When AI Interacts with Virtual Reality and Augmented Reality: A Synthesis and Evaluation of Literature

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Abstract

This study addresses that gap by examining the state of implementation, the conditions that enable or constrain adoption, and the outcomes reported across various library settings. The objectives of the study are to systematically map how AI, VR, AR, and metaverse technologies are being proposed, piloted, and evaluated within library contexts and to identify key application areas, enabling and impeding factors, reported outcomes, and existing gaps in the literature and practice. This study synthesizes the current literature and recent trends on how artificial intelligence enhances AR and VR, its applications, technological enablers, challenges, and future directions along with new developments. A literature review as a method of discovering what is known about the topic has been applied in this study to find relevant literature. Preparation of

literature utilized a PRISMA flow diagram to provide a clear picture of the literature search process from identification, screening and inclusion. Initial searches were made using known online databases. Themes were derived by importing the documents, reviewing their content, highlighting relevant statements, and assigning tags to key excerpts. Concepts were validated by cross-checking them against the designated keywords and the themes consistently emphasized across the articles. The findings reveal that between 1994 and 2025, libraries have piloted and evaluated AI/VR/AR primarily for orientation, instruction, discovery, and user support, with a notable acceleration after 2018 and a pronounced surge after 2022. Libraries are increasingly adopting AI, AR, VR, and metaverse technologies for enhanced access, engagement, and learning. Literature shows a progression from conceptual models to bibliometric/systematic reviews, with growing global interest. The paper examines the emerging intersection of artificial intelligence with virtual and augmented reality. The paper provides a novel synthesis that brings together technological domains often studied separately. This integrative perspective adds conceptual clarity and contributes fresh insights for researchers and practitioners evaluating next-generation library technologies.

Keywords: Augmented reality,virtual reality, artificial intelligence, digital transformation, intelligent technologies,data-driven ecosystems, intelligent environments

Introduction

There has been dynamic changes among the various components of artificial intelligence (AI), augmented reality (AR), virtual reality (VR), and library and information science (Adigun et al., 2024; Greene &Groenendyk, 2021). The developments of intelligent systems and user interactions in a given institutional preparedness have shown the vibrant, and user-centred spaces.The emergence of interdisciplinary collaboration and professional training in the context of ethical oversight has become mandatory for the successful and equitable implementation (Wojcik, 2021).The responsive and data-driven libraries are shifting toward user-centred services where intelligent technologiesare gaining tractionand enhancing service accessibility as well as scalable solutions.

The aspects such as advanced interaction of users and machine, personalization and highly intuitive intelligent design are paving way for library system transformation. From virtual assistants to real-time adaptive learning, AI is transforming virtual reality from passive simulations to intelligent environments. While challenges remain, particularly in terms of energy efficiency and ethical considerations, innovations in infrastructure and pervasive AI (Weijia, 2022; Wani & Bhat, 2023; Sukula, 2023) are helping to address these challenges. As research advances, the convergence of AI and VR is likely to define the future of learning, collaboration, and digital experiences.

Problem Statement and Research Objectives

Rapid advancements in AI, VR, and AR including metaverse-related technologies are transforming information environments into a dynamic ecosystem. Libraries are long recognized as spaces for learning, access, and innovation. They are increasingly exploring these emerging technologies to enhance services, user engagement, and operational efficiency. However,initiatives from recent pastoften remain fragmented, with limited systematic understanding of how such technologies are being proposed, piloted, and evaluated in library contexts. This synthesis addresses that gap by examining the state of implementation, the conditions that enable or constrain adoption, and the outcomes reported across various library settings. The objectives of the study are to systematically map how AI, VR, AR, and metaverse technologies are being proposed, piloted, and evaluated within library contexts and to identify key application areas, enabling and impeding factors, reported outcomes, and existing gaps in the literature and practice.

The following questions have been considered to accomplish the synthesis:

- In what areas of library service delivery or internal operations are AI, VR, and AR currently applied?
- What technologies and methods are most common in applying these technologies?
- What outcomes are reported in relation to usability, learning, engagement, efficiency, and cost?
- What recurring issues arise in terms of readiness, acceptance, ethics, and curriculum?
- What evidence gaps exist, and what future research or practice directions emerge from them?

Methodology

A detailed and critical examination and synthesis of the research literature associated with AI, VR and AR was conducted. As a product and a process, the literature review as a method of discovering what is known about the topic has been applied in this study to find relevant literature (University at Buffalo University Libraries, 2025).

Framework and Guidelines - This synthesis follows the scoping review methodology proposed by Arksey & O'Malley (2005) and adheres to PRISMA-ScR reporting standards to ensure systematic identification, screening, and synthesis of relevant literature. Given that scoping reviews systematically map existing research, the present study, which focuses on synthesizing the literature, adopts this methodology to comprehensively identify and integrate relevant findings.

Data Collection - Data was collected from the Google Scholar search engine. The phrases used to collect data from Google Scholar are listed below (Table 1). Major academic databases were also consulted including industry sources such as IEEE, Springer, and Elsevier. Several reports from Accenture, McKinsey, NVIDIA, and PwC were also included. A total of 88 references were selected. There was no specific time/year range for data collection; the default setting on Google Scholar was kept on. To retrieve the maximum possible relevant results, no Boolean operators were applied.

Selection Criteria - Inclusion criteria comprised English-language studies (1994–2025) focusing on AI, AR, and VR within library, information, and educational contexts. Exclusion criteria eliminated purely technical studies lacking practical relevance to libraries or education, ensuring the review remained focused on applied, user-centred, and context-specific technological implementations.

Search Strategy

The literature for this study was retrieved using **Google Scholar** as the primary search engine. Google Scholar is widely used in systematic reviews for its broad coverage of scholarly publications across disciplines.

a. Time Frame

- The search was conducted with **"any time"** selected
- Filters such as:
  - Since 2026 – *not applied*
  - Since 2025 – *not applied*
  - Since 2022 – *not applied*
  - Custom range – *not applied*

However, for specific queries, **time ranges were manually incorporated within the search phrases** to target recent studies (e.g., 2024–2025 publications).

b. Sorting and Filtering Options

- **Sort by relevance** – applied
- Sort by date – *not applied*
- Document type – **any type**
- **Review articles** – applied, with inclusion of cited works to ensure scholarly reliability

c. Search Phrases

Studying the experiences of libraries worldwide with AR and VR offers a way to enhance the user experience. However, the recent romance with AI and all the periphery is intriguing in VR, AR, and library applications. Browsing the vast and comprehensive libraries, it was essential to frame specific phrases.

The following phrases were used:

1. *"Augmented reality applications in libraries in 2025."*
2. *"Augmented reality applications in the library during 2024–2025."*
3. *"Virtual reality applications in libraries in 2025."*
4. *"Virtual reality applications in the library during 2024–2025."*

((*"Augmented reality applications in libraries*" OR "*Virtual reality applications in libraries* " AND ("artificial intelligence"))

These queries were designed to capture **recent advancements in artificial intelligence with a focus on VR and AR applications in libraries, including**navigation, digital collections, and user engagement. This strategy ensured a **comprehensive yet focused retrieval of relevant literature,** combining broad search settings with targeted keyword-based refinement to capture the most recent and high-quality studies on augmented reality in library contexts.

The literature search was conducted during January, February, June, and July 2025.

Two researchers agreed to independently review and screen records for inclusion. In case of disagreements, a consensus among them needs to be resolved.

Dataset and Analysis

A total of 88 references were selected. Data charting included author(s), year, library context, intervention type, research design, and reported effects (Figure 1). Industry reports are retained as contextual background to capture emerging trends, supporting the primary evidence.

Identifying the dominant themes is crucial. Key ideas were extracted from each study. Each code were labelled manually and similar codes were grouped together. After assigning initial codes, every record with similar concepts were again grouped together and was provided headings as discussed in the results of the study.

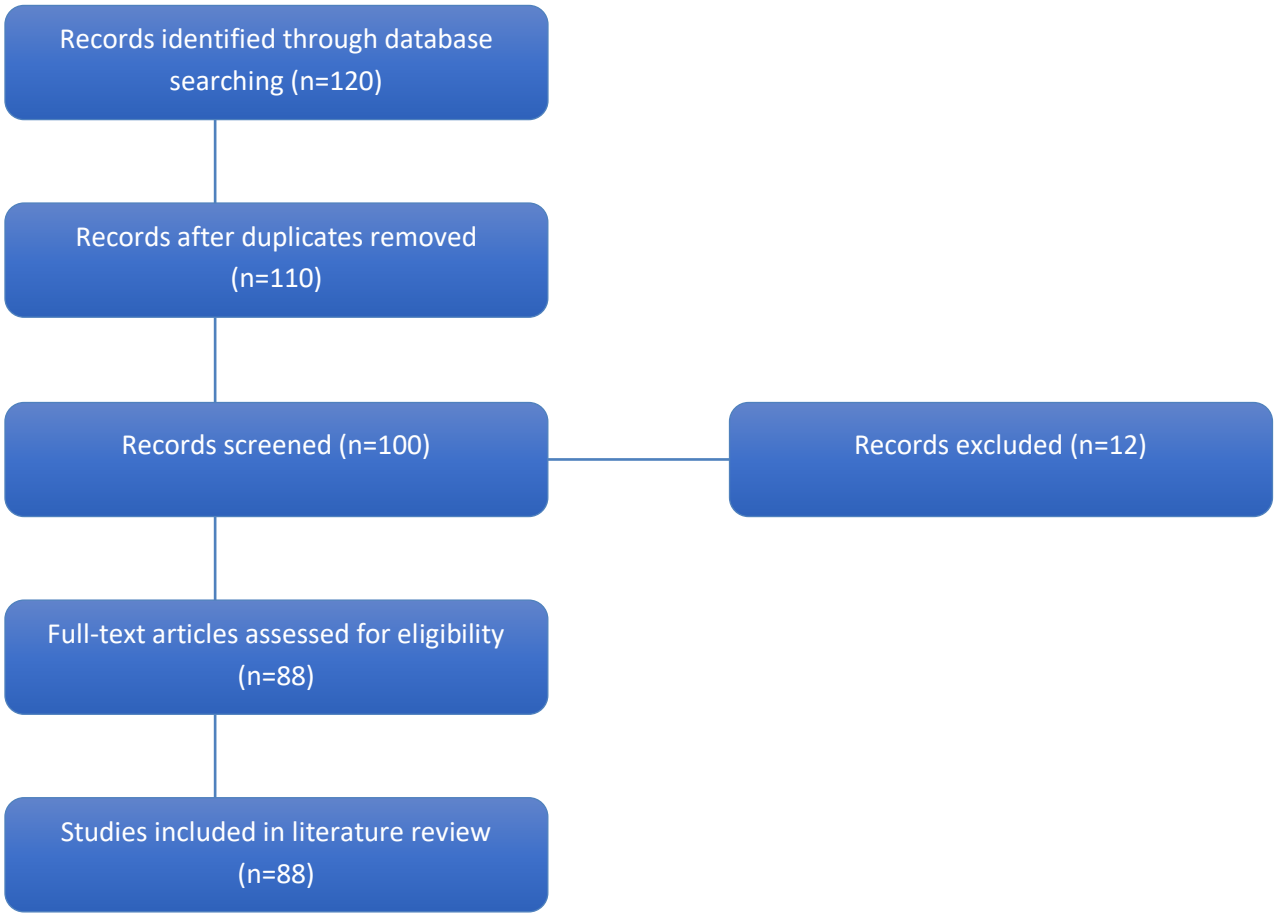

Fig. 1. PRISMA Flow
Source: Authors own work

The PRISMA-style flow diagrams shows how 88 references as records retrieved were included, along with a concept map (Figure 2) that visualizes the main thematic areas and sub-themes in AI, AR, and VR library research (1994–2025).

Reasons for Key References' Inclusion

The selected references represent a chronological progression from foundational theories of mixed reality and early AI integration to contemporary AR/VR applications in libraries. This ensures a comprehensive understanding of the field's evolution from conceptual frameworks to practical implementations (Milgram & Kishino, 1994; Hahn, 2012; Sulastri, 2025). The studies capture a wide range of technological developments, including mobile AR, AI-driven automation, immersive learning, and metaverse applications. This diversity allows for a holistic analysis of AR/VR use across library services, education, and knowledge management (Shatte et al., 2014; Lu, 2021; Guo et al., 2024). The inclusion of systematic reviews, bibliometric studies, and global case studies ensures balanced insights into user acceptance policy and implementation challenges across different regions and contexts (Shahzad et al., 2024; Sahu & Maharana, 2025; Jeong & Park, 2024).

Limitations and Scope of the Study

This study explores the application of artificial intelligence, virtual reality, and augmented reality in library services. It examines their roles in information retrieval, user assistance, learning environments, and navigation. The analysis focuses on commonly used technologies and evaluates outcomes like usability, engagement, efficiency, and cost to understand their impact on modern library systems and users.

Table 1
Included studies on AR/VR/AI in libraries

Study (Author, Year)	**Context**	**Intervention Type**	**Research Design**	**Reported Effects**
Abdulwahid et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Accenture (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Adamu et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Adewojo et al. (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Adewusi et al. (2024)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Adeyemi et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Agwuna et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Aini et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Al-Ani et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Anthes et al. (2016)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Avila (2017)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Bao & Zhang (2022)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Baumgartner-Kiradi et al. (2018)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Bhattacharya (2019)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Chawan&Lingappa	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Chen et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Chen & Tsai (2012)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Chitra (2019)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Dalili Saleh et al. (2022)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
De Sarkar (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Devagiri et al. (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Eltemasi	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Green et al. (2014)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Gul & Bano (2019)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Guo et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Hahn (2012)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Hannah et al. (2019)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Huang et al. (2016)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Hussain (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Jedlicka & Eaton (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Jeong & Park (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Kharat et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Ranavagol et al. (2025)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Koukopoulos (2018)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Kulkarni et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Kunkel (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Liu et al. (2020)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Lu (2021)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Luck & Aylett (2000)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Luhova (2021)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Lund et al. (2020)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Luthfi et al. (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Massis (2015)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
McKinsey (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Milgram & Kishino (1994)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Mojapelo & Maneli (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Netragaonkar (2024)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Nik Ahmad et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Noh & Shin (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
NVIDIA (2021)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Okada et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Okunlaya et al. (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Okwu (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Omame& Alex-Nmecha (2020)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Oyelude (2017)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Panda & Chakravarty (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Pineda-Torres & Rodriguez-Lopez (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
PwC (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Ribeiro de Oliveira et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Safadel et al. (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Sahu & Maharana (2025)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Santos & Esposo-Betan (2018)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Shahzad et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Shatte et al. (2014)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Slater & Sanchez-Vives (2016)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Sonawane et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Sreeramoj& Batcha (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Sukula (2023)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Sukula et al. (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Sulastri (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Taha et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Tait & Pierson (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Wang (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Wani & Bhat (2023)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Wei (2019)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience
Wei et al. (2024)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Weijia (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Williams & Nwagwu (2025)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Wójcik (2021)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Ylipulli&Luusua (2019)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Yoon et al. (2022)	Academic / Public / Digital Libraries	AR/VR/AI Systems, Navigation, Gamification, Automation	Survey / Experimental / Review / Case Study	Improved engagement, efficiency, access, and user experience
Yu et al. (2019)	Academic / Public / Digital	AR/VR/AI Systems, Navigation,	Survey / Experimental / Review / Case	Improved engagement, efficiency,

	Libraries	Gamification, Automation	Study	access, and user experience

Source: Authors own works

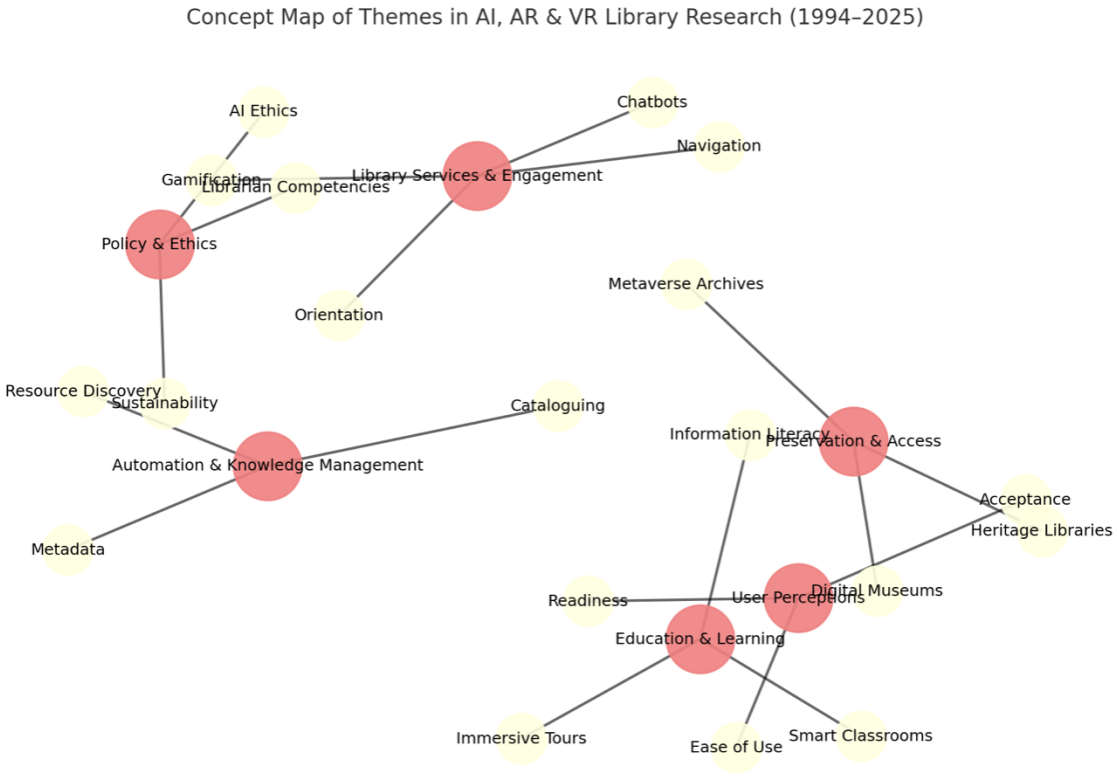

Fig. 2. Concept visualization

Source: Authors own work

Figure 2 illustrates the timeline conceptual visualization that shows the evolution of AI, AR, and VR research in libraries from 1994–2025, moving from early foundations to recent trends and systematic reviews.

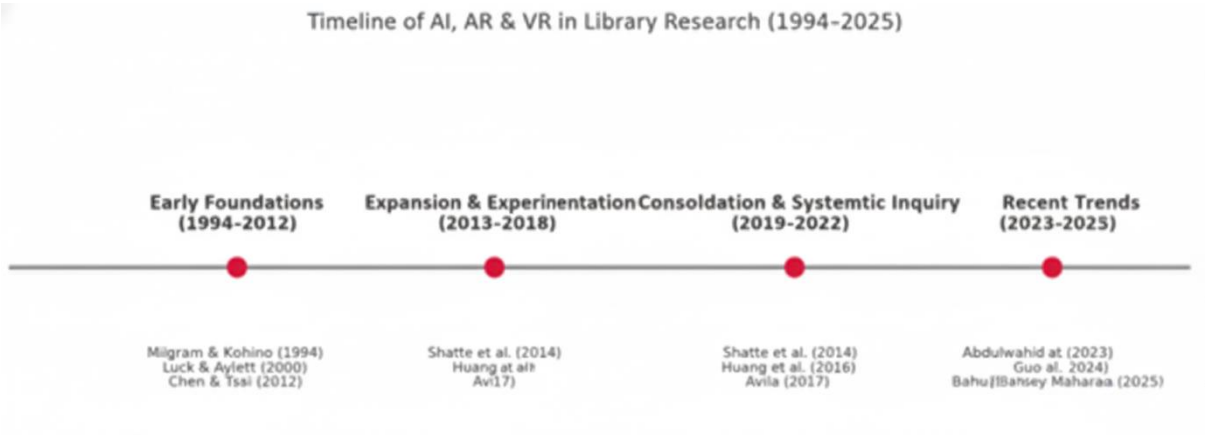

Fig. 3. Timeline
Source: Authors own work

Figure 3 shows the timeline of VR, AR, and AI in the field of library science during the period 1994-2025

The visuals generated to produce PRISMA flow diagram, concept map, and timeline were created using Python with these libraries:

- Matplotlib → is used to plot the PRISMA diagram and visualize the timeline
- NetworkX → for building and visualizing the thematic concept map as a network graph.

These tools (Hunter, 2007; Hagberg, et al., 2008) are widely used in research data visualization. Matplotlib was employed for plotting diagrams and timelines, while NetworkX was used to construct and visualize the thematic concept map. These tools clearly represented inclusion processes, thematic structures, and chronological trends in AI, AR, and VR library research.

To explain the timeline (Figure 3), below is a summary of highlights from the early foundations to recent trends.

Early foundations (1994–2012)

- Milgram & Kishino (1994) → taxonomy of mixed reality
- Luck & Aylett (2000) → AI in virtual environments
- Chen & Tsai (2012), Hahn (2012), Hahn & others → first AR-based library services

Expansion &experimentation (2013–2018)

- Mobile AR in libraries (Shatte et al., 2014; Huang et al., 2016)
- VR/AR for library orientations (Anthes et al., 2016; Avila, 2017; Oyelude, 2017)

- Usage scenarios & evaluation (Koukopoulos, 2018)
- AR for empowerment in smart cities (Ylipulli&Luusua, 2019)

Consolidation &systematic Inquiry (2019–2022)

- Reviews and frameworks (Hussain, 2022; Panda & Chakravarty, 2022; Okunlaya et al., 2022)
- AI + AR in service automation (Yu et al., 2019; Lu, 2021)
- Metaverse & immersive future (McKinsey, 2022; PwC, 2022)

Recent trends (2023–2025)

- AI-powered library operations (Abdulwahid et al., 2023; Sonawane et al., 2024)
- AR in navigation, tours, and gamified learning (Al-Ani et al., 2023; Mojapelo & Maneli, 2024)
- Bibliometric/Scientometric mappings (Sahu & Maharana, 2025; Sulastri, 2025; Luthfi et al., 2025)
- Systematic reviews (Shahzad et al., 2024; Pineda-Torres & Rodriguez-Lopez, 2025)
- National contexts: Nigeria (Adewojo et al., 2025), India (Kharat et al., 2024), Korea (Jeong & Park, 2024)
- Metaverse applications (Guo et al., 2024a, Guo et al.,2024b)

Results

Applying the search syntax to the search strategy, a total of 120 citations wereidentified through several databases (Figure 1). During the screening process, 12 records were excluded and 88 records with full text access were identified as eligible. Between 1994 and 2025, libraries have piloted and evaluated AI/VR/AR primarily for orientation, instruction, discovery, and user support, with a notable acceleration after 2018 and a pronounced surge after 2022. Libraries are increasingly adopting AI, AR, VR, and metaverse technologies for enhanced access, engagement, and learning. Literature shows a progression from conceptual models → pilots → bibliometric/systematic reviews, with growing global interest. The future depends on scalability, ethics, librarian training, and sustainable infrastructure.

The integration of artificial intelligence (AI) in library systems

Information organisation, access and usage are being altered by AI inclusion into library systems. Abdulwahid et al. (2023) presented a functional manual for an AI-driven library management system, demonstrating the degree of automation in cataloging. and user management, as well as decision-making processes. Yu et al. (2019) reviewed an example of a

smart library that utilizes AI technologies to optimize its services and enhance the user experience. engagement. Ylipuri and Luusua (2019) even support a broader justification, claiming that public libraries are developing into innovative technology empowerment centers within smart cities. This helps reduce the digital divide through the use of AI and big data. Lund et al. Adewojo, Amzat, and Abiola (2025) have noted that AI-based knowledge repositories can enhance service delivery and efficacy. Use of AI in chatbots now enhances user engagement (Panda & Chakravarty, 2022). A growing interest is being noticed in virtual and augmented reality among libraries (Okada, Shi, and Kaneko, 2023). Research also reveals that libraries serve as hubs for digital content communities and are responsive to users' interests (Jeong & Park, 2024).

How AI is changing the information environment?

Libraries and information services are gradually deploying artificial intelligence tools to enhance user experiences and improve effectiveness. The success of AI implementation in various kinds of libraries depends largely on staff attitudes and institutional readiness. Professional development and change management strategies are vitally needed. Staff perceptions, readiness, and ethical considerations are critical. Human factors, including librarians' attitudes and institutional readiness, affect the successful implementation of AI. These are the ethical and practical challenges associated with augmented intelligence in libraries, which raise concerns about data security, transparency of decision-making, and the potential loss of human decision-making ability.

Artificial intelligence and virtual reality in the library

The library experience is changing due to the growing presence of VR and AI services (Weijia, 2022). It may be that VR promotes engagement in learning spaces, while AI is changing how library services are being offered (Omame& Alex-Nmecha, 2020). These changes may evoke a range of emotions in librarians. When adequate systems, training, and support are in place, AI and VR will be integrated in a discipline's academic library. Yoon, Andrews, and Ward (2022) surveyed public and academic librarians in North America regarding their use of AI (Weijia, 2022).

In a detailed study on AI-enabled VR products, Ribeiro de Oliveira et al. (2023) suggest a multitude of education, training, and digital application contexts. Pioneering research by Luck and Aylett (2000) investigated the use of intelligent agents in virtual environments, ultimately leading to the concept of intelligent virtual environments. More recently, AI and robotics have solidified as essential future knowledge and practice in library science, espoused by those committed to educating the next generation of this profession (Gul & Bano, 2019; Tait & Pierson, 2022). Guo et al. (2024) described how metaverse technology is deployed in civic libraries across urban US contexts and is fundamentally changing library-member interactions with information. In addition to libraries and use case contexts mentioned above, VR and AI

have been crafted into new pedagogical approaches, exemplified by the use of immersive contextual learning for language teaching and learning (Ma, 2021).

Artificial intelligence and augmented reality in the library

Technologies range from mobile-based AR navigation of libraries to more traditional tour-based engagement with virtual libraries, which are designed to be more immersive and involve local users in user-centered practice. A situational analysis and systematic review of current trends also provide an indication of specific potential impact and growth areas in the library sector, which include, but are not limited to, digital messaging boards, smart shelves, and AR-based learning modules. Augmented intelligence, a particular form of AI in which human decision-making is informed rather than replaced, is gaining traction in the library world. It informs intelligent information retrieval, predictive analytics, and self-service with the assurance of human oversight. AI, meanwhile, automates library functions, from cataloging and recommendation systems to analyzing user behavior and providing chatbot assistance, thereby making the organization more efficient and improving user satisfaction.

All of these developments have possible inadequacies. Scholars identify issues in the areas of infrastructure deficit, digital gap problems, ethical issues, and resistance to change from the part of technology itself (Dalili Saleh et al., 2022; Agwuna, Ejezie, & Nwankwo, 2024; Wójcik, 2021). Literature suggests that students and staff generally have a positive attitude towards AR and AI-enabled systems, particularly when these systems are designed to support the objectives and processes of education (Adewusi et al., 2024; Hussain, 2022). According to scholars, for institutions to unlock the potential of these technologies, a conceptual framework review, staff training, and institutional policy reform are necessary for the sustainable use of technology within institutions (Devagiri et al., 2022; Chitra, 2019; Adamu, Yusuf, & Ahmed, 2024). The integration of AI and AR/VR technologies is transforming libraries into dynamic and immersive spaces of knowledge (Yoon, Andrews, & Ward, 2022; De Sarkar, 2023; Netragaonkar, 2024), enhancing service provision and making the library a vital instrument in higher education, research, and lifelong learning processes.

Strategic and policy-level developments in academic libraries

Micro-level analysis of AR and VR in the libraries, highlighting strategic trends, upcoming research hotspots, and central trends and knowledge conducted by Williams and Nwagwu (2025). Devagiri et al. (2022) place AI and AR within broader industry trends and outline a vision for the future. Wani and Bhat (2023) discussed the need for policy-level planning for AI-AR in future libraries, while Sreeramoj and Batcha (2025) introduced an inclusive AR and VR model for digital libraries.

4.1.1 Table 2

4.1.2 Themes in AI, AR & VR in Library Applications

Theme	Focus Area	Key Insights	Key References
1. Integration of AI & AR/VR in Library Services	Application & design of intelligent systems	Libraries use AI and AR to enhance search systems, reference services, and navigation. Smart libraries and chatbots are growing trends.	Massis (2015); Hahn (2012); Omame& Alex-Nmecha (2020); Panda & Chakravarty (2022); Abdulwahid et al. (2023); Adewojo et al. (2025)
2.Library Automation & Management	AI in backend operations and decision-making	AI improves university library collection development, cataloging, circulation, and space management.	Sonawane et al. (2024); Yu et al. (2019); Puneeth et al. (2021); Okunlaya et al. (2022)
3. AI/AR for User Engagement & Experience	Personalized services, immersive learning	AI and AR create personalized reading recommendations, gamified learning, and immersive digital environments.	Adamu et al. (2024); Agwuna et al. (2024); Aini et al. (2023); Safadel et al. (2023); Netragaonkar (2024)
4. Ethical & Adoption Challenges	Perception, ethics, readiness, barriers	Ethical implications, librarian attitudes, and institutional readiness affect adoption of intelligent systems.	Wójcik (2021); Yoon, Andrews & Ward (2022); Weijia (2022); Lund et al. (2020)
5. Educational Libraries & AR/VR Instruction	Instructional technology in academic settings	Libraries in schools and medical colleges use VR/AR to support curriculum delivery and interactive learning.	Chen & Tsai (2012). Wei (2019); Ma (2021); Dalili Saleh et al. (2022); Mahadik et al. (2016)
6. Trends, Reviews & Bibliometric Analyses	Mapping global research trends in AI/AR/VR	Bibliometric and systematic reviews identify hotspots, research gaps, and future AR/VR adoption directions.	Shahzad et al. (2024); Sahu & Maharana (2025); Luthfi et al. (2025); Williams & Nwagwu (2025); Jeong & Park (2024)
7. Metaverse & Smart Library Futures	Next-gen environments using XR/AI	Libraries explore the metaverse, immersive VR tours, and intelligent environments for smart city alignment.	Guo et al. (2024); Okada et al. (2024); Sreeramoj& Batcha (2025); Ribeiro de Oliveira et al. (2023)

Source: Authors own work

Integrating AI, AR, and VR in libraries is reshaping not just service delivery but the role of libraries in society (Table 2). The literature reflects a dynamic transformation from intelligent chatbots and immersive experiences to ethical considerations and professional readiness.

Conceptual integration of AI and AR/VR in libraries

Initial work was conducted on the early adoption of AR/VR in libraries. Massis (2015) described the scope of AR and VR in library environments, marking its first conceptual application. Chitra (2019) and Puneeth (2021) also emphasized the use of AI and AR technologies in the design of smart libraries. Wani and Bhat (2023) showed a future orientation by discussing their role in Industry 5.0-based libraries. Likewise, Sreeramoj and Batcha (2025) also presented a complete AR/VR system for digital libraries.

Improving user engagement and experience

Several studies have investigated the use of AI and AR in enhancing user engagement and information access. Adamu et al. (2024) investigated how AI and AR can enhance the user experience in libraries and information centres. Adewusi et al. (2024) examined student perceptions of AR in library automation, while studies ofHahn (2012),Chen & Tsai (2012), De Sarkar (2023) and Avila (2017) designed mobile AR tools and learning systems to facilitate navigation and learning. Both AR and AI have been utilized as means of improving user engagement and access to information.

Library operations and service optimization

AI is at the forefront of streamlining libraries. Various studies and works have been instrumental in reflecting the outcomes (Sonawane et al., 2024; Okunlaya et al., 2022) such as efficiency of workflows and classification and recommendation systems(Netragaonkar 2024). Libraries have become the new place for mobile AR and context-aware systems to thrive (Shatte et al., 2014; Mahadik et al., 2016; Lu, 202; Hahn, 2012; Shatte et al., 2014).The use of AR has progressed to be embraced in almost all academic areas. For instance, Dalili Saleh et al. (2022) have examined the benefits and drawbacks of augmented reality and its applications in medical sciences libraries at universities. Besides this, Hussain (2022) has analyzed the academic libraries that are using AR, and in a similar vein, De Sarkar (2023) and Shahzad et al. (2024) conducted a systematic review of literature on the future path and influence of augmented reality in research libraries, thus proving its increasing importance in academia, particularly in research libraries.

Ethical, practical, and implementation challenges

Introducing augmented intelligence raises various ethical issues, in addition to the practicality of its application. Wójcik (2021) first discussed the ethical implications and operational considerations that come with AI and vigorously voiced his concerns regarding the issues of transparency and data usage in libraries. In a similar but more specific way, Agwuna et al. (2024) and Noh and Shin (2022) pinpointed the problems that come with the integration of AR into library service delivery, including the library having to be upgraded for new technology, and the staff getting addicted to being tech-savvy and thus having the capability and willingness to learn

new technologies. Wani and Bhat (2023) discussed the fact that users might perceive the introduction of a new AI system as a lengthy process, which could impact the library's decision to implement the technology.

Strategic and policy-level developments

Micro-level analysis of AR and VR in the libraries, highlighting strategic trends, upcoming research hotspots, and central trends and knowledge conducted by Williams and Nwagwu (2025). Devagiri et al. (2022) put AI and AR into broader industry trends, projecting a vision of direction for the future. Wani and Bhat (2023) discussed the need for policy-level planning for AI-AR in future libraries, while Sreeramoj and Batcha (2025) introduced an inclusive AR and VR model for digital libraries.

Challenges and prospects of AR/VRtechnologies

A few authors briefly addressed the AR and VR implementation issues. Agwuna et al. (2024) reveal the adoption challenges of AR for library services. Avila (2017; Santos & Esposo-Betan,2018) highlighted the efficiency of AR in user training and orientation, specifically at the academic level. Baumgartner-Kiradi et al. (2018) also set the potential and the constraints of AR in libraries.

Table 3

Themes in Artificial Intelligence and Augmented Reality in Libraries

Theme	Focus	Key References
1. Applications of AR and AI in Library Services	Implementing AR/AI tools in user services, navigation, search, and interaction.	Massis (2015); Hahn (2012); Adamu et al. (2024); Chen & Tsai (2012); Shatte et al. (2014); Shahzad et al. (2024); Lu (2021); Aini et al. (2023)
2. Enhancing Library Operations and Instruction	Automation, context-aware systems, and AI agents for instruction and circulation.	Sonawane et al. (2024). Chitra (2019); Mahadik et al. (2016); Okunlaya et al. (2022); Puneeth et al. (2021); Chen & Tsai (2012)
3. User Perception and Adoption	Attitudes of users and librarians toward AI/AR adoption; influencing factors.	Adewusi et al. (2024). Yoon et al. (2022); Agwuna et al. (2024); Noh & Shin (2022); Hussain (2022)
4. Ethical and Technical Challenges	Algorithmic bias, privacy, energy efficiency, digital divide, and implementation issues.	Wójcik (2021); Devagiri et al. (2022); Dalili Saleh et al. (2022); Agwuna et al. (2024)
5. Bibliometric and Systematic Reviews	Meta-level overviews of AR/AI literature trends in LIS domains.	Sahu & Maharana (2025); Luthfi et al. (2025); Sulastri (2025); Shahzad et al. (2024)
6. Future Prospects and Metaverse Integration	Vision of intelligent libraries, AI-powered XR services, virtual campuses.	Williams & Nwagwu (2025); De Sarkar (2023); Sreeramoj& Batcha (2025); Wani & Bhat (2023)

Source: Authors own work

Table 3 elaborates the augmented reality andartificial intelligence inlibraries.

Augmented reality applications inthe library

Between 1994 and 2025, libraries have piloted and evaluated AI/VR/AR primarily for orientation, instruction, discovery, and user support, with a notable acceleration after 2018 and a pronounced surge after 2022. Libraries are increasingly adopting AI, AR, VR, and other immersive technologies to enhance access, engagement, and learning. Literature shows a progression from conceptual models → pilots → bibliometric/systematic reviews, with growing global interest. The future depends on scalability, ethics, librarian training, and sustainable infrastructure.

Augmented Reality (AR) is a tool that typically benefits library services by increasing user participation, making processes more efficient, and providing a higher quality of learning. Firstly, Hahn (2012) and Shatte et al. (2014) demonstrated how mobile AR apps can support users visiting the library in their search for needed materials. The AR or VR increases the library space, in Massis's (2015) opinion, thus providing considerable opportunities for a fruitful transformation of libraries. New students' orientation has often been a primary focus of research on educational use of AR, besides learning support (Avila, 2017; Santos & Esposo-Betan, 2018). Other authors (e.g., Oyelude, 2017; De Sarkar, 2023) have investigated the more extensive ramifications of AR in libraries, along with its role in library innovations and knowledge creation. Bhattacharya (2019) and Baumgartner-Kiradi et al. (2018) acknowledge that AR may be useful in establishing new libraries, managing shelves, making information instantly available, and directing visitors. Dalili Saleh et al. (2022) considered AR in libraries for medical schools. Chen et al. (2023) designed AR resources to benefit children navigating through a library filled with technology, with the primary concerns of usability and user satisfaction. Likewise, Green, Lea, and McNair (2014) were concerned with school libraries and argued that AR tutorials are capable of rendering learning fun and luring students' attention. Hannah, Huber, and Matei (2019) fortified this claim, asserting that AR technology is particularly apt for the growth of information collection and the rise of digital exhibitions. Lu (2021) developed a mobile AR application that provides fast document delivery and quick alerts, thereby strengthening communication between libraries and their users

Technologies and methods

Aini, Herdina, and Nasrullah (2023) present another paradigm in introducing GARY (Game-Library), a game-based digital library through augmented reality. In this endeavor to actualize Indonesia's "Golden Generation 2045" vision, one learns how gamification and AR can support young people in engaging more deeply with digital library services. According to Okwu (2025), AR and VR technologies have affected how digital libraries interact with users in South-South Nigeria. Immersive technologies are said to increase feelings of satisfaction and retention of information, particularly when used in conjunction with culturally adapted content on mobile devices.

Outcomes, issues and gaps

Sreeramoj and Batcha (2025) have suggested an AR and VR digital library framework that is scalable, modular, and based on cloud computing. Their framework, developed by incorporating

metadata retrieval, virtual book walking, and distance learning facilitation, has made it more accessible. Shahzad et al. (2025) conducted a systematic review of the factors influencing the adoption of XR in libraries. They refer to technological preparedness, librarian training, user awareness, and library policies as the enablers of successful and innovative adoption of XR in library services.

Lastly, Sulastri (2025) offers a broad longitudinal perspective by conducting a bibliometric review of AR in tertiary education from 1997 to 2024. The research maps the development of areas of study, with an orientation to progress from prototype studies towards practice implementations and training placements within university libraries. This study is a culmination of the field's achievements and serves as a valuable filter for identifying potential research and development priorities to be undertaken in the future.

Virtual reality applications in the library

With ongoing innovation and ethical refinement, AI-powered VR revolutionizeseducation, workplace training, and digital experience design in the coming decade (Anthes et al., 2016; Shahzad et al., 2025).AI is increasingly utilized in VR to deliver dynamic and interactive experiences. In gaming, AI algorithms simulate intelligent behaviors and adapt gameplay based on user actions—capabilities now deployed in VR to create responsive environments (Slater & Sanchez-Vives, 2016; Anthes et al., 2016; Sukula, Jain, Vaidya, Rani, and Bairwa, 2025).

Using virtual assistants for operating real-time voice commands control through NLP supports various applications such as VR shopping assistants and interactive education (NVIDIA, 2021). It is observed that AI-backed computer vision methods have been instrumental in. capturing and mapping of motion and augmenting the customer realism and immersion (McKinsey & Company, 2022).

Technologies and methods

Augmented intelligence takes support of AI for enhancing human knowledge thus increasing the value in VR design scenarios according to usage of simulating limitations and optimizing real-time solutions (Accenture, 2023). AI-compatible detection in VR training platforms not only enables intelligent avatars and agents to respond to individuals' natural language inputs but also assesses the performance of students and provides real-time feedback on the subject of the training (Sreeramoj& Batcha, 2025). AI can be used to produce attractive 3D content from limited sources, such as single photos, thereby making the creation of VR for areas like historical reconstruction (Shahzad et al., 2025) and virtual museums faster and more cost-effective.

Outcomes, issues and gaps

Scalable and adaptive solutions to industrial challenges, such as skills and an aging workforce. Such systems provide secure and engaging training (Williams &Nwagw, 2025) that tailors the content to the researcher's level of achievement. For example, modules on board can assess (PwC, 2022) the user's progress and adapt the training path, making VR an effective alternative to conventional methods. Technologies like 5G and edge computing reduce latency and offload

AI processing from headsets to the cloud or edge devices. This enables VR systems to be lighter, faster, and more power-efficient, while expanding their capabilities (McKinsey & Company, 2022; Accenture, 2023). These infrastructure advancements are crucial to unlocking real-time AI-VR applications across education, healthcare, and remote collaboration.

AIintegrated into VRproduce both ethical and technical difficulties. VR headsets require more power and produce more heat because algorithms are computationally (Anthes et al., 2016; Slater & Sanchez-Vives, 2016). Underrepresentation causes speech recognition systems to perform poorly, increasing the risk of exclusion.

VR and AI are expected to the development of the metaverse—a collective virtual space enabled by intelligent systems. Metaverse remains aspirational, rapid advancements in AI and user interface design are laying the groundwork (Accenture, 2023; McKinsey & Company, 2022). Major firms such as Meta, Google, Microsoft, and NVIDIA, are investing in tools(NVIDIA, 2021; PwC, 2022) that blend VR, AR, and real-world data into digital ecosystems. Although the metaverse is being used more in library research, its definition and application in real-life situations are still unclear. It can be defined in three different ways: immersive platforms using VR and AR for archives and exhibitions, social virtual environments for multiple users to access and share information from anywhere in the world, and hypothetical concepts for future libraries. Most of the current research is based on early-stage immersive platforms for improving access, and sustainable shared virtual environments in real-life situations are hard to find. Moreover, no specific strategies have been identified in line with library policies.

Enabling and limiting factors shaping the adoption of Augmented Reality (AR) and Virtual Reality (VR) in Libraries

Enabling factors are largely technological, organisational and user-centred. Firstly, technological readiness and infrastructure, including mobile AR platforms, cloud-based systems and tools such as ARCore/ARKit, consistently support implementation (Liu et al., 2024; Sreeramoj& Batcha, 2025). Secondly, innovative service models, particularly gamification (Aini et al., 2023) and immersive navigation systems (Wang, 2024; Wei et al., 2024), enhance user engagement, learning outcomes and information retention. Thirdly, institutional and policy support, including funding opportunities and pilot initiatives (Ranavagol et al., 2025), enable experimentation and scalability. Fourthly, positive user perceptions and behavioural intentions, driven by perceived usefulness, satisfaction and social influence (Adewusi et al., 2024; Nik Ahmad et al., 2024), encourage adoption. Finally, librarian training and awareness, highlighted in XR adoption frameworks (Shahzad et al., 2025), strengthen implementation capacity and service innovation.

In contrast, limiting factors are multifaceted and often interconnected. A primary barrier is technical complexity and infrastructure cost, including the need for advanced hardware (e.g. HMDs, LiDAR) and content repackaging (Kulkarni et al., 2024; Mojapelo & Maneli, 2024). Skill gaps among library professionals and insufficient training hinder effective deployment. Additionally, low user awareness or digital literacy disparities, particularly in developing contexts (Agwuna et al., 2024; Okwu, 2025), constrain widespread acceptance. Content and contextual limitations, such as a lack of culturally relevant or localised AR materials, reduce user

engagement. Organisational challenges, including policy gaps, resistance to change and sustainability concerns, also impede long-term integration. Furthermore, interoperability and standardisation issues across AR platforms complicate seamless service delivery.

In contrast, enabling factors emphasise innovation, engagement and strategic alignment while limiting factors highlight structural, economic and human resource constraints. The literature suggests that successful AR integration in libraries depends on balancing these dynamics by leveraging technological advancements and user enthusiasm while addressing infrastructural, institutional and capacity-related barriers.

Discussion

Recent research on AI, AR, and VR in libraries, as well as past research, reveals several important gaps that future studies must address. Most existing works remain at the prototype or pilot stage, with limited scalability or evidence of sustainable large-scale implementation. Equity and access also remain underexplored, as scholarship is heavily concentrated in developed regions, with only a few contributions emerging from countries such as Nigeria and India, leaving broader developing-world contexts understudied. Interoperability is another critical challenge, with a lack of standards and frameworks to ensure seamless integration across diverse AI, AR, and VR platforms. The concept of the metaverse is increasingly mentioned in library research, it remains largely theoretical, with limited policy alignment or readiness strategies to support its integration into real-world library systems.

The period between 2013 and 2018, libraries experienced a growth and experimentation phase with AR and VR. As previously mentioned, early projects were based on mobile AR apps (the research of Shatte et al. (2014) and Huang et al. (2016) imparted the affordances of mobile and handheld devices in the user experience). In addition to a focus on mobile AR, library examples showcased testing VR and AR in orientations, instruction, and other contexts, such as Anthes et al. (2016), Avila (2017), and Oyelude (2017), which presented library spaces and resources through immersive experiences. While this work was being performed, researchers, including Koukopoulos (2018), began to examine scenarios and outcomes of using the system, providing early explorations of feasibility and engagement for users. There were also larger conceptual linkages, where AR was seen as a new mode of individual empowerment by Ylipulli and Luusua (2019), who presented the affordances of AR to connect in smart cities. They noted that bridging AR applications have the potential to extend beyond library services and into participatory urban knowledge environments.

It is relatively interesting to perceive that research on artificial intelligence, augmented reality, and virtual reality in libraries has remarkably intensified significantly between 2023 and 2025, according to the latest studies. The growth can be traced to two technological trends and the continued global focus on the following technologies. First, tools for performing library operations based on artificial intelligence are becoming available at an accelerating pace.Scholars can reflect this trend in their new work, such as Abdulwahid et al. (2023) and Sonawane et al. (2024), and provide reflections on operational management and the potential impact on operational automation and user services. Second, the scholarship on augmented reality now encompasses applications related to institutional navigation in libraries, virtual tours

of library facilities, and gamified learning experiences (Al-Ani et al., 2023; Mojapelo & Maneli, 2024), which serve to enhance engagement and access. Beyond developed studies, three mapping studies (Sahu & Maharana, 2025; Sulastri, 2025; Luthfi et al., 2025) provide meta-insights into publication experiences, research developments, and the emergence of new thematic areas in this scholarship. Systematic reviews (Shahzad et al., 2024; Pineda-Torres & Rodriguez-Lopez, 2025) play a crucial role in synthesizing research, providing a means to evaluate not only the extent of research development but also the remaining gaps. More acknowledgement of national contexts appeared in research, such as studies from Nigeria (Adewojo et al., 2025), India (Kharat et al., 2024), and Korea (Jeong & Park, 2024), which reported contextual constraints related to issues of scholarly adoption. Exploratory articles on metaverse applications (Guo et al, 2024a, 2024b) are an additional opportunity to explore approaches to learning and engagement with library resources in academic libraries.

Artificial intelligence that augments human decision-making rather than substitutes is being recognized as a major trend in technology for libraries. These interfaces are a sign of the movement from automation to collaboration between humans and machines in information centers. The interdisciplinary nature of the research presented in the article links Library and Information Science with AI ethics, educational technology, and human-computer interaction, all of which are part of the research agendas of the most established disciplines. Much of the research conducted is in the LIS field, but it also extends outward, documenting the general convergence of AI and VR. The efforts to include AI and robotics into libraries operations and learning programs are oriented towards workforce training. The AI and VR technologies are continuously playing roles for rapid development. There are various issues such as research integrity and ethical aspects once the usage components come up. In the field of library and information science education as well as professional scenario, transparent and ethical standards are crucial.

Artificial intelligence, virtual reality, and augmented reality in the library

The library experience is changing as virtual reality and artificial intelligence (AI) services become increasingly prevalent (Weijia, 2022). It may be that VR promotes engagement in learning spaces, while AI is changing how library services are being offered (Omame & Alex-Nmecha, 2020). These changes may evoke a range of emotions in librarians. When adequate systems, training, and support are in place, AI and VR will be integrated in a discipline's academic library. Yoon, Andrews, and Ward (2022) surveyed public and academic librarians in North America regarding their use of AI (Weijia, 2022).

Technology adoption as a guiding framework: Readiness and diffusion

Studies on AR-based navigation systems emphasise practical usability through indoor positioning and real-time guidance, enhancing physical library interaction (Sahu & Maharana, 2025; Wang, 2024). In contrast, scalable AR/VR frameworks focus on integrating multiple services, such as virtual browsing and remote access, to offer broader system-level functionality (Sreeramoj & Batcha, 2025). Gamified AR applications demonstrate stronger user engagement and learning motivation compared to conventional digital interfaces, particularly in educational contexts (Aini et al., 2023; Shahzad et al., 2025). These approaches improve retention and participation. Mobile-based AR solutions (e.g., ARCore/ARKit) provide cost-effective, accessible deployment, while advanced XR systems with head-mounted displays offer deeper immersion but require higher infrastructure investment (Luthfi et al., 2025; Ranavagol et al.,

2025). User perception studies highlight satisfaction and usability benefits (Okwu, 2025), whereas bibliometric and strategic studies emphasise scalability, collaboration, and long-term adoption trends (Sulastri, 2025). Studies comparing AR for instructional enhancement with broader XR adoption demonstrate that while AR improves teaching and visualisation, XR offers holistic service transformation and higher service quality (Sahu & Maharana, 2025; Williams & Nwagwu, 2025; Shahzad et al., 2025). Literature tracking AR trends highlights awareness and experimental adoption, whereas funded pilot projects and institutional support demonstrate stronger scalability and practical implementation (Luthfi et al., 2025; Ranavagol et al., 2025). Gamified applications such as GARY enhance user engagement and motivation, while culturally adapted AR/VR systems improve satisfaction and knowledge retention in diverse environments (Aini et al., 2023; Okwu, 2025). Scalable cloud-based AR/VR frameworks provide structured implementation models, whereas longitudinal studies reveal the shift from prototypes to real-world applications, indicating the maturity and sustainability of technologies (Sreeramoj& Batcha, 2025; Sulastri, 2025).

Equity and accessibility integration

Integrating equity and accessibility is crucial for AR/VR library applications. This involves incorporating inclusive design features like screen readers, captions, and adaptive interfaces to support users with disabilities. However, gaps in universal accessibility standards persist, limiting equitable use. Studies emphasise the need for user-centred and inclusive frameworks to ensure broader participation. Another challenge is device access and infrastructure. The reliance on advanced devices like head-mounted displays and high-end smartphones creates barriers. Research highlights the need for infrastructure development and cost-effective solutions to ensure wider adoption.

Language support and cultural inclusivity are also important. Limited multilingual capabilities in AR systems restrict usability for diverse populations. Enhancing localisation and language adaptability is essential for improving user engagement and accessibility. Finally, the digital divide and equity concerns are significant. Socio-economic disparities and varying levels of digital literacy continue to widen the digital divide. Studies stress the importance of inclusive policies and training to promote equitable access to AR/VR technologies in libraries.

The context of academic libraries in recent times

Academic libraries are increasingly adopting AR/VR technologies to enhance digital services. These technologies enable interactive learning, virtual exhibits, and blended instructional environments (Williams & Nwagwu, 2025; Sreeramoj& Batcha, 2025). They strengthen research support and user engagement. AR applications using head-mounted displays (HMDs), LiDAR, and collaborative filtering improve wayfinding, resource discovery, and virtual library tours in academic settings (Wang, 2024; Wei et al., 2024; Mojapelo & Maneli, 2024; Cypress et al., 2016). Game-based AR systems and makerspace applications promote active learning, student orientation, and digital literacy in academic libraries. They enhance user motivation and participation (Aini et al., 2023; Al-Ani et al., 2023; Jedlicka & Eaton, 2024). Platforms such as ARCore and ARKit enable real-time mobile-based interaction. This improves accessibility, navigation, and content retrieval. User perception studies highlight acceptance and usability in academic contexts (Liu et al., 2024; Adewusi et al., 2024; Nik Ahmad et al., 2024). AR supports library automation, digital collections, and knowledge visualisation. Global implementations demonstrate their role in transforming academic libraries into smart technology-driven ecosystems (Kulkarni et al., 2024; Guo et al., 2024; Okwu, 2025).

Recent research has highlighted several key aspects:

Future systems will utilise machine learning to create real-time, personalised learning spaces. This research predicts wider adoption in education and training platforms to enhance engagement and outcomes. Advances in natural language processing and behavioural modelling will lead to lifelike avatars. These are expected to be used in virtual classrooms, libraries, and customer service interfaces. Low-latency networks and edge AI will improve VR performance and scalability. This will support seamless multi-user environments and real-time collaboration.

Research emphasises reducing algorithmic bias and ensuring transparency. Future frameworks will focus on fairness, accountability, and responsible use of AI in immersive systems. Libraries are projected to transform into immersive knowledge hubs using VR/AR. This will enhance navigation, digital learning, and community engagement, aligning with smart city development goals.

Findings and implications

First, adaptive algorithms are revolutionising virtual environments by offering real-time customisation. This has led to increased research and adoption in education and training, boosting learner engagement and retention through data-driven personalisation. Second, AI-powered virtual assistants are making seamless voice communication in VR a reality. Future studies suggest wider adoption of conversational interfaces for immersive collaboration and user support. Third, advanced vision systems are enhancing gesture recognition and spatial interaction. Research predicts more intuitive and controller-free VR experiences, particularly in simulation-based training and healthcare. Fourth, smart avatars analyse user behaviour and respond dynamically. Their growing role is evident in virtual classrooms, professional training, and remote learning environments. And fifth, these technologies are reducing latency and processing loads. Research anticipates lighter, more efficient VR devices and scalable multi-user environments, paving the way for wider adoption across industries.

Implications for daily library work

AI-integrated virtual reality (VR) can revolutionise routine library operations. This immersive technology offers services like virtual navigation, interactive information literacy sessions, and AI-assisted reference support. Librarians can use intelligent avatars and adaptive systems for personalised assistance, virtual orientations, and remote learning. Automation of repetitive tasks frees staff to focus on user engagement and digital skill development.

Implications for future research

Future research should assess the impact of AI-powered VR on learning outcomes, user engagement, and information access. Ethical concerns such as algorithmic bias, data privacy, and inclusivity in immersive systems also warrant exploration. Interdisciplinary studies combining Library and Information Science, human-computer interaction, and AI ethics will be key to developing sustainable, user-centred VR applications.

Implications for policy decisions

Policy frameworks should prioritise ethical use of AI, transparency, and data protection in VR-based library services. Investment in digital infrastructure, including 5G and edge computing, is essential for scalable implementation. Policymakers should also focus on training library professionals and promoting inclusive access to ensure equitable use of emerging technologies in smart libraries.

Conclusion

The synthesis indicates AI-driven virtual reality (VR) is poised to significantly transform future library services by enabling immersive, personalised, and interactive user experiences. Several

authors have illustrated how libraries can adopt AI-powered VR for virtual tours, information literacy training, and remote access to resources via intelligent avatars and adaptive learning systems. Natural language processing supports voice-based search and reference services, while computer vision enhances navigation and user interaction within virtual library spaces. These technologies are particularly valuable for academic and professional training, allowing libraries to function as dynamic learning hubs. Advancements in 5G and edge computing are further supporting seamless low-latency experiences, making VR services more accessible and efficient. The integration of AI, VR, and AR in libraries recognizes important challenges, including energy consumption and algorithmic bias. The studies and the literature reviewed indicate a foundation for developing user-centered, ethically advanced technological library systems that align with future digital learning and smart environment goals.

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