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The Evolution of Smart Libraries in Universities: A Systematic Review of Technological Trends and Sustainability Challenges

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Abstract

The rapid development of digital technologies has transformed university libraries from being primarily collection-based repositories to becoming more intelligent, connected, and user-focused knowledge environments. The systematic review seeks to synthesize the literature indexed in Web of Science and Scopus to explore the technological trends, sustainability dimensions, and implementation challenges of smart libraries in universities. The publications examined covered the period from January 2015 to June 2025. A PRISMA 2020 reporting framework guided the review. The database searches yielded 16,061 records, and 4,818 duplicates were removed, leaving 11,243 records for title and abstract screening. A total of 1847 publications were taken forward for full text review, of which 42 met the stated eligibility criteria and were included in the thematic synthesis. The evidence base comprised systematic reviews, survey-based quantitative studies, mixed-methods studies, qualitative case studies, and conceptual or theoretical publications. The most often represented technology was AI, followed by the Internet of Things (IoT), big-data analytics, cloud computing, augmented and virtual reality, and blockchain. Environmental management, financial planning, human-capital development, governance, and institutional partnerships shaped sustainability. Major barriers to implementation included poor ICT infrastructure, financial limitations, absence of professional skills, resistance to organizational change, data privacy and regulatory concerns, as well as unequal access to digital technologies. The review implies that smart-library development should be viewed as a sociotechnical transformation rather than a technology-acquisition exercise. Sustainable implementation will therefore need phased investment, ongoing professional development, user-centered design, privacy-sensitive data governance, interoperable infrastructure and explicit attention to equity and inclusion.

Keywords: smart libraries; university libraries; artificial intelligence; Internet of Things; digital transformation; sustainability; emerging technologies.

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1. INTRODUCTION

Digital technologies are changing the ways in which knowledge is produced, organized, discovered, accessed, and used. University libraries are in the midst of this profound transformation. For the past several decades, the traditional library, long concerned with physical collections, cataloging, circulation, and mediated reference services, has become ever more integrated with systems, electronic resources, digital repositories, networked discovery services, and automated workflows. The current stage of this evolution is marked by the rise of smart-library environments, where technologies, people, services, data, and physical spaces are interconnected and increasingly attuned to the needs of users (Adigun et al., 2024; Schöpfel, 2018).

Smart libraries are distinct from earlier models of digital libraries in that they are characterized by more than just the digitization of collections or by online access. Instead, they blend intelligent technologies and data-driven processes with user-centered services, adaptive physical environments, and institutional governance. Cao et al. (2018) developed a conceptualization of the smart library based on a service-led principle, suggesting that technology should support meaningful outcomes for users. Gul and Bano (2019) further identified smart buildings, smart environments, smart governance, and smart people as interrelated dimensions of smart-library development. Yunus et al. (2025) also synthesized smart libraries across the dimensions of smart services, users, governance, spaces, and technologies.

The technological basis of this transformation is broad. Artificial intelligence and machine learning power intelligent search, recommendation, automation, metadata generation, conversational services, and predictive analytics. IoT technologies link physical environments and devices for inventory control, occupancy monitoring, environmental sensing, and energy management. Big-data analytics enable evidence-informed decisions for collection and service, and cloud computing provides scalable infrastructure and remote access. With AR and VR, immersive learning, navigation, exhibitions, and virtual engagement reach a new level of possibility. Blockchain has been proposed for provenance, digital rights management, identity, and transaction integrity.

However, technological sophistication alone does not necessarily translate into sustainable or equitable library services. Universities face challenges with infrastructure readiness, financial capacity, staff skills, interoperability, cybersecurity, privacy, organizational culture, governance, and accessibility. The challenges are particularly prominent in low- and middle-income countries (LMICs), where unreliable connectivity, electricity constraints, limited budgets, and lack of specialized technical skills may hinder technology adoption (Achugbue et al., 2023; Darko Adjei & King, 2024; Mwantimwa & Msoffe, 2025).

Although the literature on smart libraries has grown significantly, it remains fragmented in terms of technologies, geographical contexts, service functions, and conceptual approaches. Existing reviews have focused on specific technologies or aspects of digital transformation, but they have not integrated technology, sustainability, human capacity, governance, and equity within a single university-library perspective. Hence, a systematic synthesis is valuable in identifying convergent patterns and enduring gaps.

We aim to address this need by synthesizing literature indexed in Web of Science and Scopus for the period January 2015 to June 2025. The review is organized around three inter-related dimensions, which are technological trends, sustainability requirements, and implementation challenges. The main research question is:

What are the key technological trends, sustainability dimensions, and implementation challenges associated with the development of smart libraries in universities from 2015 to 2025?

This review aims to (a) identify the major technologies associated with the development of smart libraries, (b) examine the main dimensions of sustainability, (c) identify the recurring implementation challenges, and (d) draw practical implications for university library administrators, policy makers, ICT professionals, and researchers.

2. LITERATURE REVIEW AND CONCEPTUAL BACKGROUND

2.1 Historical Evolution from Traditional to Smart Libraries

The historical evolution of libraries is a helpful background to understand the smartlibrary concept. The earliest libraries were mainly collections of administrative, religious, and cultural knowledge. The advent of printing and later the standardization of bibliographic arrangement allowed libraries to grow their collections and their communities of users. In the twentieth century, the institutional infrastructure of modern librarianship was created by professional cataloging, classification, circulation systems, and library networks (Candela et al., 2012; König et al., 2013).

Computers and the internet brought us digital libraries and electronic information resources. Libraries introduced automated cataloging, circulation, online public access catalogs, electronic databases, institutional repositories, and remote authentication. RFID then allowed for automatic identification, inventory control, and self-service circulation (Manuwa et al., 2023; Mohideen et al., 2012). These developments laid the technological foundation for connected and intelligent library environments.

Another transition is the smart-library paradigm. Smart libraries do not consider technologies as isolated tools, but as part of an ecosystem in which data, physical infrastructure, staff, users, services, and governance are in continuous interaction. The shift in the strategic role of librarians is from primarily managing collections and access systems to a greater involvement with data governance, digital pedagogy, AI-enabled services, technology assessment, and user experience design.

2.2 Defining Smart Libraries

There is no single definition of a smart library that everyone can agree to. It has been applied to intelligent technologies, smart physical environments, data-driven services, and wider sociotechnical ecosystems. Cao et al. (2018) highlighted service outcomes, while Gul and Bano (2019) focused on smart buildings, environments, governance, and people. Schöpfel (2018) put smart libraries in a broader context of the development of smart infrastructures, and Orji and Echezonamanyira (2021) talked about the question of what is a ‘smart’ library.

For the purposes of this review, a smart library is a university-library setting that integrates advanced digital technologies such as AI, IoT, big-data analytics, cloud computing, immersive

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technologies and their associated intelligent systems with people, physical spaces, services and governance mechanisms to provide responsive, efficient, sustainable, secure, accessible and user-centered information services. This is a deliberately sociotechnical definition: technology is seen as a vehicle for institutional and service change, not as an end in itself.

2.3 Theoretical Perspectives

Smart libraries are the interaction of technical and social subsystems, and so sociotechnical systems theory is a particularly useful lens. Performance of technology depends on competence of staff, behavior of users, structures of organizations, leadership, resources of institutions and governance. This view suggests that failure to implement does not occur when the technology is not technically good enough but when the organizational system surrounding the technology is not ready to use the technology effectively (Adhikari & Paswan, 2024; Orji & Echezonamanyira, 2021).

Technology Acceptance Model views adoption in terms of perceived usefulness, perceived ease of use, attitudes, and other social influences. The adoption in the library setting is expected to be affected by the perceived relevance of intelligent services, user confidence, staff competencies, trust, and organizational support (Khan et al., 2025; Tella et al., 2025). Service-dominant logic adds to this by seeing service value as co-created through interaction between libraries and users. Governance theory introduces concepts of participation, accountability, data stewardship, privacy, and institutional decision-making (Jadhav & Shenoy, 2020; Sayogo et al., 2022). These viewpoints together present a complete picture regarding the transformation of smart libraries.

3. METHODOLOGY

3.1 Review Design and Reporting Framework

This study was designed as a systematic review of the literature. The reporting was structured following the PRISMA 2020 statement, which offers a 27-item reporting framework to improve the transparency and completeness of systematic reviews (Page et al., 2021). PRISMA 2020 distinguishes between reporting guidance and the conduct and methodological quality assessment of a review; therefore, it is only used here as a reporting framework and not as a quality-assessment instrument (Page et al., 2021).

The review question, eligibility criteria, search strategy, screening process, data extraction fields, and thematic synthesis approach were detailed before the final synthesis. The review included publications from January 2015 to June 2025.

Note on dates of search execution: The exact calendar dates on which the Web of Science and Scopus searches were executed are not recorded in the research documentation provided for this manuscript. The author states this explicitly here, rather than give an unverified date, and will include the verified search date(s) held in the original search log before submission. This is flagged again in Section 7 (Limitations) so that it is not missed at the proofing stage.

3.2 Information Sources

Two bibliographic databases were searched: Web of Science and Scopus. Their selection was based on their wide multidisciplinary scope and applicability to library and information science, information technology, computer science, education, and related fields. The search was limited to a publication window and language of publication (English).

3.3 Search Strategy

Database-specific Boolean strategies combined terms for smart or intelligent libraries, universities or academic libraries, emerging technologies, sustainability, challenges, trends, and digital transformation. Table 1 shows the search syntax and retrieved records.

Database	Search strategy	Records retrieved
Web of Science	TS=(“smart librar*” OR “intelligent librar*”) AND TS=(“universit*” OR “academic librar*”) AND TS=(technology* OR “artificial intelligence” OR “internet of things” OR IoT OR “big data” OR “cloud computing”) AND TS=(sustainab* OR challenge* OR trend* OR “digital transformation”)	6,847
Scopus	TITLE-ABS-KEY(“smart librar*” OR “intelligent librar*”) AND TITLE-ABS-KEY(“universit*” OR “academic librar*”) AND TITLE-ABS-KEY(technology* OR “artificial intelligence” OR “internet of things” OR IoT OR “big data” OR “cloud computing”) AND TITLE-ABS-KEY(sustainab* OR challenge* OR trend* OR “digital transformation”)	9,214

The two searches produced 16,061 records in total (Web of Science = 6,847; Scopus = 9,214). Zotero was used for reference management and duplicate removal, resulting in 11,243 unique records for screening.

3.4 Eligibility Criteria

Inclusion criteria were: (1) peer-reviewed journal articles or peer-reviewed conference proceedings; (2) a focus on smart libraries or emerging technologies in academic or university-library contexts; (3) publication between January 2015 and June 2025; (4) English-language publication; and (5) substantive relevance to technological trends, sustainability, implementation challenges, or conceptual development of smart libraries.

Exclusion criteria were: (1) non-peer-reviewed material such as editorials or unsupported opinion pieces; (2) studies focused exclusively on public, school, or special libraries without university relevance; (3) publications outside the review period; (4) non-English publications; and (5) publications that did not substantively address smart-library technologies, sustainability, or implementation challenges.

3.5 Study Selection

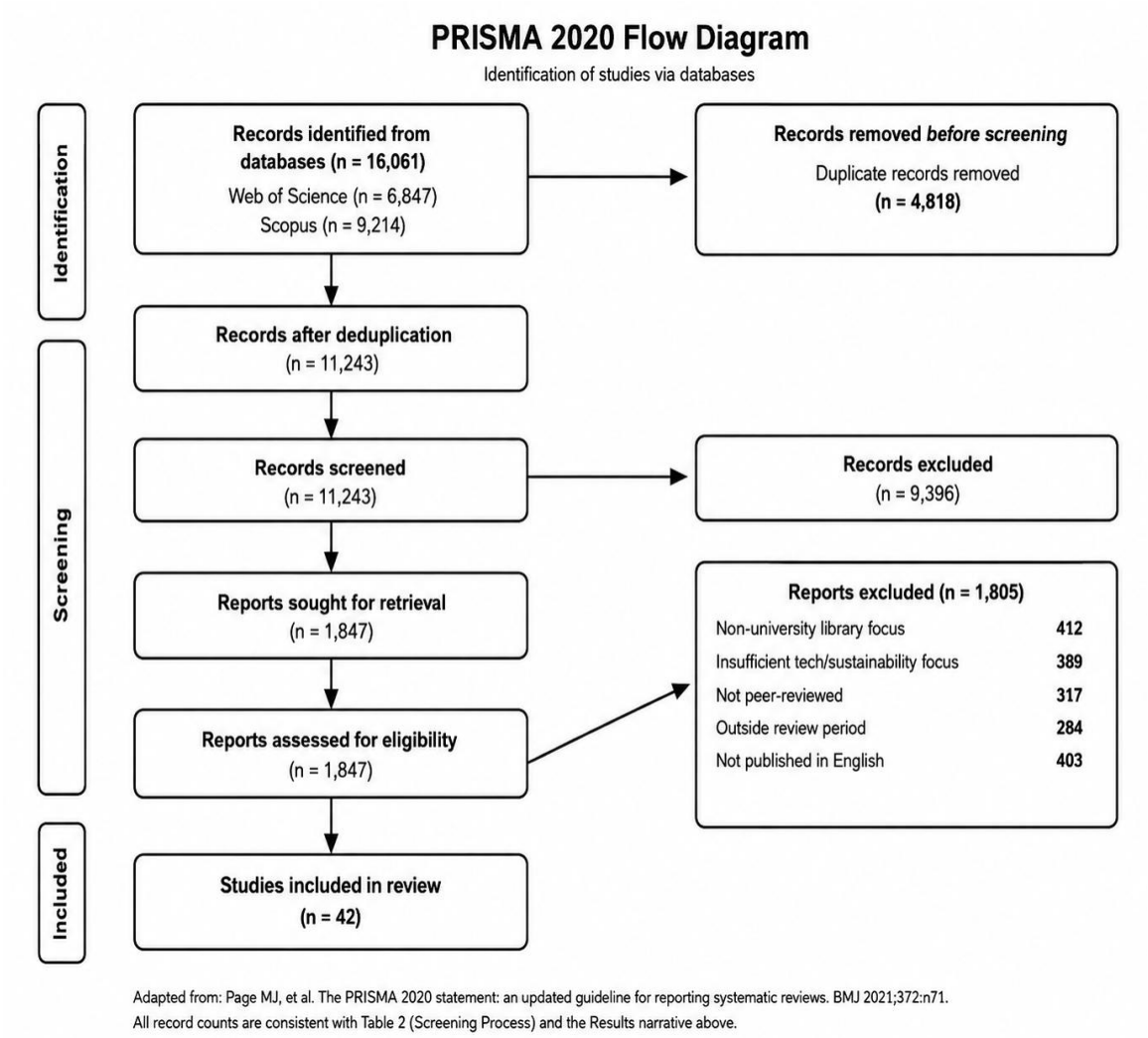
The selection process comprised title-and-abstract screening followed by full-text assessment. Two reviewers independently screened the records against the eligibility criteria. Disagreements were resolved through discussion and, where necessary, consultation with a third reviewer. Cohen's kappa was reported as $\kappa = .84$, indicating a high level of inter-rater agreement (Landis & Koch, 1977).

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Screening stage	Records	Outcome
Records identified	16,061	Web of Science 6,847 + Scopus 9,214
Duplicates removed	4,818	Records removed using Zotero
Records screened	11,243	Title and abstract screening
Records excluded at screening	9,396	Not progressed to full text
Full-text publications assessed	1,847	Eligibility assessment
Full-text publications excluded	1,805	Reasons reported below
Eligible publications included	42	Final synthesis

The PRISMA flow is presented in Figure 1. The reported full-text exclusion categories total 1,805: public/special library focus (412), insufficient focus on smart technologies or sustainability (389), not peer-reviewed (317), outside the review period (284), and non-English (403).

Figure 1. PRISMA 2020 flow diagram of the study-selection process.



3.6 Quality Appraisal

The original research record reported use of the Mixed Methods Appraisal Tool (MMAT; Hong et al., 2018) and a mean score of 3.8 (SD = 0.7) across 42 publications. However, the evidence base includes systematic reviews and conceptual/theoretical publications as well as primary quantitative, mixed-methods, and qualitative studies. Because a single aggregate MMAT score across heterogeneous publication types may not be methodologically appropriate, the present article does not use the reported mean score as a definitive quality statistic. Instead, the review transparently reports the composition of the evidence base and treats methodological heterogeneity as a limitation. Design-appropriate, study-by-study appraisal results (qualitative studies assessed with a qualitative tool, quantitative studies with a quantitative tool, and so on) are to be reported in Supplementary Table S2 once that matrix has been compiled (Section 3.8; Section 7).

3.7 Data Extraction and Thematic Synthesis

Data were extracted into a structured spreadsheet. The extraction fields included author and year, geographical setting, research design, technology focus, sustainability dimensions, implementation challenges, and principal findings. Thematic synthesis was used to organise the evidence (Thomas & Harden, 2008). The synthesis involved coding relevant findings, grouping

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related codes into descriptive themes, and developing higher-order analytical themes. Three overarching domains were retained: technological trends, sustainability, and implementation challenges.

3.8 Treatment of Systematic Reviews within the Evidence Base

Out of the 42 publications falling within the inclusion criteria, 14 were systematic (or scoping) reviews and 28 were primary empirical studies (survey-based quantitative, mixed-methods, qualitative or conceptual/theoretical work; see Section 4.1). Because systematic reviews synthesize findings from other primary studies, some of which might overlap with each other or with the primary studies that are captured independently in this evidence base, there is a legitimate concern that the reported thematic frequencies (Sections 4.2 to 4.4) might partly be a reflection of repeated counting of the same underlying evidence rather than 42 fully independent observations.

This is addressed transparently rather than treated as a minor caveat. The 14 systematic reviews were retained in the primary synthesis because they contribute their own higher-order analytical content — cross-study patterns, conceptual framing, and gap analysis — that is not reducible to the primary studies they cite, and because excluding them outright would have discarded relevant conceptual evidence rather than corrected for overlap. At the same time, the methodologically rigorous response to this concern is a sensitivity analysis that re-runs the thematic frequency counts on the 28 primary studies alone and compares the resulting pattern against the full 42-study count.

That sensitivity analysis is not reported in this version of the manuscript because it requires a study-by-study coding matrix — which publications were coded under which themes — that is not part of the research record currently available for this write-up. Approximating that comparison without the underlying matrix would risk presenting invented figures as findings, which this review does not do. The sensitivity analysis excluding the 14 systematic reviews is therefore named as the single highest-priority addition before this manuscript is finalised for submission (Section 7), and the composition of the evidence base (14 reviews / 28 primary studies) is reported throughout Section 4 so that readers can weigh the frequency counts accordingly in the meantime.

4. RESULTS

4.1 Overall Characteristics of the Evidence Base

Characteristic	**Finding**
Total records retrieved	16,061
Records after deduplication	11,243
Full-text publications assessed	1,847
Eligible publications included	42
Asia	36%
Africa	24%
Europe	21%
North America	12%
Other regions	7%
Systematic reviews	14
Survey-based quantitative studies	11
Mixed-methods studies	9
Qualitative case studies	6
Conceptual/theoretical papers	2

Geographical distribution shows a strong representation from Asia and Africa, followed by Europe and North America. China, Nigeria, South Africa, India, and the United States were found to be among the most frequently represented countries. The evidence base is methodologically heterogeneous, with systematic reviews forming the largest single category, followed by survey-based quantitative studies, mixed-methods research, qualitative case studies, and conceptual or theoretical contributions.

The dataset available also shows an increase in publications from around 2019 onward. This is consistent with the increasing interest in AI, IoT, data analytics, and intelligent service environments in academic circles toward the end of the review period.

4.2 Technological Trends

4.2.1Artificial Intelligence and Machine Learning

AI was the most frequently represented technology, appearing in 38 of the 42 included publications. Applications described in the evidence include automated cataloguing and metadata generation, recommendation systems, natural-language interfaces, intelligent discovery, predictive analytics, conversational reference, and decision support (Cox, 2023; Das & Islam, 2021; Mwantimwa & Msoffe, 2025). AI therefore appears not simply as an operational automation technology but as a mechanism for reshaping the relationship between users, information resources, and library professionals.

Generative AI represents a particularly important emerging development. Conversational systems can support reference interactions, multilingual assistance, summarisation, information discovery, and user guidance. At the same time, the literature highlights risks involving hallucination, accuracy, bias, intellectual-property concerns, privacy, and over-reliance on automated outputs. These risks reinforce the importance of AI literacy for both librarians and users (Abiolu & Akinyemi, 2025; Cox, 2023).

4.2.2Internet of Things

IoT was in 31 of 42 publications. Smart-library IoT applications comprise RFID-based inventory and circulation, environmental sensing, occupancy monitoring, energy management, intelligent lighting, security, and automated service points (Adhikari & Paswan, 2024; Mishra, 2023). IoT may establish an operational ecosystem by connecting the library building, collections, and devices, and users.

Combining IoT with AI and analytics provides opportunities for predictive and adaptive management. But more connectivity also means a larger attack surface and risks around unauthorized access, device security, data leakage, and surveillance. Therefore, the IoT implementation has to integrate cybersecurity and privacy safeguards from the design phase (Tawalbeh et al., 2020).

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4.2.3Big-Data Analytics

Big-data analytics was identified in 27 publications. Library systems generate data through discovery interfaces, circulation, electronic resources, reference interactions, institutional repositories, and physical-space use. Analysing these data can support collection development, service evaluation, resource allocation, user-experience analysis, and evidence-based management (Adewojo & Dunmade, 2024; Zeng et al., 2022).

The value of analytics depends on data quality, interoperability, staff capability, and governance. Resource-constrained institutions may face difficulties in collecting standardised data and developing analytical capacity. Consequently, smart-library strategies should prioritise data readiness and staff competencies alongside technological acquisition.

4.2.4Cloud Computing

Cloud computing was discussed in 24 publications. Cloud-based library systems can reduce dependence on locally maintained infrastructure, facilitate remote access, support scalable storage and processing, and enable collaboration among institutions. These advantages are particularly relevant to universities seeking flexible infrastructure for hybrid learning and distributed access.

Cloud adoption also introduces vendor dependency, recurring subscription costs, data-sovereignty issues, interoperability concerns, and dependence on reliable connectivity. Institutions therefore need procurement and governance frameworks that assess total cost of ownership, data location, portability, service continuity, and exit strategies.

4.2.5AR, VR and Immersive Technologies

AR and VR were discussed in 19 publications. Applications include virtual library tours, wayfinding, immersive learning, visualisation, exhibitions, data exploration, and remote engagement (Naikar & Paul, 2025; Shahzad et al., 2025; Su & Chen, 2022). These technologies can enrich the library as a learning environment rather than simply a resource-access point.

However, adoption remains constrained by hardware costs, content-development requirements, technical expertise, accessibility considerations, and limited evidence concerning long-term educational outcomes. Libraries should therefore evaluate immersive technologies through demonstrable learning and service outcomes rather than novelty alone.

4.2.6Blockchain

Blockchain was discussed in 11 publications. Proposed applications include digital rights management, provenance, transaction logging, credential verification, and protection against unauthorised alteration of records (Shahzad & Khan, 2023). Despite these potential advantages, implementation is constrained by technical complexity, interoperability, governance, and energy considerations associated with some blockchain architectures.

4.3 Sustainability Dimensions

4.3.1Environmental Sustainability

Environmental sustainability was identified in 28 publications. Smart-building technologies such as intelligent lighting, HVAC control, occupancy sensing, and environmental monitoring can contribute to more efficient resource use (Aliero et al., 2022; Gul & Bano, 2019). The environmental value of smart libraries, however, depends on the lifecycle of hardware, energy consumption of digital infrastructure, equipment replacement, and responsible e-waste management.

Environmental performance should therefore be incorporated into technology procurement and evaluation. Libraries can use indicators such as energy use, equipment lifecycle, server utilisation, paper reduction, and e-waste management to connect digital transformation with institutional sustainability goals.

4.3.2Financial Sustainability

Financial sustainability was identified as a critical issue in 35 publications. Smart-library systems require expenditure not only for initial procurement but also for licences, maintenance, upgrades, cybersecurity, staff development, replacement cycles, and technical support. Short technology lifecycles can create recurrent financial pressures.

A sustainable financial model should therefore evaluate total cost of ownership rather than acquisition price alone. Shared infrastructure, consortial procurement, open standards, open-source systems where appropriate, competitive grants, institutional partnerships, and phased implementation can help reduce financial risk. However, funding strategies must also preserve service equity and avoid excessive dependence on short-term external projects.

4.3.3Human Capital and Capacity Building

Human capital emerged as one of the strongest sustainability dimensions, appearing in 39 publications. Continuous professional development is required in AI literacy, data management, IoT, cybersecurity, digital preservation, user-experience design, analytics, and technology evaluation. The smart-library transition therefore expands the professional competency profile of librarians.

The literature also highlights user capacity. A technologically advanced library cannot be considered successful if users lack the skills or confidence to engage with its services. Digital-literacy programmes, user orientation, accessible interfaces, multilingual support, and inclusive design should therefore be treated as core components of smart-library development.

4.3.4Governance and Institutional Frameworks

Governance was identified in 30 publications. Smart-library governance includes strategic alignment, stakeholder participation, accountability, data governance, privacy, cybersecurity, procurement, interoperability, and technology evaluation. Libraries that operate outside university-wide digital strategies risk duplication of infrastructure and fragmented decision-making.

Institutional governance should therefore integrate library leadership into university digital-transformation planning. Governance frameworks should also define responsibility for data stewardship, algorithmic accountability, cybersecurity, vendor management, and ethical use of emerging technologies.

4.4 Implementation Challenges

4.4.1Infrastructure Deficits

Infrastructure deficits were the most frequently reported implementation challenge, appearing in 40 of 42 publications. Problems include unreliable electricity, limited bandwidth, inadequate network coverage, outdated hardware, insufficient computing resources, and weak technical support. These barriers

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directly affect service reliability and user trust, particularly in resource-constrained environments (Adhikari & Paswan, 2024; Mwantimwa & Msoffe, 2025).

A phased infrastructure strategy is therefore preferable to technology adoption that exceeds institutional readiness. Basic connectivity, backup power, network security, equipment maintenance, and reliable access should be established before complex intelligent services are introduced.

4.4.2Financial Constraints

Financial constraints appeared in 38 publications. The challenge extends beyond initial investment to recurring costs associated with licensing, maintenance, upgrades, staff training, security, and technology replacement. Sustainable implementation requires multi-year financial planning and explicit recognition of total cost of ownership.

4.4.3Resistance to Organisational Change

Resistance to change was identified in 29 publications. Staff may fear job displacement, disruption of established routines, or loss of professional autonomy, while users may question the value or reliability of unfamiliar systems. Participatory implementation, communication, training, and co-design can reduce resistance by giving stakeholders a meaningful role in transformation (Cao et al., 2018; Tella et al., 2025).

The evidence therefore supports a change-management approach in which smart technologies are framed as augmenting professional work rather than simply replacing human labour. Librarians remain essential for contextual judgement, ethical oversight, information-literacy education, and user advocacy.

4.4.4Data Privacy and Regulatory Compliance

Privacy and regulatory concerns appeared in 33 publications. Smart libraries may process borrowing histories, search behaviour, electronic-resource use, location-related data, and, in some settings, biometric or sensor-generated information. AI and analytics can create additional risks because apparently innocuous data may be combined to infer sensitive patterns.

Privacy-by-design principles should therefore include data minimisation, purpose limitation, access controls, retention schedules, transparency, consent where appropriate, security safeguards, and mechanisms for accountability. Regulatory obligations vary by jurisdiction, making institutional data-governance policies essential (Mone & Sivakumar, 2022; Rajačić et al., 2025).

4.4.5Digital Divide and Equity

The digital divide was identified in 26 publications. Smart-library systems can unintentionally widen inequality when services depend on device ownership, high-speed connectivity, advanced digital skills, or physical access to well-resourced campuses. Students and researchers with disabilities, those from disadvantaged backgrounds, and users with limited digital experience may be disproportionately affected.

Equity therefore needs to be designed into smart-library services through accessible interfaces, assistive technologies, multilingual resources, alternative service channels, digital-literacy support, and outreach. Smartness should not be equated with technological complexity; an equitable smart library is one that improves meaningful access across diverse user groups.

5. DISCUSSION

5.1 Smart Libraries as Sociotechnical Ecosystems

The synthesis indicates that smart-library development is best understood as a sociotechnical transformation. AI, IoT, analytics, cloud platforms, and immersive technologies are important, but their value depends on the organisational and human environment in which they are implemented. The prominence of human capital in the evidence base reinforces this conclusion: technological systems require professionals capable of evaluating, configuring, governing, explaining, and ethically using them.

This finding challenges technology-centred approaches to library innovation. Purchasing intelligent systems does not itself create a smart library. Smartness emerges when technology is connected to institutional objectives, user needs, professional capabilities, data governance, and measurable service outcomes. This interpretation is consistent with service-led conceptualisations of smart libraries (Cao et al., 2018) and broader sociotechnical perspectives (Schöpfel, 2018; Orji & Echezonamanyira, 2021).

5.2 Technology Adoption Must Be Needs-Driven

The evidence suggests that universities should resist technology adoption driven primarily by novelty. AI, IoT, AR/VR, blockchain, and analytics each have different costs, competencies, risks, and potential benefits. Institutions should begin with clearly defined service problems and then identify the technology that provides the most appropriate response.

A needs-driven approach is particularly important in LMIC settings. Rather than attempting to replicate high-resource smart campuses immediately, institutions can prioritise high-impact interventions such as reliable connectivity, RFID-based inventory, cloud-supported discovery, digital-literacy services, open-source platforms, and targeted AI applications. Progressive development can then occur as infrastructure, funding, and professional capacity mature.

5.3 Sustainability Requires More Than Financial Resources

The review demonstrates that sustainability has environmental, financial, human, organisational, and governance dimensions. A library may possess sufficient funds to purchase advanced technology but still fail to sustain it because staff lack competencies, systems cannot interoperate, data governance is weak, or recurrent costs are underestimated. Sustainability should therefore be assessed across the entire technology lifecycle.

The strongest evidence for human-capital development is particularly important. Continuous learning should be institutionalised through professional-development plans, communities of practice, vendor training, peer learning, and collaboration with academic departments in computer science, education, data science, and related fields.

5.4 Trust, Privacy and Ethical Governance

The expansion of AI and IoT increases the quantity and sensitivity of information processed by libraries. This creates a tension between personalisation and privacy. Smart services may become more responsive when they have more information about users, but the collection and analysis of such information can undermine trust if users do not understand what is collected or how it is used.

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Ethical governance should therefore be considered a core infrastructure component. Libraries should adopt transparent data policies, minimise unnecessary collection, establish retention and deletion procedures, conduct privacy and security assessments, and maintain human oversight of high-impact automated decisions. These principles are especially important because libraries traditionally occupy a trusted position in the information ecosystem.

5.5 Equity as a Defining Characteristic of Smartness

The digital-divide findings indicate that technological sophistication should not be treated as synonymous with institutional progress. A library that provides advanced AI services to a subset of technologically privileged users while excluding users with disabilities, low connectivity, or limited digital literacy cannot be considered fully successful.

Equity should therefore be embedded in technology selection, interface design, service delivery, training, and evaluation. Accessibility and multilingualism should be considered during procurement rather than added after implementation. This approach positions smart libraries as inclusive knowledge infrastructures rather than technology-intensive facilities.

5.6 Toward an Integrative Conceptual Model of Smart-Library Sustainability

Sections 5.1–5.5 discuss five sustainability-relevant themes largely as parallel considerations. Read together, however, the evidence base suggests a more directional relationship among them, which this section makes explicit as a conceptual contribution of the review.

Across the included publications, technology adoption (AI, IoT, analytics, cloud, immersive systems) is consistently described as the visible entry point of smart-library transformation, but its consequences are reported downstream, in organisational change (workflow redesign, new service models), which in turn depends on human capabilities (the professional-development and digital-literacy findings in Section 4.3.3), which in turn is bounded by governance (data stewardship, accountability, procurement — Section 4.3.4), which finally determines whether sustainability outcomes (environmental, financial, and equity-related — Sections 4.3.1, 4.3.2, 5.5) are realised or eroded. Expressed as a chain:

technology adoption -> organisational change -> human capabilities -> governance -> sustainability outcomes

This reframes the six technologies discussed in Section 4.2 not as independent variables competing for institutional attention, but as entry points into a single sociotechnical chain in which the weakest link — often human capabilities or governance rather than the technology itself — determines whether adoption converts into durable sustainability.

This model is explicitly a conceptual, review-derived heuristic. It is induced from recurring patterns and sequencing described across the 42 included publications; it has not been tested against longitudinal or causal data, and the review does not claim to have validated it empirically. It is offered as a framework that future primary research — particularly longitudinal and comparative case studies — could test directly, and as a practical lens for the roadmap presented in Section 6.5.

6. IMPLICATIONS FOR POLICY AND PRACTICE

6.1 Implications for University Administrators

University administrators should incorporate libraries into institutional digital-transformation and sustainability strategies. Smart-library projects should have clearly defined outcomes, multi-year budgets, governance structures, staff-development plans, and evaluation indicators. Library leadership should participate in institutional ICT and data-governance committees to ensure that library-specific requirements are represented in university-wide decisions.

6.2 Implications for Library Administrators

Library administrators should conduct readiness assessments before investing in advanced technologies. Such assessments should examine infrastructure, staffing, data quality, cybersecurity, financial capacity, user needs, accessibility, and institutional support. Implementation should proceed in phases, beginning with interventions that produce demonstrable improvements in service quality and operational efficiency.

6.3 Implications for Library Professionals

Librarians need a broader competency portfolio encompassing AI literacy, data literacy, digital preservation, cybersecurity awareness, analytics, user-experience design, and ethical technology evaluation. Professional development should be continuous rather than limited to one-time technology training. Librarians should also develop the ability to explain AI-generated outputs, identify limitations, and teach users to evaluate algorithmically mediated information critically.

6.4 Implications for ICT Professionals and Vendors

Smart-library systems should be designed for interoperability, scalability, accessibility, security, and portability. Open standards should be preferred where practical, and procurement contracts should address data ownership, portability, service continuity, cybersecurity responsibilities, and exit arrangements. Privacy and security should be built into systems from the beginning rather than addressed as post-implementation compliance issues.

6.5 Proposed Smart-Library Implementation Roadmap

The roadmap below is a conceptual, review-derived planning tool, not an empirically validated implementation model. It synthesises the recurring sequencing of priorities described across the included publications (readiness -> foundation -> intelligent services -> sustainable integration -> continuous evaluation) and applies the technology -> organisational change -> human capabilities -> governance -> sustainability chain proposed in Section 5.6. Institutions should adapt the phases and timelines to their own infrastructure baseline, funding cycle, and governance context rather than applying them as a fixed prescription.

Phase	Priority actions	Expected outcome
Phase 1: Readiness	Infrastructure audit; needs assessment; data audit; governance baseline; staff competency assessment	Institutional readiness profile
Phase 2:	Reliable connectivity;	Stable digital

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Foundation	backup power; secure networks; integrated library platforms; digitisation priorities	infrastructure
Phase 3: Intelligent services	AI-supported discovery; analytics; automation; IoT monitoring; personalised services	Improved service responsiveness and operational efficiency
Phase 4: Sustainable integration	Energy management; lifecycle planning; interoperability; advanced training; privacy governance	Sustainable and accountable smart-library ecosystem
Phase 5: Continuous evaluation	User feedback; accessibility audits; security review; cost-benefit analysis; impact assessment	Evidence-based continuous improvement

7. LIMITATIONS

This review has several limitations. First, the search was restricted to Web of Science and Scopus. Relevant literature indexed in databases such as LISTA, LISA, regional indexes, and other disciplinary databases may therefore have been missed.

Second, only English-language publications were included, which introduces a language bias and may underrepresent scholarship from non-English-speaking regions.

Third, the review covers January 2015 through June 2025, so later developments in rapidly evolving technologies—especially generative AI—are not comprehensively represented in the evidence base.

Fourth, the included publications are methodologically heterogeneous, ranging from systematic reviews and conceptual papers to quantitative, qualitative, and mixed-methods studies. This heterogeneity limits direct comparison and precludes a conventional statistical meta-analysis.

8. CONCLUSION AND RECOMMENDATIONS

This systematic review demonstrates that smart-library development in universities is a multidimensional transformation involving technology, people, services, infrastructure, governance, sustainability, and equity. Across the 42 eligible publications, AI emerged as the most frequently represented technology, followed by IoT, big-data analytics, cloud computing, immersive technologies, and blockchain. At the same time, the evidence shows that technology alone does not determine successful implementation.

Sustainability depends on reliable infrastructure, realistic financial planning, continuous professional development, environmental responsibility, institutional governance, strategic partnerships, and user-centred service design. The most persistent barriers are infrastructure deficits, financial constraints, skill gaps, organisational resistance, privacy and regulatory risks, and unequal access. These challenges are especially important for universities operating in resource-constrained environments.

The review therefore recommends the following:

- Adopt phased, needs-driven smart-library strategies aligned with institutional readiness and clearly defined service outcomes.
- Prioritise reliable connectivity, power resilience, cybersecurity, interoperability, and data quality before introducing highly complex intelligent services.
- Establish continuous professional-development programmes covering AI literacy, data management, analytics, cybersecurity, digital preservation, and user-experience design.
- Develop institutional data-governance and privacy frameworks based on data minimisation, transparency, accountability, appropriate retention, and security.
- Integrate environmental and lifecycle considerations into technology procurement and infrastructure planning.
- Use participatory and user-centred approaches to reduce resistance and ensure that smart services respond to actual academic and research needs.
- Embed accessibility, multilingualism, assistive technologies, and alternative access channels into smart-library design.
- Strengthen collaboration among libraries, university ICT units, academic departments, technology vendors, consortia, and policymakers.
- Evaluate smart-library initiatives through service quality, user outcomes, inclusion, sustainability, security, and total cost of ownership rather than technology adoption alone.
- Future research should develop validated smart-library maturity models and longitudinal evidence on the educational, organisational, environmental, and social impacts of intelligent library services.

Smart libraries should ultimately be understood not as collections of fashionable technologies but as adaptive knowledge ecosystems. Their long-term success will depend on the ability of universities to align technological innovation with professional expertise, responsible governance, sustainable investment, and equitable access.

9. DECLARATIONS

9.1 Funding

No external funding is reported for this review.

9.2 Conflict of Interest

The author declares no conflict of interest in relation to this manuscript.

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9.3 Protocol and Registration

No protocol registration number is reported in the available research record.

9.4 Reporting Guideline

The review was reported with reference to the PRISMA 2020 statement (Page et al., 2021).

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