. This trust-mediated relationship has implications for Social Influence, as early adopters share positive experiences with peers, gradually shifting professional and user norms toward acceptance of these technologies.

The integration of BCT and IoT for user engagement remains a promising frontier requiring further empirical investigation. Conceptualizing how blockchain-secured user identities could enable seamless access across multiple library systems, or how IoT behaviour data (with appropriate privacy safeguards) could inform personalized recommendations, represents a rich agenda for future research.

6. Discussion

The synthesis of literature presented in this review confirms that libraries are progressively integrating Industry 4.0 technologies, specifically Blockchain and the Internet of Things, to construct smart, technology-driven service ecosystems. The findings corroborate and extend previous research (Haque et al., 2024; Innovative technologies in libraries under industry 4.0, n.d.) by demonstrating that these technologies are not peripheral innovations but central enablers of automation, transparency, and efficiency in contemporary library management. This discussion interprets the thematic findings through the UTAUT2 theoretical framework and articulates the theoretical and practical implications of this research.

6.1 Technological Affordances for Library 4.0

The literature consistently affirms blockchain's decentralized and immutable architecture as a solution to long-standing challenges in library operations. Consistent with Research on the construction scheme of smart library based on blockchain technology (2024) and Laboso et al. (2026), this review finds that blockchain enhances data integrity, strengthens digital rights management, and reduces dependence on centralized authorities for functions such as cataloguing and circulation. Khan's (2025) characterization of blockchain's "amorousness" in libraries reflects genuine professional enthusiasm grounded in these demonstrated affordances.

Similarly, the findings reinforce prior surveys highlighting IoT's capacity to enable real-time connectivity and intelligent resource management through RFID, smart shelves, sensors, and access control mechanisms (Rouf & Raja, 2023; Khan et al., 2021). The evidence indicates that IoT improves inventory accuracy, optimizes space utilization, and enhances user service experiences, collectively contributing to measurable efficiency gains in library operations.

The most significant contribution of this review, however, lies in synthesizing the *integrated* potential of blockchain and IoT. Consistent with Almarri and Aljughaiman (2024) and Haque et al. (2024), this study finds that blockchain provides the essential security and trust layer for IoT-generated data. Frameworks developed for non-library domains, such as Kharche et al.'s (2024) IoT-blockchain architecture for intelligent transportation, offer transferable models for managing secure, real-time data flows in library environments. This synergistic integration addresses what previous literature treated as separate challenges, real-time automation (IoT) and trustworthy record-keeping (blockchain), as interconnected dimensions of a unified smart library infrastructure.

6.2 Behavioural and Organizational Drivers of Adoption: A UTAUT2 Analysis

Applying the UTAUT2 framework to the synthesized findings reveals a structured understanding of adoption determinants.

Performance Expectancy emerges as the most prominently discussed driver. The literature consistently emphasizes that BCT and IoT enable librarians to perform tasks more efficiently (automated inventory, streamlined circulation) and effectively (enhanced security, transparent records). This performance benefit is the primary rationale cited for institutional investment in these technologies.

Effort Expectancy presents a more complex picture. While IoT applications are often designed to reduce staff effort through automation, the literature also acknowledges significant learning curves associated with implementing and maintaining both BCT and IoT systems. Hussain (2021) and Khan (2025) explicitly identify technical complexity and skills shortages as barriers, suggesting that perceived effort may impede adoption unless addressed through comprehensive training.

Facilitating Conditions emerge as critically important. The successful implementations documented by Khan et al. (2021) occurred in contexts with robust technical infrastructure and organizational support. Conversely, the barriers identified across multiple studies, financial costs, inadequate infrastructure, lack of technical expertise, represent absent or insufficient facilitating conditions. This finding underscores that technology adoption depends as much on organizational readiness as on technological capability.

Social Influence operates at multiple levels. Professional discourse, represented in the literature itself, shapes librarian perceptions of these technologies' legitimacy and importance. Institutional expectations from administrators and funders create top-down pressure for adoption. Patron expectations, particularly among digital-native generations, may create bottom-up demand for smart library services.

Hedonic Motivation, while less emphasized, appears in discussions of enhanced user experience. The enjoyment and engagement that patrons derive from interactive, responsive library environments may accelerate adoption beyond purely utilitarian considerations.

Perhaps most significantly, this analysis reveals Trust as an emergent construct that permeates multiple UTAUT2 dimensions. Trust in the technology's security (addressing Performance Expectancy), trust in the institution's ability to implement it effectively (addressing Facilitating Conditions), and trust that patron privacy will be protected (a prerequisite for adoption) all feature prominently in the literature. Ennajeh and Najjar (2024) explicitly identify trust's mediating role, suggesting that theoretical models of library technology adoption should incorporate trust as a distinct construct.

6.3 Barriers to Adoption and Implementation Challenges

The discussion must also acknowledge persistent barriers. Hussain (2021) comprehensively catalogues financial constraints, technical complexity, skills shortages, and privacy concerns as formidable obstacles. These challenges are particularly acute for smaller libraries or those in under-resourced settings. The cost of RFID infrastructure, blockchain development expertise, and ongoing maintenance may prove prohibitive without external funding or collaborative arrangements.

Privacy concerns merit particular attention. While blockchain's transparency is often celebrated, libraries must carefully navigate the tension between transparent operations and patron confidentiality. Implementing these technologies requires deliberate design choices, such as off-chain storage of personally identifiable information, that preserve privacy while leveraging blockchain's security benefits.

The findings also reveal gaps between conceptual promise and empirical evidence. Many blockchain applications remain theoretical or confined to controlled experiments; large-scale, longitudinal evaluations in

authentic library settings are conspicuously absent. This gap between rhetoric and evidence represents a critical limitation in the current literature.

6.4 Theoretical Implications

This review advances theoretical understanding of technology adoption in libraries in several ways. First, it extends the application of UTAUT2 to the specific context of emerging Industry 4.0 technologies in library settings, demonstrating the framework's utility for analysing both individual and organizational adoption determinants.

Second, the analysis reveals that "Trust" operates as a critical overarching construct that, while implicit in UTAUT2, deserves explicit attention in public sector and privacy-sensitive contexts. Future theoretical work should consider incorporating a "Perceived Trust" variable that mediates relationships between technological features and adoption intentions.

Third, the synthesis demonstrates that integrated technologies (BCT + IoT) create value beyond the sum of their parts, suggesting that theoretical models must account for technological complementarity. Libraries considering these technologies face not independent adoption decisions but choices about interconnected systems.

6.5 Practical Implications for Library Stakeholders

The findings yield actionable implications for diverse stakeholders.

For Librarians and Library Administrators

- Begin with manageable IoT pilots, RFID inventory systems or smart study space monitoring, that demonstrate value with manageable investment and complexity.
- Invest proportionally in staff training and development; addressing the "Effort Expectancy" barrier is as important as acquiring technology.
- Engage patrons early in the design process, communicating clearly how technologies enhance service while protecting privacy to build the "Trust" essential for adoption.
- Develop phased implementation roadmaps that sequence IoT and blockchain investments strategically, recognizing their interdependencies.

For System Developers and Technology Vendors

- Prioritize user-centred design that minimizes complexity for both staff and patrons, addressing Effort Expectancy concerns.
- Develop integrated BCT-IoT platforms specifically tailored to library workflows rather than expecting libraries to adapt generic solutions.
- Build privacy-preserving features by design, incorporating techniques such as zero-knowledge proofs or off-chain data storage.
- Provide clear, jargon-free documentation and training materials that demystify these technologies for non-specialist audiences.

For Policymakers and Funding Bodies

- Recognize that technology adoption requires investment not only in hardware but in standards development, open-source software, and comprehensive training programs.
- Support collaborative initiatives that enable resource-sharing among libraries, reducing individual institutional burdens.
- Fund demonstration projects and longitudinal evaluations that build the evidence base for BCT-IoT effectiveness in libraries.
- Develop policy frameworks that address data governance, privacy protection, and ethical guidelines for smart library technologies.

7. Conclusion and Future Research Directions

7.1 Conclusion

This systematic review has synthesized the fragmented literature on Blockchain and Internet of Things integration in library management, revealing a coherent trajectory toward what is increasingly termed "Library 4.0." The evidence demonstrates that these technologies collectively promise unprecedented levels of automation, transparency, and operational efficiency.

Blockchain's immutable, decentralized ledger offers a robust foundation for securing circulation records, managing digital rights transparently, and establishing trusted interlibrary loan systems. These capabilities fundamentally address libraries' historical challenges of data integrity and patron trust. IoT extends this intelligence into the physical realm, enabling real-time resource management, automated inventory, and personalized, context-aware services that respond dynamically to user behaviour and environmental conditions.

The critical insight emerging from this synthesis is the synergistic potential of BCT-IoT integration. Blockchain provides the essential governance and security layer for IoT-generated data streams, transforming raw sensor data into verifiable, trustworthy records. This integration creates value beyond the sum of its parts, enabling automated processes that remain transparent and accountable, a combination essential for public institutions like libraries.

However, the literature equally documents significant barriers. Financial costs, technical complexity, skills shortages, and unresolved privacy concerns remain formidable obstacles, particularly for under-resourced libraries. These challenges are not merely technological but organizational and strategic, requiring institutional commitment, professional development, and thoughtful policy frameworks to overcome.

Ultimately, the successful transition to BCT-IoT-enabled smart libraries depends on balancing technological promise with human factors. The UTAUT2 analysis reveals that adoption will be shaped by perceived performance benefits, ease of use, organizational support, social influence, and critically trust. With strategic planning that addresses both technological capabilities and human concerns, the integrated BCT-IoT model offers a compelling pathway toward more resilient, responsive, and engaging libraries.

7.2 Future Research Directions

This review identifies significant gaps in the current literature and proposes five priority directions for future research.

1. Development of Standardized, Scalable Reference Architectures. The literature lacks open-source, standardized architectural models for BCT-IoT systems tailored to libraries of varying sizes and resource levels. Future research should focus on developing reference architectures that specify technology stacks, data standards, interoperability protocols, and security requirements. Such frameworks would lower implementation barriers, promote best practices, and enable comparability across different library settings.

2. Empirical Case Studies and Longitudinal Evaluations. The predominance of conceptual frameworks and theoretical proposals in the current literature highlights an urgent need for empirical research. Future studies should implement and evaluate real-world pilot projects in diverse library settings—academic, public, special, and school libraries. Longitudinal designs tracking implementation over multiple years would capture evolving challenges, user perceptions, and realized benefits, building the evidence base that practitioners and policymakers require.

3. Integration with Artificial Intelligence and Machine Learning. The convergence of BCT, IoT, and artificial intelligence represents a powerful but underexplored opportunity. Future research should investigate how AI and machine learning algorithms can analyse the secure, trustworthy data generated by BCT-IoT systems to deliver predictive analytics for collection management, personalize user recommendations, and enable intelligent, automated decision-making. Questions of algorithmic transparency, bias, and accountability in this integrated context require particular attention.

4. Ethical, Legal, and Governance Frameworks. As libraries adopt increasingly powerful technologies, robust governance frameworks become essential. Future research must critically examine the ethical implications of pervasive sensing (IoT) and immutable record-keeping (blockchain) in public institutions. Key questions include: How can libraries balance transparency with patron privacy? What data governance models ensure that patron information is protected while enabling beneficial services? How should intellectual property rights be managed in blockchain-based DRM systems? Research should propose clear policy guidelines that enable innovation while protecting fundamental library values.

5. User-Centred Design and Adoption Studies. While this review has analysed adoption through the UTAUT2 lens, primary research directly engaging librarians and patrons is needed. Future studies should investigate how different user groups perceive BCT-IoT technologies, what factors facilitate or impede their

adoption, and how system design can address diverse user needs. Special attention should be paid to equity considerations, ensuring that smart library technologies serve all community members, including those with limited digital literacy or access.

6. Cross-Sectoral Learning and Knowledge Transfer. Finally, future research should facilitate cross-sectoral learning by systematically analysing BCT-IoT implementations in domains such as healthcare, education, and supply chain management, distilling lessons applicable to libraries. Conversely, insights from library implementations may inform other cultural heritage institutions, including archives and museums, creating opportunities for collaborative development and shared infrastructure.

By pursuing these research directions, the library and information science community can build the theoretical understanding and practical knowledge necessary to realize the transformative potential of Blockchain and IoT technologies, ensuring that libraries remain vital, trusted institutions in an increasingly digital world.

Authors Contributions

All the authors participated in the ideation, development, and final approval of the manuscript, making significant contributions to the work reported

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Conflict of Interest

The authors declare no conflict of interest.

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Data Availability Statement

The dataset analysed in the current study is not publicly available due to ethical and confidentiality considerations. However, it is available from the corresponding author upon reasonable request, subject to institutional approval.

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