Internet of Things and Its Applications to Smart Campus: A Systematic Literature Review

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Abstract—A smart campus is an emerging trend that will revolutionize the education system by enabling universities to improve services, and processes as well as achieve sustainability goals. With the proliferation of advanced technologies, a smart campus has emerged as an important concept that integrates technology into higher education. A smart campus takes advantage of IoT technologies to facilitate teaching and research activities. The purpose of this study is to identify the IoT technologies that are required in the development of a smart campus. This study uses a Systematic Literature Review (SLR) methodology and PRISMA processes to analyze high-quality articles on the IoT-based smart campuses from the last five years (2017-2022) as extracted from three databases like Scopus, ScienceDirect, and IEEE. The findings of the study reveal that the implementation of an IoT-based smart campus offers many advantages and benefits but also presents challenges requiring further exploration. Because of the chosen research approach, the research results may lack generalizability. Therefore, researchers are encouraged to test the proposed propositions further. The paper explores the many benefits and advantages that are brought by the implementation of IoT-based smart campuses. It also identifies key challenges that are presented by such implementations. Researchers, policymakers, teachers, and students can benefit from this study by gaining insights into the IoT-based smart campus.

Keywords—smart campus, smart university, Internet of Things, IoT applications, big data

1 Introduction

With the proliferation of advanced technologies, a smart campus has emerged as an important concept that integrates technology into higher education. The arrival of the Internet of Things (IoT) has revolutionized the education industry [1] and increased competition among universities to improve quality in an attempt to become excellent

universities [2]. Moreover, the quality of the university is an important factor that students consider when choosing a university to pursue their education further. The availability of an array of devices and the reach of the Internet has made the IoT a perfect solution for building a smart campus as well as applications previously requiring human intervention. IoT is about collecting accurate raw data, analyzing it, and then converting it into information of value [2]. A smart campus takes advantage of IoT technologies to improve the performance of processes and activities [3]. In alignment, Liang and Chen [4] contend that a smart campus supports teaching, scientific exploration, and services through the use of IoT, cloud computing, and geographic information systems.

On the other hand, another new technology, artificial intelligence, has also brought a conceptual shift to the concept of a smart campus. It has transformed the education and teaching methods of the university to become more diverse and advanced [5] and identified seven areas of a smart campus including governance, environment, buildings, people, mobility, living, and economy [6]. Furthermore, a smart campus serves as a major gateway to information for university students. It strives to improve its technological infrastructure to provide quality education and improve user experience [7] by providing the university community with sophisticated and personalized information. Through this system, students gain access to an interactive learning platform with global content and can adapt their learning strategies according to the gathered data [8].

Through a smart campus, educational institutions can improve their sustainability performance and enhance research experiences through easy access to data and campus facilities [9]. Additionally, they can improve the operation and management of university buildings, including energy conservation and environmental sustainability [10]. Furthermore, the Covid-19 outbreak has placed tremendous pressure on educational institutions to take advantage of advanced technologies to revolutionize their teaching methods. The Internet of Things connects people, devices, processes, and data, enabling stakeholders in education to turn the data collected by sensors and portable devices into useful information [8]. Although technological advancements have enabled education to advance rapidly, the implementation of smart technologies is not without challenges that still require further exploration.

It is therefore within the objective of this study to determine which IoT applications are required to achieve a smart campus. Through a systematic literature review, this study aims to identify various applications providing answers to the formulated research questions:

- RQ1: What is the distribution of publications over the years?
- RQ2: What is the publication's geographic distribution?
- RQ3: Which research methodologies have been used?
- RQ4: Which technologies are required for a smart campus?
- RQ5: What are the advantages/benefits of deploying IoT in a smart campus?
- RQ6: What are the challenges experienced in deploying IoT in a smart campus?

2 The theoretical framework

2.1 Internet of Things

Things Internet of (IoT) is an innovation arising from current technological advancements. The term refers to a system of devices or things that interact with each other to collect, exchange and use data from the environment and the users [2] and integrates various technologies to deliver smart services to the users [10]. In simpler terms, IoT is a way of connecting devices and objects through a private network (intranet) or a public network (internet), so they are visible to each other and can communicate with each other [11]. Zhou et al. [12] stated that it has three characteristics: Comprehensive perception, reliable data transmission, and intelligent processing. IoT is the aggregation of connected devices, data analytics, and physical objects [13] and brought along desirable technological advances of Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), and 3D immersive learning [14]. There is a greater opportunity for these tools to revolutionize the teaching and learning processes, as they would allow students to engage in immersive learning that is a hugely effective elevating learning experience.

The use of IoT applications is essential in managing things efficiently and economically. It can support the process of improving campus quality of life by implementing a smart campus system [2]. As IoT-enabled services generate large amounts of data, they are useful for a multitude of applications and optimizing critical infrastructure as well as providing new insights and modern advancements [15]. The majority of this data will be sensitive, demanding unobtrusive treatment that will not compromise the freedom and privacy of the users. IoT can support key functions of university education, such as teaching, learning, research, innovation, and support functions. As a result, faculty and administration processes are integrated seamlessly and campus infrastructure is managed more efficiently, effectively, cost-effectively, and at a high standard of quality. Additionally, IoT supports the interactive learning of students by inspiring their innovation everywhere on campus [16].

2.2 Smart campus

A literature search has not provided a universal definition of a smart campus. However, many authors have provided various definitions in their studies. According to Anagnostopoulos et al. [15], smart campuses are popular solutions among universities willing to experiment intuitively with unknown situations and receptive to change management. This aligns with a definition presented by Zaballos et al. [17] that a smart campus facilitates efficiency and allows for miniature experimentation by leveraging technology. A smart campus is a small-scale version of a smart city with advanced capabilities that facilitate creativity, social interaction, and intellectual exploration [18] [19]. The similarities between a smart city and a smart campus anchor on many aspects: They cover large urban areas with many different buildings (administrative buildings, residential halls, research laboratories, lecture halls, bars, and cafés) and are inhibited by a variety of people including university staff and students [20]. Additionally, Chagnon-Lessard et al. [6] shared an organizational structure that encompasses seven

smart areas such as "smart building, smart economy, smart environment, smart governance, smart living, smart mobility, and smart people". This structure can expand to include information and communication infrastructure that enables the smartness of all these smart areas.

The construction of a smart campus uses IoT technologies to combine learning activities with supporting devices to achieve intelligent management of university services [21]. A smart campus is a vital platform for students to access all types of information. It strives to improve its technological infrastructure to provide quality education and improve the user experience [7] by providing the university community with sophisticated and personalized information. Additionally, it integrates learning and living environments, bringing many benefits to campus users [21]. Nevertheless, the IoT-powered smart campus is still in its infancy and has a long way to go before fulfilling all its potential. Most IoT implementations used the same technologies to achieve a smart campus [11] and these are Artificial Intelligence (AI), Big Data, Cloud Computing, and many other newer technologies [22-24] [7] [11] [3]. The application of these technologies is essential for building capacity at the university campus to improve processes and achieve sustainability. Cloud computing enables intelligent and secure management of information in a private cloud created within the university's existing infrastructure [25]. Big data analytics facilitates better data processing, analysis, and information sharing to enhance decision-making [9]. The processing of big data through artificial intelligence can contribute greatly to creating innovative learning solutions and delivering sophisticated solutions [18].

3 Methodology

3.1 Research design

Following the guidelines proposed by Kitchenham and Charters [26], a Systematic Literature Review (SLR) was carried out. This guideline suggests a strict predefined protocol that guides a researcher throughout the research process. This meticulous process identifies researchers' biases, flaws, and gaps in knowledge, as well as indicates the direction in which further research may be of benefit. Kitchenham and Charters [26] defined a systematic literature review as a means by which researchers "identify, evaluate and synthesize all available research relevant to a particular research question, topic area, or phenomenon of interest" (p. 3). Lamé [27] provided a summary of the steps involved in the development of a systematic literature review: (1) Structuring a clear question for review, (2) Definition of the inclusion and exclusion parameters, (3) Identification of relevant studies, (4) Selection of the studies to be included or excluded from the study, (5) Quality assessment of the studies, (6) Extraction of relevant data (7) Summarizing and synthesizing the evidence and (8) Interpretation of the results.

3.2 Search strategy

As shown in Figure 1, a systematic literature search was conducted in three databases: Scopus, ScienceDirect, and IEEE following the PRISMA flow. In this search, only English-language papers published in the last five years, between January 2017 and January 2022 were considered. The keywords and search operators used were ("Internet of Things" OR "IoT") AND ("smart campus" OR "smart university").

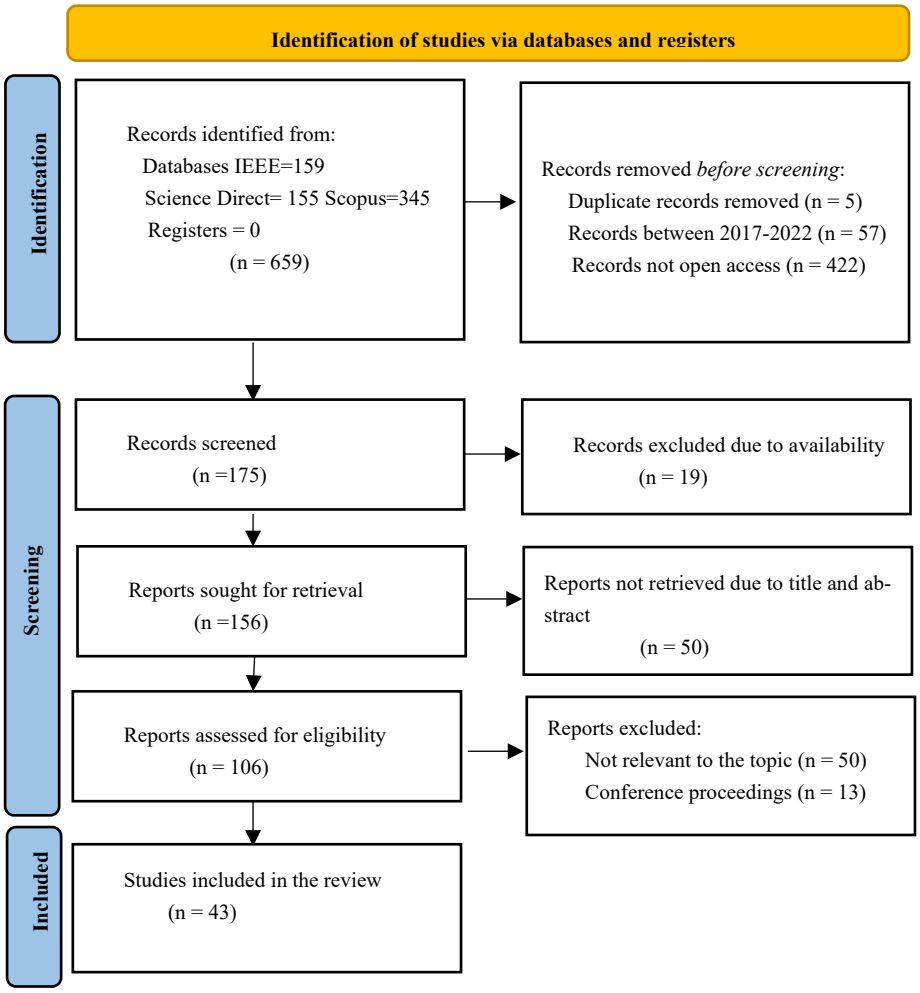

Fig. 1. PRISMA flow diagram of the study

3.3 Inclusion and exclusion criteria

To obtain relevant studies that fall within the scope of this study, the inclusion and exclusion criteria were considered during the study selection process [26]. To ensure a

rigorous selection process, inclusion criteria were clearly outlined; papers were to be published in English and fully accessible in the named databases, as indicated in Table 1. Published works that failed to meet these conditions were excluded.

Table 1. Inclusion and exclusion criteria of the study

No.	Inclusion Criterion
IC1	The English language articles.
IC2	Published articles between 2017 and 2022.
IC3	Articles focused on IoT and smart campuses.
IC4	Articles exploring the applications of IoT to a smart campus.
IC5	Articles are available in full text.
No.	**Exclusion Criterion**
EC1	Books, book reviews, editorial materials, conference proceedings, and theses.
EC2	Duplicated studies.
EC3	Full text of the article is not available for download.
EC4	Articles that are not relevant to the stated research question.
EC5	Articles lacking adequate detail to answer the research questions.

3.4 Selection criteria

The search on the databases yielded 659 records: ScienceDirect = 155; IEEE = 159; and Scopus = 345. Before the screening, the records were checked to be certain no duplicate records were obtained from the databases. Five duplicates were detected and removed. The research was limited to open access records, 422 records were eliminated. Records not published within 2017-2022 were also eliminated. A further 19 records were eliminated as the full text of the records was not available for retrieval. In implementing the inclusion and exclusion criteria, 156 articles were generated, of which 50 were eliminated, as they were unrelated to the topic. A further 63 articles were removed for not exactly fitting inclusion criteria or were outside the scope of the study. The remaining 43 articles were retained for further review and analysis in the results section. Table 1 itemizes the key items of the inclusion and exclusion criteria used in the study. It must be noted that even though a rigorous approach has been followed for selecting the studies that were reviewed, it is unreasonable to claim that all smart campus facets were fully covered. Furthermore, it is also possible that a search in other databases could have yielded additional studies in these categories (see Figure 1).

3.5 Data analysis

Using the retrieved articles that meet all the inclusion criteria, data is categorized as follows:1) Title; 2) Year of publication; 3) Objectives; 4) Geography; 5) Methodology; 6) Key findings; 7) Recommendations; 8) Technologies; 9) Challenges; 10) Benefits; 11) Advantages; 12) Citation.

3.6 Data analysis

To standardize the data extraction process, the data extraction stage [28] considered 43 studies and complied with a list of elements established specifically for this study.

Table 2. Data extraction from the selected studies

Data item	Description
Reference	Name(s) of the author(s) and year of publication
Geography	The country in which the research was undertaken
Study objectives	The main aims of the study
Methodology	The study approach
Findings	Key findings of the study
Technologies	Which are the IoT technologies implemented
IoT applications	Which are the IoT applications implemented
Challenges	The challenges that are encountered in the implementation of the technologies
Benefits	The benefits/advantages brought by the applications of the technologies
Recommendations	What are the recommended research areas for future works

4 Results

4.1 The distribution of publication by time frame

Figure 2 depicts the distribution of reviewed papers published from 2017 to 2022. There were no significant research studies related to this topic in 2017 and 2019. This is because the majority of studies focused on the implementation of smart campuses with sustainability and energy efficiency options [29]. There was a numerical increase in 2018, 2020, and 2021, reflecting an increased interest in this area. The decrease in the number of publications in 2022 is a function of time as the search includes only two months of that year.

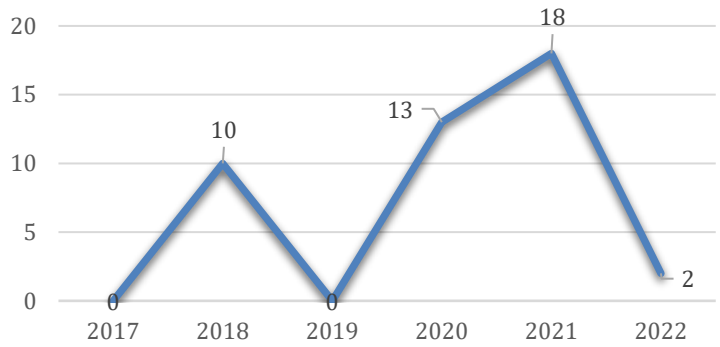

Fig. 2. The publications' distribution over the period 2017 – 2022

4.2 The geographical and demographic distribution of the studies

Figure 3 illustrates the distribution of the authors' countries per article. A significant number of authors are from Asia (n=29) followed by Europe (n=16) and South America (n=4). Asia and Europe combined, contributed 85% of all papers published. There is a great deal of research opportunity on the subject in North America and Africa, as each region published only 4% of the articles.

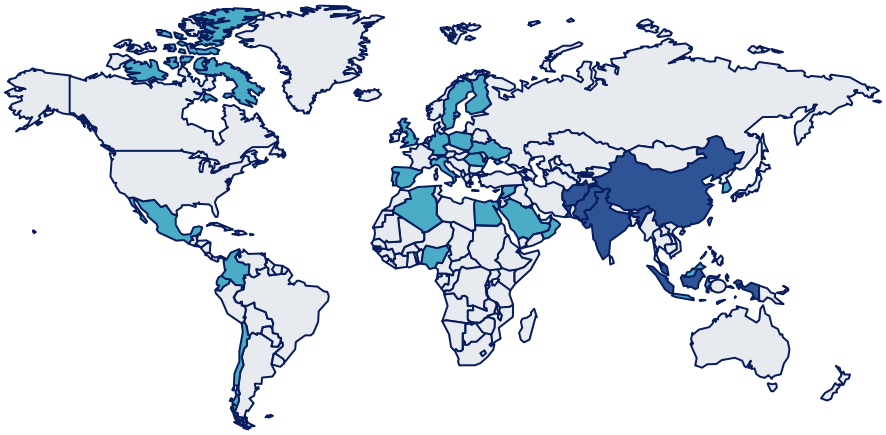

Fig. 3. Authorship geographical distribution of the selected studies

4.3 The research methodologies implemented

The distribution of methodologies in this study suggests that the IoT-based smart campus deployments have largely been conducted as experiments, opening up opportunities for real-world applications (see Figure 4). Moreover, most researchers have acknowledged that smart campuses are excellent testbeds for IoT implementation [29] [30].

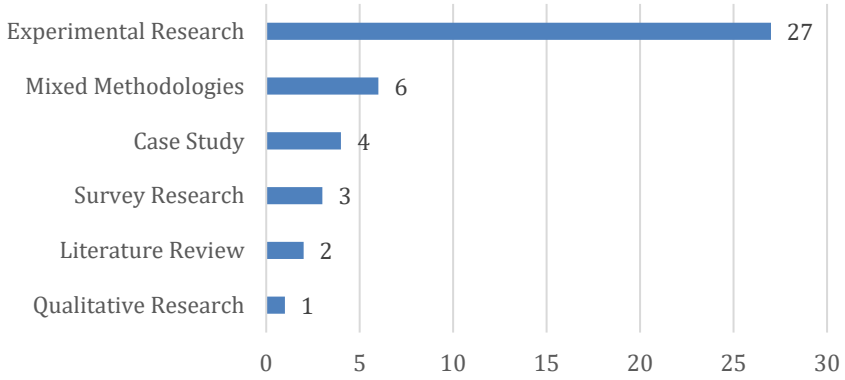

Fig. 4. The research methodologies implemented

4.4 The technologies required for the smart campus

A smart campus utilizes an IoT-enabled network infrastructure that synchronizes all data transmission and processing devices on a university campus (see Figure 5). IoT involves complexity and diversity and includes a variety of technologies [1]. Rico-Bautista [7] suggested four key smart technologies: Artificial Intelligence, Big Data, Cloud Computing, and the IoT.

- Artificial Intelligence enables machines to learn from experience and mimic human intelligence [23]. Using deep network technology, the authors developed a campus virtual assistant that is emotionally aware.
- Big Data Analytics has become instrumental in analyzing large and complex data sets that are used for the improvement of students' learning experiences [1].
- Cloud computing is among the main technologies that enable infrastructure, software, and platforms to operate together using common logic in a smart campus [22]. It is valuable in keeping the information in a central and safe place [7].
- Communication networks are applied to the smart campus to enable the transmission of information. The most common communication networks include Wi-Fi, 3G, and 4G/LTE [18]. On the other hand, Xu et al. [31] proposed an online teaching platform based on a 5G network to improve the learning experience. Furthermore, Jurva et al. [14] expected a 5G network together with IoT sensor networks and big data analytics to transform the education sector.

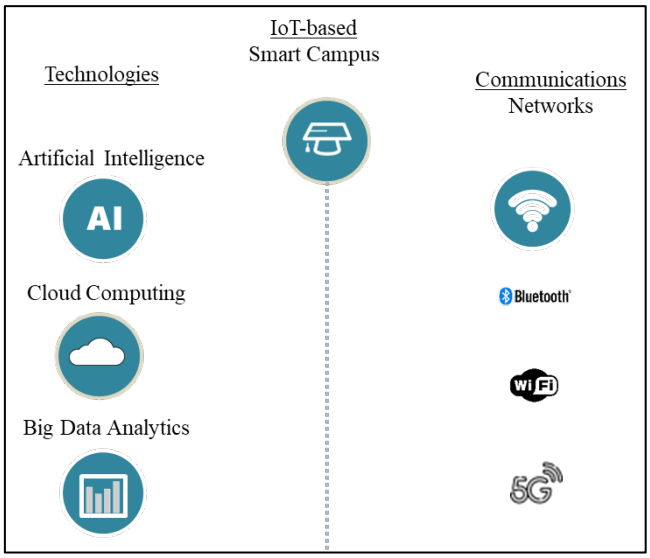

Fig. 5. The technologies required for the smart campus

4.5 The advantages/benefits of deploying IoT in a smart campus

The research findings highlight numerous benefits and advantages brought by the applications of IoT technologies on a smart campus. The main benefits of an IoT-based smart campus include agility, cost efficiencies, flexibility, interaction, scalability, resilience, the creation of intelligent classrooms, and the stimulation of creativity to support personalized learning, to list but a few [8]. With IoT deployment, access control systems can manage access control and provide enhanced security to the university community. Comprehensive campus surveillance and real-time incident warning are important applications to improve security standards and campus safety [32] [33]. The biggest advantage of an IoT-based smart campus is that it enhances campus management efficiencies [1], improves response times, and elevates user experience [19]. Additionally, an IoT-based campus enables the sharing of important educational resources and the delivery of interactive and creative services to the campus community and external stakeholders. It has an enormous potential to transform the existing teaching models to achieve desired innovations [5]. For example, Lin et al. [16] described an IoT application that enables students not majoring in computer science to create their innovations without coding. Noor et al. [34] presented another interesting innovation, finding innovative ways to improve the campus bus management service by predicting the shuttle travel times, fuel consumption, and harmful emissions. Furthermore, an IoT-based smart campus delivers rich content that makes learning more interesting [9] and produces learning-enthusiastic students and better-quality human resources [2]. An IoT-based smart campus combines physical space and technology to enhance student-teacher relationships resulting in improved communication and collaboration, as well as the promotion of personalized learning [24]. A key role for IoT in advancing the educational environment in universities is to improve teaching staff and educational flexibility [25] as well as deliver adaptive learning to support students with disabilities and learning challenges [8]. Also, they stated that it connects people (students, teachers, and administrators), processes, devices, and data enabling stakeholders in education to turn data collected from sensors and portable devices into valuable information for decision-making. Its full usage can greatly reduce the workload of the administrative staff [31] and enhance operational effectiveness by saving time and cost for the university management processes [33]. Furthermore, sustainable and responsible management of buildings using IoT technologies can minimize energy consumption and environmental footprint during construction, usage, and decommissioning [6]. IoT is primarily about digitizing everyday activities, so it has a very broad range of applications and market opportunities [1]. Table 3 summarizes the advantages and benefits of IoT applications spread across the seven smart areas.

Table 3. The advantages/benefits of deploying IoT applications in a smart campus

Smart Area	Benefits
Smart Environment	● Efficient measurement of consumption and conservation of energy and water conservation. ● Real-time surveillance to ensure safety within the parameters of the campus estate. ● Enhancing environmental sustainability by reducing the temperature in the environment. ● Optimization of waste management
Smart People	● Accurate recording of attendance for students and teaching activities by the academic staff. ● Reduction in the online sign-in time and improvement in the delivery of learning material. ● Improvement is the student's attitude towards learning. ● Strengthened relationship between students and teachers
Smart Building	● Accurate occupancy detection and optimal utilization of space in the campus buildings ● Improvement in the quality of the indoor environment (temperature, noise pollution, lighting, ventilation, humidity). ● Automation of maintenance improves the response time to restoring functionalities of the university buildings.
Smart Living	● Accurate management of the parking space on campus grounds. ● Seamless access control to campus facilities ● Incorporation of teaching staff and students with learning facilities and the information generated by them.
Smart Governance	● The ability to make data-driven decisions to benefit the university community and external stakeholders. ● Improvement in the university services and the administrative management processes. ● Detecting the learning habits of the students to inform developments of the academic agenda.
Smart Mobility	● The ability to calculate fuel consumption and gas emissions by the campus shuttles. ● The ability to measure the travel time for all campus shuttles to facilitate better planning and enhance the quality of service.
Smart Economy	● The ability for students to create new mobile applications to contribute to the innovation efforts at their universities.

4.6 The challenges experienced in deploying IoT in a smart campus

Implementing an IoT-based smart campus offers many benefits, but also presents challenges including resistance to changing academic learning methods, high costs of smart applications, and privacy and data security issues [7] [18]. This systematic literature review identified that most of the existing approaches to smart campuses have inherent challenges that limit their applications [15] [35]. Chagnon-Lessard et al. [6] stated that these include "sustainability and energy issues, acceptability and ethics, learning models, open data policies and interoperability" (p.1). The five key barriers to overcome to implement IoT-based smart campuses are explored:

a) *Privacy and security issues*. Due to the interconnected nature of IoT devices, any device with poor security will potentially compromise network security and privacy. Moreover, the full potential of IoT depends on respect for privacy preferences [15] [36]).
b) *Operational issues.* The software accompanying many IoT devices may not necessarily integrate with the standard IoT gateways and protocols. Due to a lack of integration between the interfaces, failures are more likely to happen and detection times are longer [30] [11].
c) *Interoperability and integration*. IoT environments face many challenges due to increased connectivity. Interoperability allows IoT devices to communicate with each other (e.g., students-to-students, students-to-teacher, and teacher-to-teacher) and facilitate the integration of various components to improve the quality of communication [14].
d) *Energy and environmental issues*. Physical environments such as humidity and high temperatures can adversely affect the performance of IoT devices. There is a need for operations to enable autonomous detection, prevention, and improvement of issues at certain scales without human intervention. The IoT devices are energy-intensive and deployments of IoT applications required energy consumption efficiencies [18] [37] [10] [38].
e) *Legal and compliance issues*. The implementation of IoT-based devices raises many legal and compliance issues including cross-border data flows, data misuse, and Internet legal frameworks [15].

5 Discussion

A smart campus is an outcome of rapid developments in technology to deliver quality services [25] and achieve advanced management on a university campus [21] [39,40]. The development of a smart campus requires the integration of existing information systems and IoT technologies to create a holistic and intelligent platform [1]. By leveraging technology, the university can improve processes while extending control over actions that are otherwise performed by people [19]. The universities face the challenge of delivering quality education efficiently through digitalization, which allows for streamlining academic processes and the development of smart services. Due to the outbreak of the Covid-19 pandemic, universities around the globe are using new technologies to transform their teaching methodologies. Consequently, many students engaged in some kind of remote education and are aware of the several advantages and possibilities offered by various teaching and learning methods [6]. With the aid of e-learning concepts and digital technologies, students could continue their educational pursuits safely from a distance [41].

There are numerous advantages and benefits to using IoT applications across the university campus [3]. Students want a learning environment that is technically advanced and content-rich. In the same way, universities are becoming intelligent campuses and technology is becoming the major factor in their growth [19]. It enables the

development of smart classroom teaching [42-45] that facilitates both individual learning and interactive learning [24]. It plays a pivotal role in facilitating fast access to educational services [10] which results in the digitization of university teaching [3]. Additionally, Fu, Chen, and Cheng [46] explored the integration of wearable smart devices that leverage the power of computer graphics and image technology to enhance students' learning enthusiasm and improve participation in the classroom.

In the administration of the university, the management of physical resources enables the university to implement innovative educational models. On the other hand, the management of academic resources is more complex since it includes variables for measuring the development of learning and the discovery of paradigms like identifying the learning habits of students [35] [47-50]. Missed opportunities or financial losses can be attributed to poor management of these resources. Therefore, the utilization of real-time data monitoring and dynamic data visualization on dashboards are powerful tools in the decision-making process [13] [52,53]. The university campus usually consists of large energy-intensive buildings. The use of sensors, actuators, metering devices, and various forms of network activities [38] facilitates the operation and management of such buildings [10] for energy conservation and environmental sustainability [29]. Several studies have shown that smart campuses have successfully deployed IoT-based environmental monitoring systems. The integration of the Building Energy Management System (BEMS) with IoT sensors facilitates the monitoring of indoor conditions and optimizes energy use in university residences [53] [54]. The deployment of an irrigation system that uses IoT nodes to collect environmental data such as soil and air temperatures and activate the system remotely through intelligent automated actions [55][56]. An installation of a green rooftop using LoRa to monitor and sense temperature changes as well as to minimize energy consumption [57]. The above studies focused on university buildings where cost optimization and cost savings were the main goals for integrating IoT, BEMS systems, and other advanced technologies. Moreover, a green campus with long-term sustainability can be achieved with the characteristics of IoT technology.

Disaster management is another underexplored area. Several disasters like fire, storms, floods, and earthquakes can occur on a university campus resulting in huge losses including human life. Ali et al. [37] suggested the implementation of an affordable IoT-based disaster management solution to escape these kinds of disasters. Furthermore, comfort and space are essential elements for successful learning [58] and social advancement [17][59][60]. In this area, the efficient management of open spaces and occupancy of university buildings is one of the beneficiaries of IoT applications [19][61][62]. Scientists are exploring the potential synergies between IoT and Building Information Modeling (BIM) in the environmental monitoring and emotion detection fields to provide insights into comfort levels, the researchers are exploring the potential synergies between the two technologies. The authors further explore the ability of universities to contribute to local sustainability projects by sharing knowledge and experience across a multi-disciplinary team. Lastly, an intelligent bus dispatch system improves campus bus operations by improving efficiency [63] and optimization of bus routes [34] as well as improving the bus user experience [19].

The most significant obstacles encountered with the IoT application in a smart campus are concerns about data security and dependability, as well as operational challenges [31][64][65]. Additionally, Mircea, Stoica, and Ghilic-Micu [8] stated that the dependence on excessive technology might result in vulnerabilities of information systems and IT infrastructures in education. To implement IoT-based smart campuses, these are the greatest barriers to overcome. Nonetheless, IoT continues to play a vibrant contribution in the future and the improvement of education reforms [25] and universities can increase both their long-term success as well as the quality campus experiences that their students have [66].

6 Conclusion and future works

In response to the plethora of issues affecting service delivery at universities, smart campuses have gained increased popularity. The combination of IoT technologies, sensors, and computer networks has enhanced the development of a smart campus. In this study, the existing literature on IoT applications that will enable a smart campus has been systematically reviewed. The results revealed that a smart campus is developing, yet the important concept that is driving informatization and digitization in higher education. Moreover, the advanced technologies including IoT, big data analytics, cloud computing, and artificial intelligence complement each other in the construction of a smart campus.

A smart campus is a sustainable and connected environment that aims to enhance education, experience, and efficiency. Through interconnected devices and IoT technologies, a smart campus can facilitate communication and open many opportunities for performance management in numerous areas of the university campus. Despite its many advantages and benefits, the IoT-based smart campus presents some challenges that deserve further exploration. The challenges of rising electricity costs and environmental impacts are clear motivators for achieving efficiency and sustainability goals. Future research should analyze the energy consumption of IoT deployments from a cost-effectiveness perspective. Furthermore, the study will benefit researchers, policymakers, teachers, and students by gaining insights into the IoT-based smart campus. However, like many other systematic literature reviews, this study has limitations that are associated with many others. Firstly, the selection of the studies was limited to the last five years. Secondly, this review was limited to publications from three databases. Thirdly, the review included only peer-reviewed studies available in full text. Future research may expand the inclusion criteria to include other scientific disciplines and extend the study period to at least ten years to determine if additional studies are relevant.

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