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Mapping the research landscape of recommender systems for digital libraries: A bibliometric analysis of two decades (2004-2023)

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Abstract

Background of the study: In today's information-rich environment, researchers face the difficulty of managing information overload and struggle to identify meaningful information among a plethora of choices. A recommender system plays a crucial role in assisting users in discovering relevant information from a digital library.

Purpose: This study aims to provide a bibliometric analysis of research publications on recommender systems for digital libraries.

Method: The research method involved the quantitative bibliometric approach to analyse the research publications from the Web of Science and Scopus databases using Biblioshiny. The dataset retrieved comprises 374 documents published between the period of 2004-2023.

Findings: The study's findings highlight that the number of publications was notably high in 2009 and 2018 within the analyzed period. The most significant contributors are Porcel C, Herrera-Viedma E, and Beel J. There is a considerable international collaboration between the countries- China, USA, and Germany.

Conclusions: This study indicates an emerging interest in recommender systems for digital libraries with the continuous evolution of new recommendation models. There is a huge potential for research considering the availability of multimodal data, the continuous evolution of new technologies such as deep learning, and opportunities for the development of an architecture for integrating different digital libraries.

Keywords: *Recommender System, Digital Library, Information Overload, Fuzzy Linguistic Modeling, Deep Learning, Collaborative Filtering*

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Introduction

We live in a society that is overwhelmed with an unprecedented amount of information. The rapid expansion of information technologies serves as a catalyst for the explosive growth of digital information (Anas & Salim, 2023). As a result, researchers consistently find themselves engaged in an ongoing battle against information overload and encounter different challenges to discover relevant information precisely when needed or aligned with their preferences. This problem appears especially in the context of the library where the rate of information overload exceeds users' processing capabilities (Porcel et al., 2018). As a result, traditional library systems have transformed into smart and digital libraries. The application of digital libraries extends across various contexts; however, our study specifically concentrates on their usage within an academic environment. University Digital Libraries (UDL) surpasses traditional libraries by providing a variety of services and resources, such as digital collections, online databases, and multimedia data to meet the different needs of students, faculty, and staff in their learning, teaching, and research endeavors (Al-Qallaf & Ridha, 2019; Kato et al., 2023).

This constant fight against information overload requires the development of effective strategies and tools. The Recommender Systems (RS) plays a crucial role in tailoring information to individual research interests, aiding in the battle of overwhelming data by providing personalized recommendations (Adomavicius et al., 2021; Burke et al., 2015). This system assists users in navigating relevant information based on their past preferences and provides personalized suggestions for various library resources. These recommendations encompass a wide range of recommendations including book (Mo et al., 2019), research article/paper (Magara et al., 2017), journal (Ghosal et al., 2019), audio (Roy et al., 2020), and many more within digital libraries.

Various types of RS have been implemented within digital libraries based on fuzzy linguistic modelling (Tejeda-Lorente et al., 2014a), collaborative filtering (Shen, 2018; Nugraha et al., 2020), and hybrid approaches (Amolochitis, 2018). The users of digital libraries have varied interests and to deal with these unpredictable needs, some attempts have been made to model and understand user behavior through implicit user activities to improve recommendations for digital library services (Akbar et al., 2014; Liu, 2022). However, the quality of recommended items remains a challenge in many existing approaches. Tejeda-Lorente et al., (2014b) addressed this gap by proposing a novel recommender system based on item quality, incorporating a fuzzy linguistic approach, and testing it within a UDL to enhance users' access to relevant research resources. Despite the progress made, personalized recommendations in digital libraries still face challenges such as cold start problems. To address this issue, Tejeda-Lorente et al., (2018) incorporated a fuzzy linguistic approach utilizing bibliometrics to reduce the necessity for user interaction. Porcel et al., (2017) examined various proposals for RS to improve information access, with a focus on identifying the best fuzzy linguistic modeling RS to assist users in academic library services.

Recent advancements have been made in RS within digital libraries based on user preferences utilizing the Latent Dirichlet Allocation model to recommend items (Zhao, 2021), ontology-based multi-attribute collaborative filtering RS to enhance the access to learning resources within digital libraries (Senthil Kumaran & Latha, 2023). Liu (2021) proposed a personalized RS using SOM neural networks to enhance the web access behavior of users for UDL. Despite the ongoing development of various RS in the field of digital libraries, the existing literature remains somewhat limited. This field is still in its nascent stage, and there are very few articles, especially in UDL. Thus, we consider the landscape of the digital library to take into account the potential for the development of a unified RS model for digital libraries.

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To the best of our knowledge, nevertheless, so far, no research has been conducted to study the bibliometric analysis of RS for digital libraries. The measurement of research using bibliometrics typically focuses on topics, scientific fields, and publications (Muntiah & Dewi, 2023). Our research addresses the gap by analyzing previous studies, offering important insights, and highlighting potential research opportunities within the field.

The objective of our study is to provide an overview of the field's current state, progress, and influence through bibliometric analysis. The extensive datasets were obtained from the Web of Science (WoS) and Scopus covering a span of two decades (2004-2023). The analysis not only investigates publication trends and collaboration patterns within the field but also underscores the need for a unified RS framework for digital libraries. This need is highlighted, especially in the context of UDL, where the current landscape displays a diverse spectrum of RS implementations. To confront this inevitable challenge, this study aims to provide valuable insights that have the potential to shape the development and standardization of RS by addressing the unique requirements and complexities of academic environments within the UDL. This research would facilitate further research endeavors. The following research questions to ensure the continuity of RS for digital libraries:

RQ1. How has the annual scientific publication growth in RS for digital libraries evolved over the past two decades (2004-2023)?

RQ2. Who are the most prolific authors in this relevant field?

RQ3. What is the structure of the co-citation network between authors working in this field over the past two decades (2004-2023)?

RQ4. Which countries make the largest contributions based on publications and citations in this field?

RQ5. Which keywords are the most frequently used and what are the upcoming trends in this field?

Method

This study conducted an in-depth bibliometric analysis of RS for digital libraries. To conduct bibliometric analysis, we retrieved our data as per the guidelines discussed in Snyder, (2019). We extracted relevant papers from the WoS and Scopus databases. The publication period of the research document is from 2004 to 2023. Figure 1 outlines the flow of the methodology followed for document identification based on the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) approach. The PRISMA framework includes data sourcing, data retrieval, data screening, and data constraints (Page et al., 2021). The chosen timeframe was taken because of the high interest in RS for digital libraries, which emerged in response to the information overload problem in libraries, and RS gained prominence in the late 90s and early 2000s. The search was conducted in English using the following query:

Query- (("Recommendation System" OR "Recommender System") OR ("Recommendation" AND "Information Retrieval")) AND ("Library Science" OR "Digital Library" OR "Library and Information Science" OR "Digital Libraries" OR "University Digital Library" OR "Digital Library and Archives" OR "Scientific Library")

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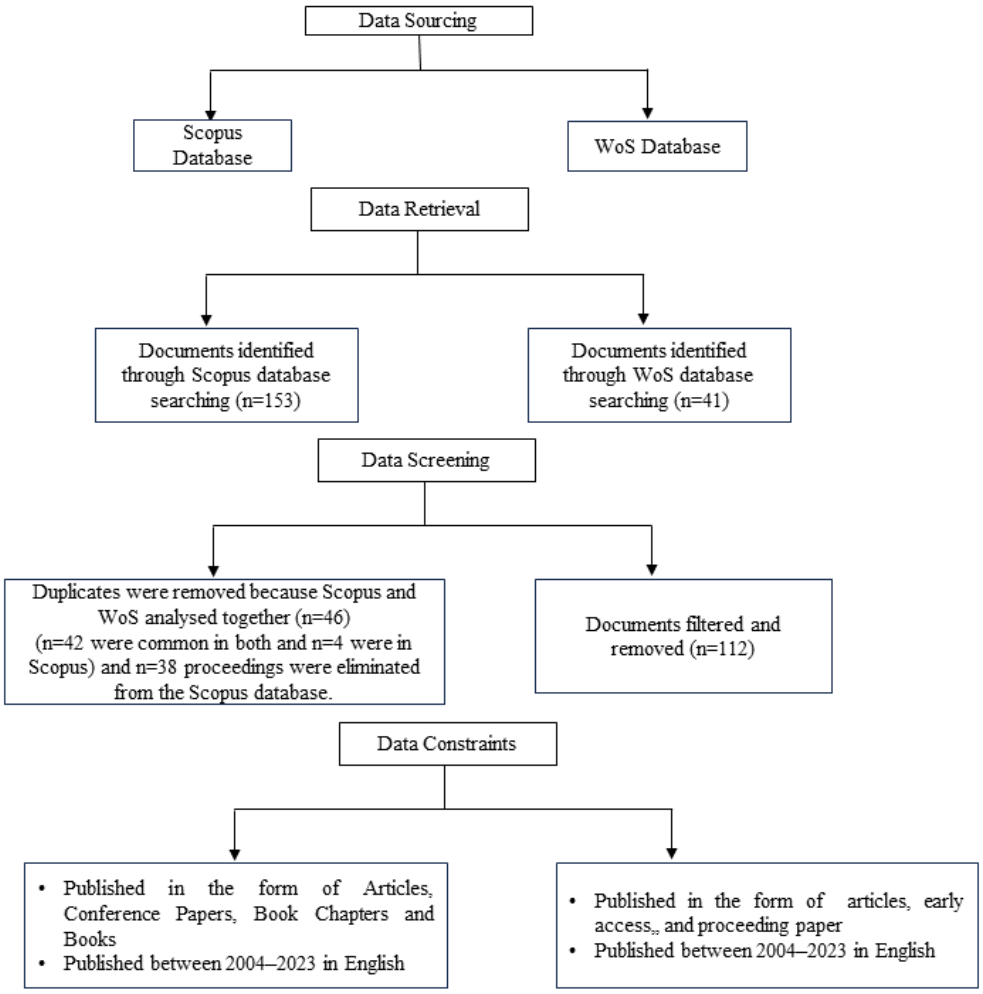

Figure 1. Research Framework of Methodology for Document Identification

Articles, Early Access, Proceeding Papers from WoS, and Articles, Conference Papers, Proceeding Papers, Book Chapters, and Books from Scopus are taken into consideration as document types. Following a manual review of 54 documents from WoS and 516 documents from Scopus, we eliminated 46 duplicate documents (42 common to both Scopus and WoS and 4 exclusives to Scopus) and excluded 38 proceedings from Scopus. Subsequently, another phase of screening was carried out by thoroughly reviewing each document. In this step, the primary criterion for inclusion or exclusion was the document's alignment with the research topic, specifically the application of RS for digital libraries. Finally, the data of 374 documents utilized in the study were consolidated into a csv file for bibliometric analysis. The data analysis for this study utilized the "Biblioshiny" (Bibliometrix package) of R studio software. This tool was developed to facilitate the comprehensive evaluation of the dataset through a visual representation of statistics.

Result and Discussion

The summary of the main findings drawn from the data using descriptive statistics is shown in Table 1. The data comprises a total of 374 documents, which include conference papers, articles, book chapters, books, and review papers. The papers within this domain exhibit 1985 distinct keyword distributions and involved 920 authors.

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Table 1. Main Information about the Dataset

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2004:2023
Sources (Journals, Books, etc)	198
Documents	374
Annual Growth Rate %	3.44
Document Average Age	10.1
Average citations per doc	15.33
References	8346
DOCUMENT CONTENTS	
Keywords Plus (ID)	1985
Author's Keywords (DE)	872
AUTHORS	
Authors	920
Authors of single-authored docs	37
AUTHORS COLLABORATION	
Single-authored docs	41
Co-Authors per Doc	3.2
International co-authorships %	13.9
DOCUMENT TYPES	
article	124
book	1
book chapter	10
conference paper	232
review	7

Growth Analysis of the Published Documents

The analysis presents a comprehensive overview of publication trends in RS for digital libraries in Figure 2. The graph shows some fluctuations in the annual number of published articles. The number of publications was notably high in 2009 and 2018. However, in recent years, the rate of scientific production growth has slowed down a bit. The findings highlight that the knowledge base of RS for digital libraries has expanded, and there remains considerable potential for further development.

Author Analysis

Figure 3 illustrates the productivity of the authors and their publication timeframes. Herrera-Viedma E, Beel J and, Porcel C are the most significant contributors to the research field. The more extended research careers of Porcel C and Herrera-Viedma E, spanning from 2008 to 2018, suggest a greater likelihood of concurrent research activities in this field and have consistently produced articles for almost a decade. Beel J began publishing articles more recently, starting in 2013. Herrera-Viedma E and Porcel C collaborated extensively, making notable contributions to fuzzy linguistic and quality-based RS for digital libraries, particularly focusing on UDL. Beel J also played a significant role in digital library recommendations, primarily focusing on research paper recommendations within the digital library domain. Their collective efforts have significantly advanced the understanding of researchers and practitioners in this field.

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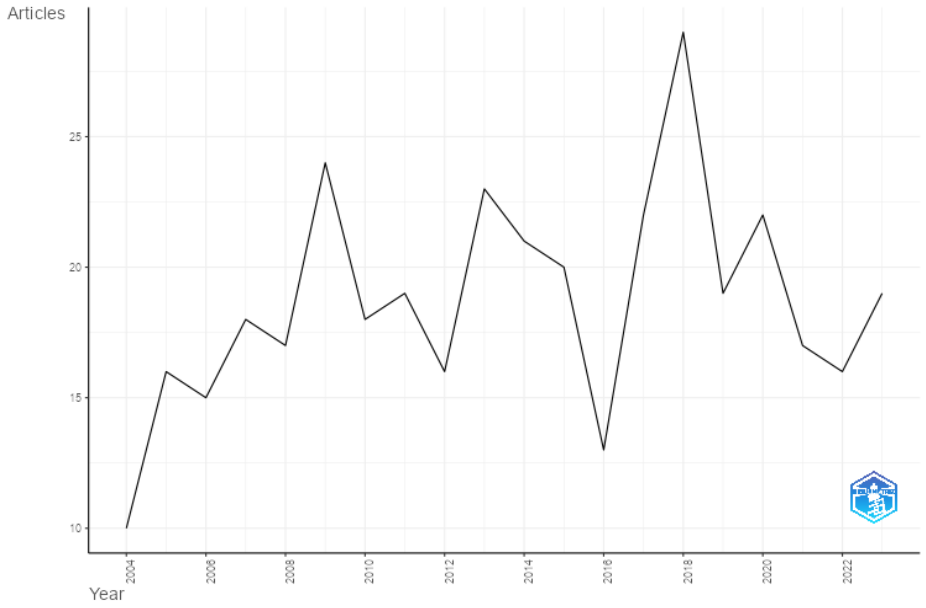

Figure 2. Growth of Annual Scientific Publications of RS for Digital Library over the past two decades (2004-2023)

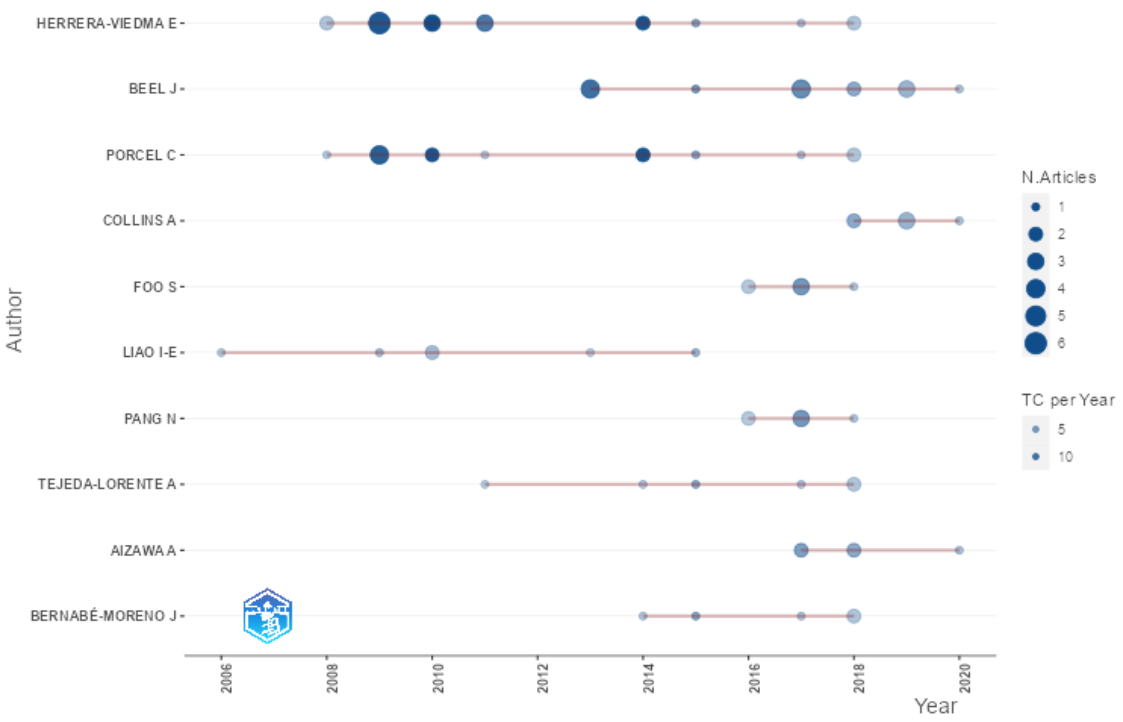

Figure 3. Growth of Author's Production over the past two decades (2004-2023)

Figure 4 shows the co-citation network between authors of the RS for the digital libraries. Notably, Beel J, Burke R, and Adomavicius G underscore a significant degree of interconnectedness and highlight their influence within this field. Authors in the green cluster, such as Adomavicius G, Salton G, Resnick P, and Huang Z, are associated with key theories, methodologies, or applications relevant to RS, highlighting their foundational contributions.

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The authors in the blue cluster, including Burke R, Porcel C, Sarwar B, Tejeda Lorente A, and Herrera-Viedma E focus on the practical aspects of RS for digital libraries, especially in the context of UDL. Their research focuses on the design, implementation, and evaluation of various recommendation algorithms based on fuzzy linguistic, hybrid, and ontology-based models to meet the varied needs of users for academic digital libraries. Authors in the red cluster, such as Beel J, McNee S, Sugiyama K, and Torres R, show significant contributions to the application of RS for digital libraries, particularly focusing on recommendations of various resources and components such as research papers, articles and other scholarly materials to enhance the accessibility of the relevant resources to the users within digital libraries.

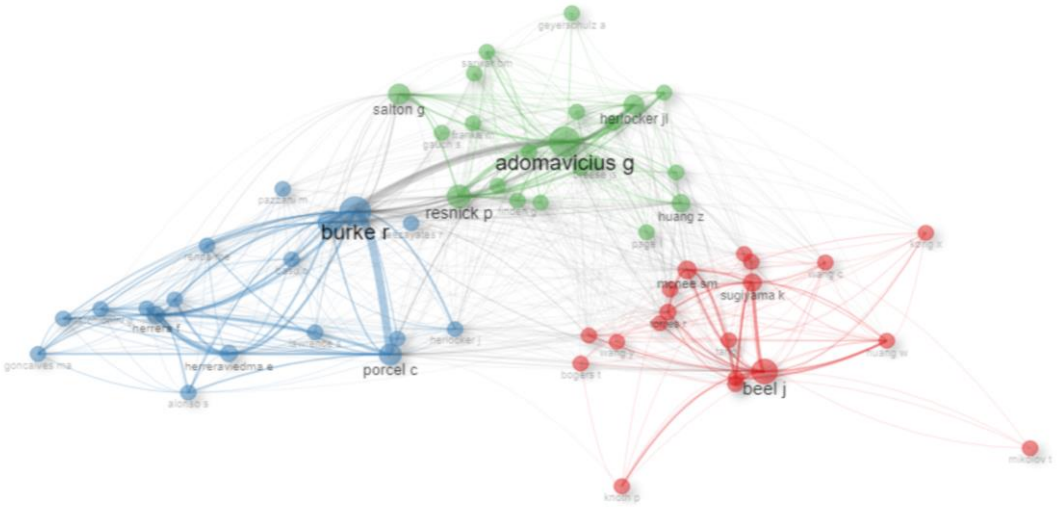

Figure 4. Co-Citation Network between Authors on the RS for Digital Library

Country Analysis

Figure 5 provides an overview of the countries in terms of total number of publications and total citations. The figure shows the plot of the top 20 countries sorted by total citations. It helps to gain insights into global distribution and its impact, in terms of citations. The analysis aims to identify which country is the most prolific in terms of publications and which one receives the most citations. Spain ranks first in terms of the total number of citations followed by the USA, China, and Brazil, whereas China was the most productive country in terms of the total number of publications followed by the USA and Spain. Sorting the countries by the total number of citations allows a deeper understanding of the influence and relevance of research in the research domain. This highlights that although China has the highest number of publications, Spain's research output exhibits a greater citation impact, showcasing the quality and influence of its contributions to the field of RS for digital libraries.

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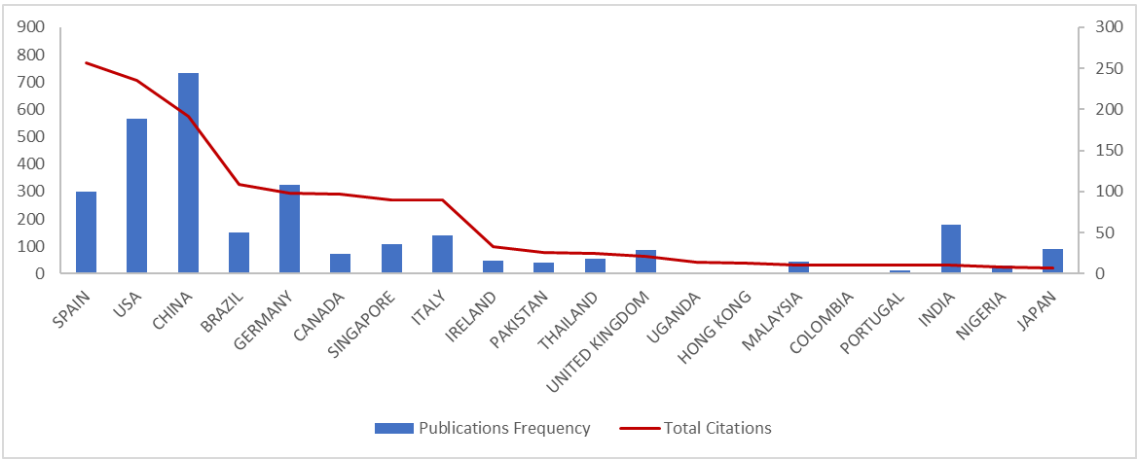

Figure 5. Plot of the Top 20 Countries' Total Publications and Total Citations, sorted by Total Citations

Figure 6 depicts a collaboration network between countries to provide valuable insights into the global landscape in this research domain. The visualization showcases different clusters with distinct colors, indicating cooperative relationships among countries of the same color. The analysis reveals that China, USA, Germany, and Spain demonstrate high levels of collaboration. Notably, the USA exhibits significant collaboration with leading countries such as China and Germany, indicating strong cooperative ties in RS for digital library.

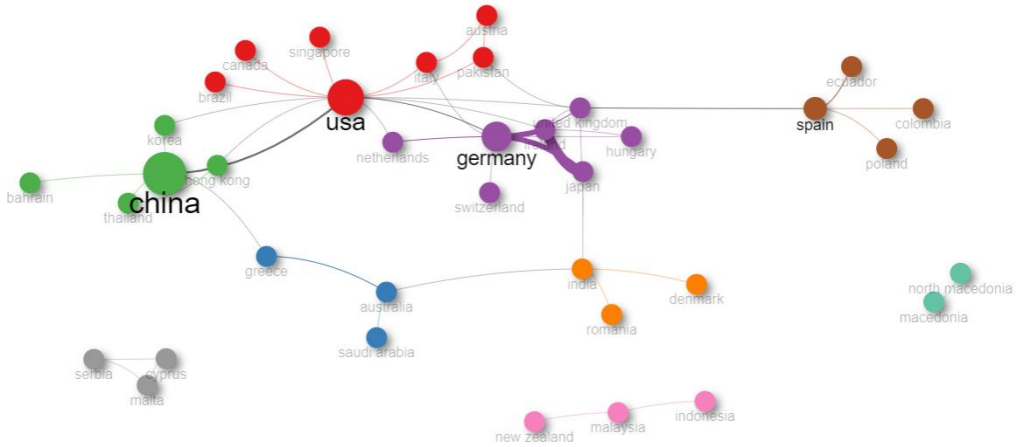

Figure 6. Collaboration Network between Countries

Keyword Analysis

Keyword analysis helps in identifying themes to uncover hotspots, frontiers, and research trends. Figure 7 displays a word cloud of the most frequent keywords, formed by eliminating all keywords used in the search query. Notably, collaborative filtering and search engines emerge as prominent terms, followed by semantics, user interfaces, and linguistics, among others. This underscores that previous research has largely focused on collaborative filtering, fuzzy linguistics modeling, and ontology-based recommendations for digital libraries.

Figure 8 illustrates the treemap of the top *50 keywords plus*. Overall, the treemap provides researchers with a straightforward method to visualize the primary themes and

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Figure 7. Word Cloud of Most Frequent Keywords

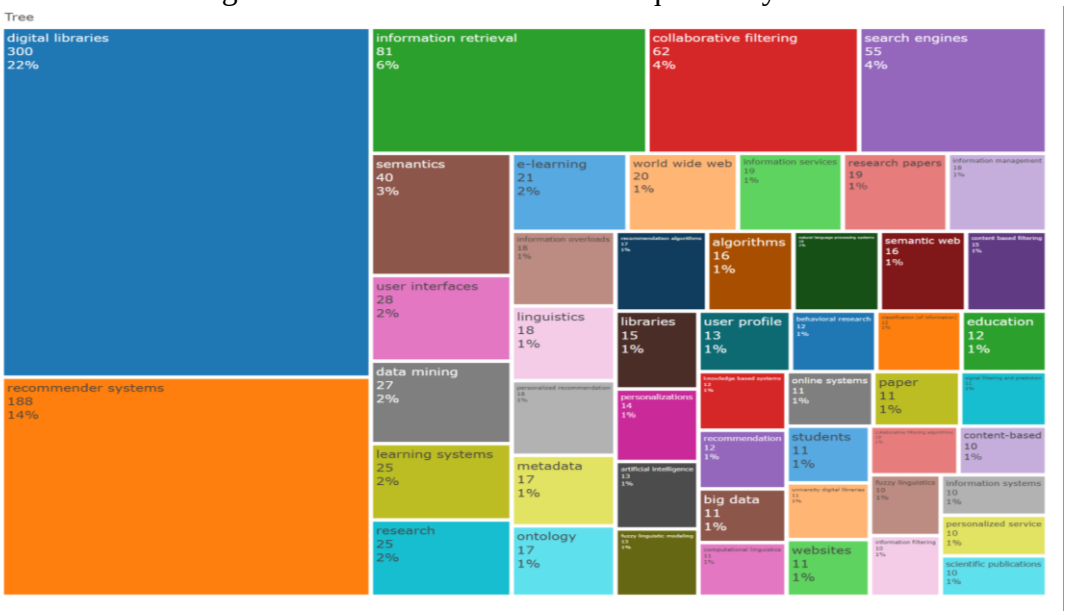

Figure 8. Treemap of Top 50 *Keywords Plus*

Figure 9 illustrates a significant increase over time in terms such as "digital information," "deep learning," "association rules," "big data," and "learning algorithms," particularly in recent years. This trend suggests a growing interest among researchers in leveraging deep learning techniques within the domain of digital libraries for personalized recommendations of books, articles, and other resources to users. Emerging methodologies such as deep learning and personalized recommendation are experiencing a surge in popularity, indicating a growing preference among researchers within the digital library domain. Conversely, traditional techniques such as fuzzy linguistics and content-based filtering are witnessing a decline in usage. Moreover, advancements in personalized RS for library services have led to a shift toward analysing social networks, user profiles, and ontology-based approaches. Presently, the focus has expanded to encompass hybrid RS, leveraging natural language processing, and extracting information from web-based data within digital libraries. This evolving landscape reflects ongoing efforts to enhance recommendation systems and improve information access and retrieval for users.

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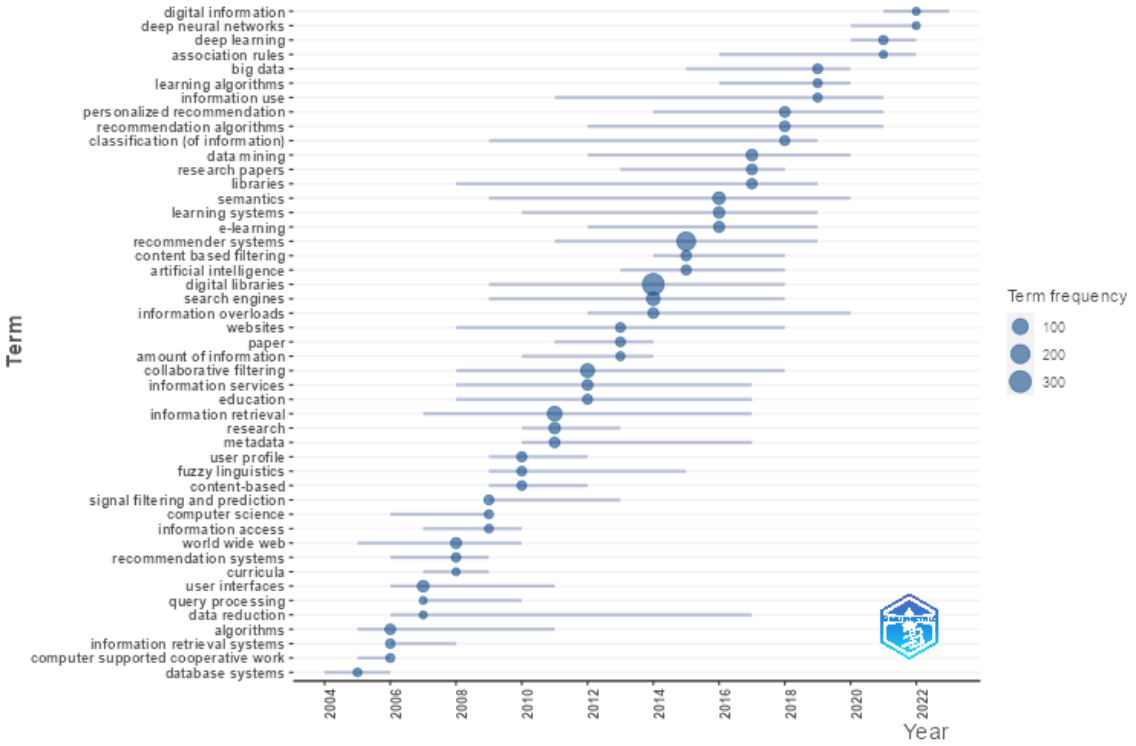

Figure 9. Trending Topics based on *Keywords Plus* over the past two decades

Discussion

The rapidly evolving technological landscape of RS and the digitalization of library resources offer great research opportunities in this amalgamated field of RS for digital libraries. The analysis of our findings reveals substantial efforts in this area and timely integration of emerging RS algorithms for developing better recommendation models for digital libraries.

Our analysis highlights the widespread use of collaborative filtering based RS for digital libraries. However, with the increasing complexity of data and the growing availability of multilingual content in digital libraries (Stiller et al., 2019), there arises a critical need for RS to address diverse language preferences among users. This necessitates the importance of integrating semantics and ontologies into RS (Senthil Kumaran & Latha, 2023), not only to offer more accurate recommendations but also to enhance user engagement and satisfaction by tailoring to their linguistic preferences. There exists a significant potential to implement natural language processing within RS to navigate the complexity of multilingual content and accommodate user interactions from diverse linguistic backgrounds. This endeavor to develop multilingual RS aims to bridge linguistic divides and enhance user experiences in globalized digital environments.

The digital libraries offer a wide range of data formats, such as text (Ajij et al., 2023), video (Dias et al., 2023), image (Shi & Zhu, 2020), audio (Smith et al., 2019), cultural heritage (Otegi et al., 2014), and mathematical jargon (Schubotz et al., 2018), which poses a significant challenge for efficient information retrieval and effective recommendations to users. To address this inevitable challenge and deliver more personalized suggestions aligned with diverse user preferences, there is a need to develop a comprehensive framework that can effectively handle multimodal data. It opens up future avenues for incorporating the latest technological advancements like meta-heuristic algorithms (Awal & Bharadwaj, 2014; Awal & Bhardwaj, 2019), deep learning techniques (Almaghrabi & Chetty, 2020; Chu et al., 2023), ensemble techniques (Rhanoui et al., 2022), and large language models (Zhao et al., 2024).

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These advanced models have the capability to understand users' interests, process large amounts of heterogeneous data, and empower users to access and interact with digital library resources more efficiently.

A growing body of literature reflects a trend towards various types of recommendations, including articles/papers (Beierle et al., 2017), books (Fu et al., 2022) and journals (Ghosal et al., 2019). However, there is a pressing need for an integrated and holistic recommendation framework tailored specifically for UDL. This open area of research should also prioritize fairness, transparency, and ethical considerations to ensure equitable access to digital library resources (Sonboli et al., 2020). By addressing these concerns, it becomes possible to enhance the user's navigational journey within a digital library, catering to his/her needs and preferences.

Conclusion

Our research is a pioneering attempt, to the best of our knowledge, which provides valuable insights into the research landscape of RS for digital libraries using bibliometric analysis and scientific mapping. Our findings indicate that the emerging methodologies in RS have found widespread use and popularity in the realm of digital libraries. The limitation of this study is that it focused specifically on RS for academic digital libraries, which may not fully capture the broader aspects of different forms of digital libraries across varied similar applications. Additionally, our study utilizes two major databases- Scopus and WoS, to capture all high-quality research publications in this area. However, these databases may not comprehensively cover all relevant publications as certain research published in non-indexed journals, and conference proceedings, which are not included in these databases may have been unintentionally excluded. Despite these limitations, our study provides substantial valuable insights into the significance of RS within academic digital libraries.

The following theoretical implications are underpinned by the findings of our study which encompasses several key areas for the advancement of personalized suggestions within UDL. 1) The unprecedented growth of data over time has led to information overload in digital libraries. Our study findings indicate that RSs have found widespread application within digital libraries, and the research in RS has contributed to the evolution of effective information retrieval systems for UDL by providing personalized recommendations and ease of accessibility for users. This is evident from the research by Rakhmatullaev et al., (2023) which emphasizes the need for recommendation techniques for information retrieval systems to provide relevant information at the right time to the library users as per their needs and preferences. 2) The results of our study suggest the development of RS has led to advancements in user modeling techniques like collaborative filtering, content-based, and hybrid approaches based on natural language processing, semantics, and ontology to cater to users' varied linguistic preferences and tailored to their behaviors. Such RS for digital libraries would help in finding the right balance between serendipity and relevance of recommendations impacting users' engagement and satisfaction which is emphasized in the research (Omisore & Samuel, 2014; Troussas et al., 2023).

The practical implications of this study would foster ideas for further research in this field including; 1) Identification of need to develop an integrated and holistic RS for UDL to facilitate relevant content discovery amidst a huge volume of available heterogeneous resources in multimodal data formats. Our study would provide motivation to the researchers to bridge the gap between the latest technological advancements in RS and its subsequent exploration, applicability, and implementation in UDL for efficient utilization of digital library resources. 2) Our study would serve as an opportunity for researchers to develop systems that focus on providing equitable access to digital library resources to library users

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including specially-abled users. These systems should focus on providing enhanced user experience and efficient navigational interfaces. 3) Further deliberation needs to be done to explore, compare, and evaluate existing recommendation systems in UDL in terms of algorithmic bias, user engagement metrics, fairness, accountability, transparency, and ethical considerations regarding user data collection and its use.

By uncovering key trends and opportunities in this field, we believe our research would inspire researchers to address the research gaps left unexplored in the application of RS for digital libraries thereby improving digital library services worldwide.

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Authors' Contributions

All authors have contributed to the final manuscript. The contribution of all authors: conceptualization, methodology, formal analysis, writing original draft preparation, writing review and editing. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare that they have no conflicting interests.

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