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Recommender Systems in Libraries: A Systematic Review of Service Quality and Engagement

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ABSTRACT

This study presents a systematic literature review (SLR) on recommender systems (RS) in library contexts, covering both service-provider perspectives and user engagement. Using the PRISMA framework, 14 studies from ScienceDirect and IEEE Xplore were synthesized to map dominant use cases, data sources, and algorithmic strategies. Hybrid approaches combining collaborative filtering and content-based filtering are most frequently reported, supporting libraries in mitigating cold-start and sparsity in circulation data. Fuzzy linguistic modeling and association rule mining are also used to handle imprecise preferences and identify co-borrowing patterns. Emerging work highlights knowledge graphs and graph neural networks for capturing semantic relationships between readers and collection attributes. Evaluation commonly relies on offline metrics (e.g., precision, recall, NDCG) and is complemented by user studies in fewer cases. The review provides practical recommendations for phased, privacy-aware RS deployment in regional and public library services. Key implementation enablers and barriers include metadata quality, integration with OPAC/digital portals, and privacy-ethics governance for using user interaction and borrowing logs.

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1. INTRODUCTION

Libraries face the challenge of improving service quality while sustaining user engagement amid shifting information-seeking behaviors and an abundance of available resources (Dhage & Verma, 2025; Simović, 2018). Recommender systems (RS) provide personalization mechanisms that support collection discovery, enrich the user experience, and inform data-driven decisions in collection management. In library settings, RS function not only as information-filtering tools that reduce overload, but also as proactive service components that connect users with relevant books, e-books, and research resources through catalogs, OPAC, digital library portals, and other integrated modules. From the provider perspective, RS can strengthen evidence-based collection development by supporting acquisition and weeding decisions and aligning collections with evolving community needs (M. Pal, 2025; Rhanoui et al., 2022), while from the user perspective, RS can improve search and browsing effectiveness, increase satisfaction, and stimulate repeated interactions through more relevant suggestions.

Despite this potential, empirical evidence and implementation practices in various library settings remain fragmented, characterized by heterogeneous use cases, data sources, algorithmic strategies, and evaluation designs. Reported applications are dominated by book and collection discovery and research resource recommendation, typically integrated into search, profiling, or re-ranking modules. Hybrid models combining collaborative filtering and content-based methods are widely adopted to mitigate sparsity and cold-start, alongside association rule mining, fuzzy linguistic approaches, and more recent knowledge graph and graph neural network models. Evaluations also vary, ranging from offline metrics such as precision, recall, F1, RMSE, MAE, and NDCG to online trials and user studies based on interaction logs, borrowing activity, and perceived usefulness.

This diversity creates practical challenges for translating research into operational services, because differences in indicators hinder cross-study comparison and advanced models depend on data readiness, metadata quality, and system integration maturity. These constraints are especially salient for public and regional libraries, where user heterogeneity, sparse interaction traces, and privacy-ethics governance are critical. Therefore, a structured systematic literature review (SLR) is needed to consolidate evidence, map relevant use cases, data and integration requirements, and evaluation practices, and to identify enablers, barriers, and gaps in public and regional contexts. The review should also derive implementable recommendations for phased deployment, starting from a privacy-aware hybrid baseline using loan logs and bibliographic metadata, supported by clearly defined service quality and engagement indicators suitable for routine monitoring.

2. THEORETICAL BACKGROUND

2.1. Overview of Recommender Systems in Libraries

Recommender systems (RS) in the library domain are crucial information-filtering tools for addressing the problem of information overload faced by users when navigating very large catalogs (Anwar et al., 2020; Nykänen, 2021). RS aim to predict a user's level of interest in, or the utility of, an item and to rank items based on these predicted values to facilitate decision-

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making (Uta et al., 2024; Zarindast & Wood, 2021). In smart library environments, RS do not merely function passively but also proactively offer tailored information for individuals and communities to support knowledge acquisition. The use of RS integrated with modern technologies such as Big Data has been shown to enhance users' long-term satisfaction and motivation in continuous learning processes (Amin et al., 2023; Bourkoukou & El Bachari, 2022; G. Pal, 2022).

2.2. Recommendation Models and Strategies

The implementation of recommender systems (RS) in libraries generally adopts three main approaches based on their knowledge sources:

(i) Collaborative Filtering (CF): This approach operates on the assumption that users who shared similar interests in the past will have similar tastes in the future (Hikmatyar & Ruuhwan, 2020; Koren et al., 2022; Najafabadi et al., 2019). It identifies "neighbors" of the active user to predict item preferences without requiring in-depth analysis of item content.

(ii) Content-Based Filtering (CBF): This strategy provides suggestions based on the similarity between item features (such as book metadata) and a user preference profile learned from past interactions. It is particularly useful for scholarly documents, where rich metadata enables better recommendation explainability (Sakib et al., 2021; Xia et al., 2025; Zhu et al., 2019).

(iii) Hybrid Approach: Hybrid models combine CF and CBF to compensate for their respective weaknesses, such as cold-start (new users/items) and sparsity (limited data) issues. A commonly used hybrid strategy is the switching hybrid, which selects a particular recommendation component depending on the data situation available at the time (Çano & Morisio, 2017; Subudhi et al., 2025; Widayanti, 2023).

2.3. Fuzzy Linguistic Modeling and Uncertainty Handling

The use of fuzzy logic in library RS is especially prominent for handling human preferences that are often imprecise or vague. The 2-tuple fuzzy linguistic model is used to represent qualitative information without losing data during the aggregation process (Morawski et al., 2017; Serrano-Guerrero et al., 2011). This technique enables systems to manage information from multiple sources with different levels of granularity (multi-granular) and to handle incomplete preference relations when users provide only limited ratings for collections (Porcel & Herrera-Viedma, 2010; Ye et al., 2023).

2.4. Data Mining Techniques and Knowledge Graphs

To extract more complex patterns of user behavior, libraries have begun applying advanced data mining techniques:

(i) Association Rule Mining (ARM): Used to discover relationships among books that are frequently borrowed together, such as the FUCL technique that combines faculty features, book categories, and borrowing logs (Jomsri et al., 2024; Zhang & Zhang, 2023).

(ii) Deep Learning and Graph Neural Networks (GNN): State-of-the-art models employ graph structures such as an Entity-attribute Interactive Knowledge Graph (EIKG) to semantically connect readers, books, and collection attributes. Deep learning enables the system to

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capture non-linear patterns from borrowing transactions and demographic characteristics to predict user loyalty (Wang et al., 2019; Wu et al., 2023; Xiao et al., 2026).

3. RESEARCH METHODOLOGY

3.1. Review Design and Research Question

This systematic literature review (SLR) follows the PRISMA principles to ensure transparency in the identification, screening, eligibility, and inclusion stages. The workflow comprised: (i) database searching, (ii) metadata consolidation (RIS) and deduplication (DOI and title), (iii) rule-based title/abstract screening to retain studies explicitly related to recommender systems and libraries while excluding non-article publication types (CHAP/BOOK/STD), (iv) full-text retrieval and eligibility assessment, and (v) data extraction based on RQ1–RQ6, such as:

(i) **RQ1**. What types of RS implementations are used to improve library services, and at which service touchpoints are RS most frequently integrated?
(ii) **RQ2**. What outcomes are reported regarding the impact of RS on library service quality, and how are these outcomes measured?
(iii) **RQ3**. To what extent do RS contribute to user/visitor engagement, and which indicators are most commonly used?
(iv) **RQ4**. What algorithmic approaches are employed, what data are used, and what strategies are applied to address cold-start and sparsity?
(v) **RQ5**. What enabling and inhibiting factors affect RS implementation in libraries, particularly in public or government services?
(vi) **RQ6**. What research gaps and practical recommendations are identified for developing RS in public/regional libraries, for example in the Indonesian or West Java context?

3.2. Data Sources and Search Strategy

Searches were conducted in ScienceDirect and IEEE Xplore. Metadata were exported in RIS format and processed in R for deduplication and screening. For the eligibility stage, full-text PDFs were collected and assessed prior to inclusion.

3.3. Inclusion and Exclusion Criteria

Table 1 summarizes the inclusion and exclusion criteria applied under the PRISMA workflow to systematically filter the retrieved records. Only journal or conference studies that explicitly address recommender systems in library-related contexts and provide accessible full-text PDFs were included, while duplicates, non-article publication types, papers using “recommendation” only in a generic sense, and inaccessible full texts were excluded.

Table 1. Inclusion and exclusion criteria

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No	Inclusion Criteria	Exclusion Criteria
1	Studies explicitly discuss a recommender system or book/library recommendation.	Duplicate metadata records (same DOI/title) across sources.
2	The application context is within library environments (public, academic, research, or digital libraries) or closely related information services.	Non-article publication types: CHAP/BOOK/STD, editorials, short articles/briefs/notes, theses/reports.
3	Publication type is a journal article (JOUR) or conference proceeding (CONF).	Studies using the term "recommendation" only as general advice rather than a recommender system.
4	Full-text (PDF) is available for data extraction.	Full text is unavailable or inaccessible.

3.4. Study Selection Process and Data Extraction

In total, 3,340 records were identified, 2,462 records remained after deduplication, 73 full text articles were assessed for eligibility, and 14 studies met all criteria and were included in the synthesis Figure 1. Data extraction was performed using a structured template aligned with RQ1 to RQ6, enabling consistent mapping of each study to use cases, service outcomes, engagement outcomes, technical approaches, data characteristics, evaluation strategies, implementation factors, and identified research gaps.

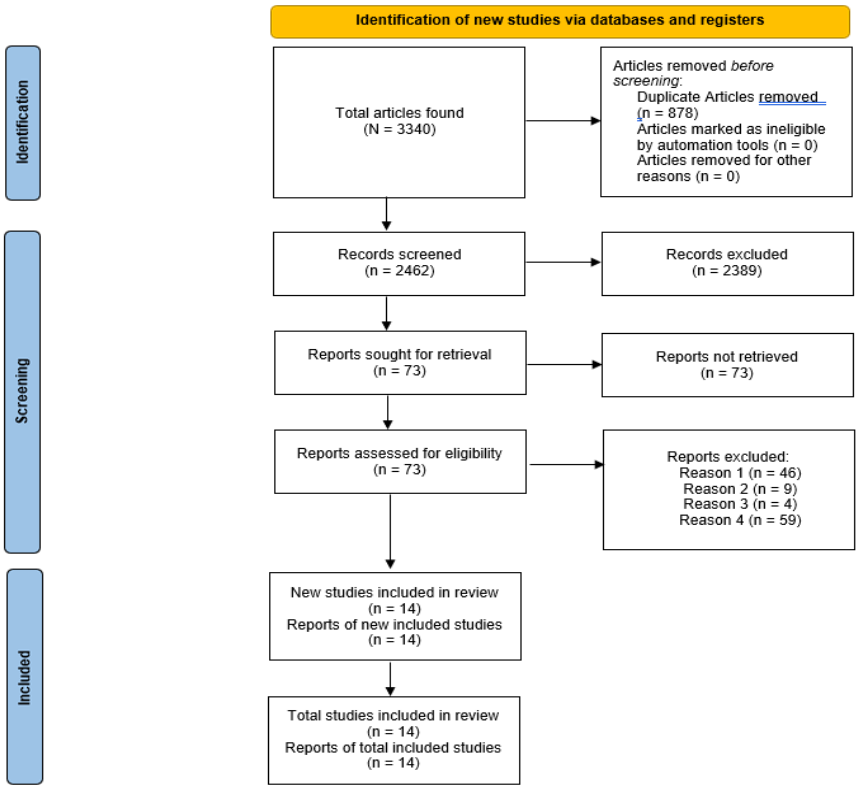


Figure 1. PRISMA flowchart

4. RESULTS AND DISCUSSION

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4.1. Study Characteristics and Overall Mapping of Findings

A total of 14 studies as in Table 2 were included in the synthesis, spanning publication years from 2009 to 2026. Most studies were conducted in university, digital, or research library settings, accounting for 11 studies, while 3 studies addressed public, regional, or national library contexts. Implementation platforms included web portals, catalogs and OPAC interfaces, digital library systems, as well as applications or service components connected to broader library information systems.

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Table 2. Summary of included studies and their characteristics

ID	Year	Country/Region	Library type	Platform	Integration point/Context	Use case (bucket)	Approach (bucket)	Evaluation (bucket)
1	2022	Morocco	Regional (National)	Web (Catalog & Amazon API)	Staff/Decision Support	Collection management (acquisition/weeding)	Hybrid	Case study / deployment
2	2020	Indonesia	Other (University)	Desktop application	Book search system	Book/collection discovery	Collaborative filtering	Case study / deployment
3	2020	India	Public/Academic context	Multi-platform (Web/OPAC)	Digital catalog	Book/collection discovery	Association rules / ARM	Other
4	2023	Algeria	Public context	Web (Python/Surprise)	Personalized suggestion engine	Book/collection discovery	Hybrid	Offline
5	2018	Belgrade, Serbia	University	Web/LMS (Moodle)	Logon point, Moodle API	Book/collection discovery	Hybrid	Mixed (offline + user/online)
6	2014	Udine, Italy	Scientific	Web (RES System)	Profile management	Research resources recommendation	Content-based	Mixed (offline + user/online)
7	2011	Castilla-La Mancha, Spain	University digital library	Google Wave platform	Collaborative space	Program & service recommendation	Hybrid	Online
8	2009	Jaén, Spain	University digital library	Web portal	Information dissemination	Research resources recommendation	Hybrid	Online
9	2014	Granada, Spain	University digital library	Web application	Re-ranking module	Research resources recommendation	Hybrid	Online
10	2010	Jaén, Spain	University digital library	Web portal	User profiling step	Program & service recommendation	Hybrid	Online
11	2018	Bangkok, Thailand	University	Library website	Search system	Book/collection discovery	Association rules / ARM	Mixed (offline + user/online)
12	2014	Granada, Spain	University digital library	Web-based	Re-ranking module	Research resources recommendation	Hybrid	Online
13	2026	Guangdong, China	University	Web (Backbone FM-KGAT)	Recommendation engine	Book/collection discovery	KG / GNN / DL	Offline
14	2020	Hamadan, Iran	Medical university	Integrated software (Pars Azarakhsh)	Loan transaction management	Service optimization / behavior prediction	Association rules / ARM	Offline

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4.2. Mapping RQ1 and RQ4: Use Cases, Approaches, Data, and Evaluation

For RQ1, RS use cases were dominated by book/collection discovery recommendations (6 studies) and research resource recommendations (4 studies). Other use cases included program and service recommendations (2 studies), collection management for acquisition and weeding (1 study), and service optimization or behavior prediction (1 study). Frequently reported integration points were catalog/OPAC/web portals, as well as service modules that leverage transactional data.

For RQ4, hybrid approaches were most prevalent (8 studies), followed by association rule mining (3 studies), and additional variants including pure collaborative filtering, content-based models, and KG/GNN-based models. The most commonly used data sources were circulation logs or transaction histories, bibliographic metadata, user profiles, and ratings or reviews. Evaluation designs varied across studies, including online (5 studies), offline (3 studies), mixed (3 studies), and deployment or case study approaches (2 studies). Table 3 provides a concise mapping of RQ1–RQ4 for each included study.

Table 3. Mapping of RQ1 and RQ4 for each included study

ID	Year	Country/ Region	Library type	RQ1: Use case	RQ4: Approach	RQ4: Data used	RQ4: Evaluation design
1	2022	Morocco	Regional (National)	Collection management (Acquisition & Weeding)	Hybrid (CF + Content-based + Sentiment Analysis)	Books metadata, text review, Amazon rating	Evaluation on real case study national library
2	2020	Indonesia	Other (University)	Collection Discovery (Personalized Search)	User-Based Collaborative Filtering	Loan logs (transaction data)	Black-box testing (trial-and-error)
3	2020	India	Public/Academic context	Collection & Service optimization	Multi-approach (Classification, NN, ARM, Clustering)	User profile, load history, metadata	Literature benchmark analysis
4	2023	Algeria	Public context	New Collection Discovery	Hybrid (Memory-CF, Content, Model-SGD)	Goodreads data (ratings, genres, authors)	Offline comparison with KNN & NMF
5	2018	Belgrade, Serbia	University	Collection Discovery (Books & E-books)	Hybrid (CF + Big Data Hadoop)	Loan logs, Profile, Online Bookstore logs	Mixed (log analysis & user impressions)
6	2014	Udine, Italy	Scientific	Research Resource Recommendation	Content-Based (Concept Graph)	Full text (Key phrases), Metadata	Mixed (offline benchmarking and user study)

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ID	Year	Country/ Region	Library type	RQ1: Use case	RQ4: Approach	RQ4: Data used	RQ4: Evaluation design
7	2011	Castilla-La Mancha, Spain	University digital library	Program & Collaboration Recommendation	Fuzzy Linguistic (Hybrid)	User profiles, Resource vectors	Online (user interaction analysis)
8	2009	Jaén, Spain	University digital library	Multidisciplinary Research Resource Recommendation	Hybrid (CF + Content-based)	Resource metadata, user interest topics	Online Experiment
9	2014	Granada, Spain	University digital library	Research Resource Recommendation	Switching Hybrid (Content-based + CF)	Preference relations, Rating matrix	Online Study
10	2010	Jaén, Spain	University digital library	Collection and Collaboration Recommendation	Hybrid (KB-like Fuzzy)	Incomplete preference relations	Online Trial
11	2018	Bangkok, Thailand	University	Collection Discovery (Books)	Association Rule Mining (FUCL)	Loan records, Categories, Faculty data	Mixed (offline and expert rating)
12	2014	Granada, Spain	University digital library	Research Resource Recommendation	Switching Hybrid (Content-based + CF)	Incomplete preference, Quality score	Online test
13	2026	Guangdong, China	University	Collection Discovery (Diversified Books)	ML/DL (GNN + KG + Contrastive)	Loan records, Entity-attribute Graph	Offline Experiment
14	2020	Hamadan, Iran	Medical university	Service Optimization (Behavior Prediction)	Data Mining (ANN, DT, Clustering, ARM)	Loan transactions, user demographics	Offline Analysis

4.3. Mapping RQ2 and RQ3: Service Quality and Engagement Outcomes

For RQ2, service quality outcomes were generally assessed using offline evaluation metrics, such as precision, recall, and F1, as well as RMSE and MAE, and ranking-oriented measures, including NDCG, or through user-centered assessment methods such as user studies. Studies closer to operational settings also examined changes in recommendation quality based on user interactions in online trials and the observed effectiveness of recommendations within service delivery platforms.

For RQ3, engagement was most often proxied through interactions with recommended items, including clicks and accesses, repeated usage patterns, and behavioral indicators such as borrowing or circulation activity and resource exploration. Although not all studies measure physical visits, digital indicators can serve as an initial proxy for engagement in public library contexts. Table 4 shows the mapping of RQ2 and RQ3 on each study.

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Table 4. Mapping of RQ2 and RQ3 for each included study

ID	Year	Country/ Region	Library type	RQ2: Service outcomes	RQ2: Measurement (method; metric)	RQ3: Engagement outcomes	RQ3: Engagement metrics
1	2022	Morocco	Regional (National)	Supports accurate acquisition and weeding decisions	Real-world case study; Trusted Rating & Weighted Score	Builds bilateral relationships & user engagement in collection policy	Number of reviews & user trust score
2	2020	Indonesia	Other (University)	Improves search time efficiency & reduces reference errors	Blackbox testing (Trial and Error); Most Similar Member Ranking	Easier selection of books matching the user profile	Member similarity rank (KNN)
3	2020	India	Public/Academic context	Improves prediction & recommendation accuracy	Systematic review; Precision, Recall, F-measure, RMSE, MAE	Enhances user experience in decision-making quality	Rank correlation coefficient (Spearman)
4	2023	Algeria	Public context	High accuracy in discovering relevant books	Offline (Train-Test Splits); RMSE, MAE	Increases reader satisfaction & loyalty	Novelty; Coverage
5	2018	Belgrade, Serbia	University	Long-term satisfaction & search efficiency	Survey & Log analysis; Likert Scale, Mean Grade	Increase in the number of loans by 269.5%	Loan count increase; Clickstream
6	2014	Udine, Italy	Scientific	Improves explainability of recommendations by explanations	User Study & Experiment; RMSE, nDCG	Content fit with researchers' interests	Novelty; Accuracy
7	2011	Castilla-La Mancha, Spain	University digital library	Improves collaboration effectiveness among researchers	Experiment/ Prototype test; Precision, Recall, F1	User satisfaction with collaborator/ partner recommendations	Acceptance rate (invitation)
8	2009	Jaén, Spain	University digital library	Accuracy of cross-disciplinary recommendations	Experiment (Trial version); Precision, Recall, F1	Researchers' satisfaction with complementary suggestions	Satisfaction Score
9	2014	Granada, Spain	University digital library	Increase in rating prediction accuracy (4.80%)	Online Experiment; MAE, Precision, Recall, F1	User satisfaction via improved item quality	F1 Measure

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ID Year	Country/ Region	Library type	RQ2: Service outcomes	RQ2: Measurement (method; metric)	RQ3: Engagement outcomes	RQ3: Engagement metrics
102010	Jaén, Spain	University digital library	Facilitates user profile acquisition	Experiment; Precision, Recall, F1	Satisfaction with received recommendations	User feedback judgements
112018	Bangkok, Thailand	University	High accuracy of specific book category recommendations	Experiment/ Evaluation Matrix; Precision (Top-1, Top-5)	Satisfaction in faculty-specific book search	Relevancy score
122014	Granada, Spain	University digital library	MAE reduction (4.8%) through quality integration	Online Experiment; MAE	Improved service accuracy and usefulness	User satisfaction score
132026	Guangdong, China	University	Improved recall & topical diversity	Experiment on real dataset; Recall, HR, NDCG, ILD, Coverage	Exploration of new genres by readers	Channel Weight; Prediction Score
142020	Hamadan, Iran	Medical university	Delay prediction accuracy (90.1%)	Analytical Survey (CRISP-DM); Accuracy, Sensitivity, Specificity, R2, MSE	Identifies user loyalty (loyalty vs churn)	Loyalty classification score

4.4. Mapping RQ5 and RQ6: Implementation Factors, Gaps, and Practical Recommendations

For RQ5, the main enablers for implementing recommender systems in libraries include data availability and metadata quality, the maturity of system integration across OPAC portals and integrated library systems, and staff capacity to manage and maintain models. Recurring barriers include sparse user interactions, cold start conditions, heterogeneous preferences, integration challenges, and sustained concerns regarding privacy and ethics in processing user profiles and behavioral traces.

For RQ6, three major gaps are evident. First, studies remain limited in public and regional library contexts compared with university and digital library settings. Second, substantial variation in service and engagement indicators constrain cross study comparability. Third, privacy governance and recommendation transparency are still discussed only to a limited extent. Practical implications for public and regional libraries include establishing a data pipeline that combines loan logs and OPAC interaction data, adopting hybrid approaches as a baseline to mitigate cold start, and defining operational service and engagement metrics that can be implemented in routine service monitoring. Table 5 summarizes key enablers and barriers, along with gaps and implications for public and regional libraries.

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Table 5. Mapping of RQ5 and RQ6 for each included study

ID	Year	Country	Library type	RQ5: Enablers	RQ5: Barriers	RQ5: Privacy/Ethics	RQ6: Reported gaps	RQ6: Implications for public/ regional libraries
1	2022	Morocco	Regional (National)	Availability of External APIs (Amazon) & Machine Learning	Lack of internal library preferences data & reviews	Third-party data integration	Limited RS studies specifically for weeding	Highly relevant for budget optimization & shelf space management in regional libraries
2	2020	Indonesia	Other (University)	Python programming & MySQL database	Information overload in legacy search methods	Confidentiality of member IDs	Lack of automated systems in local libraries	Improves reference quality at the local level
3	2020	India	Public/Academic context	Advances in machine learning algorithms	Profile privacy threats & language ambiguity	Security of personal data in user profiles	Lack of contextual information integration (time/ mood)	Need to adopt context-aware models
4	2023	Algeria	Public context	Surprise library & public datasets	Sensitivity to initial parameters (SGD)	Ethics of providing reading suggestions	Suboptimal novelty optimization tuning	Hybrid models are well-suited for heterogeneous profiles of regional readers
5	2018	Belgrade, Serbia	University	Hadoop & Open source big data tools	Need for data science expertise; input data quality	Personal data security & user trust	Lack of surveys on big-data RS in libraries	Highly relevant for integrating community interest data
6	2014	Udine, Italy	Scientific	Algoritma Dikpe & reliable metadata	Cold-start problem for new user profiles	Algorithm transparency (white box)	Lack of public datasets for scholarly literature	Relevant for concept-based non-fiction book discovery
7	2011	Castilla-La Mancha, Spain	University digital library	Google Wave Protocol & Robots	Technology still in preview stage	Google account security	Changing user-profile dynamics	Useful for reader communities or book clubs

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ID	Year	Country	Library type	RQ5: Enablers	RQ5: Barriers	RQ5: Privacy/Ethics	RQ6: Reported gaps	RQ6: Implications for public/ regional libraries
8	2009	Jaén, Spain	University digital library	Proactive information tailoring	Staff workload for metadata input	Ethics of delivering relevant information	Need tools to assist information gathering	Suitable for cross-genre book recommendations for the community
9	2014	Granada, Spain	University digital library	Integration of popularity & quality metrics	Staff interaction for representation	Protection of preference data	Limitations of automated representation techniques	Important for promoting high-quality books in regional contexts
10	2010	Jaén, Spain	University digital library	Efficiency in user-profile acquisition	Complexity in defining initial relations	Security of vague/implicit preference data	Need tools to simplify user input	Helps new users quickly identify reading interests
11	2018	Bangkok, Thailand	University	Reduced storage costs	Infrequent visitors	Data anonymity	Lack of rating data in loan logs	Can be adapted using citizens' occupational categories
12	2014	Granada, Spain	University digital library	Popularity-based quality model	Need for initial quality inputs	Ethics: "first do no harm"	Automated collection representation techniques	Helps citizens find best-selling yet high-quality books
13	2026	Guangdong, China	University	GNN; Knowledge Graph	Minimal borrowing history required (at least 3 events)	Explainable recommendation paths for librarians	Popularity bias in diversification	Relevant for mitigating community filter bubbles
14	2020	Hamadan, Iran	Medical university	CRISP-DM standard methodology	Need for automated transaction updates	Research ethics code IR.UMSHA.REC.1396.27	Static database analysis	Helps librarians anticipate peak service demand

5. DISCUSSION

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RQ1 Analysis. Overall, the synthesis indicates that recommender systems are most frequently used to enhance the discovery of library collections and research resources, and this pattern is reflected in how RS have expanded from a basic OPAC search enhancement into a strategic instrument deployed across multiple service touchpoints. Beyond catalog and portal interfaces, RS are increasingly embedded in learning environments such as LMS Moodle, in digital research collaboration spaces, and in staff-facing decision support components that inform collection management. This evolution is particularly salient in operational use cases such as acquisition and automated weeding, where recommendations can guide budget allocation and shelf-space optimization by leveraging both internal circulation evidence and external signals, including user opinions extracted via third-party APIs. Consequently, RS should be understood as a dual-purpose capability that supports patron-facing discovery while also strengthening internal service efficiency and evidence-based collection governance.

RQ2 Analysis. In terms of service quality outcomes, the reviewed studies suggest that improvement is not captured solely by traditional accuracy metrics. While offline measures such as RMSE, MAE, precision, recall, F1, and ranking-based indicators including NDCG remain widely used, service quality is increasingly tied to explainability and trust. Systems that provide intelligible reasons for recommendations tend to be perceived as more credible, particularly for research-oriented contexts where users require justification for adopting suggested resources. In addition, operationally meaningful outcomes, such as reduced search time and fewer reference errors, frequently appear as tangible indicators of service enhancement. These results imply that evaluation should connect algorithmic performance to user-perceived utility and to service-level indicators that libraries can monitor in routine operations.

RQ3 Analysis. Engagement outcomes further reinforce the relevance of RS to both digital and physical library use. Across the literature, engagement is commonly proxied through interaction-based measures, such as clicks and accesses to recommended items, repeated usage patterns, and behavioral signals that reflect deeper participation, including borrowing and circulation activity, collaboration invitation acceptance rates, and exploration of new genres. Notably, one study reports a substantial increase in physical borrowing following RS integration, illustrating how personalization can translate into measurable service uptake (Li, 2024; Simović, 2018). These findings underscore the importance of aligning RS objectives with engagement indicators that reflect meaningful participation rather than only short-term interactions.

RQ4 Analysis. The predominance of hybrid approaches across studies provides a technical explanation for these observed outcomes. Hybrid models, combining collaborative filtering and content-based methods, represent a pragmatic response to sparsity and cold-start challenges in library data, since they can exploit both behavioral traces and bibliographic or semantic content. Complementary strategies, such as association rule mining, capture co-borrowing patterns, while fuzzy linguistic modeling addresses the reality that user preferences are often incomplete or imprecise. More recent work introduces knowledge graphs and graph neural networks to represent richer relationships among users, items, and attributes, expanding the scope of RS beyond transactional similarity. Importantly, these approaches also influence the data strategy, as effective deployment depends on integrating

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loan logs with bibliographic metadata, and in some cases, extending to textual reviews, institutional profiles, or contextual signals.

RQ5 Analysis. Within public and regional library contexts, the primary constraints relate to user heterogeneity and data governance, which directly shapes implementation feasibility and ethical acceptability. Enablers repeatedly highlighted in the literature include strong metadata quality, mature integration across OPAC, portals, and integrated library systems, and adequate human capacity to operate and maintain models, potentially supported by Big Data infrastructures such as Hadoop. Conversely, recurring barriers include sparse interactions for many patrons, cold-start conditions for new users and items, integration complexity across legacy systems, and heightened privacy and ethics considerations when profiling users and analyzing behavioral traces. These concerns elevate the importance of transparency, anonymization, and careful governance so that RS do not operate as opaque black boxes that amplify popularity bias or compromise user trust, particularly when third-party data sources are introduced.

RQ6 Analysis. Taken together, these insights motivate a phased implementation strategy, starting with a metadata and loan log-based hybrid baseline, which is more realistic than models requiring very rich interaction data. Such a baseline can be incrementally enhanced as data pipelines mature, for example by adding OPAC interaction logs, incorporating lightweight contextual cues, and improving explainability to support trust. At the same time, the synthesis identifies research gaps that limit current guidance for public and regional libraries, including the relative scarcity of studies in these settings compared with university and digital libraries, wide variation in reported service and engagement indicators that hinders cross-study comparability, limited integration of contextual factors such as time and mood, and insufficient attention to privacy governance and transparency in operational deployments. To bridge service objectives, namely service quality, and engagement objectives, public libraries can position recommender systems as both a collection discovery feature and a thematic curation and literacy program feature, for example by recommending events or topics that are popular within a local community.

Evaluation should integrate offline metrics with online indicators such as clicks, save-to-list actions, and borrowing activity, complemented by user feedback, to ensure that service benefits are measurable and actionable. In practical terms, this implies defining a small set of operational indicators that can be routinely monitored, coupling them with periodic user studies to validate perceived usefulness, and embedding privacy-aware practices and explainable outputs as default design requirements. Through this linkage between use cases, technical choices, governance constraints, and outcome measurement, RS can be translated from fragmented research evidence into implementable service innovations for public and regional libraries.

The following paragraphs elaborate each element of Figure 2: Conceptual Framework of Library Recommender System, which was developed through a synthesis of empirical findings reported in the reviewed studies. Together, these explanations clarify how inputs and enabling conditions are translated into algorithmic processes, operational implementations, and measurable outcomes within library services.

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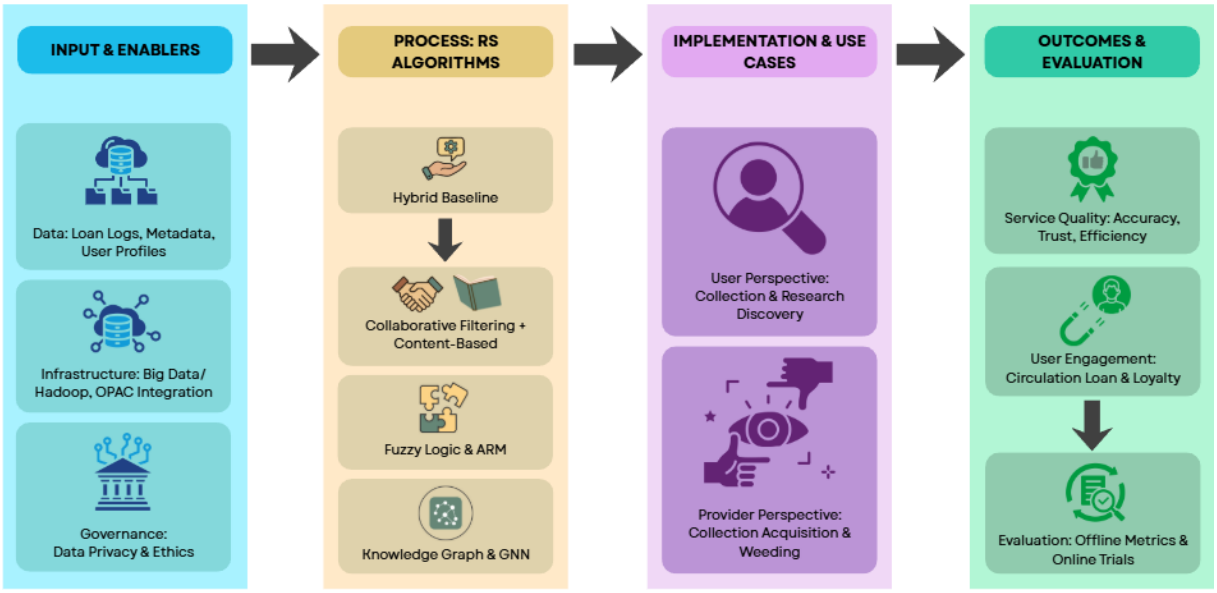


Figure 2. Conceptual framework of library recommender system

Part 1: Input & Enablers. The framework begins with Input & Enablers, which consolidates the data requirements and supporting conditions most consistently identified across the included studies. Core inputs include loan logs, bibliographic metadata, and user profiles, which jointly provide the behavioral and content signals needed for personalization. In addition to data availability, effective deployment depends on technological readiness, such as scalable data infrastructure, including Big Data platforms like Hadoop, and mature integration with OPAC or related service portals. This layer also foregrounds privacy and data ethics governance as a foundational enabler, ensuring that the processing of behavioral traces remains secure, transparent, and aligned with user trust expectations.

Part 2: Process: RS Algorithms. Building on these prerequisites, the Process layer specifies the algorithmic strategies most frequently adopted in library RS research and practice. A hybrid baseline combining collaborative filtering and content-based filtering is emphasized as a pragmatic core approach because it addresses data sparsity and cold-start conditions while leveraging both interaction history and bibliographic features. To accommodate preference uncertainty and limited explicit feedback, fuzzy logic and association rule mining are incorporated as complementary techniques. The framework further highlights knowledge graphs and graph neural networks as advanced pathways for modeling richer semantic relationships among users, items, and attributes when data maturity and integration capabilities allow.

Part 3: Implementation & Use Cases. The Implementation & Use Cases layer then connects these algorithmic choices to concrete library service touchpoints and operational objectives. From the user perspective, RS primarily supports the discovery of books, e-books, and research resources through web portals, digital catalogs, or OPAC interfaces. From the service-provider perspective, RS functions as a decision-support capability for collection management, including acquisition prioritization and evidence-informed weeding based on borrowing patterns and community interests. This dual-purpose framing positions RS not merely as a front-end feature, but as an integrated service mechanism that also improves internal efficiency and collection governance.

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Part 4: Outcomes & Evaluation. Finally, the Outcomes & Evaluation layer defines how performance and impact should be assessed to ensure the system delivers measurable value. Service quality outcomes extend beyond prediction accuracy to include search efficiency, perceived usefulness, and trust supported by explainable recommendations. Engagement outcomes are operationalized through a combination of digital interaction signals, such as clicks and save-to-list actions, and physical service indicators, such as circulation and repeat borrowing that reflect loyalty and sustained use. Accordingly, the framework recommends evaluation designs that combine offline metrics, such as precision, recall, RMSE, MAE, and NDCG, with online trials and user feedback, enabling continuous improvement and accountable deployment in real-world library contexts.

Furthermore, the framework incorporates Collection & Management Outcomes from a provider perspective to evaluate the system's impact on internal library operations. Beyond user-centric metrics, this category assesses how recommendation data enhances the accuracy of collection development, specifically informing data-driven acquisition and strategic weeding processes. By integrating these management-focused indicators, the Recommender System (RS) functions as a dual-purpose decision support tool that optimizes resource allocation and ensures the collection remains aligned with evolving institutional needs. This holistic evaluation approach ensures that the system provides measurable value not only to the end-user but also to the library as a curated knowledge repository.

6. LIMITATIONS

This SLR is constrained by database coverage limited to ScienceDirect and IEEE Xplore and by reliance on full-text accessibility. Heterogeneity in use cases and evaluation designs limits the feasibility of quantitative meta-analysis. Therefore, the synthesis was conducted using a narrative and thematic approach aligned with the research questions.

7. CONCLUSION

This study concludes that recommender systems have become a central pillar in the information transformation of modern libraries by enabling personalized collection discovery, supporting research resource recommendation, and strengthening data-driven managerial decision-making. Across the SLR findings, hybrid approaches emerge as the dominant paradigm because they can effectively combine behavioral and content signals to mitigate sparsity and cold-start while balancing recommendation accuracy with topic diversity, as reflected in improvements in recommendation-quality metrics, user satisfaction, and, in some cases, substantial increases in physical circulation.

The synthesis of all research questions further indicates that successful RS deployment depends heavily on data infrastructure readiness, including scalable pipelines and, where applicable, Big Data technologies such as Hadoop, as well as on the system's ability to provide explainable recommendations that foster trust and actionable use. However, empirical studies in public and regional library contexts remain limited, highlighting the need for more evidence in operational government service settings. For public and regional libraries in Indonesia, strategic priorities should focus on establishing integrated data pipelines that

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connect loan logs and OPAC interactions, implementing strict privacy governance for user profiles and behavioral traces, and defining engagement indicators that combine digital interactions with physical circulation activity. Future research should explore the integration of contextual information, such as time and readers' mood, to further enhance recommendation relevance for heterogeneous community populations.

8. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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