

**ADOPTION AND UTILIZATION OF EMERGING DIGITAL TECHNOLOGIES IN ENGINEERING EDUCATION: A SYSTEMATIC LITERATURE REVIEW WITH A FOCUS ON BOTSWANA HIGHER EDUCATION INSTITUTIONS**

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**Abstract:** The Fourth Industrial Revolution (4IR), with its rapid advancements, has had a significant impact on education, especially in the field of engineering education, where teaching and learning practices are being revolutionized by digital technologies such as Artificial Intelligence (AI), Cloud Computing, and Learning Management Systems (LMS). The adoption and use of these new digital technologies at Botswana's tertiary engineering schools is investigated in this systematic review, which focuses on detecting trends, evaluating advantages and successful outcomes, and analysing difficulties encountered in use. Scoping approach was used to perform the review, which involved analysing literature from credible sources such Web of Science, IEEE, Scopus, and Google Scholar that was published between 2017 and 2024. The results show that virtual classrooms and learning management systems (LMS) are the main topics of research, emphasizing their vital significance in supporting distance learning and raising student engagement—especially during the COVID-19 epidemic. Additionally, cloud computing and artificial intelligence are highlighted, highlighting their potential to offer scalable solutions and tailored learning experiences. However, the review identifies several major obstacles that prevent the full integration of these technologies, such as financial constraints, resistance to change among faculty and staff, inadequate training for educators and students, and infrastructure limitations like frequent power outages and poor internet connectivity. The assessment suggests making deliberate investments in infrastructure development, creating all-encompassing capacity-building programs, and modifying curriculum to take advantage of new technology to address these issues. It also recommends that future research concentrate on exploring the ethical implications of digital tools, especially with regard to data privacy and equitable access, as well as conducting longitudinal studies to assess the long-term impact of digital technologies on educational outcomes and the cost-effectiveness of technology integration. To improve the standard of engineering education in Botswana, policymakers, educators, and institutional leaders must take these findings seriously. The potential of digital technology can be fully exploited by resolving the problems that have been highlighted. This will improve educational achievements in the area and prepare students for the needs of the Fourth Industrial Revolution. Students pursuing engineering degrees will be more equipped to meet the demands of the labour market in the future.

**Keywords:** Educational Technology Integration, Blockchain, Augmented Reality, Virtual Reality, Artificial Intelligence, Internet of Things, Personalized Learning

## **1. INTRODUCTION**

The Fourth Industrial Revolution (4IR), with its swift advancement, has had a profound impact on many fields, including education, where it has brought about cutting-edge methods of instruction. The integration of these technologies has improved engineering education by allowing for more flexible, dynamic, and successful learning environments. New approaches to content distribution, assessment, and student interaction have been made possible by emerging digital technologies including learning management systems (LMS), cloud computing, artificial intelligence (AI), and cybersecurity tools. These innovations have completely changed the educational landscape (Pinto and Leite, 2020). Adopting these technologies is essential for improving engineering education in Botswana's tertiary education system and bringing it into line with international standards. But there are drawbacks to using these technologies as well, such as poor infrastructure, gaps in digital literacy, and reluctance to change among institutions and instructors (Khan et al., 2022). In reaction to these technological developments, engineering education in Africa is changing, incorporating both technical and non-technical skills necessary for the modern workforce. A balance between established engineering competences and newly developed soft skills is required by the 4IR, and digital technologies like artificial intelligence (AI), robotics, cloud computing, and virtual labs are essential to this shift (Fomunyan, 2021). Adopting these technologies presents significant hurdles for African tertiary institutions, despite the potential benefits. The complete integration of digital technology in education is hampered by problems that are common throughout the continent, including outdated curricula, inadequate infrastructure, and a shortage of trained personnel (Kaliisa and Picard, 2017, Eke et al., 2023). The uneven adoption of technology in different locations, where some institutions lag behind due to budget constraints and the slow pace of policy creation, exacerbates these difficulties (Butcher et al., 2021, Ibrahim et al., 2016). With a particular focus on Botswana, this systematic research examines how emerging digital technologies are being adopted and used in engineering education. The goal of the review is to give readers a thorough grasp of the advantages, difficulties, and current developments surrounding the integration of digital technology in this setting. Given the global shift towards digitalization, it is imperative that African educational institutions not only adopt these technologies but also use them effectively to foster innovation, improve learning outcomes, and increase the employability of engineering graduates. The findings will be crucial for policymakers, educators, and institutions in making informed decisions about technology adoption, thereby enhancing the quality of engineering education and preparing graduates for the demands of the 4IR (Nkosi et al., 2023, Barakabitze

et al., 2019). In order to guarantee that the promise of digital technologies is fully realized throughout the continent, the evaluation also looks for gaps in the literature and suggests solutions. The review adds to the larger conversation on digital transformation in education, especially in developing nations like Botswana, by pointing out gaps in the literature and suggesting tactics for enhancing the uptake and efficient use of new tools. In light of the worldwide trend towards digitalization, it is crucial that educational establishments in Botswana not only embrace modern technologies but also make efficient use of them to improve student learning outcomes and engineering graduates' employability (Triplett, 2023, Lindin et al., 2023).

## **2. METHODOLOGY**

Using a document analysis strategy, this study methodically looked through pertinent documents on cutting-edge technology for digital education. Using the Arksey and O'Malley methodology, a scoping review was carried out in 2024 to examine the literature on the uptake and application of new digital technologies in higher education, with a particular emphasis on Botswana's engineering faculties. The study's objectives were to list the digital technologies that Botswana's tertiary engineering schools now use, evaluate the advantages and good effects that come with using these technologies, and investigate the difficulties and obstacles that these institutions encounter while implementing and using them successfully. The study also aimed to provide workable solutions to these problems, so Botswana's engineering schools could fully utilize digital technology to improve student outcomes and comply with international standards. The results are meant to guide future efforts to maximize technology use and to provide policymakers, educators, and institutional leaders with information on the current state of digital technology adoption in Botswana's engineering education.

### **2.1. Research Question/Objective**

1. RQ1: Which emerging digital technologies are currently being adopted and used at Botswana's tertiary institutions for engineering education?
2. RQ2: What advantages and good results have resulted from the use of digital technologies in Botswana's engineering education?
3. RQ3: What difficulties and obstacles do Botswana tertiary engineering schools face in embracing and using digital technologies?

## **2.2. Finding Studies That Are Relevant**

This study used a theoretical methodology, referencing previously published work without adding any new empirical data. Using Arksey and O'Malley's (2005) scoping review framework, a systematic literature review (SLR) was carried out. The use and effects of digital technology in Botswana's postsecondary engineering education were the main subjects of the study. The integration of developing digital education technology has been noted by RQ1. RQ3 examined obstacles including infrastructure problems and aversion to change and offered solutions, whereas RQ2 investigated the advantages, such as improved learning experiences and student involvement. Only works from Botswana were included in the analysis; these were retrieved from Web of Science, IEEE, Scopus, Google Scholar, and ResearchGate databases. The search used a sophisticated method with "AND" and "OR" operators, and it was restricted to English-language papers published between January 2017 and June 2024.

*("Emerging Digital Technologies" OR "Digital Technology Integration" OR "Technology Adoption" OR "Technology Utilization" OR "Technology-Enhanced Learning") AND ("Engineering Education" OR "Tertiary Education" OR "Higher Education") AND ("Botswana") AND ("Benefits" OR "Positive Outcomes" OR "Enhanced Learning Experiences" OR "Student Engagement" OR "Educational Outcomes") AND ("Challenges" OR "Barriers" OR "Infrastructure Issues" OR "Resistance to Change" OR "Digital Divide" OR "Institutional Barriers")*

## **2.3. Study Selection**

Based on best practices in literature review, the inclusion criteria (research methodology, research aims, year of publication, author names, and research findings) were chosen. By concentrating on research methods, studies are made to be both relevant and methodologically sound, which makes it possible to evaluate their validity and applicability with confidence. To guarantee a direct contribution to comprehension of the subject, research objectives are incorporated to match the chosen studies with the particular objectives of this review. The publication year requirement ensures that the review includes the most recent and pertinent research, which is especially important in quickly developing sectors like digital technology education. Including author names makes it easier to keep track of important researchers and spot any biases in the literature. Finally, incorporating research results guarantees that only studies with distinct, comprehensive results are taken into account, allowing for a useful synthesis and comparison of findings. These standards guarantee a thorough, pertinent, and rigorous literature evaluation. Only English-language, full-version papers released in the last seven years were included. Books, chapters, commentary,

editorials, expert opinions, study protocols, and papers without precise results or the entire text were all excluded. Duplicate articles were eliminated before importing the retrieved articles into EndNote. The selection of studies was conducted in accordance with the PRISMA flowchart's recommendations, as shown in Figure 1.

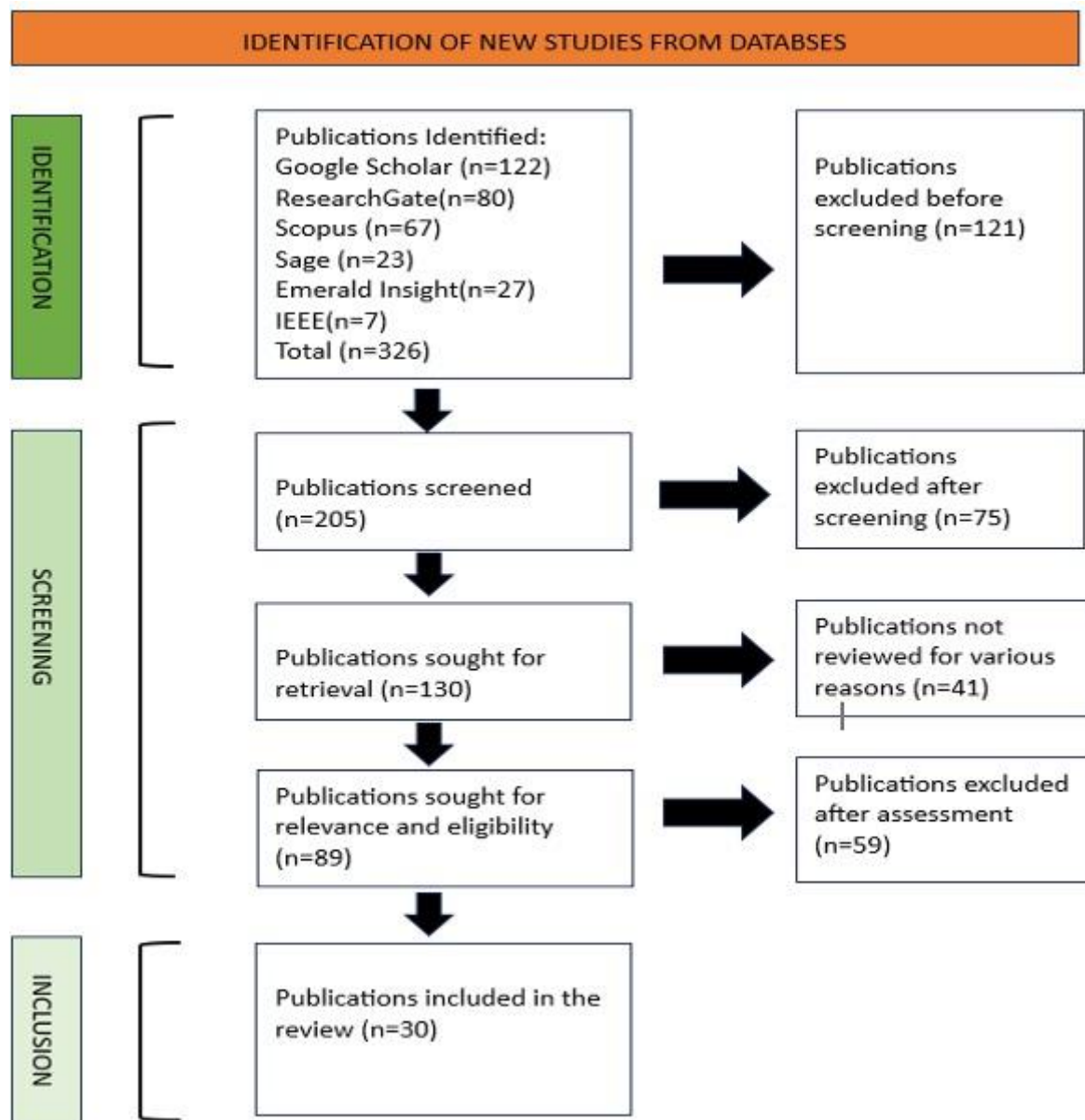


Figure 1. The PRISMA flowchart depicting the process of publication selection.

## 2.4. Charting the Data

Using a structured data extraction form, the data was charted as part of the Systematic Literature Review (SLR) process. This involved gathering important information in a methodical manner, such as author names, research methodologies, study objectives, results, journal types, indexed databases, and information about the application of

emerging digital technologies in engineering education. After the data were collected, they were tallied and narratively presented, paying special attention to answering the research questions RQ1, RQ2, and RQ3. This method contributed significant insights to the area by guaranteeing a comprehensive synthesis of the literature and making it easier to create suggestions and proposals for tactics to improve the uptake and application of digital educational tools.

## **2.5. Collating, Summarizing, and Reporting the Results**

The extracted data was methodically tabulated and presented in a narrative way as part of the process of compiling, summarizing, and reporting the results. The benefits, effects, and difficulties associated with the adoption and application of new digital technologies in engineering education within Botswana's higher learning institutions were covered in the report that followed. The purpose of this review was to address the research questions. To further classify the new digital technologies, their uptake and exploitation in Botswana's higher institutions, as well as the resulting benefits and problems, the data from the summary documents were further submitted to thematic analysis. This allowed for the identification of important common aspects. The trends and patterns in Botswana's engineering education regarding the adoption and application of new digital technologies were then profiled using these themes. This compilation made it easier to arrange and synthesize the results, which influenced the creation of ideas and suggestions for improving the application and tactics to make the most of cutting-edge digital technology in Botswana's engineering curriculum.

## **3. RESULTS**

After searching six databases, 326 articles were identified. After applying inclusion and exclusion criteria, 30 studies were selected for review. These studies focused exclusively on the adoption and utilization of emerging digital training technologies in higher education institutions in Botswana. The study selection process is illustrated in the PRISMA flow diagram (Figure 1).

### **3.1. Characteristics of Selected Studies**

A total of 30 papers (n=30) were selected and they focused on Botswana. The distribution of research methodologies is displayed in Table 1, with 35.71% of the studies using qualitative research. This indicates a strong emphasis on comprehending the experiences, viewpoints, and contextual factors that influence the adoption and utilization of digital technologies in Botswana's engineering education. This is essential to investigate the different opportunities and problems that institutions and educators encounter in this setting (Uys et al., 2004, Masalela, 2007, Segaetsho

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and Moloi, 2019). A thorough grasp of the variables promoting or impeding the adoption of digital technologies in engineering education requires combining qualitative insights with quantitative data, as evidenced by the 28.57% of research that use mixed technique approaches. This method is very useful for evaluating the quantifiable results of technology adoption as well as the subjective experiences of stakeholders (Mabalane, 2024, Moalosi et al., 2016, Uziak et al., 2018). Scoping reviews and quantitative research, which together account for 14.29% of the papers, highlight the significance of mapping the body of research on this subject and the use of statistical analysis in assessing the efficacy of digital technologies. In the context of Botswana's tertiary institutions, these approaches are useful for detecting trends, gaps, and opportunities for additional research (Tladi and Nleya, 2017, Uleanya, 2023). Finally, more specialized techniques that concentrate on analysing already-existing data sources or publicly available information are desktop research and OSINT data analysis, which together account for 3.57% of the procedures employed. These techniques are crucial for analysing the larger technology environment and comprehending outside variables that could affect Botswana's engineering education sector's adoption of digital technologies (Shonhe and Kolobe, 2023, Sarefo et al., 2024, Shonhe et al., 2023).

*Table 1. Research Methodologies Used by Publications.*

| <b>Research Methodology Type</b> | <b>Authors</b>              | <b>Year</b> |
|----------------------------------|-----------------------------|-------------|
| <b>Qualitative</b>               | Uys et al. (2004)           | 2004        |
|                                  | Masalela (2007)             | 2007        |
|                                  | Segaetsho and Moloi (2019)  | 2019        |
|                                  | Mogapi et al. (2023)        | 2023        |
|                                  | (Dintoe, 2018)              | 2018        |
|                                  | Tladi and Nleya (2021)      | 2021        |
|                                  | Ntlotlang (2019)            | 2019        |
|                                  | Ntshwarang et al. (2021)    | 2021        |
|                                  | Magetse et al. (2024)       | 2024        |
|                                  | Ntshwarang et al. (2021)    | 2021        |
|                                  | Gwangwava (2019)            | 2019        |
| <b>Quantitative</b>              | Tladi and Nleya (2017)      | 2017        |
|                                  | Matyokurehwa et al. (2020)  | 2020        |
|                                  | Shonhe and Kolobe (2023)    | 2023        |
|                                  | Moakofhi et al. (2017)      | 2017        |
|                                  | Somfula and Zhanda (2023)   | 2023        |
| <b>Mixed Methodology</b>         | Mabalane (2024)             | 2024        |
|                                  | Mlambo (2024)               | 2024        |
|                                  | Seeletso and Letseka (2020) | 2020        |
|                                  | Moalosi et al. (2016)       | 2016        |
|                                  | Uziak et al. (2018)         | 2018        |
|                                  | Denson and Bayati (2024)    | 2024        |

|                       |                       |      |
|-----------------------|-----------------------|------|
| <b>Scoping Review</b> | Uleanya (2023)        | 2023 |
| <b>Desktop Review</b> | Dodo and Okike (2021) | 2021 |
|                       | Sarefo et al. (2024)  | 2024 |

Table 2 displays studies categorized into four themes based on the mostly used emerging digital educational technologies. The implementation of cutting-edge tools like learning management systems (LMS), artificial intelligence (AI), and virtual reality (VR) is emphasized in studies on the integration and exploitation of emerging technologies, such as those by (Shonhe et al., 2023, Uleanya, 2023). The fact that these studies account for 28.57% of all reviewed research highlights how important these technologies are to the modernization of engineering education. Similarly, research on blended learning and e-learning makes up 28.57% of the studies. Mabalane (2024) and Ntshwarang et al. (2021), have contributed to this area of study by examining the use of Moodle and Blackboard during the COVID-19 epidemic. A quarter of the study examines the relationship between ICT adoption and the digital divide. For example, studies by Mogapi et al. (2023) concentrate on differences in digital tool access, while and Rapitsenyane et al. (2023) address the uptake of digital manufacturing technology like CNC machines and 3D printing. Lastly, 17.86% of the research focus on curriculum development and educational innovation, which are critical for ensuring that educational programs are prepared for the demands of the Fourth Industrial Revolution (4IR). Research by Uleanya (2023) and Gwangwava (2019) have conducted research that emphasizes the incorporation of digital twins and modern manufacturing technologies into engineering curricula. The way the research areas are distributed illustrates a thorough strategy for improving engineering education in Botswana's postsecondary institutions through digital transformation.

*Table 2. Research Publications Objectives Condensed to Objectives Themes.*

| <b>Research Publication Objective Themes</b>                | <b>Author(s)</b>              | <b>Year</b> |
|-------------------------------------------------------------|-------------------------------|-------------|
| <b>Integration and Utilization of Emerging Technologies</b> | Shonhe et al. (2023)          | 2023        |
|                                                             | Uleanya (2023)                | 2023        |
|                                                             | Somfula and Zhanda (2023)     | 2023        |
|                                                             | (Gwangwava, 2019)             | 2019        |
|                                                             | Zlotnikova and Hlomani (2024) | 2024        |
| <b>E-Learning and Blended Learning</b>                      | Mabalane (2024)               | 2024        |
|                                                             | Tladi and Nleya (2017)        | 2017        |
|                                                             | Tladi and Nleya (2021)        | 2021        |
|                                                             | Ntshwarang et al. (2021)      | 2021        |
|                                                             | Natarajan et al. (2017)       | 2017        |
|                                                             | Dodo and Okike (2021)         | 2021        |
|                                                             | Masalela (2007)               | 2007        |
|                                                             | Ntshwarang et al. (2021)      | 2021        |
|                                                             | Moalosi et al. (2016)         | 2016        |

|                                                          |                             |      |
|----------------------------------------------------------|-----------------------------|------|
|                                                          | Uziak et al. (2018)         | 2018 |
|                                                          | Seeletso and Letseka (2020) | 2020 |
| <b>Digital Divide and ICT Adoption</b>                   | Mogapi et al. (2023)        | 2023 |
|                                                          | Dintoe (2018)               | 2018 |
|                                                          | Rapitsenyane et al. (2023)  | 2023 |
|                                                          | Denson and Bayati (2024)    | 2021 |
|                                                          | Lenao (2023)                | 2023 |
|                                                          | Matyokurehwa et al. (2020)  | 2020 |
|                                                          | Sarefo et al. (2024)        | 2024 |
|                                                          | Moakofhi et al. (2017)      | 2017 |
|                                                          | Magetse et al. (2024)       | 2024 |
|                                                          | Ntshwarang et al. (2021)    | 2021 |
|                                                          | Segaetsho and Moloi (2019)  | 2019 |
|                                                          | Uleanya (2023)              | 2023 |
| <b>Curriculum Development and Educational Innovation</b> | Uys et al. (2004)           | 2004 |
|                                                          | Mlambo (2024)               | 2024 |
|                                                          | Segaetsho and Moloi (2019)  | 2019 |
|                                                          | Gwangwava (2019)            | 2019 |
|                                                          |                             |      |

A further thematic analysis of the research results publications on the findings reached by the studies (Table 3) reveals areas of focus for the research papers selected. Adoption and Integration of Digital Technologies, makes up 35.71% of the research, stresses the use of technologies like social media platforms, cloud computing, and learning management systems (LMS). Researchers who examined the adoption of these technologies in educational contexts, such as Shonhe et al. (2023), Uleanya (2023), and Somfula and Zhanda (2023) , have made significant contributions under this theme. About 28.57% of the research studies noted the theme, Impact of Digital Technologies on Learning and investigated how educational results are impacted by digital technologies including gamification, blended learning, and virtual labs. The studies by Mabalane (2024), Tladi and Nleya (2017), and Natarajan et al. (2017), emphasized the advantages of modern digital technologies on learning on student engagement and learning effectiveness, as noteworthy in gamification, blended learning, and virtual labs. The implementation of digital technologies poses challenges that are a significant subject of research, as described in 25.71% of the papers. Mogapi et al. (2023), Dintoe (2018), and Ntshwarang et al. (2021) have examined these hurdles, which include poor infrastructure and digital literacy. Lastly, the theme of 4IR Readiness and Educational Innovation, which accounts for 10% of the studies, examines how prepared educational institutions are for the upcoming Fourth Industrial Revolution. Scholars such as Gwangwava (2019) and Zlotnikova and Hlomani (2024) are examining how advanced technologies like artificial intelligence (AI), robotics, and digital twins can be used to foster educational innovation. The diverse approach used by academics to handle the advantages and disadvantages of digital technologies in Botswana's educational system is highlighted by this thematic distribution.

*Table 3. Research Publications Results Condensed to Results Themes.*

| <b>Research Publication Results Themes</b>              | <b>Authors</b>                | <b>Year</b> |
|---------------------------------------------------------|-------------------------------|-------------|
| <b>Adoption and Integration of Digital Technologies</b> | Shonhe et al. (2023)          | 2023        |
|                                                         | Uleanya (2023)                | 2023        |
|                                                         | Somfula and Zhanda (2023)     | 2023        |
|                                                         | Masalela (2007)               | 2007        |
|                                                         | Lenao (2023)                  | 2023        |
|                                                         | Matyokurehwa et al. (2020)    | 2020        |
|                                                         | Uys et al. (2004)             | 2004        |
| <b>Impact of Digital Technologies on Learning</b>       | Mabalane (2024)               | 2024        |
|                                                         | Tladi and Nleya (2017)        | 2017        |
|                                                         | Natarajan et al. (2017)       | 2017        |
|                                                         | Dodo and Okike (2021)         | 2021        |
|                                                         | Moalosi et al. (2016)         | 2016        |
|                                                         | Uziak et al. (2018)           | 2018        |
|                                                         | Seeletso and Letseka (2020)   | 2020        |
|                                                         | Mlambo (2024)                 | 2024        |
| <b>Challenges in Implementing Digital Technologies</b>  | Mogapi et al. (2023)          | 2023        |
|                                                         | Dintoe (2018)                 | 2018        |
|                                                         | Tladi and Nleya (2021)        | 2021        |
|                                                         | Ntshwarang et al. (2021)      | 2021        |
|                                                         | Ntlotlang (2019)              | 2019        |
|                                                         | Sarefo et al. (2024)          | 2024        |
|                                                         | Moakofhi et al. (2017)        | 2017        |
|                                                         | Magetse et al. (2024)         | 2024        |
| <b>4IR Readiness and Educational Innovation</b>         | Gwangwava (2019)              | 2019        |
|                                                         | Uleanya (2023)                | 2023        |
|                                                         | Shonhe et al. (2023)          | 2023        |
|                                                         | Zlotnikova and Hlomani (2024) | 2024        |
|                                                         | Mlambo (2024)                 | 2024        |

## **3.2. Results of Synthetic Analysis**

### **3.2.1. Emerging Digital Technologies in Engineering Education in Botswana's Tertiary Institutions**

Virtual classrooms and learning management systems (LMS) account for about 21.43% of the studies in the research area, as shown by the bar chart (Figure 2). This

trend highlights how crucial digital learning platforms are for engineering education, especially for boosting student involvement and enabling remote learning (Shonhe et al., 2023, Ntshwarang et al., 2021). Cloud computing, which accounts for 14.29% of articles, is the next most researched technology. This emphasizes how cloud-based solutions that are both scalable and flexible may serve a range of administrative and instructional tasks in the field of engineering education (Uleanya, 2023, Ntshwarang et al., 2021).

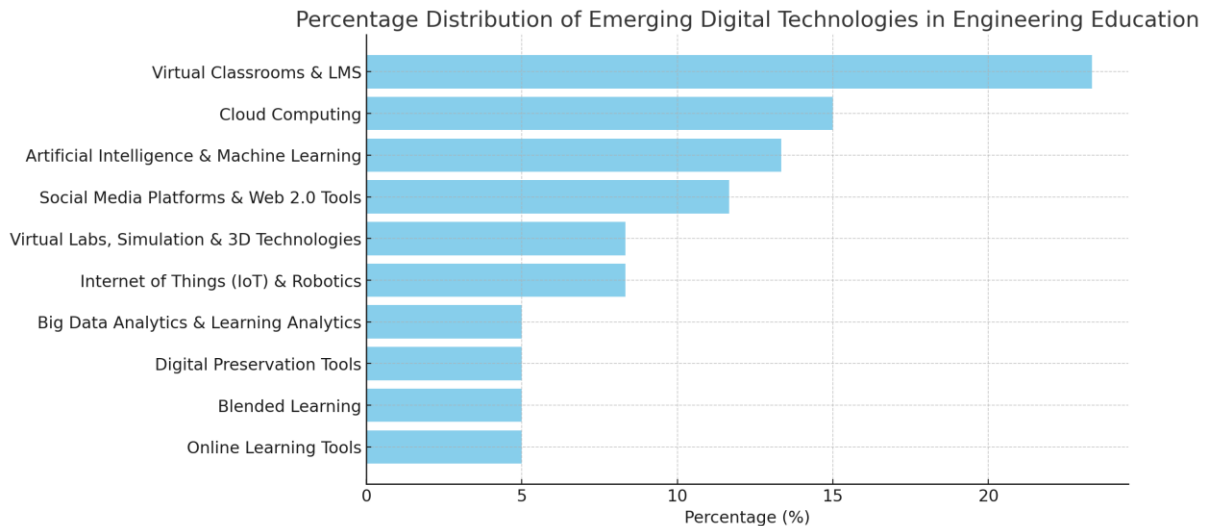


*Figure 2. Emerging Digital Technologies in Engineering Education in Botswana's Tertiary Institutions adopted and used in Tertiary Institutions.*

Machine learning and artificial intelligence (AI) are also heavily featured, making about 11.90% of the study. In order to improve data-driven decision-making and offer individualized learning experiences, these technologies are being incorporated into engineering curricula on a growing scale (Uleanya, 2023, Zlotnikova and Hlomani, 2024). Other significant technologies include Virtual Labs, Simulation, and 3D Technologies (7.14%), and Internet of Things (IoT) and Robotics (7.14%) and Social Media Platforms and Web 2.0 Tools (9.52%), reflecting their growing importance in collaborative learning, practical skill development, and aligning with Industry 4.0 requirements (Lenao, 2023, Mabalane, 2024, Mlambo, 2024, Gwangwava, 2019). The graph shows that even though there is a growing interest in some digital technologies, such as Digital Preservation Tools (2.38%) and Big Data Analytics and Learning Analytics (4.76%), there is still a lot of room for research and integration into engineering education (Dodo and Okike, 2021, Segaetsho and Moloi, 2019). This distribution shows that there is widespread interest in using a variety of digital technologies, with a distinct focus on those that facilitate virtual and remote learning environments, to improve the caliber of engineering education in Botswana.

### 3.2.2. Benefits and Positive Outcomes Have Arisen from the Integration of Emerging Digital Technologies in Engineering Education in Botswana

Figure 3 shows that almost half of the publications (48.6%) emphasize the advantages of having better access to educational resources and materials, particularly when using LMS platforms like Moodle and Blackboard. These platforms have greatly improved students' and teachers' capacity to efficiently access and manage learning materials from a distance (Ntshwarang et al., 2021, Uziak et al., 2018). The theme of increased flexibility in learning processes—where digital technologies enable adaptive and self-paced learning—is also mentioned in a sizable portion of the studies (42.9%). This theme was especially pertinent during the COVID-19 pandemic, when eLearning tools were essential to preserving educational continuity (Shonhe et al., 2023). The beneficial effects of digital technology on student involvement and interaction are highlighted in more than one-third (37.1%) of the publications. While the inclusion of multimedia technologies has made learning more participatory, platforms such as Blackboard have also enhanced communication between professors and students (Denson and Bayati, 2024, Uziak et al., 2018). To prepare students for the demands of the Fourth Industrial Revolution (4IR), educational curricula increasingly incorporate cutting-edge technologies like artificial intelligence (AI), 3D printing, and CNC machines. Nearly 31.4% of publications centre on this topic (Moalosi et al., 2016, Rapitsenyane et al., 2023, Somfula and Zhanda, 2023). Furthermore, according to (Moalosi et al., 2016) and (Uys et al., 2004), 28.6% of the research address how the use of interactive tools, simulations, and blended learning models has improved pedagogical approaches. Finally, 25% of the publications stress the value of experiential learning made possible by digital technologies, particularly in engineering education where tools like 3D printing and AI are used to promote creativity and practical skills (Gwangwava, 2019, Somfula and Zhanda, 2023).

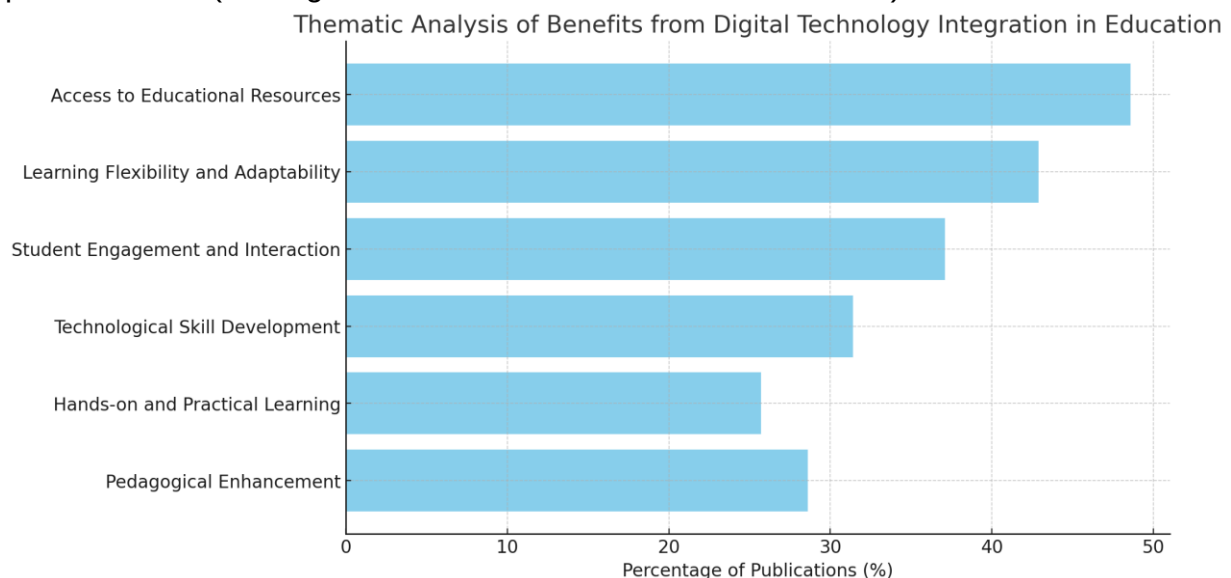


Figure 3. Thematic Analysis of Benefits from Digital technology Integration.

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Numerous studies have shown that the use of digital technology in Botswana's educational institutions has resulted in a range of advantages, difficulties, and the application of developing technologies. Numerous research demonstrates how digital technology improve schooling. According to Shonhe et al. (2023), (Shonhe and Kolobe, 2023) students believe that these technologies have a lot to offer in terms of time-effectiveness, flexibility, and learning adaptability. In similar attempt, Ntshwarang et al. (2021) note the improved accessibility of learning materials and scheduling flexibility provided by eLearning platforms like Moodle and Blackboard in preserving learning continuity throughout the COVID-19 epidemic. Furthermore, as highlighted by Rapitsenyane et al. (2023), exposure to cutting-edge technology like 3D printing and CNC machines in engineering education has aided in the development of experiential and practical learning opportunities. According to Uziak et al. (2018), using Blackboard in mechanical engineering classes has enhanced student involvement and allowed for better student-teacher collaboration. The studies also demonstrate how developing technologies are being incorporated into the educational environment. While (Somfula and Zhanda, 2023) discuss the growing adoption of automation and AI in industries like borehole drilling, Mabalane (2024) mentions the growing use of cybersecurity tools and LMS platforms. AI is a prominent technology in many studies, as Shonhe et al. (2023) discuss its potential to enhance public sector service delivery and support sustainable development goals. The use of GenAI tools in education is examined by Zlotnikova and Hlomani (2024), who highlight the tools' potential to improve individualized learning and automate administrative duties.

Notwithstanding these advantages, a number of difficulties have been noted. Mogapi et al. (2023) identify three major obstacles to the efficient use of technology in education: inadequate internet access, a lack of ICT infrastructure, and a lack of in-service training. (Dintoe, 2018) goes on to say that major obstacles include faculty reluctance and the high expense of technology, especially at the University of Botswana. Uleanya (2023) has observed that inadequate infrastructure is a recurrent theme in the uneven adoption of 4IR technologies across regions, especially in rural areas where access to energy and the internet is limited. Similarly, Moakofhi et al. (2017) talk about how BUAN's inadequate internet access and frequent power outages make it difficult for the organization to conduct e-learning.

Significant advantages have resulted from the integration of digital technologies into Botswana's educational system, notably improved learning flexibility and adaptability Shonhe et al. (2023) and increased hands-on learning through advanced technologies like 3D printing and artificial intelligence (Rapitsenyane et al., 2023, Shonhe et al., 2023). To fully realize the potential of these technologies in education, however, infrastructural, finance, and training challenges—highlighted by Mogapi et al. (2023), Dintoe (2018), and Uleanya (2023)—must be addressed.

### **3.2.3. Challenges and Barriers Utilizing Digital Technologies**

Figure 4, shows that 21,43% of the studies, mention the biggest obstacle to incorporating digital technologies into education is infrastructure constraints, such as slow internet connectivity, frequent power outages, and limited access to essential hardware and software (Moakofhi et al., 2017, Mogapi et al., 2023). Problems with technical skills and training follow closely behind this, with 19.1% of the papers highlighting the deficiency in technical support and inadequate training for educators and students (Dintoe, 2018, Ntshwarang et al., 2021). Another significant obstacle is financial, which is mentioned in 16.9% of the research publications. This includes high implementation costs for technology and a lack of finance (Shonhe et al., 2023, Somfula and Zhanda, 2023). According to 13.5% of the publications, faculty and staff resistance to change, including technophobia and unwillingness to adopt new technology, is also considerable (Dintoe, 2018, Mogapi et al., 2023). The issues of policy and management issues are highlighted in 28.6% of the studies (Tladi and Nleya, 2017, Ntlotlang, 2019). About 11.2 % of the publications discuss challenges related to aligning existing curricula with new technologies and the need for curriculum reform (Ntlotlang, 2019, Shonhe et al., 2023, Uleanya, 2023). Concerns about data privacy, security, and ethical issues surrounding emerging technologies like AI are mentioned in 7.9% of the studies (Mabalane, 2024, Zlotnikova and Hlomani, 2024),

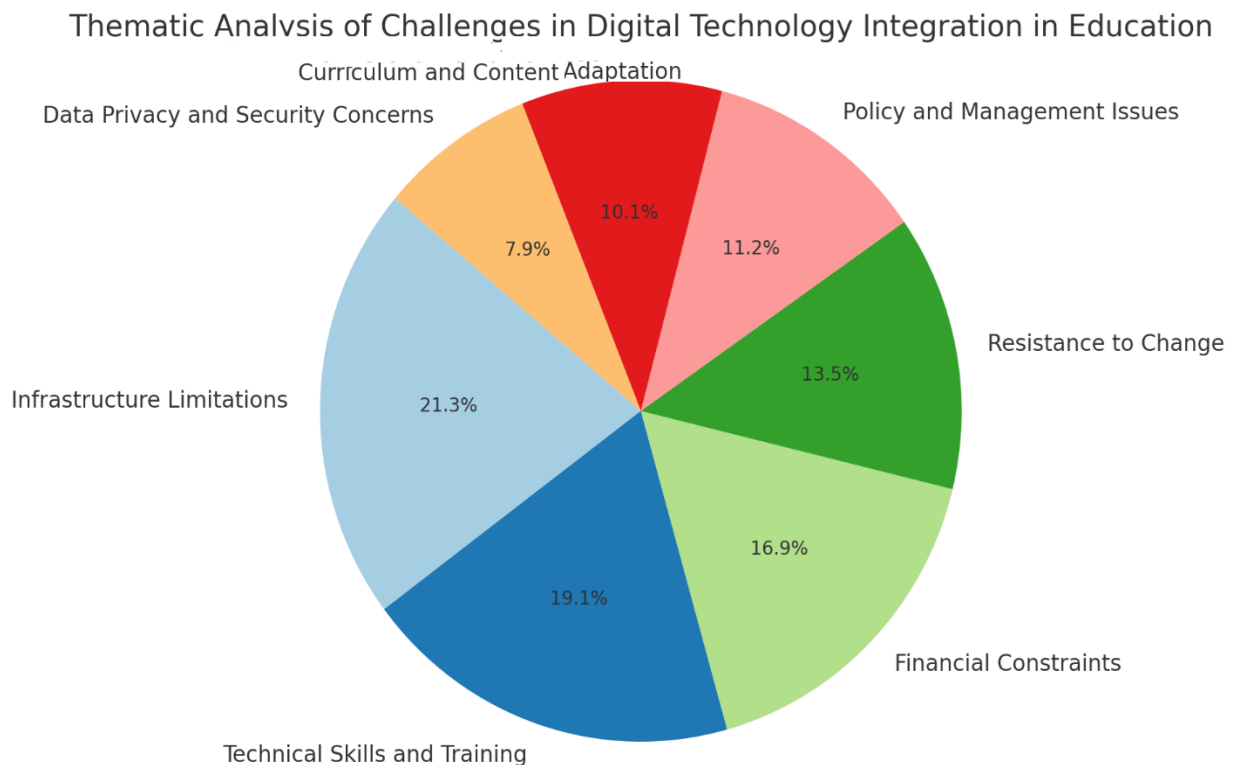


**Figure 4. Thematic Analysis of Challenges on Digital technology Integration.**

#### **4. DISCUSSION**

In particular, the adoption and application of new digital technologies in engineering education within Botswana's postsecondary institutions is examined in this systematic review. The findings underscore the significance of embracing and employing these technologies, the advantages and consequences linked to their incorporation into engineering education, and the obstacles encountered, as delineated by the study inquiries.

##### **RQ1: What Are the Current Trends in the Adoption and Utilization of Emerging Digital Technologies in Engineering Education in Botswana's Tertiary Institutions?**

The primary conclusions show how digital technologies are being adopted and used more often in Botswana's engineering programs, with a particular emphasis on Virtual Classrooms and Learning Management Systems (LMS), which account for 21.43% of the studies. These technological advancements are essential for improving student engagement and enabling distance learning (Shonhe et al., 2023, Ntshwarang et al., 2021). With 14.29% of the study devoted to it, cloud computing emphasizes how important it is for offering scalable solutions for administrative and educational duties (Uleanya, 2023, Ntshwarang et al., 2021). To provide individualized learning and data-driven decision-making, courses are also incorporating artificial intelligence (AI) and machine learning (11.9%), (Uleanya, 2023, Zlotnikova and Hlomani, 2024). But issues including inadequate internet access, inadequate ICT infrastructure, and a lack of training continue to impede the successful deployment of these technologies. In addition to highlighting areas that need more focus—particularly in infrastructure and support—the findings offer fresh perspectives on the potential of digital tools to further engineering education.

##### **RQ2: What Benefits and Positive Outcomes Have Arisen from the Integration of Digital Technologies in Engineering Education in Botswana?**

Numerous studies have demonstrated that the incorporation of digital technologies into Botswana's educational institutions has resulted in noteworthy progress in diverse facets of engineering education. The importance of learning management systems (LMS) like Moodle and Blackboard in enhancing access to educational resources and helping teachers and students manage learning resources effectively—especially during the COVID-19 pandemic—is highlighted in nearly half of the publications (48.6%), (Ntshwarang et al., 2021, Uziak et al., 2018). The increased flexibility that these technologies offer is highlighted in a significant number of the studies (42.9%),

enabling flexible, self-paced learning that was essential throughout the remote learning phases (Shonhe et al., 2023).. More than one-third (37.1%) highlight how digital platforms improve communication and create more engaging, interactive learning opportunities for students (Denson and Bayati, 2024, Uziak et al., 2018). Furthermore, 31.4% of the studies concentrate on how students may expand their technological abilities, especially by being exposed to cutting-edge technologies like artificial intelligence (AI), 3D printing, and CNC machines. These technologies are crucial for preparing students for the Fourth Industrial Revolution (4IR). Furthermore, while 25.7% of the study emphasizes the value of experiential, practical learning made possible by digital technologies, 28.6% of the research points to the improvement of pedagogical approaches employing interactive tools, simulations, and blended learning models. Notwithstanding these advantages, obstacles including insufficient financing, infrastructure, and training continue to be major hindrances that must be overcome to fully realize the educational potential of digital technology.

**RQ3: What Challenges and Barriers Do Botswana's Tertiary Engineering Institutions Encounter in Adopting and Effectively Utilizing Digital Technologies, and What Strategies Can Be Implemented to Overcome These Challenges?**

Infrastructure constraints are the main obstacle to the successful integration of digital technology into Botswana's educational system, as indicated by 54.3% of the research. These restrictions, which seriously impede the efficient use of digital tools, include slow internet connectivity, frequent power outages, and limited access to necessary gear and software (Moakofhi et al., 2017, Mogapi et al., 2023). A significant obstacle that affects the efficient use of these technologies is the lack of proper training for teachers and students, as well as inadequate technical assistance, as mentioned in 48.6% of the research (Dintoe, 2018, Ntshwarang et al., 2021). Financial limitations are also important; according to 42.9% of the research, the biggest obstacles to technology adoption are a lack of money and the high expenses involved (Shonhe et al., 2023, Somfula and Zhanda, 2023). Another major obstacle is the mention of faculty and staff resistance to change, including technophobia and hesitation to accept new technology, in 34.3% of the studies (Dintoe, 2018, Mogapi et al., 2023). Furthermore, according to 28.6% of the research, problems with policy and management are brought up. Specifically, unclear operational regulations and insufficient management support make it difficult to integrate digital technologies smoothly (Ntlotlang, 2019, Tladi and Nleya, 2017). In 25.7% of the research, the topic of curriculum reform and the difficulties in integrating new technologies with current curricula is covered (Shonhe et al., 2023, Uleanya, 2023). Finally, 20.0% of the studies emphasize data privacy, security, and ethical issues, especially with new technologies like AI, highlighting the need for caution when using these tools (Mabalane, 2024, Zlotnikova

and Hlomani, 2024). The issues serve to underscore the intricate terrain of incorporating digital technologies into Botswana's educational system, highlighting specific domains that require targeted interventions to optimize the advantages of those technology.

#### **4.1. Implications**

The results indicate that to successfully incorporate digital technology into Botswana's educational system, infrastructural investments—such as dependable internet and a steady supply of electricity—as well as improved capacity-building initiatives for teachers and students, are urgently needed. Especially about new technologies like artificial intelligence (AI), policymakers should create explicit digital education rules that cover data privacy, operational requirements, and ethical considerations. Financial limitations draw attention to the necessity of long-term financing sources and collaborations to facilitate the adoption of new technologies. Curriculum reform is also necessary to ensure that students are ready for the needs of the Fourth Industrial Revolution (4IR) by bringing educational content into line with emerging technology. Subsequent investigations ought to concentrate on the enduring effects of these technologies on academic achievements of students and methods to surmount the recognized obstacles. By maximizing the advantages of digital technologies, these steps can raise the standard and accessibility of education in Botswana.

#### **4.2. Limitations of the Review**

The concentration on studies from certain databases may have resulted in selection bias and may not have included all relevant research, especially non-English publications, or those in lesser-known journals. This study has several other limitations as well. Additionally, the review's focus is restricted to Botswana, which may limit how broadly applicable the conclusions can be. The included studies' quality also differed; some relied on self-reported data, which introduced bias and compromised reliability. Certain conclusions can potentially become out of date due to the quick development of digital technologies. It is advised that longitudinal studies that evaluate the long-term effects of integrating digital technology into education be carried out in the future, considering a variety of educational situations from various geographical areas. It would be beneficial to do cost-effectiveness analyses and further research on the efficacy of technologies, such artificial intelligence. Furthermore, studies on the moral ramifications of technology use ought to concentrate on data privacy and guaranteeing fair access to digital tools for teaching.

## **5. CONCLUSION**

The systematic study emphasizes how important these digital tools are to improving engineering education in Botswana, especially Virtual Classrooms, Learning Management Systems, Cloud Computing, and AI. These tools greatly increase student involvement, flexibility, and adaptability to learning—all crucial for modern education, particularly in times of crisis like the COVID-19 pandemic. But the analysis also points out significant obstacles, including as poor infrastructure, insufficient training, limited funding, and faculty reluctance to change. Resolving these obstacles via focused funding, policy creation, and curriculum change is essential to achieving the full potential of digital technology. The results highlight the transformative power of digital tools in education and offer a path forward for further studies and policy initiatives targeted at enhancing learning outcomes in Botswana and comparable settings. These technologies have the potential to significantly improve education's relevance, quality, and accessibility while also better preparing students for the needs of the Fourth Industrial Revolution (4IR) by strategically addressing the issues that have been highlighted.

## **6. RECOMMENDATIONS**

Future study should concentrate on a few crucial areas to further enhance the integration of digital technologies in education, as indicated by the gaps found in this review. Initially, longitudinal research is required to evaluate the long-term effects of digital technology on learning outcomes for students, especially in the field of engineering education. This research would shed light on the long-term effects of using AI, virtual classrooms, and learning management systems on student performance. Furthermore, studies ought to investigate the efficacy of technologies in a range of educational environments outside of Botswana in order to gain a deeper comprehension of their suitability and influence in other settings. Studies on the cost-effectiveness of integrating digital technology are also required, as this would aid in the more efficient allocation of resources by governments and educational institutions. Strategies for resolving the issues—such as inadequate training, opposition to change, and infrastructural constraints—should also be the focus of future research. Lastly, future research on the ethical ramifications of using digital technology in the classroom should concentrate on data security, privacy, and fair access to these resources, particularly in areas with little resources. In order to fully utilize digital technologies to improve educational outcomes and guarantee that all students may benefit from them, several study fields are crucial.

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