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Future-Ready Library Buildings: AI and IoT for Equity and Compliance

Sunil Sharma[1], Sobhagyawati Gupta[2,*]

Abstract

Libraries are buildings presenting unique challenges when integrating different types of spaces under a single roof, like quiet reading spaces, central lobbies, book staging areas, archival rooms, discussion zones, seminar rooms, e-resources labs, etc. These spaces require specialized norms related to construction and involve varied daylighting requirements, anthropometric needs, indoor air environment requirements, and other specific functional needs. Moreover, libraries must follow various requirements mentioned in relevant IS codes, fire safety norms, the National Building Code, etc. Recent advancements in energy efficiency and sustainability codes, like the Energy Conservation and Sustainable Building Code (ECSBC), and their likely change in implementation from voluntary to mandatory for university library buildings have made library construction a complex interdisciplinary exercise requiring collective efforts between architects, energy consultants, and civil and mechanical engineers. Given this complexity, the role of Artificial Intelligence (AI) and the Internet of Things (IoT) will likely grow to fulfill mandatory requirements of the codes and standards mentioned above. AI can be effectively used in the generation of appropriate architectural plans, code compliance, and energy modeling. Its integration with IoT would be handy in achieving inclusive design standards (architecture for differently-abled people) and universal design standards. Moreover, Machine Learning (ML), a subset of AI, can be used for user-behavior forecasting, post-occupancy learning, and creating data-driven planning. This paper forecasts the prospects and presents a comprehensive study of the integration of AI and IoT, stressing the creation of inclusive buildings that support neurodiverse users with cognitive disabilities.

Keywords: Artificial intelligence, code compliance, inclusive design, Internet of Things, universal accessibility

INTRODUCTION

As humanity progresses with the evolution of Artificial Intelligence (AI), the technological sector has opened new avenues to create more inclusive buildings that were never thought possible before. Libraries are complex buildings with high foot traffic and are generally used by different age groups of people with diverse abilities and disabilities. Creating an ideal design for libraries has always been a key and challenging issue among architects and designers. Also, as the complexities of various codes, like the Energy Conservation and Sustainable Building Code (ECSBC), increase in achieving the desired building results becomes more difficult daily. These codes generally stress creating green, energy-efficient, and sustainable buildings. The BEE has upgraded the Energy Conservation Building Code (ECBC) to ECSBC, where sustainability is a newly incorporated section. Although the code is voluntary, looking at the scenario in developed nations, the code may become mandatory soon in India as well, increasing the complexity of modern building design. Also,

***Author for Correspondence**
Sobhagyawati Gupta
E-mail: shobha.library@curaj.ac.in

[1]Assistant Professor, Department of Architecture, Central University of Rajasthan, Bandar Seendri, Rajasthan, India
[2]Assistant Librarian, Department of Library, Central University of Rajasthan, Bandar Seendri, Rajasthan, India

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there are various codes, like IS codes, the National Building Code (NBC), etc., to examine various architectural and design aspects of buildings, including libraries. This increases tremendous scope in the field of architecture; architects and designers need to upgrade themselves, especially in the fields of AI and IoT, to create future buildings and upgrade existing buildings to comply with the most stringent compliance levels and achieve the targets set by these codes. Further, making inclusive buildings is also gaining importance as we move toward universal design to address differently-abled users. Inclusiveness is the need of the hour, and its incorporation not only increases the greenness of the building but also makes buildings more user-centric.

This research paper explores the avenues of AI and IoT that can be leveraged to create inclusive designs addressing the needs of modern libraries, as well as newly established libraries, to meet current codes and standards. Further, this research tries to investigate various challenges faced by architects and designers to fulfill requirements of these codes and standards.

LITERATURE REVIEW

Traditional building design is equipped with climate-responsive architecture, implementing various design features and elements to achieve optimum design. Now, following the lines of developed nations, building creation is becoming more sophisticated with the advent of green rating systems and the Energy Conservation Building Code. Now, with the creation of ECSBC and looking at its applicability, the complexities are increasing year by year. Moreover, as the codes evolve and focus on inclusive design, addressing various forms of disability is becoming a key issue. Buildings must be designed for at least 50 years, considering the prospective users – who will be the users 20–30 years from now [1]. In the Indian context, most users in India will be well above 50 years at that time, and with the present rate of disability, the number of disabled users will be large. Also, observing changing trends in US universities, it is seen that people above age 60 are again enrolling in universities to get education and higher education; so, in the Indian context, libraries may be needed for senior citizens. Further, one of the most essential functions is access to resources for all regardless of any disabilities, caste, class, or gender [2]. So, creating inclusive libraries in the modern age is becoming a horrendous and tedious work for architects and designers.

Inclusive design integrates the concepts of universal design, based on equality, and accessibility design, based on equity [3]. AI assistive technology can aid the differently-abled by providing more independence to them and providing equal opportunities, enhancing experience, and thus promoting inclusiveness [4–5]. AI clubbed with IoT and cloud computing increases the activeness of a library and increases its usability as an interactive learning space [1]. The disabled population constitutes a large population; for example, according to estimated blind people in India as per a 2001–02 survey, about 1.15 percent of the entire country's population was blind (as per NPCB definition visual acuity <6/60). Given the population size of India, this population amounts to 1.21 crore [6]. Legislations are created to have equal access and services for differently-abled persons, but there is still a gap in this area even in developed nations, like the United States [7], and AI seems to be one of the tools that can bridge the gap.

Barrier-free designed buildings are today's requirement for inclusive architecture; they create an accessible, safe, and comfortable environment for all users, regardless of their physical or sensory abilities. For inclusive architecture, barrier-free designed buildings are today's requirement for addressing different disabilities, and this will enhance accessibility and a safe, comfortable environment for all users, regardless of physical or sensory abilities [5]. If libraries are to be relevant and succeed in the new knowledge economy and changing paradigm, it is necessary to integrate AI into their operation and functioning [8]. Innovative architectural solutions in the form of color schemes, physical infrastructure, furniture, signage, ramps, etc. can actively create a barrier-free environment and can be used not only for new infrastructure but for the renovation of libraries [9] as well. Integrating each solution with either AI or IoT or a combination of both can create spaces where all people, including those with disabilities, can use the building without creating confusion, chaos, or conflict. Libraries, by

virtue of their typology and with all innovations, can act as role models for surrounding communities [10–11]; hence, small interventions in libraries make an immediate impact on the surroundings.

AI IN LIBRARY ARCHITECTURE

AI can be very helpful to architects, especially related to specific code compliance of the building. Multiple software programs and tools are available in the United States and some European countries that provide code compliance; for example, eQUEST provides California Title-24 code compliance. However, presently in India, code compliance is generally a manual job. Also, there is no Indian software for performing code compliance specifically related to energy efficiency, GRIHA rating, or related to ECSBC pertaining to libraries or other educational buildings. We rely upon foreign software which follows their codes only. ECSBC (formerly known as ECBC) is vastly revised and updated, and there is ample opportunity for an Indian tool, software, or app to fulfill and show ECSBC compliance for buildings. Site analysis can also be made part of the tool. Further, AI-based tools can be used for both new construction and modifications in existing buildings. Following are the areas where AI can be integrated into library design:

- *Generative Design:* AI tools, like Autodesk's Generative Design, can produce multiple layout options based on goals like maximizing daylight, minimizing energy use, or optimizing visitor flow. The effect of surrounding structures on energy efficiency can also be found and an optimum layout of buildings can be achieved.
- *Site Analysis:* AI can analyze terrain, climate, and urban context to suggest ideal building orientation and massing.
- *Code Compliance:* AI-driven tools can automatically check designs against ECSBC 2024 and local building codes, flagging violations early.
- *Energy Modeling:* AI-based tools can be used to model energy models of libraries to model future energy needs, which can help in expansion or modifications related to libraries.
- *Integration of Inclusive Design Features:* AI tools with trained data can automatically generate accessible design elements, such as Braille Signage, voice-activated doors, etc., and provide walkthroughs. AI-driven virtual reality can be used for visualizing the scenario related to the perspective of differently-abled users, which can be handy to architects to take final decisions.

By integrating AI assistive technologies into the design process, architects can move beyond compliance and toward true inclusion, creating spaces that empower and welcome everyone.

ML FOR PREDICTIVE AND ADAPTIVE DESIGN

Machine Learning is a subset of AI. It is mentioned separately here due to its use during the operational phase of libraries. Machine Learning can be handy especially in the operational stage of libraries. Some ML-based approaches, such as data-driven space planning, can help create modular library designs that accommodate multiple uses when needed. So, ML empowers users to take informed decisions. Some of the benefits of ML pertaining to libraries are as under:

- *User Behavior Forecasting:* ML models trained on library activity data can anticipate peak times, popular areas, and seasonal trends, informing space planning and HVAC zoning.
- *Post-Occupancy Learning:* Once the library is operational, ML can analyze IoT data to iteratively improve future designs based on real-world performance, optimize ergonomic furniture layouts across zones, and integrate enhanced accessibility features where needed for users with disabilities.
- *Data-Driven Space Planning:* ML evaluates foot-traffic patterns, seating choices, and resources used to steer layout optimization. Architects can leverage these insights to create adaptable zones – quiet study areas, collaborative spaces, and tech hubs – aligned with observed behavior. By modeling how people with disabilities navigate the building, it strengthens inclusive design and guides improvements to accessibility features.
- *Acoustic and Lighting Optimization:* The use of ML empowers architects to simulate various layouts and check how sound and light travel through these layouts. This helps architects choose

materials and configurations that enhance comfort for end-users. It also helps in designing optimal lighting schemes by combining natural and artificial lighting within libraries, and with the help of IoT-based technologies in the form of smart sensors, it can be implemented.

- *Personalized User Experience:* ML enables adaptive environments in buildings by providing adjustable techniques that adjust the indoor environment, such as lighting levels or temperature conditions, based on occupancy or time of day.

IOT FOR SMART, RESPONSIVE SPACES

IoT has revolutionized buildings and adds smartness to buildings using various sensors and tracking devices. Apart from this, architects can also improve the layout of buildings by incorporating latest technologies, like RFID systems, and can design shelving layouts that improve access, reduce clutter, and support intuitive navigation. Some IoT uses are as under:

- *Environmental Sensors:* IoT devices monitor indoor air quality and thermal comfort scenarios and can adjust them as per the end-user need or code requirement. These sensors monitor temperature, humidity, CO_2 levels, air quality, and light levels, allowing dynamic control of HVAC and lighting systems. This helps architects integrate passive design strategies and smart systems that adjust automatically, reducing energy use and improving user comfort. Also, the integration of ML with IoT can help optimize operations pertaining to thermal comfort and lighting systems.
- *Occupancy Tracking:* Sensors detect which areas are used most, helping architects design flexible spaces that adapt to changing needs. Real-time tracking can also track movement and occupancy in various zones of the library, such as reading areas, study rooms, lobbies, etc., which can be helpful not only in managing the library but also in helping architects in retrofitting projects and expansion projects; they can use this data to design layouts that reduce congestion, improve accessibility, and support flexible use.
- *Energy Optimization:* Smart meters and controls reduce energy waste by adjusting systems based on real-time demand.
- *Security and Access Control:* IoT-powered systems manage entry, surveillance, and restricted zones. Architects incorporate secure layouts and privacy-enhancing features based on usage patterns.

INCLUSIVE ARCHITECTURAL DESIGN WITH AI AND IOT

The inclusive architectural design can help persons having impairments related to mobility, vision, hearing, etc., by providing appropriate infrastructure at suitable places and levels. Some of the physical infrastructure includes handrails, ramps, braille description areas, accessible card catalogs, zones where guiding sticks can be used by people suffering from vision loss, changes in floor texture based on different areas, curved walls, ergonomic curved furniture, appropriate color schemes, wheelchair-accessible zones, robotic assistance, etc. [9]. Some of the solutions provided with AI and IoT are as under:

For Mobility Impairments

- *IoT-Enabled Smart Entrances:* Automatic doors with motion sensors and wheelchair-accessible ramps. RFID or smartphone-triggered access for hands-free entry.
- *Wide Corridors and Adjustable Furniture:* IoT-controlled desks and shelves that adjust height automatically based on user profile or voice command.
- *Robotic Assistance:* Autonomous robots guide users to specific areas or retrieve books, reducing the need for physical movement.

For Visual Impairments

- *AI-Powered Voice Interfaces:* Natural language assistants help users search catalogs, navigate spaces, and access services.
- *Tactile and Audio Navigation Systems:* IoT beacons paired with mobile apps or wearables provide real-time audio directions and alerts.

- *Text-to-Speech and Braille Stations:* AI converts printed and digital content into speech or braille, enhancing independent access to resources.

For Hearing Impairments

- *Visual Alert Systems:* IoT-enabled screens and lights notify users of announcements, emergencies, or service updates.
- *AI-Based Sign Language Avatars:* Interactive kiosks or mobile apps offer real-time translation of spoken content into sign language.
- *Captioning and Transcription Services:* AI tools automatically generate captions for video content and transcribe audio materials (Table 1).

Table 1. Use of AI and IoT in library buildings for various types of disabilities.

Disability type	AI features	IoT features
Mobility Impairments	Robotic guides, voice assistants	Smart doors, adjustable furniture.
Visual Impairments	TTS, voice search, Braille AI	Audio navigation, tactile maps.
Hearing Impairments	Sign language avatars, captions	Visual alerts, smart screens.

DISCUSSION AND FUTURE COURSE OF ACTION

AI and IoT can assist architects and designers in creating inclusive, modern libraries that comply with building codes. However, it is equally important to maintain simplicity in design, ensuring that buildings do not appear mechanical or overly complex. Is it not true that beauty lies in simplicity while still addressing contemporary challenges? Future researchers can explore Inclusive Architectural Design using AI and IoT to support neurodiverse users (such as those with Autism, ADHD, and other cognitive disabilities). Architects can incorporate design features in libraries that help individuals with these conditions feel secure, enhance their skills, and reach their full potential.

CONCLUSION

This research demonstrates that integrating AI and IoT into library architecture is essential for creating future-ready, inclusive, and code-compliant buildings. By embedding generative design, automated code-checking, and energy modeling into the design phase, architects can meet stringent compliance norms for various pertinent codes and standards, green rating systems, etc., such as ECSBC and GRIHA, while optimizing circulation and resource efficiency. ML strengthens the operational lifecycle through predictive space planning, post-occupancy learning, and adaptive user experiences that respond to real usage patterns and diverse accessibility needs. IoT sensors enable dynamic HVAC zoning, personalized lighting and acoustics, intuitive navigation, and enhanced resource access that make libraries safer and more comfortable for elderly and differently-abled users. Together, these technologies shift the practice from mere compliance toward proactive inclusivity and sustainability, allowing libraries to remain relevant as demographic and educational trends evolve. When implemented thoughtfully, smart, barrier-free libraries will not only fulfill regulatory targets but also model equitable, community-centered spaces that foster lifelong learning, social inclusion, and environmental stewardship. Promoting inclusive libraries in line with the Sustainable Development Goals, prioritizing equity and equality, and integrating AI and IoT can contribute to a higher Human Development Index.

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