

Augmented Reality in Library Management System and Services: A Roadmap for Future Innovations and Applications

Naseem Eqbal* and Mehtab Alam Ansari

Department of Library and Information Science, Aligarh Muslim University, Aligarh, U.P. - 202 002, India

**E-mail: naseemeqbal314@gmail.com*

ABSTRACT

Augmented Reality (AR) has emerged as a transformative technology in library systems, enhancing user engagement, information retrieval, and interactive learning. This study investigates the integration of AR in library services, focusing on its role in resource accessibility, digital literacy development, and user experience. Significantly, Aurasma, PoLAR, myLibrARy, etc., determine that AR technologies contribute to automated book sorting, wayfinding, interactive storytelling, and digital content visualisation. Furthermore, this study explores global implementations of AR, including National Library of Medicine (USA), National Library of Korea, and National Library of Sweden, etc. These initiatives highlight the potential of AR-driven interactive exhibits, immersive learning environments, and historical content augmentation in enhancing knowledge dissemination and cultural heritage preservation. This study emphasises the necessity of strategic funds, standardised implementation frameworks, and interdisciplinary collaboration to maximise the benefits of AR in library services. Furthermore, the present study evaluates the application of AR in libraries so that library management services can be improved. Additionally, the study tries to fill the research gap by providing different applications of AR in libraries and its impact on global libraries.

Keywords: Aurasma; ShelvAR; ARLib; MagicBook; PoLAR; LiDAR

1. INTRODUCTION

Technological advancements have significantly influenced the evolution of libraries from physical book repositories to digital and interactive spaces¹. While traditional library services remain essential for academic and research purposes, AR-based libraries offer immersive and interactive experiences². Augmented Reality (AR) is an advanced technological system that facilitates human-machine interaction by seamlessly integrating digital substances into the physical world. AR involves converging real and virtual environments, real-time interaction, and precise alignment of virtual and physical objects³. Augmented reality is a revolutionary technology that connects digital content to physical-world objects, incorporating audio-visual effects to enrich the informational experience. This innovation has gained traction across various sectors, including education, healthcare, and industrial applications. Libraries have begun integrating AR to create dynamic and interactive environments, enhancing user engagement⁴. AR enables the visualisation of digital elements within a physical space, enhancing users' experiences with additional layers of information⁵. AR provides a conscious, direct or indirect perception of the physical world and is augmented

with computer-generated sensory inputs such as visual, auditory, haptic, somatosensory, and olfactory elements. Its primary significance lies in its ability to merge digital components with real-world perception, which offers an immersive experience beyond mere data visualisation⁶. Augmented Reality (AR) seamlessly integrates digital information into the user's physical-world in real-time, augmenting perception and interaction⁷. In this paper, the researchers have highlighted the augmented reality application and their use in upgrading library activities. Furthermore, this study also depicts the integration of AR in promoting digital library resources. Moreover, this study further discussed the adoption of augmented reality applications in global libraries and global augmented reality projects. This study also reveals the advantages and challenges libraries face when implementing AR applications. Augmented reality has gained momentum in different areas in recent years. This study also tries to highlight the advantages of AR technology in library settings. Besides, the application of AR in some famous libraries in India as well as abroad has also been discussed in a nutshell.

2. HISTORY OF AUGMENTED REALITY

The term "augmented" originates from the Latin word "*Augere*", meaning "to add" or "to increase"⁸. The concept of Augmented Reality (AR) has highlighted

significant transformations since its early conceptualisation. In the early 1990s, Caudell and Mizell introduced the term “Augmented Reality” while working at Boeing, where they developed an AR system to assist assembly line workers by covering virtual schematics onto real-world components⁹. Simultaneously, Rosenberg developed one of the first fully functional AR systems, Virtual Fixtures, demonstrating its effectiveness in enhancing human performance in military applications. Around the same time, Steven Feiner, Blair MacIntyre, and Doree Seligmann presented KARMA, one of the first AR system prototypes that highlighted the potential of AR in interactive environments. The first comprehensive survey on AR was conducted by Azuma in 1997, which characterised it as a system that combines the real and virtual world, cooperating in real-time, and is enumerated in three dimensions (3D)¹⁰. These foundational principles have since guided the evolution and development of AR technologies. During this period, marker-based AR emerged as a practical approach for real-time applications. Hirokazu Kato developed ARToolKit, a system utilising tracking markers such as QR codes to enable real-time AR experiences¹¹. This innovation covered the way for the widespread adoption of AR across various domains, including education, medicine, industries and libraries.

The integration of AR into libraries and information centres has revolutionised information retrieval, navigation, and archival preservation. ShelvAR, ARLib, PoLAR, myLibRARY, etc. AR-powered applications have been introduced to enhance book organisation, digital interaction, and immersive learning. For instance, ShelvAR assists librarians in organising and locating books more efficiently, while Find the Future, an AR-powered initiative at the New York Public Library, enables users to explore historical archives interactively⁶. As AR continuously

evolves in its integration with Artificial Intelligence (AI), Virtual Reality (VR), and immersive digital learning platforms, it is expected to drive further advancements. The convergence of these technologies will facilitate context-aware AR applications, enabling intelligent and adaptive learning environments¹². The ongoing development of wearable AR devices, cloud-based AR solutions, and real-time AI-driven content generation suggests AR will play an increasingly pivotal role in education, research, and digital knowledge management.

3. TRADITIONAL LIBRARY SERVICES VS AR-BASED LIBRARY SERVICES

Traditional and AR-based library services exhibit significant differences in terms of accessibility, interactivity, information retrieval, and user engagement Herpich¹³, *et al.*; Wu¹⁴, *et al.* and Manuri & Sanna¹⁵). These distinctions between traditional and AR-based library services are shown in the Table 1.

4. COMPONENTS OF AUGMENTED REALITY

The effectiveness of AR relies on several core components that facilitate seamless interaction between virtual and real-world elements. These components include hardware, software, tracking technologies, and user interface mechanisms that contribute to the immersive nature of AR applications. Silva¹⁶, *et al.* define the three most significant components used in AR applications:

4.1 Scene Generator

The scene generator is the hardware or software that renders the virtual environment. In Augmented Reality (AR), the system typically requires the illustration of only a limited number of virtual objects.

Table 1. Traditional library services vs AR-based library services

S. No.	Factor	Traditional library services	AR-based library services
1.	User experience	Standard experience with physical catalogues and librarian assistance.	Interactive, immersive, supports 3D visualisation and AR navigation.
2.	Accessibility	Relies on physical access and manual catalogue searches.	AR offers real-time translations, voice commands, and digital overlays.
3.	Information retrieval	Manual catalogue searches, reference books, and librarian guidance.	Instant AR-based digital summaries, multimedia integration.
4.	Interactivity	Primarily physical interaction with books and librarians.	Engages users with 3D models, AR-enhanced book covers, and interactive learning.
5.	Learning & engagement	Conventional reading and study methods.	AR simulations and virtual storytelling enhance learning.
6.	Implementation cost	Lower technology costs, but regular book acquisition is needed.	Requires investment in AR devices, software, and maintenance.
7.	Maintenance & updates	Books require occasional replacement; infrastructure is long-lasting.	Frequent software updates and technical support are needed.
8.	Space utilisation	Requires extensive space for book collections and seating.	Reduces physical storage needs through digital integration.

4.2 Tracking System

The tracking system represents a critical challenge in Augmented Reality (AR) systems, primarily due to the registration issue. Effective alignment between objects in real and virtual environments is essential.

4.3 Display

Display technology remains a critical limitation in advancing AR systems. Most AR display devices rely on Head-Mounted Display (HMD) systems. However, current see-through display technologies do not provide the necessary brightness, resolution, field of view, and contrast to seamlessly integrate real and virtual visual elements.

5. LITERATURE REVIEW

The presented literature review covers the different aspects which were identified in the previous literature on augmented reality. This review part covers the objectives of the present study, and highly relevant studies have been reviewed here. The study by Dargan¹⁷, *et al.* stated that Augmented Reality (AR) seeks to enhance the perception of real-world visuals by superimposing digital information onto them. Several sectors show real-time computer-generated content, including education, healthcare, and entertainment. The study highlighted innovative digital technology that offers extensive applications in the contemporary digital landscape. According to Avila¹⁸, libraries can utilise affordable applications to develop augmented reality content, improving their usability and marketing efforts. This study identified that librarians can utilise it to promote their services and offer enhanced support to patrons. Hussain⁵ examined augmented reality applications and revealed that academic libraries in developed nations utilise the technologies to enhance information delivery. De Sarkar⁴ emphasised the potential of AR to revolutionise libraries into immersive and interactive spaces. The study identified key AR applications in modern libraries, including document tracking, support for innovation and research, and developing digital literacy skills, reflecting a shift toward operational efficiency and user engagement.

Fernandez¹² examined emerging trends that enable information professionals to engage actively in the development and application of AR. This study also emphasised that AR technologies were committed to addressing challenges, including breaking free from the preventive app development ecosystem and enabling AI applications on mobile devices. Massis¹⁹ outlined the context for libraries to evaluate the advantages of adopting augmented reality technology. Augmented reality is recognised as an authentic and valuable addition to the collection of tools available to libraries. Berryman²⁰ demonstrated that AR superimposes digital information with physical world objects and enriches the user's goal. This study explored augmented reality and its mechanisms, applications, and prospective influence on libraries.

Arena⁸, *et al.* highlighted the fundamental principles of augmented reality applications and essential insights. This study focused on the hardware and software elements which integrate AR systems.

Carmigniani¹⁰, *et al.* outlined the applications of augmented reality and projected future advancements within the domain. The study addressed the barriers to augmented reality development from laboratories to industrial applications. Bhattacharya⁶ explained that Augmented Reality works alongside digital devices with software, sensors, and projectors, enabling digital interfaces to interact with physical objects. The capacity of AR to enrich existing knowledge makes it particularly significant in library settings. Videnov²¹, *et al.* investigated the integration of Augmented Reality (AR) within higher education training materials. Moreover, integrating AR creates training materials that align with the visual and kinesthetic learning styles prevalent among digital native students.

Yuen²², *et al.* investigated the consequences of AR for learning and educational activities. Luhova²³ analysed the challenges of AR technologies in preparing professionals characterised by the ambiguity of the surroundings and applied the provisions of library and archival associations. Shahzad²⁴, *et al.* highlighted the influence of augmented reality on libraries and enhanced user engagement, experiential learning, management, and librarian support. The study offered a framework for adopting augmented reality in libraries to enhance services for patrons. Gul & Bano²⁵ highlighted smart libraries as next-generation systems integrating advanced technologies, user-centric services, and automation. These libraries enhance accessibility, interactivity, and efficiency, creating a dynamic and responsive environment for users by leveraging AI, IoT, and AR. Huang²⁶, *et al.* developed an information system to enhance self-regulated learning and address domain unawareness. Similarly, newcomers often face spatial unawareness in large libraries due to vast collections and complex layouts. Augmented Reality (AR)-based navigation can effectively improve user orientation and resource accessibility.

Mayesti²⁷, *et al.* examined AR adoption in Indonesian university libraries, assessing library and librarian readiness. The findings emphasised the need for institutional support and professional development to facilitate successful implementation and digital transformation in academic libraries. Saleh²⁸, *et al.* presented a model for integrating Augmented Reality (AR) in university medical science libraries and emphasised the role of AR in enhancing learning, information retrieval, and navigation while noting challenges such as high costs and technical limitations. The findings provide a foundation for further research on AR adoption in academic libraries. Taha²⁹, *et al.* examined students' acceptance of Augmented Reality (AR) in Al Ain University (AAU) libraries. The study indicated a positive perception, with students viewing AR as useful, user-friendly, and beneficial for accessing library resources and services. Sample³⁰ conducted a study

on augmented and virtual reality in information literacy instruction to minimise anxiety among the students of Oral Roberts University. The author mentioned in this article that the university library is conducting online tutorials to reduce library anxiety among non-traditional and international graduate students.

Adewusi³¹, *et al.* stated that students identified augmented reality applications in the library as influential in enhancing their engagement and overall learning experiences. Wojcik³² studied the characteristics of augmented reality technology and explored the practical challenges and ethical considerations involved in its adoption within library environments. Based on the above studies, the benefits, applications, advantages, and challenges associated with adopting augmented reality in libraries have been extensively discussed. Furthermore, this study incorporates diverse perspectives from various researchers on the role of augmented reality in library services. However, this research specifically focuses on applying augmented reality platforms in library operations and services. It is important to highlight that, so far, limited studies have explored the global implementation of augmented reality in library management and service enhancement.

6. OBJECTIVES OF THE STUDY

The objectives of the present study are as follows:

- To discuss the role of AR in enhancing and modernising library management services.
- To assess the practical applications of AR in improving library services.
- To identify key components of AR relevant to library operations and resource management.
- To examine global initiatives and adoption trends of AR in library systems.
- To explore the benefits and transformative potential of AR in various library activities.
- To investigate the challenges associated with the implementation of AR in libraries.

7. RESEARCH METHODOLOGY

The study is based on different works carried out by academicians and researchers in the field of augmented reality. However, this study adopts a qualitative approach based on a descriptive research method to explore and analyse the role of Augmented Reality (AR) in modernising library management and improving user engagement. The research is constructed in a systematic literature review of scholarly works, reports, and case studies by academicians and researchers focused on AR integration within library settings. The study incorporates thematic analysis to identify recurring patterns, benefits, challenges, and ethical considerations to ensure a comprehensive understanding of AR deployment in a library environment. This approach facilitates categorising data into meaningful ideas, enabling a structured evaluation of the findings. Additionally, the research includes a comparative analysis of real-world AR-powered library applications, such

as Aurasma, ShelvAR, libARi, ARLib, MagicBook, PoLAR, myLibrARy, and LiDAR. These case studies offer a fundamental understanding of the operational use of AR technologies, evaluating their effectiveness in streamlining library workflows, enhancing user interaction, and supporting information literacy. The significant factors such as usability, application costs, technical infrastructure, and user feedback were considered in the comparative analysis. By combining literature-based analysis with an evaluation of practical implementations, this methodology provides a well-versed perception of the potential and limitations of AR in library environments. It also addresses the financial, technical, and ethical dimensions critical to sustainable AR integration.

8. APPLICATION OF AUGMENTED REALITY IN LIBRARIES

Augmented reality applications have significantly improved the efficiency of existing library workflows. Libraries must adopt and implement innovative AR solutions to fully leverage the advancements to facilitate seamless access to information while enriching user experiences. Some of the most prominent AR applications in libraries include:

8.1 Aurasma

Aurasma was an AR platform developed by the UK-based software company Autonomy, which was later acquired by Hewlett-Packard Enterprise (HPE) in October 2011. The platform was available as a Software Development Kit (SDK) and a free mobile application for iOS and Android devices. Aurasma's image recognition technology enabled smartphones and tablets to detect real-world images and overlay digital content, such as animations, videos, 3D models, and web pages, enhancing user interaction with physical environments. Aurasma also provided a cloud-based studio for creating, managing, and tracking AR campaigns, creative services, white-label app development, and an SDK for integration into third-party applications. The Aurasma app was accessible via Google Play and the App Store, offering users an intuitive AR experience³³⁻³⁴.

8.2 ShelvAR

The ShelvAR app is an innovative AR application designed to streamline library management by assisting librarians in organising books more efficiently. This AR-powered application enables librarians to identify misplaced books on shelves quickly. Using image recognition technology, ShelvAR intersects digital indicators on books, displaying a checkmark for correctly placed items and a red "X" for those that require relocation. ShelvAR offers a user-friendly interface that simplifies the book-sorting process and enhances the accuracy and speed of library systems. Library staff can activate the app and point their camera at a bookshelf to instantly detect misplaced books, reducing manual effort and improving operational efficiency³⁵.

8.3 libARi

libARi is designed to assist users in locating specific books within a library. Students must comprehend the book numbering system and identify these numbers on library shelves to utilise library resources efficiently. Furthermore, the application enables users to access specific books seamlessly, mirroring the intuitive search experience typically associated with online platforms⁶.

8.4 ARLib

ARLib is a location-based augmented reality application designed to enhance library operations by assisting users in locating books more efficiently. The system is based on a mobile AR setup with a notebook computer and a head-mounted display with a FireWire camera. It is powered by Studierstube 2.0 software. ARLib facilitates everyday library tasks by augmenting the real-world environment with digital overlays, enabling users to identify the precise position of books on shelves quickly³⁶.

8.5 MagicBook

MagicBook is an advanced AR application designed to enhance children's learning by integrating traditional reading with interactive digital experiences effortlessly. MagicBook transforms static pages into immersive learning environments where children can engage with stories and educational concepts dynamically and interactively. For instance, readers can witness dinosaurs appearing to roar off the page or planets orbiting in three-dimensional space, making learning both engaging and experiential. MagicBook was founded in 2004 and is dedicated to revolutionising education by fostering curiosity, creativity, and more profound comprehension through interactive storytelling. MagicBook offers a transformative approach to early childhood education by merging conventional reading with cutting-edge AR technology³⁷.

8.6 PoLAR

PoLAR stands for 'Portable Library for Augmented Reality', an open-source framework written in C++ and distributed under the GNU General Public License (GPL). It was developed with the support of Inria's Magrit Team and funded through an Inria Technology Development Action grant (2014-2016). The primary development was led by Pierre-Jean Petitprez during his tenure as a research engineer at LORIA, under the supervision of Erwan Kerrien and Pierre-Frederic Villard, who also played key roles in its design and development³⁸. PoLAR is a comprehensive framework designed to facilitate the development of Augmented Reality (AR) applications, image visualisation, and medical imaging. Its primary objective is to provide accessible and efficient tools for developers, eliminating the need for specialised expertise in AR or medical imaging. The framework offers a suite of graphical tools that are both user-friendly and powerful, enabling the creation of advanced visualisation applications³⁹.

8.7 myLibRARY

The University of Applied Sciences Potsdam launched myLibRARY in 2014 to explore the applications of AR in public libraries. The primary objective of the myLibRARY was to advance the Smart Library model, where intelligent technologies are seamlessly integrated into library services to enhance user engagement and accessibility. myLibRARY aimed to redefine traditional library services, offering innovative navigation tools, interactive information retrieval, and context-aware digital experiences. This initiative highlights that AR in modernising libraries have paved the way for more adaptive, immersive, and user-friendly learning environments⁴⁰.

8.8 LiDAR

Light Detection and Ranging-Augmented Reality (LiDAR-AR) technology integrates the precise distance measurement capabilities of LiDAR with the engaging and immersive features of AR. LiDAR is a remote sensing technique that employs laser beams to gauge distances and generate intricate three-dimensional models of the surroundings. The application of LiDAR-AR in libraries across Africa holds significant relevance. LiDAR-AR focuses on the University of the Western Cape (UWC) library tour. It involves the development of a mobile application prototype designed to provide an immersive real-time experience that facilitates navigation and learning for students and staff within the library⁴¹.

9. ADOPTION OF AUGMENTED REALITY IN GLOBAL LIBRARIES

Barman⁷ discussed some renowned libraries that have successfully adopted AR technologies to create immersive and interactive environments:

- The University of Maryland Libraries in College Park, USA, have incorporated Augmented Reality (AR) technology to enhance multimedia content and contextual information, user engagement and facilitate a deeper comprehension of the library's collections.
- The University of California, San Diego (UCSD) Libraries in San Diego, California, have introduced AR-driven interactive library tours that allow users to explore resources within a fully immersive digital environment.
- The National Library of Medicine in Bethesda, USA, has integrated Augmented Reality (AR) technology to enhance its exhibitions, particularly the Doorway to the Past exhibit curated by the History of Medicine Division.
- The National Library of Korea in South Korea has integrated AR-based interactive exhibits, including the History of Korean Medicine, which allows users to explore additional historical and contextual information through AR-enhanced visual displays.
- In Europe, the National Library of Sweden, located in

Stockholm, has integrated AR technology to enhance the “Treasures of the National Library” initiative to enable visitors to engage with rare and valuable library artifacts through digital overlays, offering enriched historical context and deeper insights into the collection.

10. GLOBAL AUGMENTED REALITY LIBRARY PROJECTS

Various institutions have successfully implemented AR-driven applications to transform the users to interact with resources and historical collections available in the libraries:

Librarian-in-Black is a Layer-based mobile application designed to facilitate local historical tours by integrating AR capabilities. The Miami University Augmented Research Group (MUARG) has developed ShelvAR, an AR-based application that utilises a mobile camera to scan bookshelves and identify misplaced books, significantly improving shelf organisation and management. The New York Public Library’s Find the Future project combines game-based learning and augmented reality⁴². Similarly, Expedition Deventer was developed by the Public Library Deventer and integrates AR

into game-based learning to provide users with insights into the past, present, and future of Deventer as an information hub. Further advancements in AR applications are evident in the Smart Library project, which was developed and tested at Oula University Library⁶. The Wolf Walk application, developed for the North Carolina State University Campus and explores the university’s history through a location-aware map and photo viewer, offering historical insights into various campus landmarks⁴³.

In addition to AR-driven projects, Sahel is a Virtual Reality (VR) application created by the Vikram Sarabhai Library at the Indian Institute of Management (IIM), Ahmedabad. It has been developed and is maintained through a collaborative effort between TCS Entrepreneurship Junction Labs and the Vikram Sarabhai Library. Sahel is an AR-based application that allows users to take a virtual library tour by scanning a QR code⁴⁴. A new Augmented Reality



Figure 1. Indian Institute of Management⁴⁴.



Figure 3. North Carolina State University⁴⁷.



Figure 2. Georgetown University Library⁴⁵.



Figure 4. Toronto Public Library⁴⁸.

(AR) application, developed by Georgetown University student Julian Dowell in collaboration with Multimedia Project Manager Barrinton Baynes, is designed to offer an immersive walking tour of campus sites connected to the university's Slavery, Memory, and Reconciliation (SMR) initiative. The app integrates AR technology with SMR research and resources, providing users with an engaging, location-based educational experience that develops their understanding of the university's historical ties to slavery⁴⁵. The TPL AR application (tpl:ar) is a complimentary mobile application that utilises Augmented Reality, developed by the Toronto Public Library. This innovative tool enables the library to enhance its offerings by integrating videos, images, and hyperlinks into printed materials and displays⁴⁶.

11. ADVANTAGES OF AUGMENTED REALITY IN LIBRARY ACTIVITIES

The key advantages of integrating Augmented Reality (AR) into library management systems are as follows:

11.1 Boosting User Engagement

The integration of AR-based applications enhances user engagement, particularly among digitally adept younger generations. AR facilitates interactive learning and research by enabling users to visualise 3D models, access multimedia content, and interact with digital overlays, enriching the library experience and fostering more profound engagement with information resources².

11.2 Enhancing Resource Discovery

AR facilitates efficient access to library resources. Through AR-enabled catalogues, wayfinding tools, and real-time shelf-scanning applications, users can effortlessly locate books, journals, and other materials, significantly improving resource accessibility and retrieval processes⁴⁹.

11.3 Augmenting Learning Skills

Academic libraries can influence AR technology to enrich educational experiences by providing interactive supplementary materials. AR-based applications allow users to access 3D models, videos, and interactive quizzes, fostering deeper comprehension and engagement in various subject areas.

11.4 Providing Virtual Assistance

AR enables libraries to extend their support beyond physical boundaries by offering virtual assistance. Users can access real-time guidance from librarians via AR-powered applications, facilitating research assistance, information retrieval, and user support, irrespective of geographical constraints.

11.5 Remote and Mobile Access

AR applications enable users to access library resources remotely through mobile devices, providing an immersive and

interactive experience beyond physical library spaces. These applications integrate digital overlays, 3D visualisations, and interactive elements, allowing users to engage with digital content in real-time. AR bridges the physical and virtual information environment gap, enhances accessibility and user engagement, and makes library services more adaptive to digital-age learners and researchers¹.

12. CHALLENGES OF IMPLEMENTING AUGMENTED REALITY IN LIBRARIES

Augmented Reality (AR) technology presents revolutionary opportunities for libraries and information centres. Its adoption is accompanied by many challenges that must be addressed to ensure sustainable implementation. Some of the most significant challenges are as follows:

12.1 Financial Barriers

Libraries may encounter significant challenges in acquiring and maintaining the hardware, software, and network infrastructure required to implement AR experiences effectively. These challenges include high initial costs of hardware and software, continuous technological upgrades, compatibility issues with existing systems, and requiring skilled personnel to manage and support AR integration. Additionally, ensuring seamless connectivity and adequate bandwidth to support AR applications can pose logistical and financial constraints, particularly for resource-limited institutions⁵⁰.

12.2 Technological Proficiency

The successful implementation of Augmented Reality (AR) in libraries requires that librarians and patrons acquire technical proficiency for system operation and troubleshooting. However, the lack of structured training programs and the frequency of limited digital literacy present significant challenges to the effective adoption and utilisation of AR technologies in library environments⁴⁹.

12.3 Technical Support

The absence of adequate technical support presents a significant challenge in adopting AR applications in libraries. Librarians may encounter difficulties integrating AI technologies into teaching and research activities due to the limited availability of technical assistance⁵¹.

12.4 Ethical Considerations

Educational materials and training should improve user understanding and acceptance to enhance AR integration in library services. Sustainable resource allocation is essential for maintaining AR infrastructure. AR should be integrated into existing systems, supported by ethical guidelines for responsible use. Collaboration with experts can address technical challenges related to infrastructure, compatibility, and computational requirements²⁴.

13. CONCLUSION

The integration of Augmented Reality (AR) into library systems represents a significant paradigm shift in information access, user engagement, and resource management. AR offers many benefits, including enhanced interactivity, optimised resource discovery, improved accessibility, and enriched learning experiences. The implementation of AR-based applications such as Aurasma, ShelvAR, libARi, ARLib, MagicBook, PoLAR, myLibrARy, etc. highlights the transformative potential of this technology in facilitating seamless interaction between users and digital content, thereby redefining the traditional library experience. Furthermore, large-scale initiatives such as the University of Maryland Libraries' interactive exhibits, UCSD Libraries' AR-guided tours, and the National Library of Sweden's digital heritage displays highlight the increasing global commitment to integrating AR into library systems. Despite its potential, the widespread adoption of AR in libraries is contingent upon overcoming several challenges, including technological infrastructure limitations, financial constraints, and user adaptation barriers. Addressing these challenges necessitates strategic investment in AR-compatible systems, capacity-building initiatives for library professionals, and collaborative research efforts to refine AR-based solutions tailored to the specific needs of library users.

This study recommends that strategic efforts focus on several key areas to fully leverage the transformative potential of Augmented Reality (AR) in library systems. Libraries should invest in AR-ready infrastructure, implement training for professionals, and develop standardised frameworks for effective adoption. Collaborative research involving librarians and users is essential to create user-centric AR solutions tailored to informational needs. Additionally, promoting user awareness through demonstrations and interactive programs can enhance engagement and facilitate the transition toward AR-enhanced services. These efforts will help to overcome current challenges and enable libraries to redefine user experience, improve accessibility, and have enduring relevance in the evolving digital information landscape.

REFERENCES

1. Carmigniani J, Furht B. Augmented reality: An overview. handbook of augmented reality. New York: Springer; 2011:3-46.
doi: 10.1007/978-1-4614-0064-6_1
2. Dey A, Billinghurst M, Lindeman RW, Swan II JE. A systematic review of usability studies in augmented reality between 2005 and 2014. 2016 IEEE International symposium on mixed and augmented reality, Merida, Mexico;2016:49-50.
doi: 10.1109/ISMAR-Adjunct.2016.0036.
3. Lee K. Augmented reality in education and training. Tech Trends. 2012;56(2):13-21.
doi: 10.1007/s11528-012-0559-3
4. De Sarkar T. Augmented reality applications and the future library, Library Hi Tech News. 2023;40(9):7-11.
doi: 10.1108/LHTN-07-2023-0129
5. Hussain A. Review of augmented reality in academic and research libraries, Library Hi Tech News. 2022;39(9):23-25.
doi: 10.1108/LHTN-06-2022-0082
6. Bhattacharya A. Augmented reality applications in modern day library: A study. J of Indian Lib Ass. 2018;54(4):189-194.
7. Barman E. Augmented reality in libraries -IFLA;2023. <https://www.ifla.org/news/augmented-reality-in-libraries/> (accessed on 30 January 2025).
8. Arena F, Collotta M, Pau G, Termine F. An overview of augmented reality. Computers. 2022;11(2):1-15.
doi: 10.3390/computers11020028
9. Caudell TP, Mizell DW. Augmented reality: An application of heads-up display technology to manual manufacturing processes. In: Proceedings of the 25th Hawaii International Conference on System Sciences. 1992;2:659-669.
10. Carmigniani J, Furht B, Anisetti M, Ceravolo P, Damiani E, Ivkovic M. Augmented reality technologies, systems and applications. Multimedia Tools and Applications. 2011;51:341-377.
doi: 1007/s11042-010-0660-6
11. Kato H, Billinghurst M. Marker tracking and HMD calibration for a video-based augmented reality conferencing system. In: *Proceedings of the 2nd International workshop on augmented reality*. 1999:85-94.
12. Fernandez P. "Through the looking glass: envisioning new library technologies" A glimpse into the future of augmented reality, Library Hi Tech News. 2024; 42(1):1-5.
doi: 10.1108/LHTN-10-2024-0183
13. Herpich F, Guarese RLM, Tarouco LMR. A comparative analysis of augmented reality frameworks aimed at the development of educational applications. Creative Education. 2017;8:1433-1451.
doi: 10.4236/ce.2017.89101
14. Wu H-K, Lee S W-Y, Chang H-Y, Liang J-C. Current status, opportunities and challenges of augmented reality in education, Computers & Education. 2013; 62:41-49.
doi: 10.1016/j.compedu.2012.10.024
15. Manuri F, Sanna A. A survey on applications of augmented reality. Advances in computer science: An Int J. 2016;5(1):18-27.
16. Silva R, Oliveira JC, Giraldo GA. Introduction to augmented reality. National Laboratory for Scientific Computation. 2003;11:1-11.
17. Dargan S, Bansal S, Kumar M, Mittal A, Kumar K. Augmented reality: A comprehensive review. Archives of Computational Methods in Engineering. 2023;30:1057-1080.
doi: 10.1007/s11831-022-09831-7
18. Avila S. Implementing augmented reality in academic libraries, Public Services Quarterly. 2017;13(3):190-

199.
doi: 10.1080/15228959.2017.1338541
19. Massis B. Using virtual and augmented reality in the library, *New Library World*. 2015;116(11/12):796-799.
doi: 10.1108/NLW-08-2015-0054
20. Berryman DR. Augmented reality: A review, *Medical Reference Services Quarterly*. 2012;31(2):212-218.
doi: 10.1080/02763869.2012.670604
21. Videnov K, Stoykova V, Kazlacheva Z. Application of augmented reality in higher education. *Applied researches in technics, technologies and education*. 2018;6(1).
doi: 10.15547/artte.2018.01.001
22. Yuen S, Yaoyuneyong G, Johnson E. Augmented reality: An overview and five directions for AR in education. *J of Edu Technol Development and Exchange*. 2011;4(1):119-140.
23. Luhova T. Development of augmented reality technologies for academic libraries as an experience of synergetic learning. *Open educational E-environment of modern university*. 2021;10:116-135.
doi: 10.28925/2414-0325.2021.1011
24. Shahzad K, Khan SA, Iqbal A. Impact of augmented reality on libraries: A systematic literature review. *J of Lib & Inf Sci*. 2024 0(0).
doi: 10.1177/09610006241259492
25. Gul S, Bano S. Smart libraries: An emerging and innovative technological habitat of 21st century *The Electronic Library*. 2019;37(5):764-783.
doi: 10.1108/EL-02-2019-0052
26. Huang T-C, Shu Y, Yeh T-C, Zeng P-Y. Get lost in the library? An innovative application of augmented reality and indoor positioning technologies, *The Electronic Library*. 2016;34(1):99-115.
doi: 10.1108/EL-08-2014-0148
27. Mayesti N, Huang CH, Azmir AF, Adzani DM. Librarians' views of the readiness of university libraries in Indonesia to adopt virtual and augmented reality. *Digital Library Perspectives* 2024;40(2):212-230.
doi: 10.1108/DLP-05-2023-0041
28. Saleh MD, Salami M, Soheili F, Ziaei S. Augmented reality technology in the libraries of universities of medical sciences: identifying the application, advantages and challenges and presenting a model. *Library Hi Tech*. 2022;40(6):1782-1795.
doi: 10.1108/LHT-01-2021-0033
29. Taha S, Kaba A, Al-Qeed MA. Exploring students' perceptions toward the use of augmented reality for digital library services. *Digital Library Perspectives*. 2024;40(1):53-66.
doi: 10.1108/DLP-06-2023-0053
30. Sample A. Using augmented and virtual reality in information literacy instruction to reduce library anxiety in nontraditional and international students. *Information Technology and Libraries*. 2020;39(1):1-29.
doi: 10.6017/ital.v39i1.11723.
31. Wójcik M. Augmented intelligence technology. The ethical and practical problems of its implementation in libraries. *Library Hi Tech*. 2021;39(2):435-447.
doi: 10.1108/LHT-02-2020-0043
32. Adewusi MA, Kazibwe S, Odekeye OT, Egbowon SE. Augmented reality in the library automation: students' perception. *Educational Perspectives*. 2024;12(1):199-210.
33. Aurasma. Aurasma. 2025. <https://www.auganix.org/hud/aurasma/> (accessed on 20 February 2025).
34. Holzschuh VRB, Bogoni TN. Aurasma: A tool for education. In: 19th Symposium on Virtual and Augmented Reality (SVR), Curitiba, Brazil. 2017:257-260.
doi: 10.1109/SVR.2017.40.
35. DeLuca C. ShelvAR app uses augmented reality to arrange library books, *TrendHunter.com*. 2011. <https://www.trendhunter.com/trends/shelvar-app> (accessed on 30 January 2025).
36. Umlauf EJ, Piringier H, Reitmayr G, Schmalstieg D. ARLib: The augmented library. *First IEEE International Workshop Augmented Reality Toolkit*, Darmstadt, Germany. 2022.
doi: 10.1109/ART.2002.1106996.
37. MagicBook. Magicbooks. 2025. <https://www.magicbooks.shop/> (accessed on 31 January 2025).
38. Portable library for augmented reality (PoLAR). (2025). <https://polar.inria.fr/> (accessed on 31 January 2025).
39. Petitprez P, Kerrien E, Villard P. PoLAR: A portable library for augmented reality. In: 15th IEEE International Symposium on Mixed and Augmented Realit, Merida, Mexico. 2016; 4. hal-01356012 (accessed on 20 February 2025)
40. Baumgartner-Kiradi B, Haberler M, Zeiller M. The Potential of augmented reality in the library. *Bibliosphere*. 2024;2:30-37.
doi: 10.20913/1815-3186-2024-2-34-45
41. Mojapelo AK, Maneli MA. LiDAR-based augmented reality implementation for library tours. In: 2024 IST-Africa Conference (IST-Africa), Dublin, Ireland. 2024:1-9.
doi: 10.23919/IST-Africa63983.2024.10569719
42. Fakiragoudar AP. A brief study of utilisation of augmented reality in context with modern library. *Int J for Res in Applied Sci & Engineering Technol*. 2012; 9(3):1342-1347.
doi: 10.22214/ijraset.2021.33505
43. NC State University Libraries. Wolf Walk. 2021. <https://www.lib.ncsu.edu/projects/wolfwalk> (accessed on 20 March 2025).
44. Vikram Sarabhai Library, IIM Ahmedabad. Sahel - Virtual reality (VR) App for library. 2025. <https://library.iima.ac.in/vrapp.html> (accessed on 06 February 2025)
45. Augmented reality app connects to SMR research. *Georgetown university library*. 2025. <https://library.georgetown.edu/news/augmented-reality-app-connects-smr-research> (accessed on 25 May 2025)
46. Augmented reality app. *Toronto public library*. 2025

- <https://www.torontopubliclibrary.ca/ar/> (accessed on 06 February 2025)
47. Wolf walk. Wolf walk mobile web screenshot. 2018. <https://www.lib.ncsu.edu/documents/dli/projects/wolfwalk/screenshots/web/> (accessed on 20 March 2025)
 48. TPL Teens. tpl:ar Augmented Reality App. YouTube. 2019. <https://www.youtube.com/watch?v=cf2LAr2DIPU> (accessed on 20 March 2025)
 49. Karthick M, Shanmugam PNL. Augmented reality in library information mobilisation-An overview. Multidisciplinary approaches in web and open educational resources: Opportunities and challenges, periyar maniammai institute of science and technology. 2023:140-144.
 50. Chen C-M, Yang, Y-C. A game-based augmented reality navigation system to support makerspace user education in a university library. The Electronic Library. 2024;42(1):78-101.
doi: 10.1108/EL-05-2023-0107
 51. Greene D. and Groenendyk M. An environmental scan of virtual and augmented reality services in academic libraries. Library Hi Tech. 2021;39(1):37-47.
doi: 10.1108/LHT-08-2019-0166

CONTRIBUTORS

Mr. Naseem Eqbal is currently working as a Senior Research Fellow (SRF) at the Department of Library and Information Science, Aligarh Muslim University, Aligarh, India. He has done his BLISc and MLISc from Aligarh Muslim University, India. His contribution to the present study is the conceptualisation of the manuscript, which includes introduction, literature review, historical background, application of AR, conclusion, and compiling references.

Dr. Mehtab Alam Ansari is currently working as a Professor in the Department of Library and Information Science at Aligarh Muslim University, Aligarh, India. His contribution to the current study is constant supervision and subsequent useful feedback.