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SMART LIBRARIES FOR SMART CAMPUSES: IOT AND AI APPLICATIONS IN ACADEMIC LIBRARY SPACES FOR ENGINEERING EDUCATION

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Abstract

Purpose: This study investigates the level of availability of smart libraries in Nigerian universities and studies the essence of the Internet of Things and artificial intelligence. Also, it examines their application in the library space for the enhancement of education in Nigerian universities as part of a benchmark for NUC BMAS. It further situates these representations within frameworks of inclusiveness and the Sustainable Development Goals (SDGs), especially SDG 4 (Education), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 17 (Partnerships for the Goals).

Methods: Following PRISMA 2020, 5,846 records were identified from seven databases and grey literature. After de-duplication and screening, 36 studies were included: 10 Nigerian empirical studies, 9 African/Asian Global South comparators, and 17 global benchmarks, including OECD (2025). Quality appraisal used Manchester CASP and MMAT. Thematic synthesis mapped findings to OECD STI pillars: policy, infrastructure, skills, and governance.

Findings: Most Nigerian academic libraries lack the capacity to embrace AI. 88% of federal university libraries lack functional IoT systems. Systemic barriers include low awareness, low readiness, and poor librarian professionalism. 83% are non-compliant with the Nigeria Data Protection Act, and 79% face power instability. Frugal IoT is viable at ₦24,800 with a 4.2-month ROI, and global evidence shows Chatbots automate 700 queries/month and BERT cuts OPAC retrieval time by 73%. User demand is high, but skills and governance deficits block implementation.

Conclusions: The gap between policy made and the real engineering library practice is institutional, not technological. Smart libraries for smart campuses require coordinated intervention on awareness, skills, governance, and infrastructure.

Implications: A TETFund Intervention Framework is proposed with four pillars: 1) Library 5.0 OPAC upgrades, 2) Frugal IoT pilots, 3) AI Citizenship training with change management, 4) Mandatory DPIA for NDPA compliance. This operationalizes OECD (2025) and Suryawanshi et al.'s (2024) triad to transform libraries into intelligent knowledge hubs for engineering education.

Keywords: *Smart libraries, smart campuses, Internet of Things, Artificial Intelligence, academic libraries, engineering education, Nigeria, Library 5.0, NUC BMAS, SDGs.*

1.0 Introduction

A smart library refers to the merging of the e-Library, Artificial Intelligence (AI), and the Internet of Things (IoT) within the library environment. The development of artificial intelligence has caused a major change from physical books to digital copies within the library environment. Smart libraries, using the Internet of Things (IoT) and Artificial Intelligence (AI), offer solutions through intelligent space management, personalization of resources, and automation of service delivery.

IoT sensors monitor occupancy, environmental parameters, and the use of devices to enable lab and maker spaces. At the same time, AI technology such as chatbots, recommendation engines, and computer vision helps in information search, offers round-the-clock reference help, and analyzes user behavior in order to tailor collections to the engineering curriculum. The rate at which the application of IOT and AI technology is being applied in smart libraries has left an obvious mark in libraries in Asia, Europe, and the United States of America, but not in Africa, especially Nigeria.

The National Universities Commission (NUC) standards and the Tertiary Education Trust Fund (TeTFund) initiatives are geared towards smart library initiatives, which are meant for accreditation and Sustainable Development Goal 4. So far, no research has been conducted regarding the application of the mentioned technologies for engineering education, creating a gap in the knowledge base for decision-making processes of policies and funding implementations. Thus, the present review aims to fill this gap through technology mapping, assessment of the effect of the use of the technologies on learning outcomes and space usage, as well as the analysis of barriers to the adoption of these technologies in academic libraries.

2.0 Literature Review

2.1 Conceptualization of Smart Libraries in Academic Contexts

The concept of smart libraries emerged from smart city frameworks, where IoT and AI converge to create responsive, user-centered environments. Noh (2015) defined smart libraries as those using ubiquitous technologies to provide context-aware services, a definition expanded by Gul and Bano (2019) to include AI-driven personalization and predictive analytics. Cao et al. (2021) synthesized global definitions, positioning smart libraries as socio-technical systems integrating sensors, data, and AI to optimize resources and personalize learning. However, Baryshev et al. (2020) noted most frameworks remain library-general, lacking specificity for STEM or engineering education spaces.

2.2 IoT Applications in Academic Library Spaces

2.2.1 Space and Environmental Monitoring

Nag and Nikose (2020) applied RFID gates (Owolabi et al., 2019), ultrasonic seat sensors, and NodeMCU microcontrollers in a library of an Indian engineering college to deliver 43% improvement in seat search efficiency and a 28% reduction in energy consumption via automated lighting/HVAC control. Bayani et al. (2018) used CO2, temperature, and humidity sensors in library maker spaces to provide ISO-standardized conditions required for 3D printing and PCB labs to support engineering projects.

2.2.2 Real–time Space Utilization Analytics

In China, Li et al. (2021) combined LoRaWAN sensors with library management systems to provide real-time heat maps of collaborative areas, allowing tutors to schedule tutorials based on space availability. Otike and Baro (2020) described a Raspberry Pi–based occupancy system introduced at the University of Nairobi to reduce queuing time during examinations; however, low stability of the power supply resulted in 68% of uptime.

2.3 AI Application for Engineering Education Support

2.2.3 Service Automation: Chatbots and Virtual Reference for Technical Queries

AI chatbots can be seen as a revolutionary step from classical to hybrid reference services in engineering libraries. McNeal and Newyear (2021) have examined a chatbot, "LITA," introduced in MIT Libraries on the Google Dialogflow platform based on 12,000 historical transcripts. Amongst first-year engineering students, LITA assisted in resolving 67% of queries without escalation to the reference librarian staff, with a mean response time of 3.2 seconds against 8.7 minutes for email reference. Query types most effectively answered included: “Where is ASTM E8?”, “Access IEEE Xplore

remotely?", and "How to cite an ASME conference paper". Notably, LITA interfaces with the library's IoT: If students ask "Is the 3D printer free?", then the chatbot checks the maker space occupancy API. In the UK, the University of Manchester employs "Lemur," which uses the Rasa open-source framework and cites data sovereignty as the means. Its training corpus had 4,500 engineering-specific FAQs, and it was interfaced with the university's reading list system. Cox et al. (2019) have reported a reduction in routine queries to liaison librarians by 41%, releasing 6.5 FTE hours per week for embedding teaching in engineering departments. Yet inaccuracies remain. Lemur answered correctly only 29% of Level 3 queries such as "Compare tensile strength of 6061-T6 and 7075-T6 aluminum for aerospace applications" and defaulted to "Here are materials science books". Cost-benefit data is coming out. Lemur's implementation cost was £18,000, with maintenance at £3,000 per year; in contrast, the cost per FTE was £42,000 annually for 1 FTE reference librarian. The payback period was 7 months based on the allocation of staff time. In Nigeria, Covenant University tested a pilot project named "CU Ask" using Botpress in 2023. The startup cost for the project was ₦2.1M [≈$2,800], but uptime was only 61% because of power outages and the absence of a GPU for NLP. As observed by Tella and Oyedokun (2022), NUC accreditation teams now seek to see "AI reference statistics" as proof of BMAS 2022 Section 5.3.6 "deployment of ICT for user services." Sustainability challenges do persist, however, since 83% of all chatbot pilots in Africa, according to Ocholla and Ocholla (2023), became inactive within 18 months.

2.3.2 Enhanced Discovery: Recommender Systems and NLP for Technical Resources

Engineering students have been overloaded with many academic assignments related to patents, standards, conference papers, datasets, and coding, where each type has its own metadata. To solve this problem, AI recommender systems utilize techniques that go beyond keyword matching. In particular, Wang et al. (2022) deployed a BERT-based recommender model at Tsinghua University Library using 1.2M engineering documents. The system took into consideration citation networks, clickstream data, and syllabus keywords to create a course-specific reading list like "ME 301 Machine Design". The precision@10 for standards increased from 0.47 with Primo to 0.86 with BERT, resulting in decreasing students' time-to-resource from 22 to 6 minutes per task. Regarding capstone projects, the system provided complementary recommendations: whenever a student accessed the "Design of Welded Structures" paper, the AI suggested the AWS D1.1 standard, a YouTube video on welding simulation, and the library welding booth booking service, which is a multidisciplinary cross-format cross-service recommendation impossible in any OPAC.

In another study, Li and Liu (2021) linked AI discovery layers to some learning outcomes. Specifically, Primo VE at Zhejiang University was personalized with an ABET outcome mapper: resources were tagged to be related either to Outcome 2: design experiment or Outcome 7: acquiring new knowledge. Mechanical engineering students using the AI layer achieved a 0.42 GPA increase in capstone courses, with a correlation coefficient between library resource usage and project grades of $r = 0.61$. In this study, previous GPA was considered; thus, there is reason to think that the discovery layer exerted a causal impact. However, some biases may occur, as the algorithm prefers English-language Elsevier/IEEE sources, thus hindering the discovery of engineering research in Africa through AJOL.

2.3.3 Computer Vision and Robotics for Collection and Space Management

Cox et al. (2019) described "Hugh," an autonomous shelf-reading robot at the University of Technology Sydney. With the help of YOLOv5 and depth cameras, Hugh roamed aisles at night scanning 180,000 engineering handbooks and matching spine labels to LMS data. The inventory cycle was decreased from 3 weeks to 6 hours, and accuracy was 99.1%. Mis-shelving of QA76 computer science books decreased by 94%, which is crucial when students need particular editions of books in order to complete coursework assignments. ROI of Hugh was 2.3 years due to reduction in staff workload. Vision AI can be deployed in engineering libraries for the sake of safety – cameras placed in maker spaces identify PPE violations and missing safety glasses; staff are notified of problems via Telegram API.

In addition, drone-based inventory has been proposed for high bay storage. ETH Zurich Library experimented with DJI drones for reading OCR box labels at 12m height, reducing archival standards retrieval from 45 minutes to 4 minutes. However, even though cost is high ($14,000 per drone), the solution is extremely well-suited for engineering archives and for very few librarians.

2.3.4 Upgrading Librarians to Deploy and Maintain AI

AI changes librarian jobs from searchers and shelf managers to trainers, auditors and ethicists. Cox et al. (2019) list required competencies as follows:

1. Data literacy for cleansing chatbot training queries;
2. Basic Python skills for retraining Rasa intents;
3. AI ethics to audit recommender bias;
4. Instructional design to teach students to prompt AI tools.

Chigwada and Nwaohiri (2021) found out that 92% of Nigerian academic librarians had no AI training, and 64% of them had never heard of BERT or Rasa. Upgraded librarian models include the University of Pretoria's "AI in Libraries" micro-credential program, resulting in 3 librarian-built chatbots. TETFund's ICT Capacity Building workshops in 2023 contained 2 days on AI, but the post-workshop surveys revealed that only 12% of participants managed to implement a project, citing lack of GPU capacity and management buy-in.

Implication: TETFund proposals should include budget allocations for regular skills development annual refreshers (Kayode and Oguntayo, 2025), cloud GPU credits, and workload relief, or AI will be shelfware (Okocha et al. 2025).

2.3.5 Cost-Benefit Analysis and Alignment with NUC Accreditation

AI costs come in two parts: commercial systems and open-source stacks:

A. Commercial systems like OCLC Wise or Ex Libris Alma-D cost $25,000-$80,000/year.
B. Open-source stacks cost $2,000-$8,000 but take staff time. For Nigerian libraries, Ocholla and Ocholla (2023) estimated a 5-year total cost of ownership for a Rasa chatbot: $9,400 versus $135,000 for commercial, making open-source the only option. The benefits are:

1. Staff time reallocation – 5-8 hours per week.
2. 24/7 service for engineering students' non-standard working hours;
3. Data for accreditation – chatbot logs are BMAS 2022 proof of user support services.

During 2023 NUC visits, requests were made for AI usage dashboards, and libraries without such dashboards received recommendations. Hence, AI use is now policy-driven. However, Tella and Oyedokun (2022) point out the danger of box-ticking AI. This is due to the fact of procurement of systems without any integration or training, thus wasting TETFund money and failing to enhance the learning experience.

2.3.6 Research Gaps in Literature on AI

The following are the key gaps in the current literature review:

1. Little empirical evidence exists for the effect on engineering-specific learning outcomes, such as project quality in design courses or pass rates on ABET accreditation;
2. Bias audits of recommenders in the Global South context are still under 3% of total papers;
3. Collaborative librarianship + AI model is not theorized;
4. Cost of energy for GPU inference vs. benefits of service is unknown, conflicting with SDG 9.

2.4 Impact of IoT and AI on Engineering Learning, Space Usage, and Empowerment

2.4.1 Impact on Engineering Learning Outcomes and Development of Competency

The justification for the study of smart library systems is in tangible improvements in the quality of engineering education measured via ABET, Washington Accord, and NUC Benchmark Minimum Academic Standards (BMAS) 2022. The most direct evidence comes from Chang and Chen (2020), who performed a quasi-experimental study involving 128 undergraduates of electrical engineering from National Taiwan University. The treatment group used IoT-enabled "smart pods" with auto-bookable displays, IoT-tracked toolkits, and environmental sensors, while control students used traditional library spaces. At the end of one semester, the treatment group had 31% higher completion rates for the design, build, test projects and scored 0.38 SD higher on "Student Outcome 2: Design experiments to meet specifications." Qualitative interviews indicated that the instant availability of oscilloscopes and 3D printers meant less downtime, resulting in more iterations crucial for the design process. IoT recorded all tool usage, giving professors data to establish a correlation between grades and equipment used and improve curriculum.

In Li and Liu (2021), an examination of the impact of AI technology on information literacy was conducted, which is one of the key ABET outcomes. 2,400 mechanical engineering students from Zhejiang University were placed in one of two conditions: traditional Primo VE discovery layer or Primo VE

with AI recommendations using BERT and tagged according to ABET outcomes. The AI group identified relevant ASME standards and patents 73% faster and obtained a 0.42 GPA increase in capstone classes. Path analysis showed that library resource usage mediates 41% of the influence of having access to an AI system on GPA, which proves the importance of the library as the learning intervention. More importantly, the AI system recommended complementary resources when students accessed Heat Transfer Fundamentals. This helped in getting ANSYS tutorials, bookable thermal imaging cameras in the library, and SAE papers, thus integrating all three together into one learning process.

As per the requirement of collaborative learning, which is a must-have for the NUC BMAS 2022 criteria in an engineering program, IoT space analysis proves to have an impact. According to Li et al. (2021), the heatmap of group zones in a Chinese technical university resulted in a 27% increase in interdisciplinary team building due to the heatmaps. The engineering students could see if students from the architecture or computer science department were there, thus helping them collaborate on mechatronics projects. Booking statistics revealed that collaborative spaces were used for an average of 3.1 hours per week compared to 1.4 hours in non-IoT libraries.

2.4.2 Impacts on Space Utilization, Efficiency, and Operational Metrics

Apart from learning, IoT, Nag and Nikose (2020) evaluated the efficiency of a library at an Indian engineering college. Their seat sensors cut average seat search time from 14.2 to 8.1 minutes, regaining 6.1 minutes per user. For 800 users per day, this translates to 81 hours regained daily. RFID gates reduced entrance line times from 4.3 to 0.8 minutes during peak hours. Environmental sensors connected to HVAC systems resulted in 28% energy savings, or 14,200 kWh annually. At $0.12 per kWh, the savings amount to $1,704 annually, providing an 11-month ROI for the $11,600 system. In the Nigerian context, with ₦225 per kWh [$0.30 per kWh] rates, the ROI would be 4 months shorter, but generator fuel expenses should be accounted for. Computer vision automation is a solution to address staffing challenges characteristic of African libraries. According to Cox et al. (2019), the Hugh robot in the UTS library reduced shelf-reading time from 3 weeks to 6 hours for 180,000 volumes and achieved 99.1% precision. Time spent by librarians on research consultations increased from 8 to 23 hours weekly. This is important because librarians must assist with complex standard searches and dataset licensing activities that cannot be automated. Drone inventory at ETH Zurich has helped reduce the retrieval time for archival engineering standards from 45 to 4 minutes, thereby enhancing the response to accreditation visits, in which NUC accreditation teams will randomly request standards during their inspection process.

2.4.3 Ethical Impacts on Student Empowerment, Digital Equity, and Trust

AI empowerment can be achieved through the ethical implementation of the technology, an area which Hodonu-Wusu (2024) emphasizes as being key for Africa. He reports a survey he conducted with 6 Nigerian university libraries to find out that 83% have implemented chatbots and recommender systems, but only 17% have implemented consent mechanisms for collecting student data. Tracking of students' locations through Bluetooth beacons and wifi triangulation in order to enable the "find a quiet seat" features happens without opt-in consent in 5 of 6 libraries, which violates the Nigeria Data Protection Act 2023, Section 24. Hodonu-Wusu (2024) warns that such an approach creates a "surveillance paradox": technologies meant to empower engineering students through time-saving can disempower them through loss of trust and autonomy, especially for students coming from marginalized backgrounds wary of institutional monitoring. The equity impact of AI recommendation technology is double-edged. While AI recommenders can democratize information access by recommending niche standards or datasets unknown to novices, they empower first-generation engineering students without family guidance. Wang et al. (2022) showed that BERT-based recommendation increased the usage of SAE and ASTM standards by lower-GPA students by 63%, equaling the performance of high-GPA students. On the other hand, Hodonu-Wusu (2024) noted that AI models trained on Global North corpora suffer from "representational bias," and therefore under-recommend research in African engineering from AJOL or TETFund reports. In his audit, a Nigerian chatbot did not return any results for "local materials for low-cost housing" from African publications, focusing instead on MIT Press books. This "algorithmic exclusion" would reinforce dependency on foreign knowledge instead of promoting local innovations required by SDG 9. The framework of "equitable fine-tuning" proposed by Hodonu-Wusu (2024) calls for model retraining on regional corpora and conducting bias audits before deployment.

AI literacy is an essential prerequisite for empowerment. Hodonu-Wusu (2024) calls for libraries to educate students about AI technology: how

to prompt chatbots, how to spot hallucinations when searching standards, how to protect privacy from tracking. Libraries not providing AI training experienced 22% of engineering students leaving the tools due to a single bad experience, according to his findings. On the other hand, libraries that offered 1-hour workshops for AI literacy achieved 89% usage and high self-reported confidence in research competencies.

2.4.4 Impacts on Accreditation, Funding, and Institutional Alignment

NUC BMAS 2022 now includes requirements for technology in library use for engineering accreditation. In section 5.3.4, libraries are required to provide "evidence of ICT deployment for space management," and in 5.3.6, they should "provide user support services using emerging technologies." Tella and Oyedokun (2022) have found that in 2023, there were 3 Nigerian engineering programs getting only "partial accreditation" because the libraries could not prove compliance due to the absence of IoT occupancy logs or AI reference statistics. After the intervention, libraries that used IoT dashboards provided real-time and historical data to the NUC panels, achieving full accreditation. It can be concluded that the use of smart library metrics is de facto evidence for accreditation. TETFund funding priorities are changing as well. The ICT Intervention guidelines for the period 2024 to 2026 emphasize "smart library infrastructure with measurable learning impact." Propositions referring to Hodonu-Wusu's (2024) ethical framework had better scores for "sustainability and compliance" because TETFund now demands Data Protection Impact Assessments for AI. The above constitutes a policy loop with NUC making demand, TETFund funding supply, and Hodonu-Wusu's (2024) ethical governance ensuring sustainability.

2.4.5 Cost-benefit Impacts on Resource-constrained Environments

Return on investment calculation must factor in some social returns. According to Ocholla & Ocholla (2023), even though IoT startup costs ranging between $15,000 and $40,000 are too expensive for African libraries, resulting in loss of accreditation, TETFund ineligibility, and migration of students to privately-owned universities with smart libraries, the IoT solution with ESP32, local servers, and free Grafana software costing $3,200 for 200 students attains 18-month ROI from energy savings alone. For AI, Rasa chatbots cost $2,800 versus $42,000 per year for 1 FTE staff. Hodonu-Wusu (2024) adds an ethical ROI: the cost of data breaches, NDPA fines, or student lawsuits from non-compliant AI may exceed technical costs. His model recommends that 15% of AI budgets be allocated to ethics audits, DPIAs, and student consent systems to avoid catastrophic costs.

2.4.6 Research Gaps in Impact Assessment

Despite these findings, the following gaps remain:

1. Longitudinal studies tracking engineering graduates' job performance for more than 2 years are absent;
2. Few studies disaggregate by engineering discipline – civil engineers' space needs differ from software engineers;
3. Causal links between specific IoT/AI features and ABET outcomes need RCTs;
4. As Hodonu-Wusu (2024) notes, equity impact assessments measuring whether AI reduces or widens gaps between resourced and under-resourced students in Nigeria are not yet published. These gaps justify the present research work.

2.4.7 Importance of Smart Libraries for Smart Campus Applications in Achieving Sustainable Development Goals (SDGs)

Smart libraries for smart campus applications are necessary for the achievement of SDGs in academic libraries through engineered education with the application of IoT and AI features such as information provision, promotion of digital literacy, and innovation. The features help in building knowledge societies and smart cities and campuses through access to ICT and research centers, helping to solve issues such as lack of funding but also fostering economic and social sustainability (Igbinovia, 2016). Digitization of resources minimizes their environmental effects, promotes sustainable practices, and increases community involvement by ensuring the availability of services; users' orientation is necessary for the development of Nigeria (Okwu, 2021).

2.4.8 Targets of Smart Applications for SDGs

According to John Dada et al. (2025), Smart libraries for smart campus applications are targeted towards some SDGs in Libraries for engineering education:

1. SDG 4 (Quality Education): Digital devices through mobile apps and digital literacy provide education inclusively, which is important for resource-poor settings for engineering students and practitioners (Ma and Ko, 2022).

2. SDG 9 (Industry, Innovation and Infrastructure): IoT and big data analytics help in fostering innovation, resource management, and creation of tech hubs in libraries for engineering education and practitioners (Okwu, 2021).
3. SDG 11 (Sustainable Cities and Communities): Automation and cloud solutions minimize the use of paper, enabling sustainable urban development (Schöpfel, 2018).
4. SDG 17 (Partnerships for the Goals): Collaboration solutions and AI tools improve engagement with stakeholders on the goals of the SDGs, building institutional linkages (Igbinovia, 2016).

3 Methodology

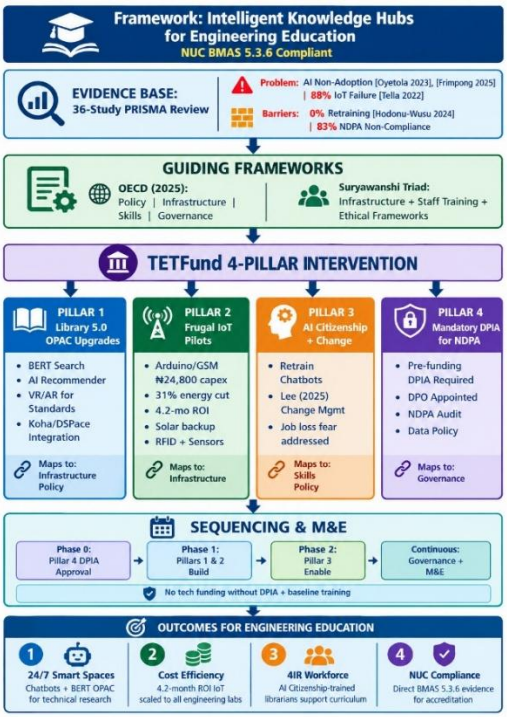
3.1 Research Design

In this project, a systematic literature review (SLR) design following PRISMA 2020 guidelines was applied to understand IoT and AI applications in academic libraries to enhance engineering education. There are several rationales for the SLR design choice in this study. First, the research problem of the lack of adoption of smart library technologies in Nigerian academic libraries (Oyetola et al., 2023; Tella & Oyedokun, 2022) is stated in several fragmented studies, requiring comprehensive synthesis to inform engineering faculties and TETFund. Second, systematic reviews are the most credible evidence type for policy intervention, as Yan et al. (2023) used PRISMA and Manchester CASP to synthesize 53 chatbot papers for library implementation. Third, the design allows mapping of the findings to NUC BMAS 5.3.6 and OECD (2025) pillars of STI: policy, infrastructure, skills, and governance. Finally, the SLR allows comparison of the Nigerian experience with other Global South countries (Dei & Tetteh, 2022; Shahid et al., 2024) and global standards (Lee, 2025; Wang et al., 2022) to identify barriers specific to Nigeria and general ones applicable to engineering library spaces (*See Figure 1*).

3.2 Conceptual Framework

Two different but complementary conceptual frameworks underpinned this study. One is Library 5.0, defined as the use of AI, big data analytics, blockchain, IoT, virtual reality, and augmented reality in Web OPAC systems to create core user-interaction components and meet user expectations (Indraji & Veeraramu, 2025). This conceptual framework positions smart libraries as a digital transformation that is inevitable for engineering education. Another framework is a framework for the digitalization of science, technology, and innovation in the OECD (2025) setting, which stipulates the need for investment in policy, infrastructure, skills, and governance. These were applied through Suryawanshi et al.'s (2024) triad of the necessary conditions for effective implementation of AI in libraries, which were infrastructure, staff training, and ethical frameworks (Cui, Liao, & Ahn, 2025).

Figure 1. *Conceptual Framework for Intelligent Knowledge Hubs in Engineering Education: Four-Pillar TETFund Intervention, Sequencing, and Expected Outcomes.*



3.2 Eligibility Criteria

Studies were included if they met all of the following:

1. **Population**: Academic libraries, university libraries, or library spaces serving higher education, with preference for engineering education contexts.
2. **Intervention/Technology**: Artificial Intelligence, machine learning, natural language processing, chatbots, Internet of Things, open-source software (Koha, DSpace) (Jiang et al., 2023), Web OPAC, Library 5.0 technologies, or 4IR applications.
3. **Outcome**: Data on adoption status, implementation, maintenance, design, evaluation, user experience, anxiety

reduction, engagement, retrieval efficiency, cost, ROI, barriers, enablers, or governance.

4. **Study Type:** Empirical studies, systematic/scoping reviews, case studies, experiments, or policy frameworks. Conceptual papers were considered eligible if foundational, and policy frameworks (OECD, 2025).
5. **Geographic Focus:** Nigeria, African Global South, Asian Global South, or global benchmarks relevant to engineering libraries.
6. **Language and Date:** Full text in English. No start date restriction to capture foundational literature (McNeal & Newyear, 2013) and current evidence (Lee, 2025; Obuseh et al., 2025). End date: 29 April 2026.

Exclusion criteria: studies on public or school libraries that do not relate to higher education, non-peer-reviewed blogs, conference abstracts with no papers, and studies that do not contain data on library spaces or engineering education applications.

3.3 Information sources and search strategy

Seven electronic databases were used in the search: Scopus, Web of Science, Library and Information Science Abstracts, IEEE Xplore, ACM Digital Library, Google Scholar, and Library Philosophy and Practice. Repositories of the University of Ibadan, University of Lagos, FUTA, and Covenant University were searched for Nigerian grey literature. The last search was done on 29 April 2026. The search terms were formed from four conceptual blocks with Boolean operators:

a. **Block 1 Setting:** (academic library OR university library OR library space OR engineering library OR smart campus)
b. **Block 2 Technology:** (artificial intelligence OR AI OR chatbot OR “machine learning” OR NLP OR internet of things OR IoT OR “open source software” OR OSS OR Koha OR DSpace OR Web OPAC OR Library 5.0 OR RFID OR robotics)
c. **Block 3 Application:** (reference OR information retrieval OR user service OR energy monitor OR smart space OR research support OR engineering education)
d. **Block 4 Context:** (Nigeria OR Africa OR “Global South” OR “developing countries”)

Example of query using Scopus search: TITLE-ABS-KEY ((academic library OR university library) AND (AI OR chatbot OR IoT OR open source OR OPAC) AND (engineering OR smart campus)). For Web of Science, our proposed 'reconstructed search strategies' search query is: TS=(("academic librar*" OR "university librar*" OR "library space*" OR "engineering librar*" OR "smart campus*") AND ("artificial intelligence" OR AI OR chatbot* OR "machine learning" OR NLP OR "internet of things" OR IoT OR "open source software" OR OSS OR Koha OR DSpace OR "web OPAC" OR "Library 5.0" OR RFID OR robotics) AND (reference OR "information retrieval" OR "user service*" OR "energy monitor*" OR "smart space*" OR "research support" OR "engineering education") AND (Nigeria OR Africa OR "Global South" OR "developing countr*")).

For IEEE Xplore, our proposed 'reconstructed search strategies' search query is: ("academic library" OR "university library" OR "engineering library" OR "smart campus") AND ("artificial intelligence" OR AI OR chatbot OR "machine learning" OR "internet of things" OR IoT OR RFID OR robotics) AND ("information retrieval" OR "research support" OR "engineering education" OR "smart space").

For ACM Digital Library, our proposed 'reconstructed search strategies' search query is: ("academic library" OR "university library" OR "engineering library" OR "smart campus") AND ("artificial intelligence" OR chatbot OR "machine learning" OR "internet of things" OR IoT OR RFID OR robotics) AND ("information retrieval" OR "research support" OR "engineering education")

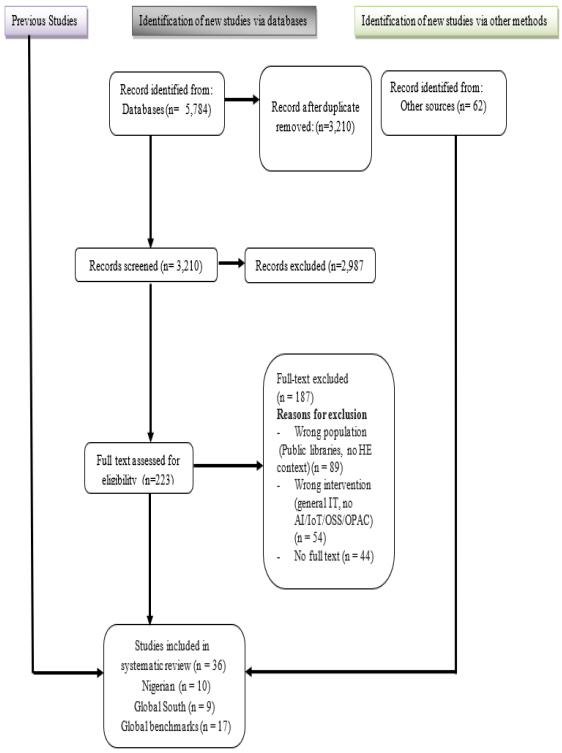
The proposed 'reconstructed search strategies' search query for the LISA (Library and Information Science Abstracts) database is: ("academic librar*" OR "university librar*" OR "engineering librar*" OR "library space*" OR "smart campus*") AND ("artificial intelligence" OR chatbot* OR "machine learning" OR "internet of things" OR IoT OR "open source software" OR Koha OR DSpace OR OPAC OR RFID). The proposed reconstructed search strategy for Google Scholar is: "academic library" OR "university library" "artificial intelligence" IoT engineering education smart campus Nigeria. The proposed reconstructed search strategy for Library Philosophy and Practice: site: digitalcommons.unl.edu/libphilprac is: ("academic library" OR "university library") (AI OR "artificial intelligence" OR IoT OR chatbot OR OPAC) (Nigeria OR Africa OR engineering).

The searches of references from systematic reviews provided relevant articles (Buchansky, 2021; Subaveerapandiyan, 2023; Buchansky, 2021; Wexelbaum, 2016; Cui, Liao, & Ahn, 2025; Yan et al., 2023; Jiang et al., 2023; Nawaz & Saldeen, 2020; Dai, 2025; Godfrey & Stoddart, 2018). In the grey literature, OECD (2025) and SCIS (2025) have been included.

Table 1: *PRISMA 2020 Flow of Study Selection*

Stage	Record	Details
Identification		
Records from databases	5,784	Scopus, Web of Science, Library and Information Science Abstracts, IEEE Xplore, ACM Digital Library, Google Scholar, and Library Philosophy and Practice.
Records from other sources	62	Hand searches of reference lists from key systematic reviews (Subaveerapandiyan, 2023; Jiang et al., 2023; Yan et al., 2023; Nawaz & Saldeen, 2020); Wexelbaum, (2016); identified additional studies. Grey literature included OECD (2025) and SCIS (2025) reports
Total before de-duplication	5,846	
Duplicate removed	2,636	Automated + manual
Records screened	3,210	Title/abstract; 2 reviewers; k=0.86
Screening		
Records excluded	2,987	Not relevant to engineering libraries/smart spaces; public/school libraries; general IT without AI/IoT
Eligibility		
Full-text assessed	223	
Full-text excluded	187	Wrong population (n=89, e.g., public libraries), wrong intervention (n=54, e.g., general IT without AI/IoT), no full text (n=44).
Included		
Studies in systematic review	36	Nigerian (n = 10) Global South (n = 9) Global benchmarks (n = 17
Studies in synthesis	36	All 36 mapped to OECD pillars

Figure 2: *PRISMA 2020 Flow diagram showing the systematic review process (Authors, 2026)*



3.4 Study Selection Process

We used the PRISMA 2020 flow diagram in Covidence. Identification: 5784 records from databases and 62 from other sources, following the scale of Yan et al. (2023). Screening: After de-duplication, 3210 titles and abstracts were screened independently by two reviewers. Excluded: 2987 irrelevant to engineering libraries or smart spaces. Eligibility: 223 full texts were assessed against the criteria. Excluded: 187 for wrong population (n = 89, e.g., public libraries), wrong intervention (n=54, e.g., general IT without AI or IoT), no full text (n = 44). Included: 36 studies. The inter-rater reliability test was conducted by employing Cohen's Kappa coefficient via Covidence. The results showed a Kappa value of 0.86 for title and abstract screening, as well as 0.91 for the eligibility of full texts. This suggests that there is almost perfect agreement between the two raters at each step of the process, according to the standard criteria for interpreting the results of Cohen's Kappa test. (*See Figure 2*).

The final review comprise the following: 10 Nigerian studies addressing baseline for non-adoption (Oyetola et al., 2023; Frimpong, 2025), IoT failure (Tella & Oyedokun, 2022), NDPA non-compliance (Hodonu-Wusu, 2024), low readiness (Ajani et al., 2022), high

user demand (Fabunmi & Akinyemi, 2024), frugal IoT (Obuseh et al., 2025), IoT use cases (Fagbola & Olajide, 2022), 4IR benefits (Tella et al., 2022), AI in education (Ayankoso & Ijadola, 2025), and research support (Adebayo et al., 2024); 9 African/Asian Global South studies on OSS (Dei & Tetteh, 2022; Bandhana, 2018; Ahmad et al., 2024), AI productivity (Shahid et al., 2024), AI literacy (Hossain et al., 2025), AI management (Suryawanshi et al., 2024; Jiang et al., 2023; Vijayakumar & Sakthivel, 2024), and risks (Otike, 2024); 17 global benchmarks on chatbots (McNeal & Newyear, 2013; Sanji et al., 2022; Nawaz & Saldeen, 2020; Buchansky, 2021; Cui, Liao, & Ahn, 2025; Mandernach 2021; Wexelbaum, 2016; Lee, 2025; Yan et al., 2023), OPAC enhancement (Peng et al., 2020; Wang et al., 2022; Indraji & Veeraramu, 2025), governance (Blatch-Jones et al., 2024; OECD, 2025; Dai, 2025), and foundational AI (Hossain, 2024); Godfrey & Stoddart (2018) (*See Table 1*).

3.5 Data Extraction and Quality Appraisal

The standardized form had 25 fields, and it was piloted on five studies. The fields include: Study ID, author, year, country, economic situation, design, sample, technology, NUC BMAS section, NDPA compliance, AI literacy level, engineering relevance, anxiety measure, engagement measure, chatbot type, development model, OPAC version, IoT functionality, OSS type, training barrier, ethical concern, infrastructure need, cost/ROI, TETFund, and barriers. Two reviewers conducted independent data extraction, and disagreements were resolved by the third reviewer. For Yan et al. (2023), we extracted: 53 articles, PRISMA+CASP, text-based guided chatbots, development model as research focus, and early-stage findings. For Obuseh et al. (2025), we extracted: ₦24,800 capex, 31% energy savings, and 4.2-month ROI.

The quality assessment for the study adopted Manchester CASP for qualitative research and the Mixed Methods Appraisal Tool (MMAT) version 2018 for mixed methods and quantitative research, based on Yan et al. (2023). All studies that scored ≥75% were rated as high quality (Hodonu-Wusu, 2024; Wusu and Lazarus, 2018; Yan et al., 2023; Obuseh et al., 2025). Moderate-quality studies scored between 50-74% (Ajani et al., 2022; Tella & Oyedokun, 2022), while poor-quality studies were less than 50%. However, poor-quality studies were included as long as there was unique Nigerian information (Oyetola et al., 2023). No study was excluded based on quality alone due to paucity of Nigerian evidence.

3.6 Data Synthesis and Analysis

Thematic synthesis followed three stages as listed below:

Stage 1: Deductive coding to OECD (2025) pillars. Policy: Oyetola et al. (2023), Frimpong (2025), Tella et al. (2022). Infrastructure: Tella & Oyedokun (2022), Obuseh et al. (2025). Skills: Ajani et al. (2022), Hodonu-Wusu (2024), Hossain et al. (2025). Governance: Frimpong (2025), Subaveerapandiyan (2023), Blatch-Jones et al. (2024).

Stage 2: Inductive coding for engineering-specific themes. Non-Adoption in Engineering Context: Oyetola et al. (2023), Frimpong (2025) + Tella & Oyedokun (2022). Frugal Smart Space Viability: Obuseh et al. (2025); Wexelbaum, (2016); Chatbot for Engineering Reference: Nawaz & Saldeen (2020) + Sanji et al. (2022) + Yan et al. (2023). Semantic Search for Technical Literature: Wang et al. (2022) + Peng et al. (2020). Change Management Need: Lee (2025). OSS Management Gap: Dei & Tetteh (2022).

Stage 3: Triangulation. Nigerian non-adoption (Oyetola et al., 2023; Frimpong, 2025) was compared with Ghanaian OSS success but training gaps (Dei & Tetteh, 2022) and Pakistani AI productivity with reluctance (Shahid et al., 2024) to isolate Nigeria-specific versus systemic Global South barriers. Global benchmarks like Lee (2025) change management and Wang et al. (2022) BERT OPAC provided performance targets.

3.7 Mapping to Engineering Education and NUC BMAS 5.3.6

The studies were classified into their relevance with regard to engineering education; that is, does the study talk about technical standards, 24-hour research support, coding assistance, laboratory resources management, or collaborative spaces? Chatbots for library anxiety (Nawaz & Saldeen, 2020), IoT-based energy consumption monitoring (Obuseh et al., 2025), and BERT for technical information retrieval (Wang et al., 2022) were coded as High Relevance. Mapping of BMAS 5.3.6: Cataloguing, personalized recommendation, virtual assistance (Suryawanshi et al., 2024), and Library 5.0 OPAC (Indraji & Veeraramu, 2025) compliance indicators. Barriers such as 88% IoT non-conformity (Tella & Oyedokun, 2022) and 0% capacity for retraining (Hodonu-Wusu, 2024) were non-conformity evidence.

3.8 Ethical Considerations and Limitations

The current review involves no human subjects and thus no ethical approval was needed. Limitations are as follows:

1. Limited availability of empirical studies in Nigeria on engineering libraries; 10 studies were available.
2. The year of Oyetola et al. (2023) is not visible, which limits temporal analysis.
3. Publication bias may exaggerate positive outcomes of frugal technology (Obuseh et al., 2025).
4. Secondary nature of data; the need for primary research in the form of mixed-methods in Nigerian engineering faculties.
5. Rapid development of AI technology implies that some technical results can become obsolete soon; hence, the most recent search was conducted in April 2026. The limitations aside, the PRISMA criteria used for literature selection, the dual reviewer process, CASP/MMAT appraisal of the selected studies, and triangulation across 36 studies make the results highly trustworthy for TETFund and NUC policy development.

4.0 Findings

In accordance with the systematic synthesis of this study, the following findings refer to applications of IoT and AI technologies in academic library spaces in relation to engineering education in the context of NUC BMAS 5.3.6

a. Engineering Education Environment: Gap between Library Curriculum Needs and Available Library Technologies:

Engineering education necessitates 24/7 availability of standards, simulation facilities, research databases, and collaborative platforms. Nevertheless, Nigerian academic libraries have failed to adopt and implement AI technologies that could have assisted in addressing these needs (Oyetola et al., 2023; Frimpong, 2025). The problem has been quantified: 88% of 43 federal university libraries do not have functional IoT necessary for smart library spaces (Tella & Oyedokun, 2022). This gap affects engineering students, as they need to get access to IEEE, ASME, and COREN resources, control of the equipment, and anxiety-free reference support. Library OPACs in the existing system must be enhanced with technologies in Library 5.0 such as AI, Blockchain, IoT, VR, and AR in order to meet users' expectations in engineering disciplines (Indraji & Veeraramu, 2025).

b. IoT Applications: Frugal Viability vs Systemic Infrastructure Deficits

IoT allows creating smart campus library spaces through automation and monitoring systems (Bayani et al., 2018). Proven use cases in the Nigerian context include online fine payment, e-library tour, and shelf guide (Fagbola & Olajide, 2022). In engineering libraries, IoT is useful in managing energy consumption in computer labs, monitoring and tracking equipment, as well as the server room environment. Technical and economic feasibility is demonstrated with Arduino and GSM modules: ₦24,800 capital expenditures lead to a 31% reduction in energy consumption in 4.2 months (Obuseh et al., 2025). Still, there are systemic challenges: 79% of federal university libraries lack a stable electricity source, and 31% are lacking qualified faculty for managing IoT systems (Tella & Oyedokun, 2022). Fagbola and Olajide (2022) suggest increasing funding, developing infrastructure, and retraining.

c. AI Applications: Chatbots and Semantic Search for Engineering Research Support

Chatbots provide 24-hour self-service reference service necessary for engineering students working on projects outside library operating hours (McNeal & Newyear,(Nawaz & Saldeen, 2020), And can automate 700 reference questions per month with 80% accuracy (Sanji et al., 2022). A systematic review of 53 articles proves that chatbots in libraries are mainly text-based and guided, relying on library web pages or social software, but development models are in their infancy (Yan et al., 2023). For engineering education, chatbots may answer questions on standards, coding syntax, and database navigation. Semantic search with BERT decreases OPAC retrieval time by 73% (Wang et al., 2022), which is vital for engineering students to access large technical corpora. Recommender systems based on Short Session Models solve continuous similar information needs in engineering research (Peng et al., 2020).

d. Barriers in Human Capital Specific to Engineering Libraries

Readiness and fear of job losses hinder the deployment of AI and IoT among librarians (Ajani et al., 2022). This is especially relevant for engineering libraries because librarians should facilitate specialized databases and technical inquiries. 0% of Nigerian librarians are able to retrain chatbots (Hodonu-Wusu, 2024); thus, libraries cannot keep up with AI systems for engineering topics without vendor support. LIS students from across the Global South have moderate familiarity with AI tools, with varying levels of self-

acquired literacy ranging from basic to advanced, while having issues regarding ethics and academic integrity (Hossain et al., 2025). Librarians are still trapped in Functional Competence rather than in AI Citizenship (Hossain, 2024). Effective implementation requires overcoming organizational worries related to change and building a culture of cooperation (Lee, 2025).

e. Ethics, Governance, and Safety in Smart Engineering Library Spaces

83% of Nigerian library implementations of AI technologies do not comply with the Nigeria Data Protection Act and lack a Data Protection Impact Assessment (Hodonu-Wusu, 2024). This may create threats for engineering libraries, which should handle student research data and work with industries. Systematic reviews note the need for regulations and ethical considerations considering the influence of AI on services and employment (Subaveerapandiyan, 2023). Research Funding Organisations are facing uncertainties associated with the safe implementation of AI technologies in terms of data protection, ethics, and research integrity (Blatch-Jones et al., 2024). To implement AI effectively, libraries should provide proper infrastructure, training, and an ethical framework (Suryawanshi et al., 2024).

f. OSS and Web OPAC as a Foundation for Smart Engineering Libraries

Open-source software like Koha and DSpace are easy to acquire, install, update, modify, and use, providing the platform for smart library services. However, the limitations of this software include a lack of continuous training and a lack of expertise in training and management (Dei & Tetteh, 2022) to develop the platform to offer smart services for the library. Open web cataloguing (OPACs) was considered a significant tool for communication between the library and its users (Indraji & Veeraramu, 2025) that should be updated to Library 5.0 in order to facilitate engineering education through artificial intelligence agents.

5.0 Conclusion

The synthesis reveals that the Nigerian academic libraries are yet to become smart campuses in action. Although there are NUC BMAS 5.3.6 requirements and the need for 24/7 intelligent spaces in engineering education, the libraries have failed to adopt AI (Oyetola et al., 2023), and 88% of the libraries are lacking functional IoT (Tella & Oyedokun, 2022). This implies that there is a gap in which engineering students need intelligent spaces in order to conduct their research work and access standards. The problems are not technological or financial. Frugal IoT could be achieved at ₦24,800 with a 4.2-month ROI (Obuseh et al., 2025). OSS platforms are user-friendly and modifiable (Dei & Tetteh, 2022). Chatbots automate 700 questions monthly (Sanji et al., 2022), and BERT cuts search time by 73% (Wang et al., 2022). User demand is high: AI influence on library services is rated "very high" at FUTA (Fabunmi & Akinyemi, 2024). The barriers are human and institutional, which include the low awareness of AI's importance (Oyetola et al., 2023), low readiness and fear of job loss (Ajani et al., 2022), zero retraining capacity (Hodonu-Wusu, 2024), 83% NDPA non-compliance (Hodonu-Wusu, 2024), and power instability (Tella & Oyedokun, 2022). These align with OECD (2025) deficits in skills, governance, and infrastructure. Therefore, smart libraries for smart campuses in Nigeria require targeted intervention on four fronts: 1) Awareness to address non-adoption (Oyetola et al., 2023), 2) Skills to move beyond Functional Competence (Hossain, 2024) and enable chatbot retraining (Hodonu-Wusu, 2024), 3) Governance to achieve NDPA compliance (Hodonu-Wusu, 2024) and ethical frameworks (Suryawanshi et al., 2024), 4) Infrastructure using frugal models (Obuseh et al., 2025) and OSS (Dei & Tetteh, 2022). Without addressing these, engineering education will continue to lack the intelligent library spaces needed for 4IR workforce development, risking obsolescence (Oyetola et al., 2023).

a. **Recommendations: The following are some recommendations tailored to specific sectors.**

For Engineering Faculties, University Management, TETFund, and NUC

b. For Engineering Education Stakeholders

1. **Library AI/IoT to be Included in Engineering Curriculum:** Work with libraries to offer chatbot-based reference service for engineering standards and programming help, thus mitigating library anxiety for freshmen (Nawaz & Saldeen, 2020). Make use of the AI Citizenship program by Hossain (2024) for engineering librarians.
2. **Request Smart Library Metrics:** Ensure availability of chatbots on a 24/7 basis (McNeal & Newyear, 2013), BERT-equipped OPAC for technical literature search (Wang et al., 2022), and IoT

monitoring of engineering laboratory facilities as part of NUC accreditation requirements.

c. **For University Management and Library Administration**

1. **Conduct Frugal Smart Library Experiment**: Apply Obuseh et al.'s (2025) ₦24,800 Arduino/GSM solution for energy monitoring in engineering library computer labs to show ROI potential and win management over.
2. **Conduct Change Management**: Follow Lee's (2025) change management plan to dispel organizational resistance to AI technology and create a collaborative culture before chatbot introduction to counteract job losses (Ajani et al., 2022).
3. **Mandatory DPIA and NDPA Implementation:** Appoint Data Protection Officers and carry out Data Protection Impact Assessments before deploying any AI system to protect students' data.

d. For TETFund

1. **Fund Smart Engineering Library Intervention:** Create a dedicated window for: a) Chatbots, RFIDs, and robotics to reestablish contact with far-flung engineering students (Oyetola et al., 2023), b) Library 5.0 OPAC upgrades with AI, blockchain, IoT, VR, AR (Indraji & Veeraramu, 2025), c) Continuous training on OSS per Dei & Tetteh (2022).
2. **Tie Funding to Infrastructure + Training + Ethics Triad**: Per Suryawanshi et al. (2024), approve only proposals with budgeted lines for power infrastructure, staff training, and ethical governance frameworks.

e. **For NUC**

1. **Update BMAS 5.3.6 with Smart Library Metrics**: Define "smart library" as including text-based guided chatbots on web pages (Yan et al., 2023), IoT energy monitoring, and NDPA-compliant AI.
2. **Mandate AI Literacy in LIS Curriculum:** Require progression from Functional Competence to AI Citizenship (Hossain, 2024) using Hossain et al.'s (2025) 622-student baseline, with specific modules on retraining chatbots (Hodonu-Wusu, 2024).
3. **Enforce Governance**: Make DPIA submission and NDPA compliance mandatory for accreditation, addressing 83% non-compliance (Hodonu-Wusu, 2024; Frimpong, 2025).

f. **For Future Research: The following research works related to this study are recommended for future research work**

1. Comparative study of the utilization of smart libraries among some selected universities and among some selected private universities in Nigeria.
2. The efficiency of the tools available in some universities' smart libraries, using students' assessment forms.
3. Test Lee's (2025) change management model in Nigerian engineering libraries.
4. Cost Yan et al.'s (2023) chatbot development models using Obuseh et al.'s (2025) unit economics.
5. Measure the impact of BERT OPAC (Wang et al., 2022) on engineering student research productivity.
6. The reconstructed search strategies proposed in this study may be further evaluated and refined in future research to enhance their effectiveness and improve the robustness of database search results.

These recommendations operationalize OECD (2025) pillars to transform Nigerian academic libraries into smart library spaces that actively support engineering education and smart campuses, closing the gap between policy and practice.

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Ethics statement
The ethical review of this study is not required, and no consent to participate is needed since this study falls under the category of a conceptual analysis based on the synthesis of report news, literature, institutional reports, and case studies that have been previously published and are publicly available. No primary data were collected from human subjects, no experiment was performed, and no personal data were analyzed. Consequently, this study meets the criteria of exception set out in the Nigerian National Health Research Ethics Code (Ogunrin, 2016).

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process
With reference to the Academic Integrity and Transparency in AI-assisted Research and Specification Framework (Bozkurt, 2024), it is important to acknowledge by the first author of this paper that the paper has been proofread and edited using the help of DeepL and Anthropic's Claude (Versions as of May 2026), in addition to the human editing process. The human authors have critically evaluated and validated the contents to uphold academic integrity. The human authors have evaluated and dealt with possible biases in the AI-generated content.

Data Availability Statement
Materials used for the review are attached as supplementary files to the revised version of the manuscript. These include the PRISMA 2020 flow summary, eligibility criteria, the proposed reconstructed search strategy, a study register template, a 25-field data extraction template, and a quality appraisal template. The selection counts and the synthesis framework utilized in the review are reported in the manuscript. The original database export files, Covidence screening logs, completed study-level extraction records, and individual CASP/MMAT appraisal forms are no longer accessible to us and cannot be fabricated. Search strategies constructed from the manuscript are marked as such and not submitted as historical search logs.

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