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An integrated Conceptual Framework to Harness Artificial Intelligence for Enhanced Data Management in Context

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ABSTRACT
This study explores the transformative impact of artificial intelligence (AI) technologies on research data management (RDM) services in higher learning institutions (HLIs), with a specific focus on the roles played by academic libraries. It highlights how these libraries strategically incorporate AI to enhance RDM effectiveness and stewardship. An integrated conceptual framework is proposed, which includes AI tools, RDM services, the functions of academic libraries, necessary support structures, and the challenges related to AI and RDM in HLIs. The findings indicate that this framework can significantly boost the efficiency of AI adoption, leading to streamlined workflows and reduced time for RDM services such as data generation, processing, storage, access, and reuse. Additionally, the framework supports the development of innovative AI technologies tailored to library users, including research management software, data security and quality assurance, and metadata generation.

Keywords: Artificial Intelligence (AI), Data stewardship, Innovative technologies, Ethical guidelines, Metadata generation, Data security

INTRODUCTION

Academic libraries play a vital role as hubs for knowledge and resources, facilitating the effective integration of artificial intelligence (AI) technologies and research data management (RDM) services in higher learning institutions (HLIs) (Bećirović & Mattoš, 2024). RDM services within these libraries focus on managing, archiving, processing, and reusing the research data generated in HLIs. RDM is defined as the organisation of data throughout the research cycle, from entry to dissemination and archiving (Chiware & Becker, 2018). The exponential growth of research data from various groups and organizations aims to address urgent social, educational, health, and environmental issues (Vuleta, 2021). This surge has introduced the "5V" challenge in big data, which is volume, velocity, variety, veracity, and value, highlighting the complexities of managing this vast information (Naeem et al., 2022). Thus, the application of AI technologies in this context is increasingly recognised (Medina et al., 2022). AI is defined as the simulation of human intelligence by systems or machines (Russell & Norvig, 2016; Xu et al., 2021). LeGun et al. (2015) defined AI as the capability of machines to perform tasks that typically require human intelligence, such as visual perception, speech recognition, decision-making, and language translation. Its primary goal is to create machines that can think and behave like

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humans, encompassing abilities such as perception, reasoning, learning, planning, and prediction (Xu et al., 2021). As industrial revolutions continue, various types of machines are increasingly taking over human labour across different fields.

AI technologies such as expert systems, artificial neural networks (ANN), natural language processing, and pattern recognition enhance the experiences of both librarians and library users. These advancements improve various aspects, including ad-hoc query processing, recommendation systems, cybersecurity, shelving, cataloguing, and overall service quality (GS & Mulimani, 2024). In the context of the Fourth Industrial Revolution (4IR), AI technologies like chatbots and mobile applications are employed to inform users about new arrivals, send reminders for due book loans, and guide them to relevant information, thereby enhancing research and scholarly communication (Kaushal &Yadav, 2022). AI is transforming every stage of the research data lifecycle, from data collection to archiving. This technology is set to revolutionise how research data is managed. As the complexity and volume of big data increase, integrating AI into RDM services becomes crucial (Klipa et al., 2022; Medina et al., 2022; Pillai, 2023). The effective integration of AI technologies with RDM practices enhances research productivity and innovation (Kamalov et al., 2023). Generative AI (GenAI) revolutionises RDM by automating tasks such as data cleaning, metadata generation, and organisation (Sela, 2024). It also facilitates the creation of synthetic datasets that maintain privacy while reflecting real-world patterns, streamlining data sharing and analysis (Soni, 2024). These advancements improve efficiency, data integrity, and reduce human error.

Academic libraries are uniquely positioned to support this integration by providing essential resources, infrastructure, training, and collaborative opportunities for researchers (Balbaa & Abdurashidova, 2024; Rabatseta et al., 2024). They can foster a culture of responsible RDM practices, ensuring compliance with ethical standards (Cox & Pinfield, 2014). AI offers benefits such as data analysis for informed decision-making and improved discoverability of texts (Mallikarjuna, 2024). However, biases in AI, concerns about privacy, and the "black box" nature of many AI systems complicate research reproducibility (Roselli et al., 2019; Memarian & Doleck, 2023). Librarians leverage AI technologies, including Natural Language Processing (NLP) tools and pattern recognition techniques, to enhance material retrieval and online searches. By integrating these technologies, libraries can improve the efficiency, accuracy, integrity, and accessibility of RDM practices, ultimately supporting researchers in their academic endeavours. This underscores the need for an integrated framework to guide the incorporation of these tools into RDM services in academic libraries. Table 1 presents various AI tools particularly beneficial for RDM services in academic libraries.

Table 1: AI tools support RDM services in academic libraries

AI functionalities	RDM services	AI tool(s)
Cloud computing services	Store and manage big data, ensuring accessibility and collaboration.	OneDrive and Google Drive
	Integrate AI to assist with citation management and the organization of research materials.	Mendeley and Zotero
	Promote standardization and consistency across datasets, automates metadata generation, improving data discoverability and usability, integrates capabilities enable seamless connections with other RDM systems and repositories, and fosters collaboration among researchers.	CEDAR (Commonly Used Data Elements for Research)
Data cleaning and quality assurance	An AI-driven tool for data cleaning and preparation that helps to identify and correct data quality issues	Trifacta

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AI functionalities	RDM services	AI tool(s)
	Works with messy data, allowing users to clean and transform data sets efficiently.	OpenRefine
Metadata generation	Automates the generation of metadata for datasets, improving discoverability and organization.	MetaGenie
	It recommends metadata standards and practices.	DataCite
Data analysis and visualization	Incorporates AI features for data visualization and analytics, enabling researchers to create interactive and insightful visual representations of their data.	Tableau
	Utilizes AI for predictive analytics and data mining.	RapidMiner
Predictive analytics	Provides a platform for building, training, and deploying machine learning models to analyze research data.	Microsoft Azure Machine Learning
Recommendation systems	Uses AI algorithms to recommend papers, datasets, and collaborators based on user profiles and activity.	ResearchGate
	Suggests relevant research articles and datasets based on user interests and previous readings.	Mendeley
Data sharing and collaboration	Facilitates the sharing of research outputs, including datasets, while ensuring proper metadata tagging.	Figshare
	Integrated with AI tools for version control and collaboration on research data, allowing teams to work together effectively.	GitHub
AI-powered chatbots and virtual assistants	A chatbot platform integrated into academic libraries to assist users with RDM queries and provide support.	LibChat
Synthetic data generation	Offers capabilities to generate synthetic datasets for training machine learning models without compromising sensitive information.	DataRobot
Compliance monitoring	Uses AI to help organizations ensure compliance with data governance and management policies, beneficial for RDM in academic settings.	Diligent
Data analysis and visualization tools	Offer a suite of data mining and machine learning tools, allowing researchers to analyze datasets and build predictive models.	RapidMiner
Natural Language Processing (NLP) tools	Provides NLP capabilities to extract insights from unstructured data, helping researchers analyze large volumes of text data.	IBM Watson
	Analyzes text and provides insights about content, sentiment, and entities, useful for qualitative research.	Google Cloud Natural Language
Machine learning frameworks	Allows researchers to develop and train machine learning models, providing tools for deep learning applications.	TensorFlow
	A user-friendly library for machine learning in Python, offering various algorithms for data mining and analysis.	Scikit-learn
Data management and repository platforms	Assist researchers in creating data management plans (DMPs) by providing templates and guidance tailored to funding agency requirements.	DMPTool

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AI functionalities	RDM services	AI tool(s)
	Web-based platforms that enables researchers to store, share, and manage their datasets, with features for metadata generation and version control.	DataVerse and Figshare
Data annotation and labeling tools	Facilitates data annotation for machine learning projects, allowing researchers to label datasets efficiently for training purposes.	Labelbox
Automated insights and reporting tools	Offer AI-powered analytics that can analyze data and generate insights, helping researchers create reports based on their datasets.	IBM Watson
	Converts data into natural language narratives, allowing researchers to generate understandable reports and summaries from complex analyses.	Narrative Science

Sources: (Fatima, Nazir & Khan, 2017; Kang et al., 2020; Kumar, Boehm & Yang, 2017; Oni et al., 2017)

Theoretical Frameworks for Enhancing RDM Services with AI in Academic Libraries

This study employs several theoretical frameworks to clarify how AI tools enhance RDM services in academic libraries. Ngulube and Mosha (2023) suggest that if no single theory can fully capture the constructs of a study, constructs from multiple theories should be applied to explain a phenomenon. In that regard, constructs from various theories were utilised to explain the role of AI in enhancing RDM in HLIs. These frameworks lay the groundwork for understanding technology adoption, knowledge management, and collaboration in research environments. The technology acceptance model (TAM) posits that perceived ease of use and perceived usefulness are critical factors influencing users' acceptance of new technologies (Kelly & Palaniappan, 2023). By comprehending these perceptions, librarians can design user-friendly AI tools and RDM services that clearly demonstrate benefits to researchers, thereby enhancing adoption rates (Lund et al., 2020). The diffusion of innovations theory (DIT) examines the spread of new ideas and technologies within a social system (Sahin, 2006). It also identifies factors affecting innovation adoption, such as relative advantage, compatibility, and complexity (Scott et al., 2008). Academic libraries can leverage DIT to strategically promote AI and RDM initiatives, ensuring they align with researchers' existing practices and needs (Almaiah et al., 2022; Frei-Landau et al., 2022).

Social constructivism theory (SCT) posits that knowledge is constructed through social interactions and experiences (Saleem et al., 2021). SCT emphasizes collaborative learning, enabling libraries to create environments that facilitate knowledge construction through workshops and interdisciplinary projects, thus enhancing the integration of AI and RDM practices (Wang, 2014). Actor-network theory (ANT) explores the relationships among various actors, both human and non-human, that shape social phenomena (Mort et al., 2009). It highlights the interconnectedness of technology and social processes (Cresswell, Worth & Sheikh, 2010). ANT can help academic libraries navigate the complex interactions between researchers, AI tools, data, and institutional policies, fostering a supportive ecosystem for AI and RDM integration (Silvis & Alexander, 2014). Collaborative learning theory (CLT) emphasises the importance of collaboration in the learning process, suggesting that knowledge is best acquired through peer interaction (Abulhassan & Hamid, 2021). Libraries can implement collaborative environments that encourage researchers to work together on projects utilising AI and RDM, thereby enhancing skills and promoting innovative research practices (Hatmanto & Sari, 2023).

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These theories provide insights into technology adoption and collaboration in academic libraries. Nilsen (2015) emphasised that defining these roles clarifies the paper's contributions. They form an integrated framework for applying AI technologies to RDM services in HLIs. The technology acceptance model (TAM) helps assess factors influencing AI tool adoption among researchers and librarians (Kelly, Kaye & Oviedo-Trespalacios, 2023). Actor-network theory (ANT) sheds light on stakeholder relationships, enhancing collaboration (Andrikopoulou et al., 2022). Utilizing TAM, DIT, SCT, ANT, and CLT is crucial for improving RDM services in academic libraries.

Integrated Conceptual Framework

An integrated conceptual framework synthesises various theories and models to address specific issues (Nilsen, 2015). This study focuses on enhancing RDM services in academic libraries through AI technologies in HLIs. By developing this framework, the study clarifies the roles of each component, making the logic behind the findings more transparent (Nilsen, 2015). It highlights the multifaceted roles of academic libraries in integrating AI and RDM practices. Several existing frameworks demonstrate the scope of AI technologies. For instance, Bawack et al. (2021) proposed a classification framework linking information systems (IS) to contemporary AI research. Ofosu-Ampong (2024) provided insights into methodologies and conceptual approaches, alongside an AI framework identifying research gaps. Hunter et al. (2018) also developed a conceptual framework for AI applications. Conversely, Azami, Sadatmoosavi, and Chashmyazdan (2023) created RDM frameworks to help organizations assess RDM system implementation, while Gunjal and Gaitanou (2017) proposed one to enhance research in higher education. Despite these contributions, there is a lack of frameworks integrating AI technologies with RDM services that specifically address the roles of academic libraries and researchers' needs. However, Collina, Sayyadi, and Provitera (2024) introduced the Data Quality Funnel Model, emphasizing data accuracy and reliability to support AI-driven business strategies.
Thus, Figure 1 presents the integrated conceptual framework developed by this study.

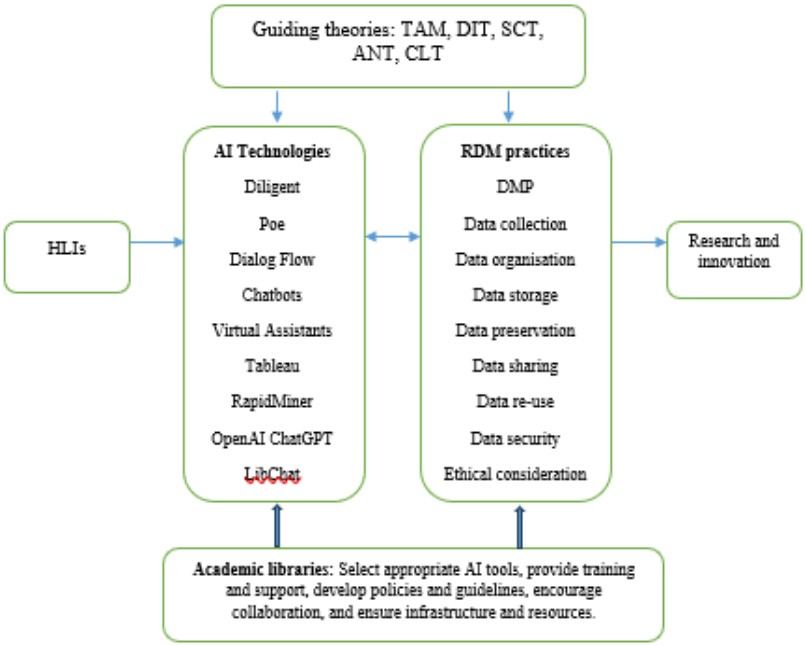

Fig. 1: An Integrated Conceptual Framework: AI Technologies and RDM Services in Academic Libraries

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Academic libraries have evolved into critical players in the research ecosystem, particularly in the context of RDM services that include various activities requiring researchers to comply (Filson & Atuase, 2024). With the increasing complexity of RDM services and the rise of AI technologies, libraries are uniquely positioned to support researchers in HLIs in effectively managing their data research (Williamson et al., 2023). However, HLIs should provide requirements and support to enhance the utilization of AI technologies to support RDM services (Buhomoli & Onyancha, 2025). Therefore, the developed integrated conceptual framework provides the concepts that could be implemented in these HLIs through their libraries.

The Impact of AI on Enhancing RDM Services in Academic Libraries

AI is revolutionising RDM services, significantly enhancing library services and the overall research experiences (Buhomoli & Onyancha, 2025). Researchers engage in various activities to improve their work, and with the advent of AI technologies, many of these tasks can now be performed more efficiently as these tools take over certain human functions (Filson & Atuase, 2024). According to Xu et al. (2021), AI simulates human intelligence through systems or machines, aiming to develop machines that can think and behave like humans, perceiving, reasoning, learning, planning, and predicting. AI tools can automate the organisation and management of research data, simplifying the processes of storing, retrieving, and sharing data effectively (Khalifa & Albadawy, 2024). Additionally, tools like ChatGPT support thesis and dissertation writing, helping researchers present data-driven arguments and logical reasoning (Khalifa & Albadawy, 2024).

Academic writing serves diverse purposes across fields; scientists use it to communicate research findings, while literary analysts develop evidence-based critiques (Bailey, 2025). Gupta et al. (2022) emphasize that academic texts must maintain high standards of accuracy, evidence, and logical structure. AI tools facilitate automatic metadata generation, enhancing the discoverability and usability of research datasets (Roman et al., 2023). AI technologies also improve user support. Chatbots and virtual assistants provide instant assistance, answering queries about library resources, research methodologies, and RDM practices (Oyetola et al., 2023). Furthermore, AI algorithms analyse user behaviour to recommend relevant resources, articles, and datasets tailored to individual research needs (Alowais et al., 2023; Malik et al., 2023). Thus, in research settings, AI facilitates data analysis and visualisation. Predictive analytics tools analyse large datasets to identify trends and patterns, enabling researchers to make data-driven decisions (Adesina et al., 2024; Alowais et al., 2023). AI enhances data visualisation tools, allowing researchers to create interactive and dynamic representations of complex data (Devineni, 2024). These technologies also assist in conducting literature reviews by quickly identifying relevant articles and summarizing key findings, thus improving the efficiency and accuracy of this fundamental research process (Molopa & Cronje, 2024).

Moreover, AI supports academic integrity by detecting potential plagiarism in research papers and proposals (Khalifa & Albadawy, 2024; Perkins, 2023). It also fosters collaboration and networking among researchers globally by analysing research profiles and facilitating connections between researchers, institutions, and industry partners (Jarrahi et al., 2023). Broekhuizen et al. (2023) note that AI can recommend potential collaborators based on shared research interests and expertise. However, the application of AI in academic settings requires adherence to ethical standards. Zondi et al. (2024) emphasize that AI tools can assist academic libraries in ensuring compliance with ethical requirements regarding data management and privacy.

The Role of Academic Libraries in Supporting AI Technologies and RDM Services in HLIs

Academic libraries are crucial in supporting researchers within HLIs as they navigate the complexities of RDM services (Boté-Vericad & Healy, 2022). As the number of researchers increases, so does the volume of data they generate, highlighting the need for effective RDM strategies and the application of

modern technologies, including AI (Dumbach et al., 2024). Academic libraries are uniquely positioned to address these challenges through the integration of AI technologies and enhanced RDM services (Healy, 2022). Thus, to facilitate RDM services, academic libraries provide essential technological resources and support for organizing and retrieving data efficiently (Dumbach et al., 2024). By integrating AI tools, these libraries can automate processes such as metadata generation and data categorization (Nehra & Bansode, 2024). This automation makes it easier for researchers to comply with data management standards, improving the accuracy and reliability of their research outputs while saving valuable time (Mosha, 2025). To maximise the benefits of AI technologies, academic libraries can offer training sessions and workshops that focus on data management best practices (Enakrire & Oladokun, 2024; Mosha, 2025). These initiatives empower researchers to utilise AI tools effectively, enhancing their ability to manage and analyse research data (Dumbach et al., 2024). Additionally, libraries can provide access to specialised software for data visualisation and analysis, further supporting researchers in their work. Academic libraries also serve as collaborative hubs, fostering connections among researchers across disciplines. By leveraging AI technologies, libraries can analyse research profiles to identify potential collaborators, facilitating interdisciplinary partnerships (Okunlaya, Syed Abdullah & Alias, 2022). Such collaborations are essential for addressing complex research questions and advancing knowledge in various fields (Mosha, 2025).

Maintaining academic integrity is another fundamental responsibility of academic libraries (Filson & Atuase, 2024). They play a pivotal role in educating researchers about ethical data management practices and the importance of proper citation (Filson & Atuase, 2024). Thus, AI technologies can assist these libraries in detecting potential plagiarism, ensuring that researchers adhere to ethical standards in their work (Mosha, 2025). In this regard, academic libraries are vital in supporting AI technologies and enhancing RDM services within HLIs (Dumbach et al., 2024). By providing resources, training, and collaborative opportunities, these libraries empower researchers to manage their data effectively and uphold academic integrity. As the research landscape continues to evolve, the proactive involvement of academic libraries will be essential for meeting the needs of researchers and advancing the mission of HLIs.

Conclusion

Academic libraries are essential in supporting researchers within HLIs by enhancing RDM services through the integration of AI technologies. As the volume and complexity of research data continue to increase, these libraries offer crucial resources and expertise that enable researchers to effectively navigate these challenges. This study utilised several theories to explain how academic libraries can enhance RDM services through AI integration. These theories contributed to the development of an integrated conceptual framework that guides the study, providing insights into improving RDM in academic libraries and the role of AI in HLIs. As the research landscape evolves, the proactive involvement of academic libraries will be vital in addressing the diverse and changing needs of researchers. Their commitment to innovation, support, and collaboration will not only facilitate successful research outcomes but also significantly advance knowledge across various disciplines within HLIs. In this way, academic libraries will remain invaluable partners in enhancing RDM services by leveraging emerging technologies, including AI.

Limitations

The study utilised an integrated framework to enhance the application of RDM services, focusing on the role of AI in academic libraries. However, the theories employed to guide the study may not capture all relevant perspectives on RDM and AI integration, which limits the comprehensiveness of the framework. Additionally, the study did not involve stakeholders such as IT staff, researchers, librarians, administration, and/or external partners who are crucial to RDM and AI implementation in academic

libraries. Their insights could provide a more holistic understanding of the challenges and opportunities present. While the emphasis was placed on AI technologies, the study may not have adequately addressed other emerging technologies that could also significantly enhance RDM services.

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