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Exploring IoT Applications for Transforming University Education: Smart Classrooms, Student Engagement, and Innovations in Teacher and Student-focused Technologies

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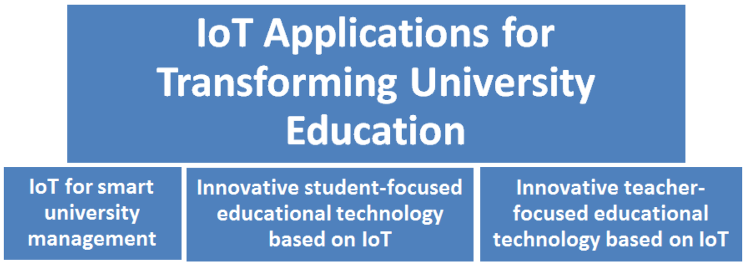
ABSTRACT



This review examines the integration of smart management systems in universities through the Internet of Things (IoT), emphasizing its transformative potential to enhance administrative efficiency, improve student engagement, and address critical challenges such as data security and ethical concerns. Using a structured review methodology, we analyzed studies focused on IoT-driven innovations in areas such as energy management, personalized learning environments, and attendance systems. Insights from global case studies, including detailed examples from The Technical University of Cluj-Napoca, Romania, were synthesized to explore the generalizability and applicability of these solutions across diverse institutional contexts. The review followed a systematic approach, selecting studies from reputable academic databases and adhering to predefined criteria for examining IoT integration within university environments. While the findings highlight the significant benefits of IoT for educational management and teaching practices, challenges such as data privacy, system interoperability, and cost barriers remain critical considerations. This comprehensive review aims to guide future research and support the practical implementation of IoT solutions in higher education.

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1. INTRODUCTION

Kevin Ashton, a British technology pioneer and co-founder of the Auto-ID Center at the Massachusetts Institute of Technology (MIT), is widely credited with coining the term "Internet of Things" (IoT) in 1999 [1]. The Internet of Things (IoT) represents a network where devices and objects communicate and share data through the Internet, enabling a wide range of applications and services across various domains that improve various aspects of daily life, enhance productivity, and contribute to more sustainable practices [1]-[4]. This interconnectedness (both wired and wireless communication) contributes to the development of intelligent and responsive systems that offer enhanced functionality, efficiency, and convenience across various applications and industries. Implementing robust security measures, including encryption, authentication, and secure update mechanisms, is essential to ensure the integrity, confidentiality, and availability of IoT systems and the data they handle [5]-[7]. The prediction of 75 billion connected devices by 2025 underscores the widespread adoption and integration of IoT technology across various sectors and applications [8], as well as the dual nature of IoT - its substantial benefits and the associated cybersecurity challenges [9]-[11].

Implementing robust security measures, including encryption, authentication, and secure update mechanisms, is essential to safeguard the integrity, confidentiality, and availability of IoT systems, particularly in university environments. As IoT devices become more integrated into campus operations, such as smart classrooms and campus security systems, they collect and analyze sensitive data, including student attendance, performance, and personal information. This heightens the risk of data breaches and unauthorized access, making cybersecurity a critical concern. While IoT significantly enhances the learning experience by optimizing classroom environments and enabling personalized learning through real-time tracking, it also introduces vulnerabilities, such as potential cyberattacks targeting interconnected systems. These attacks could compromise both educational experiences and institutional operations, including sensitive student records. Therefore, balancing IoT's advantages in enhancing operational efficiency and educational outcomes with robust security measures to mitigate data privacy risks and system vulnerabilities is essential for fostering a secure, efficient, and effective educational ecosystem. Addressing these dual aspects of IoT - its transformative potential and associated cybersecurity challenges - will ensure its safe and effective implementation in universities.

In the last decade, to keep pace with technological advancements and the digital revolution, educational university systems have embraced new and modern ways of teaching, learning, and administration, including the adoption of IoT-enabled technologies like smart classrooms, IoT-based attendance and performance tracking systems, and intelligent administrative tools. These innovations not only improve operational efficiency but also create more adaptive and personalized learning environments, thereby contributing to the provision of quality education and supporting sustainable development [12]-[16]. This transformation is essential to meet the evolving needs of students, professors, and the broader society, ultimately contributing to the advancement of efficient and effective educational processes for developing a skilled workforce for future digital economies [17]-[20]. To remain relevant, higher education institutions must integrate IoT technologies that can enhance operational efficiency and improve the learning experience, while also addressing key challenges like data privacy, system interoperability, and infrastructure demands.

While the initial concept of IoT focused on connecting physical objects to the internet for improved data sharing and automation across industries, the application of IoT in educational settings has become increasingly relevant in recent years. By enabling interconnected devices and systems within university environments, IoT can transform teaching, learning, and administrative processes. IoT solutions such as smart classrooms, real-time student performance monitoring, and automated campus management offer new ways to enhance educational outcomes, streamline operations, and support a more personalized learning experience. This evolution from the industrial uses of IoT to its application in education highlights the technology's potential to shape the future of academic institutions.

The Internet-based education management system, enhanced by IoT technologies, emphasizes flexibility, intelligence, and seamless human-computer interaction, creating a dynamic and efficient educational environment. For example, IoT-enabled smart classrooms can automatically adjust lighting and temperature based on student preferences, while wearable devices track student health and engagement levels, enabling personalized learning experiences. The ability to manage and access educational processes anytime and from anywhere not only enhances accessibility but also supports more adaptive, student-centered learning approaches, opening up new possibilities for both students and educators [21].

In addressing the challenges of implementing IoT in university education, it is important to acknowledge issues such as data privacy, infrastructure requirements, and the potential digital divide between students and faculty. Data privacy remains a significant concern, especially when dealing with sensitive student information. Universities must implement robust security protocols, including data encryption and secure authentication, to ensure the integrity and confidentiality of personal data. Additionally, infrastructure requirements for IoT adoption can be considerable, requiring significant investment in network systems, sensor technologies, and cloud storage solutions. This can present a barrier, particularly for institutions with limited resources. Finally, the digital divide, which refers to the disparity in access to technology and digital literacy between students and faculty, must be addressed to ensure equitable participation in IoT-enabled educational systems. Bridging this gap will require targeted initiatives to enhance digital access and training for all stakeholders involved, ensuring that no group is left behind in the transition to smart university systems.

By exploring these aspects, this research aims to provide valuable insights into the emerging field of IoT in university education, specifically focusing on identifying key barriers such as data privacy concerns, infrastructure challenges, and the digital divide. Additionally, the study proposes practical solutions for overcoming these obstacles, such as the development of secure IoT frameworks and cost-effective implementation strategies. Through this, the research contributes not only to understanding the potential of IoT in education but also to advancing the integration of IoT technologies in sustainable, scalable, and human-centered educational environments.

This review examines the integration of smart management systems in universities through the IoT, specifically focusing on its potential to enhance administrative efficiency, improve student engagement, and address critical challenges such as data security and ethical concerns. By synthesizing insights from global case studies, including detailed examples from The Technical University of Cluj-Napoca, we aim to explore the generalizability and applicability of IoT solutions across various institutional contexts. This research also identifies and addresses the limitations and challenges that universities face in implementing IoT solutions, including infrastructure requirements and potential digital divides. By exploring these aspects, we aim to provide valuable insights for future research and inform practical applications of IoT technologies in higher education. This interdisciplinary approach offers a comprehensive view of IoT's role in shaping the future of educational management and sustainability in smart urban environments.

2. IOT ARCHITECTURE

This traditional four-layer architecture (sensing/perception layer, communication/network layer, data processing and analysis layer, and cloud/storage layer) offers a structured approach to designing and understanding IoT systems (Figure 1). It also allows for efficient data flow, distributed processing, and scalable storage, catering to the diverse and dynamic nature of IoT applications [1][6].

Comprehensive perception, reliable transmission, intelligent processing, security, scalability, and interoperability, collectively contribute to the effectiveness and efficiency of an IoT system, depending on the application domain. As technology and the IoT field continue to evolve, additional characteristics and considerations may become prominent in defining IoT systems.

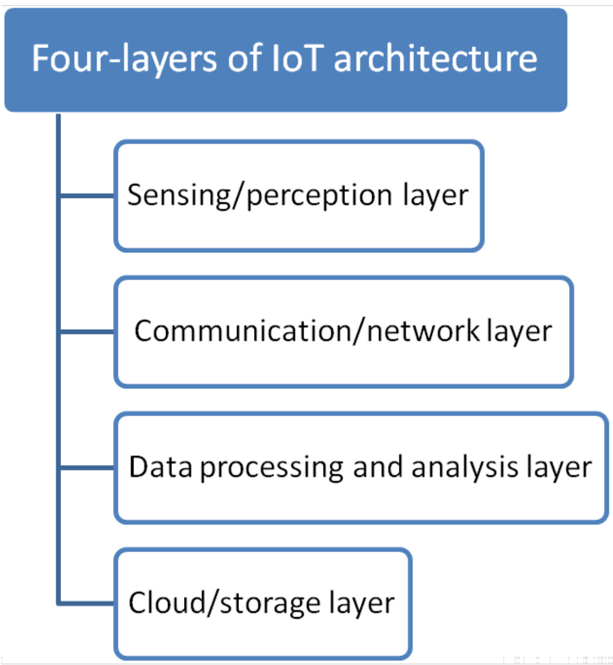

Figure 1. Traditional four-layer architecture of IoT Architecture

In the perception layer, educational institutions use a variety of sensors and devices such as environmental sensors, motion detectors, and RFID tags to optimize learning environments. These sensors monitor factors like temperature, humidity, air quality, and occupancy, playing a vital role in maintaining a comfortable and efficient campus. However, deploying these sensors requires a robust infrastructure, including reliable wireless networks and power supplies. Additionally, maintaining the devices through regular calibration and software updates is crucial to ensure they function correctly over time.

The communication/network layer shows challenges related to network congestion and latency, particularly during peak usage times, when multiple IoT devices transmit data simultaneously. Network congestion can severely affect the performance of IoT applications, such as live streaming of lectures or real-time student tracking. Furthermore, managing multiple communication protocols (Wi-Fi, Zigbee, Bluetooth) across devices complicates integration and interoperability. Effective network management is needed to ensure smooth data transmission, especially for real-time applications that require low latency.

The data processing and analysis layer involves the use of advanced analytics techniques, such as big data analytics and machine learning, to derive insights from the vast amounts of data generated by IoT devices. These techniques help institutions optimize resource allocation, improve teaching methods, and enhance student engagement. However, the computational resources required to process this data can be significant, necessitating high-performance computing and scalable storage solutions. This presents both a technical and financial challenge for universities looking to implement IoT-based solutions.

Finally, the cloud storage layer is responsible for securely storing and managing the large volumes of data generated by IoT devices. Institutions must implement robust data management strategies to ensure data privacy and security, particularly with regards to sensitive student information. While cloud storage solutions offer scalability, they also come with significant cost implications, which could be a barrier for some universities, especially those with limited budgets. Therefore, balancing scalability and cost is essential for sustainable IoT implementation in education.

3. REVIEW METHODOLOGY

The review methodology employed in this study is structured into three distinct steps to ensure a comprehensive and rigorous examination of the existing literature on IoT applications in university education, which is essential for answering the primary research question and its associated sub-questions. This methodology ensures that the review process is not only comprehensive but also scientific in nature.

These steps include: 1) gathering pertinent articles related to the research question; 2) analyzing literature review articles to assess, identify, and comprehend key findings essential for addressing research questions; and 3) undertaking a systematic review to accumulate existing evidence and systematically analyze and synthesize research findings.

In the first step, a comprehensive literature search was conducted across several reputable academic databases, including Scopus, Web of Science, IEEE Xplore, ScienceDirect, SpringerLink, MDPI, Google Scholar, and ERIC. Specific search terms such as "IoT in education," "smart campus," "IoT-based systems in universities," and "Internet of Things in universities" were used to ensure a diverse and inclusive collection of studies. The inclusion criteria for article selection focused on publications in peer-reviewed journals or conferences, a clear focus on the application of IoT technologies within university settings, empirical data or case studies directly relevant to the research questions, and a publication date within the last ten years to capture the most current advancements. Articles were excluded if they were non-English language publications, opinion pieces, or lacked empirical data. Citation chaining was employed to further expand the coverage by reviewing references cited by the selected studies and articles that cited them, ensuring a thorough and up-to-date selection of literature.

In the second step, the analysis of the literature was conducted using a thematic analysis approach. This allowed for the identification of recurring themes, patterns, and trends within the literature, which helped to understand the diverse ways in which IoT technologies impact various aspects of university education. The articles were categorized into thematic subgroups, such as "energy management," "security systems," "student support," and "sustainability," which aligned with the primary research questions and focus areas. Qualitative coding was employed to extract and compare key concepts, theories, and methodologies across studies, helping to identify common findings, discrepancies, and gaps in the literature, particularly in relation to operational efficiency and educational outcomes associated with IoT implementations.

The third step involved the systematic review process, which utilized the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure transparency and rigor throughout the review. The PRISMA guidelines provided a structured approach for article selection, data extraction, and synthesis, thereby maintaining the integrity of the review. Criteria for assessing the quality of the evidence, including study design, sample size, methodology, and relevance to the research questions, were applied.

Studies that met high-quality standards were included in the synthesis, while those with weak methodologies or insufficient evidence were excluded.

For synthesizing the findings, NVivo software was used for qualitative data analysis, enabling efficient coding and categorization of key themes across the studies. Additionally, Excel was employed to create a comprehensive matrix for comparing and contrasting the findings, highlighting trends, discrepancies, and gaps. The findings were integrated based on their relevance to the research questions, with specific themes such as "IoT applications in energy management" and "student support systems." This approach allowed for a structured integration of findings, ensuring that both positive outcomes and challenges were adequately addressed and offering clear directions for future research in the IoT and education domain.

Throughout the synthesis process, several gaps in the literature were identified, particularly in areas such as the evaluation of long-term impacts and the scalability of IoT applications in diverse university environments. Limitations of the included studies, such as small sample sizes or lack of longitudinal data, were also acknowledged to provide a balanced understanding of the evidence base.

By employing thematic analysis in Step 2 and applying the PRISMA framework in Step 3, this review ensured that the process was both rigorous and comprehensive. The integration of findings provided an in-depth understanding of how IoT is applied in university education, with a focus on key areas such as energy management, security, and student support. By employing this structured methodology, the study ensures that the review is both rigorous and comprehensive, answering the primary research question and sub-questions with clarity. The review ultimately contributes valuable insights into the role of IoT in education, highlights the benefits and challenges associated with its implementation, and offers clear directions for future research in this emerging field.

Despite its advantages, there are several potential challenges to this methodology. One challenge is the risk of publication bias, where studies with positive results may be more likely to be published and included in the review. This could result in an overrepresentation of studies with favorable outcomes, potentially skewing the findings. To mitigate this challenge, the study employed strict inclusion criteria and used a variety of academic databases to ensure a more balanced and comprehensive selection of studies. Another challenge is the variability in study methodologies, especially given the diverse range of IoT applications across university functions (e.g., energy management, student support, security). The differences in study designs, sample sizes, and methodologies can make it difficult to compare results across studies. However, by grouping findings into thematic areas, the methodology allows for a more structured synthesis that accommodates these differences while ensuring clarity in presenting the key findings. Lastly, given the rapid advancement of IoT technologies, new studies and developments may emerge after the review is completed, which could make some of the findings less current. However, by focusing on studies published within the last decade, the methodology attempts to capture the most recent advancements in IoT applications in education, ensuring the review remains as relevant as possible. In conclusion, the three-step methodology is well-suited to the research objectives of this study, providing a comprehensive, systematic, and rigorous process for addressing the research questions. While there are challenges, such as publication bias and study heterogeneity, these are mitigated through careful selection criteria and structured synthesis techniques. The methodology offers a balanced and thorough examination of the role of IoT in university education, contributing valuable insights to the field.

In this study, we have implemented several strategies to ensure these aspects throughout the methodology.

1. Inter-coder agreement in thematic analysis. To ensure reliability in the analysis of literature, a multiple-coder approach was employed. During the thematic analysis, articles were coded by two independent researchers. This approach helps minimize individual bias and increases consistency in the coding process. To assess the reliability of the coding, inter-coder agreement was calculated using a standard metric (e.g., Cohen’s Kappa). A high level of agreement (above 0.80) was considered indicative of reliable coding. In cases of discrepancies between coders, the researchers discussed and resolved the differences through consensus, ensuring that the final codes accurately reflected the themes identified in the literature.
2. Cross-verification of synthesized results. To further enhance the validity of the findings, cross-verification was applied during the synthesis process. After extracting and categorizing key findings from the selected articles, the synthesized results were reviewed by a third researcher to ensure consistency and accuracy. This cross-checking process helped verify the interpretations and conclusions drawn from the literature, ensuring that the findings were not only consistent with the original studies but also aligned with the research questions.
3. Triangulation of data. In addition to inter-coder agreement and cross-verification, we employed triangulation of data by comparing findings across different sources, methods, and perspectives. This

triangulation process increased the validity of the results by ensuring that the conclusions were well-supported by a broad range of evidence from multiple studies.

4. FEATURES OF IOT IN SMART UNIVERSITY EDUCATION

Exploring the application of IoT from various perspectives—such as resource management for university administrators, IoT-enabled teaching tools like smart boards and analytics platforms for educators, and personalized learning environments powered by wearable devices and adaptive learning systems for students - provides a holistic view of its impact on education. By integrating IoT into university management, institutions can foster a smarter, more connected campus characterized by real-time monitoring systems, energy-efficient IoT devices, and reduced resource wastage, which collectively enhance operational efficiency, improve educational experiences, and promote sustainability.

A 'smart' learning environment leverages advanced IoT technologies to automate processes, optimize resource allocation, and enhance interconnectivity, while 'sustainable' refers to the use of eco-friendly practices such as minimizing energy consumption and waste. 'Technologically advanced' signifies the integration of cutting-edge tools, like AI-powered learning platforms and cloud-based systems, to elevate the educational experience.

IoT applications may vary significantly based on regional and institutional contexts. In developed regions or large universities, IoT might involve sophisticated implementations like AI-driven campus automation or 5G-enabled smart classrooms. Conversely, in developing regions or smaller institutions, IoT adoption could focus on cost-effective solutions such as low-power sensors for basic resource monitoring or mobile-based platforms for remote learning. Addressing these disparities requires tailored strategies that consider infrastructure availability, budget constraints, and local needs, ensuring equitable access to IoT benefits across diverse settings.

For example, universities like The Technical University of Cluj-Napoca have implemented IoT-based energy management systems that optimize power usage, reduce costs, and support sustainability goals. Similarly, the University of Melbourne has used IoT-enabled analytics to adapt teaching methods and enhance student engagement, while the Open University in the UK employs IoT-powered adaptive technologies to support distance learners and foster real-time collaboration.

Several universities have successfully implemented IoT features, demonstrating the positive impact these technologies can have on education while also raising important ethical implications. For instance, The University of California, Berkeley has integrated IoT sensors in their campus facilities to optimize energy use. Through real-time monitoring of lighting, heating, and cooling systems, the university has reduced energy consumption and costs, promoting sustainability. Similarly, The University of Michigan uses IoT-enabled smart classrooms equipped with interactive whiteboards and sensors that help track student engagement, improving teaching effectiveness and student participation. In another case, Georgia State University adopted an IoT-based student support system that tracks student attendance, performance, and engagement through smart devices. The system allows faculty to intervene early when a student shows signs of disengagement, resulting in higher retention rates and improved academic performance. These implementations highlight IoT’s potential to enhance operational efficiency, learning experiences, and sustainability. However, the adoption of IoT also raises important ethical considerations. For example, while real-time monitoring of students can improve learning outcomes, it also introduces privacy concerns. Universities must ensure that data collected through IoT devices is secure, anonymized, and compliant with privacy regulations like FERPA and GDPR. For example, Georgia State University emphasizes data privacy by providing students with clear information on what data is collected and how it will be used, ensuring transparency. Additionally, IoT systems must be free of biases, particularly in adaptive learning platforms. Regular audits should be conducted to ensure that algorithms used for personalized learning or performance tracking do not disproportionately impact underrepresented groups. Regular system audits, transparency in data use, and ethical oversight are critical to preventing misuse and building trust among stakeholders. Moreover, addressing ethical considerations such as biases in IoT algorithms, excessive surveillance, and the digital divide requires inclusive policies, algorithmic transparency, and training programs for equitable and responsible use of IoT technologies.

Additionally, IoT fosters innovation in education by enabling personalized learning, collaborative projects, and new teaching methodologies. For example, personalized learning can be enhanced through platforms like Coursera or EdX, which use IoT-connected devices to track student progress and adapt content delivery to individual learning styles. Wearable devices, such as Fitbits or smart glasses, can provide real-time feedback on physical activities or monitor stress levels to tailor learning schedules. Collaborative projects benefit from IoT by connecting students and faculty across the globe. For instance, the Global Learning and Observations to Benefit the Environment (GLOBE) Program uses IoT devices to allow students worldwide to collect and share environmental data, fostering cross-cultural collaboration and research.

Similarly, institutions like MIT and Harvard have leveraged IoT-enabled platforms to integrate remote labs, where students can control real-world experiments through IoT-connected instruments. IoT also supports the integration of virtual and augmented reality into classrooms, creating immersive learning experiences. For example, the zSpace platform provides AR/VR-based interactive simulations for subjects like biology and physics, allowing students to visualize and interact with complex concepts. In architecture programs, IoT-powered AR tools like Microsoft HoloLens enable students to design and walk through 3D building models in real-time. For instance, EduLab's IoT-enabled classroom solutions use connected devices such as smart boards, interactive displays, and sensor-based tools to create an engaging and interactive learning environment. AI-driven platforms like Carnegie Learning analyze student data in real-time to adjust teaching strategies, enabling educators to focus on areas where students face challenges. Virtual labs, powered by IoT, such as Labster, allow students to conduct experiments remotely, reducing the need for physical resources while expanding access to high-quality learning experiences..IoT-enabled adaptive learning platforms provide personalized educational experiences tailored to individual students' needs. For example, DreamBox Learning utilizes IoT to track student interactions and progress, delivering customized math lessons based on their skill levels. Wearable devices like Muse headbands monitor students' focus levels, allowing educators to adjust lesson pacing or format in real-time. Moreover, tools like Smart Sparrow enable educators to design adaptive learning pathways that evolve as students engage with the content.IoT facilitates seamless collaboration between educational institutions by enabling interconnected platforms and data-sharing systems. For example, the OpenAG initiative at MIT connects universities and research centers worldwide through IoT devices monitoring plant growth in controlled environments, fostering interdisciplinary research and global cooperation. Similarly, the Erasmus+ Virtual Exchange program uses IoT and digital platforms to connect students and faculty from different countries, allowing them to collaborate on projects, share resources, and engage in virtual cultural exchanges.

The integration of IoT in education presents several ethical considerations, such as privacy, surveillance, and biases in algorithms. For instance, IoT-powered surveillance systems, like facial recognition used for attendance tracking, could lead to excessive monitoring, raising concerns about student privacy. Similarly, biases in IoT algorithms, such as those found in adaptive learning platforms like ALEKS or Knewton, may result in inequitable outcomes if the data used to train these systems is incomplete or biased, particularly when it comes to underrepresented student groups. To mitigate these issues, universities must implement ethical practices such as ensuring transparency about how IoT systems collect and use data. This could involve providing students and faculty with easy access to data dashboards that allow them to view and manage their information. In addition, algorithmic audits should be conducted regularly to ensure that IoT systems do not perpetuate biases. For example, third-party evaluations could be used to assess AI-driven grading systems, ensuring that they offer fair and unbiased assessments. Furthermore, universities must implement privacy safeguards by anonymizing data and ensuring compliance with data protection regulations such as GDPR or FERPA, while also utilizing technologies like Apple's differential privacy techniques to protect individual identities. Despite these ethical concerns, IoT also offers significant opportunities for innovation in education. It can enhance accessibility through the use of IoT-powered assistive technologies, such as OrCam MyEye, which helps visually impaired students engage with their learning materials. IoT also fosters interdisciplinary learning, allowing students from different disciplines to collaborate on real-world projects, such as engineering students using Arduino kits to design IoT systems that support environmental sustainability efforts in partnership with environmental science students. Additionally, IoT enables dynamic teaching tools, such as the use of IoT sensors in biology labs, which allow students to monitor live experiments remotely and engage with learning in a more interactive and flexible way.

These advancements transform traditional educational paradigms by promoting dynamic and adaptable learning environments, bridging geographical barriers, and fostering interdisciplinary collaboration.

However, the adoption of IoT also presents challenges, such as ensuring data privacy, mitigating cybersecurity risks, and addressing the digital divide. To tackle these issues, universities must implement robust measures, including data encryption, multi-factor authentication, compliance with regulations like GDPR, and regular system audits. Additionally, institutions can invest in training for staff and students to ensure equitable access and foster responsible use of IoT technologies. These efforts safeguard sensitive data, uphold ethical standards, and ensure IoT contributes to creating a truly smart, sustainable, and technologically advanced educational environment that adapts to diverse regional and institutional needs.

4.1. IoT for Smart University Management

IoT for Smart University Management begins with energy management, where IoT sensors play a pivotal role in optimizing energy usage and reducing waste, directly contributing to sustainability goals. Building on this, security becomes a critical component of smart management, as IoT technologies enhance surveillance and provide real-time threat detection, ensuring the safety of students and faculty across campus. In parallel, student support systems utilize IoT to create inclusive, accessible educational experiences. This includes innovations like attendance tracking, assistive technologies for students with disabilities, and remote support systems that make learning more equitable. This interdisciplinary approach - merging IoT, education, and sustainability - has the potential to reshape the future of education in smart urban environments. Specifically, IoT contributes to sustainability by enabling the creation of energy-efficient smart campuses. IoT sensors can optimize energy consumption across various campus facilities such as classrooms, dormitories, and administrative buildings. Furthermore, IoT-powered resource management systems track and reduce water and energy waste, helping universities meet their sustainability targets while enhancing operational efficiency. These innovations not only minimize the environmental footprint of educational institutions but also foster a more responsible and sustainable approach to campus management, aligning educational advancement with environmental stewardship.

A) IoT-based energy-management Platform for Higher Institutions

By promoting interconnectivity and interoperability in energy management, the universities can optimize energy usage, enhance efficiency, and reduce waste, contributing to sustainability efforts by minimizing environmental impact and promoting responsible resource use. Smart energy management in educational universities not only offers potential cost savings but also aligns with sustainability objectives, making it a compelling investment for institutions looking to improve both their financial and environmental performance. Leveraging IoT sensors for on-demand energy management in university premises is a strategic move that not only reduces operational costs but also demonstrates a commitment to environmental responsibility. Energy management is a multifaceted approach that integrates efficiency measures, engineering practices, and process management to achieve cost savings, reduce carbon emissions, and promote sustainability [22][23].

Despite the advantages, implementing IoT-based energy management systems in higher education institutions presents several challenges: a) Cost of deployment and maintenance: the initial investment for IoT infrastructure, including sensors and communication networks, can be substantial. Additionally, ongoing maintenance and system updates require dedicated resources, which may strain institutional budgets. b) Data security and privacy: Integrating numerous connected devices increases the potential attack surface for cyber threats. Universities have been targets of cyberattacks, leading to significant financial and reputational damage. c) Network congestion and latency: managing a large number of IoT devices can strain existing network infrastructure, leading to congestion and increased latency. This can affect the real-time data processing capabilities essential for effective energy management.

Various IoT solutions offer distinct advantages and limitations: a) LoRa vs. IEEE 802.15.4: A comparative study of these two networking technologies within educational buildings indicated that while both have their merits, LoRa exhibited more robust performance in real-world settings. LoRa's characteristics make it a suitable choice for indoor IoT deployments, especially in cases with low bandwidth requirements. b) Cloud-Based vs. On-Premises Solutions: Cloud-based IoT platforms offer scalability and reduced upfront costs but may raise concerns regarding data security and privacy. On-premises solutions provide greater control over data but require higher initial investments and ongoing maintenance.

B) IoT-based Security and Surveillance Measures on the Campus From Higher Institutions

The integration of IoT-based security systems in universities addresses the challenges associated with on-campus security by leveraging a combination of sensing technologies, advanced cameras, cellular technologies, wireless communication, and cloud-based networks. This approach enhances the overall effectiveness and efficiency of campus security measures.

Shyr *et al.* [24] provided more in-depth insights into the design, implementation, and outcomes of the IoT-based energy management system (EMS) for lighting control on the university campus in Taiwan. Anagnostopoulos *et al.* [25] performed research in the context of IoT-enabled Smart Campuses and surveillance systems using a proposed taxonomy as well as by adopting a weighted scoring model on the surveyed systems. Villegas-Ch *et al.* [26] proposed the integration of IoT and blockchain technologies into the processes of a university campus with various benefits, ranging from enhanced security to increased efficiency and transparency. Pinggui and Xiuqing [27] made an innovative and exploratory research to implement a campus security system based on IoT by on RFID tag chip technology, and GSM communication technology. Ikrissi and Mazri [28] performed an overview of smart campuses by highlighting the main applications and technologies used in this environment, presenting several vulnerabilities and susceptible attacks that affect data and information security in the smart campus. lhaddad [29] studied the integration of IoT technologies, including smart locks, intelligent ID systems, and geofencing, to provide a comprehensive and efficient approach to enhancing security on a smart campus. Wu *et al.* [30] proposed a campus intelligent locker system based on IoT, and provided a detailed description of the system architecture and innovative features. Gaber *et al.* [31] focuses on the development of an IoT-based autonomous drone for more comprehensive campus security and surveillance system.

IoT-based security and surveillance systems in universities significantly enhance campus safety by integrating a wide range of technologies that provide real-time monitoring and response capabilities. By combining advanced sensing technologies, high-definition cameras, wireless communication, and cloud networks, these systems can detect potential threats quickly and accurately, enabling a more proactive approach to campus security. Innovations such as RFID-based security systems ensure that only authorized individuals have access to restricted areas, while smart locks and geofencing provide enhanced control over building entry and exit. Additionally, autonomous drones equipped with IoT sensors can patrol large campus areas, providing continuous surveillance and identifying security risks in hard-to-reach locations. These systems not only streamline campus security operations but also increase transparency by offering a centralized platform for monitoring and analyzing security data. Despite these advancements, the integration of IoT into campus security also raises important concerns around data privacy and potential vulnerabilities, making it essential for universities to implement robust encryption and cybersecurity measures to protect sensitive information. Overall, IoT-enabled security systems provide a more comprehensive and efficient approach to managing campus safety, improving both security outcomes and the user experience for students, faculty, and staff.

C) IoT Technology for the Supervision and Support of Students From Higher Institutions Requiring Additional Assistance

Abiodun *et al.* [32] proposed an academic progress monitoring system that utilizes location-based tracking to provide a comprehensive overview of students' activities on campus by monitoring students' movements and interactions within various campus locations. Sivakumar *et al.* [33] introduced a sophisticated Intelligent Attendance Monitoring System that leverages the IoT and incorporates a Face Recognition Scheme for enhanced accuracy and security for tracking in educational institutions, providing a reliable and efficient solution for academic management. Lukas *et al.* [34] introduced an advanced method for automating student attendance in classrooms through a fusion approach of face recognition techniques, ensuring accurate and efficient identification of students for attendance monitoring. Hossain *et al.* [35] introduced a novel Autonomous Class Attendance System that leverages the IoT and non-biometric identification techniques to streamline and automate the attendance-taking process. Mala *et al.* [36] proposed a theoretical model and system designed to provide electronic aid for visually impaired individuals which integrates cutting-edge technologies to enhance accessibility, independence, and overall quality of life for visually impaired individuals. Bansal and Garg [37] delved into the transformative impact of the IoT on assistive devices, aiming to improve the standard of living for differently-abled individuals, and studied prototypes and advancements in higher education. O'Neill and Smyth [38] applied off-the-shelf technology to provide customizable self-management assistive technology for autistic university students. Zhou *et al.* [39] summarized the key findings and their implications for occupational health and safety, emphasizing the potential of tactile gloves as a valuable tool in ergonomic assessments for lifting tasks.

IoT technology for the supervision and support of students in higher education aims to improve monitoring, attendance management, and accessibility for students requiring additional assistance. By implementing location-based tracking systems, universities can monitor students' academic and social engagement, offering a comprehensive view of their campus activities. IoT-enabled face recognition and non-biometric identification systems streamline and automate attendance-taking, improving accuracy and efficiency. Additionally, assistive technologies, such as tactile gloves and customizable tools, are integrated to support students with disabilities, enhancing their independence and overall quality of life. These technologies collectively improve academic monitoring, support students' needs, and ensure efficient administrative processes.

D) An IoT-enabled System for Intelligent Transportation Solutions for Higher Institutions

Qoradi *et al.* [40] have emphasized the potential of integrating Intelligent Transportation Systems (ITS) and Geographic Information Systems (GIS) to significantly enhance the efficiency of campus transportation, providing a foundation for smarter and more responsive transportation systems on campuses. Alsobky *et al.* [41] presented a comprehensive solution for the university bus routing problem by designing flexible routes aimed at minimizing both students' walking distances and the total trip time taking into consideration variables such as traffic conditions and study schedules. De la Cruz *et al.* [42] enabled the implementation of bus geolocation, the display of recently updated routes, and access to real-time locations and schedules to significantly enhance transportation services within university campuses. Liu *et al.* [43] studied the socio-economic and travel traits of students who use transit, drawing comparisons with their counterparts in the young adult demographic, and quantified the variations in behavioral patterns related to public transit access between these two distinct population groups. Mbara *et al.* [44] explored the travel behaviors, features, and difficulties experienced by off-campus students, and the exploration of potential improvements to improve these issues. Nash and Mitra [45] utilized a Life Cycle Assessment approach to discern unique patterns in the transportation behaviors, specifically short- and long-term transportation lifestyles, of post-secondary students across universities. Zainuddin *et al.* [46] studied the adoption of a bike-sharing system to emerge as a cost-effective and sustainable means of travel for shorter distances on university campuses. Mohandes *et al.* [47] have developed a preference-based indoor parking system with recurrent users for university campuses, based on a system that directs registered users to one of their five topmost preferred parking spaces or the closest vacant space to their chosen pedestrian exit. Ahmed *et al.* [48] have suggested the creation of an Android application designed to enhance transportation services provided by bus rental companies serving students by minimizing students' waiting times and fostering real-time information sharing between bus drivers and students.

IoT-enabled systems for intelligent transportation solutions in higher education aim to optimize campus mobility, reduce wait times, and enhance efficiency. Integration of ITS with GIS can enhance campus transportation by creating smarter and more responsive systems. Tools like flexible bus routing models and real-time bus tracking provide solutions to minimize walking distances, reduce travel time, and improve the user experience for students. IoT applications like bike-sharing systems and preference-based indoor parking systems also enhance sustainability and convenience. Expected outcomes include better transportation services, reduced congestion, and a more efficient, user-friendly campus transportation experience.

E) IoT-based Health Monitoring System for Students From Higher Institutions

Zhong *et al.* [49] proposed advancing Physical Activity Recognition and Monitoring studies by leveraging IoT technology using connecting economically efficient wearable devices of diverse types in open environments for monitoring of college students. Akhtar *et al.* [50] introduced an innovative IoT-driven system for student health monitoring with the aim of assessing and enhancing the well-being of students to improve their overall learning capabilities. Branka *et al.* [51] advocated for the creation of an IoT system dedicated to managing students' stress with an open-architecture system integrated into the educational ecosystem, comprising two key components: one for measuring vital parameters to identify stress in students and another for stress control. Zamanifar [52] introduced healthcare technologies and methodologies based on IoT, leveraging cloud computing and edge computing to facilitate communication among various healthcare subsystems for the detection or prediction of patient's health status. Krishnan *et al.* [53] proposed a Secured College Bus Management System to monitor the student's health and the safety measures followed by the students before entering the bus during the Covid-19 pandemic situation. Abdulmalek *et al.* [54] explored the advantages and importance of IoT-based healthcare systems, emphasizing the benefits of IoT in healthcare, as well as the IoT wearable devices in healthcare systems, offering a classification of health-monitoring sensors according to the challenges and issues related to security, privacy, and Quality of Service. Mohung *et al.* [55] introduced an IoT-based intelligent health system deployed on a university campus that utilizes a web application designed to offer real-time updates on individuals' vital signs, while medical sensors, connected to a microcontroller (Arduino), facilitate data acquisition for monitoring health metrics. To enhance disease prediction, a dedicated module utilizes sensor data and a health form, to predict three primary diseases: cold flu, hypertension, and diabetes. Francisti *et al.* [56] explored the potential applications of readily accessible devices like smart wristbands (watches) and eye-tracking technology to analyze the influence of students' attention on their academic performance. Also, the research investigated correlations between eye tracking, heart rate, and student attention, aiming to understand their collective impact on learning outcomes, and the obtained data permitted to ascertain the potential dependence between students' concentration and heart rate.

IoT-based health monitoring systems for students in higher education focus on enhancing well-being, monitoring physical activity, and detecting health issues in real time. These systems utilize wearable devices, medical sensors, and cloud-based technologies to track vital signs, stress levels, and physical activity. Tools such as smart wristbands, heart rate monitors, and IoT-enabled health apps provide valuable insights into students' health status, helping institutions intervene early in case of health concerns. Expected outcomes include improved student health, better learning capabilities, and the ability to detect and predict health issues such as stress, hypertension, and flu.

F) An IoT-enabled System for Smart Sports for Students From Higher Institutions

Deng *et al.* [57] investigated the factors influencing the construction of smart sports for students in higher education, exploring design concepts and model choices to permit reform, innovation, and information management in college sports. He and Zhong [58] examined the practicality of implementing a university sports concept learning support platform incorporating big data technology. The results highlighted the importance of revising current sports concepts to underscore the dual aspects of preserving traditional sports culture and fostering innovation. Wang and Park [59] highlighted that the intelligent sports training management system developed for colleges and universities can be optimized, focusing on aspects such as functionality, performance, operability, compatibility, and security, and as the system accumulates data over time, there is a need to explore advanced technologies like big data and data mining. Ju [60] emphasized the need to integrate the 5G network with intelligent physical education classrooms for the future of physical education in colleges and universities by establishing an online platform for physical education courses, continuously optimizing the integration of online and offline physical education, and developing intelligent physical courses specifically designed for the capabilities of 5G networks. These objectives can be achieved by: a) Establishing a diverse platform for online physical education courses; b) Embracing a combination of online and offline teaching methods; c) Crafting intelligent physical courses tailored to the characteristics of 5G networks in the new era. Qin [61] highlighted the importance of collaborative employing diverse approaches to summarize and analyze the advantages and disadvantages of smart sports compared to traditional sports by integrating with smart education to construct a more scientifically grounded and effective smart education model tailored for students from colleges and universities. Zhang [62] emphasized the restructuring of soccer special classes within physical education majors at colleges and universities, guided by the principles of intelligent sports to align with emerging needs, enhance students' proficiency, and cater to both societal demands and the preferences of students. Wu *et al.* [63] explored the implementation, development, and utilization of IoT in college sports information platforms. They concluded by presenting the system standards for the information platform and addressing concerns related to its information security, to drive and facilitate the progress of college sports informatization construction and smart management.

IoT-enabled systems for smart sports in higher education not only enhance the training and management of athletic programs but also foster a more personalized approach to physical education. By integrating IoT sensors, big data analytics, and cloud-based platforms, these systems enable real-time monitoring of students' health metrics, activity levels, and performance, providing coaches and educators with valuable insights to tailor training plans and optimize results. The incorporation of 5G technology further elevates the experience by enabling seamless, high-quality virtual sports education and training, allowing for a more flexible and engaging approach. As a result, students benefit from individualized training sessions that adapt to their specific needs and progress, while universities gain greater efficiency in managing sports education programs. The expected outcomes include not only enhanced athletic performance and improved health outcomes but also a higher level of student engagement in sports and physical activities, thanks to the innovative and interactive nature of IoT-powered programs.

4.2. Innovative Student-focused Educational Technology based on IoT

Innovative Educational Technology for students and teachers follows a similar structure, first focusing on the personalized learning environments enabled by IoT technologies, which enhance both in-class and remote learning experiences. This seamlessly connects to increased efficiency in education, where IoT tools improve classroom management and student engagement. Finally, we examine teacher-focused IoT technologies, demonstrating how data analytics and smart classroom systems provide teachers with real-time feedback, improving instructional quality and fostering a more interactive learning environment.

A) Remote Education for Students Utilizing IoT

M. Brito *et al.* [64] asserted that the definitions of distance learning vary, but they consistently consider these features: (1) distance learning involves separate physical spaces; (2) distance learning enables students to study at different times; and (3) mediation is facilitated through technologies. Given the substantial level of mediation, distance learning generates data suitable for various types of analysis. Traxler [65] essentially explores three fundamental questions: first, whether the distance learning community has a clear understanding of the definition and purpose of its work; second, the impact of global political, economic, and technological forces on higher education institutions offering distance learning; and third, the implications of typical innovations and trends in educational technology for the field of distance learning. Ilieva and Yankova [66] underscored that the rapid shift to remote learning in the digital realm presented numerous challenges in higher education, and the IoT framework for educational activities needs to streamline the adaptation of university study processes to the ever-evolving circumstances. To capitalize on lasting benefits arising from changes in teaching and assessment approaches, the potential of IoT technology for continuous monitoring and flexible management of the learning process was explored. Yakoubovsky and Sarian [67] investigated the utilization of IoT in distance learning and self-education by monitoring the level of brain activity during video lessons and providing feedback to a software program. Their findings indicated that during periods of fatigue or critical moments in the lecture, the signals generated by IoT devices assisted in sustaining an active brain state, which enhanced memorization efficiency and overall effectiveness in the learning process.

In the context of remote education, IoT technologies play a crucial role in fostering personalized learning by continuously monitoring students' physical and cognitive states, which enables more tailored educational experiences. IoT-enabled wearables and sensors, integrated with learning management systems, track real-time data such as engagement levels, focus, and stress indicators, offering insights into how students are interacting with the content. This allows for the adjustment of learning materials and strategies in real-time to ensure optimal cognitive performance and prevent burnout. Furthermore, by leveraging advanced data analytics, these systems can predict when students may need breaks or additional support, promoting better learning habits and ensuring students remain engaged and productive. The expected outcomes are not only improved engagement and retention but also more effective and adaptive remote education, leading to higher academic success, increased student satisfaction, and a more interactive and dynamic online learning environment.

B) Increased Efficiency and Enhanced Engagement Enabled by IoT Technology

Avilés-Cruz and Villegas-Cortez [68] examined the implementation of a smartphone-based augmented reality (AR) system aimed at improving the comprehension of logic gate integrated circuits (ICs). Their findings concluded that analyzing logic circuits with the support of the AR system is more effective than the traditional approach of consulting paper data sheets. Marty *et al.* [69] evaluated the effects and gathered the perspectives of both students and teachers regarding the utilization of smartphones as clickers during formal lectures. The findings suggested that incorporating smartphones as clickers may streamline their use, foster increased student participation, and enhance interaction between students and teachers. Agostini and Petrucco [70] investigated the consequences of excessive or problematic smartphone usage on students' academic performance. The results suggest a notable correlation between elevated levels of smartphone addiction, challenges in concentration during studying, and a frequent tendency to procrastinate when completing assigned tasks. S. Han *et al.* [71], through a meticulous statistical analysis, discovered that students who exhibit attentiveness and maintain a satisfactory academic profile are significantly more influenced by positive motives, such as using smartphones for preparing learning materials and course contents. Conversely, inattentive students tend to demonstrate the opposite trend.

Increased efficiency and engagement through IoT technology focus on enhancing learning experiences and student participation. Tools such as smartphone-based augmented reality (AR) systems and clicker applications leverage IoT to boost interaction and comprehension in learning environments. These tools help students better understand complex concepts, like logic circuits, and facilitate active participation during lectures. The expected outcomes include improved academic performance, increased student engagement, and more efficient learning experiences. However, excessive smartphone usage may also have negative effects on concentration and academic outcomes, requiring a balance in their use for educational purposes.

C) Personalized Learning Environments Designed with IoT

Personalized digital learning environments are crafted to meet the specific needs of each student. Kanan *et al.* [72] delved into the potential of IoT-based learning environments in education, emphasizing their prospective advantages, challenges, and implications. The literature review outlined the benefits of these environments while offering insights into the challenges and opportunities linked with their implementation. Tang *et al.* [73] asserted that technological advancements have redefined education through parallel intelligent education, ushering in fundamentally new methods of teaching and learning. They proposed an artificial education system integrated into a narrative game environment to provide personalized learning experiences. Kotova [74] investigated the management of personalized learning through the application of intelligent data analysis methods to establish a controlled learning environment that considers the individual needs, goals, and personal characteristics of students, utilizing insights derived from data analysis. Spyrou *et al.* [75] outline the comprehensive system architecture of the IoT-ready platform within the MaTHiSiS H2020 EU project, designed to cater to various use cases for personalized learning experiences. The learning process, characterized by its non-linearity, is deconstructed into "learning atoms" – distinct units of knowledge that cannot be further divided – as defined by the tutor. The personalization aspect of this process can impact the difficulty of learning actions and is represented through the utilization of the "learning graph" concept. Serrano-Iglesias *et al.* [76] investigated the role of Smart Learning Environments (SLEs) in fostering a connection between formal and informal learning contexts. These environments utilize information from learning tools (such as Virtual Learning Environments, mobile devices, and IoT devices) to understand the individual learning of students, while the connection facilitated by SLEs enables students to reflect on learning concepts in real-world scenarios. Kanagarajan and Ramakrishnan [77] proposed the adoption of an IoT-based Ubiquitous Learning Environment (ULE) tailored to meet the contemporary demands of the education discipline. The objective is to imbue a higher degree of intelligence into the learning environment, thereby garnering positive perceptions from users. The authors advocate for the utilization of Ambient Intelligence (AmI) based systems, which surpass the intelligence of ULE through the incorporation of optimization and intelligent techniques. These systems, developed using deep learning processes, prioritize a student-centric and teacher-centric approach, enhancing the overall smartness and adaptability of the learning environment.

Personalized learning environments powered by IoT aim to tailor education to each student's specific needs. Tools such as IoT-based platforms, intelligent data analysis, and ambient intelligence systems are used to gather and analyze data on individual learning behaviors, goals, and preferences. These systems create adaptable learning environments that provide personalized learning paths, making education more efficient and engaging for each student. Expected outcomes include enhanced student engagement, improved learning outcomes, and more efficient education experiences, as the systems continuously adapt to the evolving needs and progress of students. However, challenges related to data privacy and implementation complexities need to be addressed for optimal results.

D) The management of responsibilities between university and home-based on IoT technology

Sheth *et al.* [78] proposed the concept of a smart laptop bag designed to integrate diverse functionalities, including location tracking, ambience monitoring, and user-state monitoring, all consolidated within a single device. This inventive design capitalizes on cloud computing and employs machine learning algorithms to not only monitor the bag's various parameters but also track the user's health.

The integration of IoT technology allows for the management of responsibilities between university and home by utilizing smart devices that track various parameters. Tools like smart laptop bags, equipped with location tracking, ambiance monitoring, and health monitoring capabilities, enable seamless communication and tracking of both academic and personal activities. The expected outcome is a more efficient management system where students, teachers, and parents can track key metrics related to student health and academic performance in real-time, enhancing overall productivity and well-being. Additionally, cloud computing and machine learning algorithms enable data analysis and feedback for better decision-making and proactive actions.

4.3. Innovative Teacher-focused Educational Technology based on IoT

A) An attendance System Utilizing IoT Technology with Autonomous Functionality

Santoso and Sari [79] proposed a system designed to address fraudulent practices in attendance management and improve the efficiency of processing student data using an IoT framework alongside a fingerprint-based attendance method. The anticipated outcomes of the system modeling include enhanced automation in academic data processing, leading to accurate statistical data and a reduction in the potential for data manipulation by untrustworthy parties. Sittampalam and Ratnarajah [80] introduced the Smart Attendance Management System (SAMS), designed to register students' daily attendance in lecture halls. This system incorporated IoT (Internet of Things) elements, including mobility, wireless networks, fingerprint sensors, and cloud computing, to offer web services that facilitated attendance management for academic staff. The SAMS effectively addressed limitations inherent in traditional attendance methods, providing solutions that are not only more accurate but also more secure, efficient, and automated. Hossain *et al.* [81] detected an individual without employing biometric sensors by leveraging the distinctive W-H Fusion function. They gathered individual information through a combination of a load cell, ultrasonic sensor, and RFID reader. The integration of sensor inputs and communication with a cloud database as an IoT device were facilitated through the use of a Raspberry Pi. Tee *et al.* [82] put forth a facial recognition attendance system as an alternative to the conventional manual attendance tracking method. S. C. Hoo et al. [83] conducted a comprehensive study on authentication and attendance systems in academic settings. It delved into an extensive analysis of historically employed systems, scrutinizing the vulnerabilities of each advanced system, and explored various technologies, including barcode-based systems, RFID, and biometric or facial recognition. Al-Amoudi *et al.* [84] introduced an automatic attendance system through face recognition that eliminates the requirement for installing extra devices in classrooms, enhancing its cost-effectiveness. Comprising three components—attendance system, student profile system, and training—the system utilizes a fusion of two deep learning algorithms: Multi-Task Cascaded Convolutional Neural Network (MTCNN) and FaceNet in developing the face recognition system. Chaudhari *et al.* [85] employed a blend of facial recognition and facial recognition algorithms to construct a video-based system for efficiently and accurately recording participant attendance. The approach involved utilizing FaceNet for feature extraction and MTCNN for detecting the student's image for recognition. Subsequently, the output underwent analysis by a Support Vector Machine (SVM) to identify the person of interest in the image. Thakur *et al.* [86] suggest integrating cutting-edge frameworks for object detection and face recognition to create an automated attendance system capable of detecting and recognizing students in a lecture. By employing a camera sensor and connecting to the university's server, the attendance information can be promptly updated in the database in real time. Hasan *et al.* [87] proposed an automated attendance mechanism utilizing Deep Convolutional Neural Networks (DCNN), by employing SeetaFace, a DCNN-based face detection system, in real-time video capture for face detection. This implementation is based on VIPLFaceNet, while for image categorization, AlexNet, another DCNN, is utilized. The experimental outcomes identify four distinct situations in the classroom, including absence, delayed arrivals, early departures, and unauthorized entries during sessions. The system captures relevant information such as name, student ID, and section, and integrates this data into an attendance sheet for evaluating the presence of students or individuals in the classroom. A. N. Prasetya and S. Supriyanto [88] developed the Reglab application to automate attendance tracking in the Informatics Engineering Practicum at Ahmad Dahlan University, addressing issues with manual attendance systems such as data inaccuracies and lost sheets. By incorporating GPS technology and using the Agile methodology, Reglab enhances efficiency, ensuring secure data management and improved user experience while meeting the growing demands of student and practicum schedule data.

An IoT-enabled attendance system not only automates attendance tracking but also provides enhanced security through advanced biometric technologies, ensuring that students are accurately identified in real-time. By incorporating tools like fingerprint sensors, RFID readers, and facial recognition systems, the system reduces the risk of proxy attendance and increases the overall reliability of the data collected. The use of cloud computing further facilitates the secure storage and easy retrieval of attendance data, making the system more accessible and efficient. With advanced algorithms like MTCNN and FaceNet, the system can accurately recognize students, even in challenging environments, while maintaining high levels of privacy and data security. Additionally, integrating systems like the SAMS ensures that the data is tamper-proof, providing transparency and reducing the chances of manipulation or errors, which ultimately enhances the integrity of the attendance management process.

B) An IoT Technology Integrated with Advanced Pedagogical Approaches

Azamat *et al.* [89] conducted a thorough examination of two popular modern teaching approaches: the flipped classroom and gamification. They incorporated the flipped classroom model, enhanced by the IoT, into the computer networks course using Cisco networking academy tools instead of conventional teaching methods and found that the flipped classroom strategy surpassed the traditional approach, showcasing an approximately 20% improvement in average attendance, lab activities, quiz results, midterm exams, and final exam performance. Marunevich *et al.* [90] have contributed significantly to the advancement of more sophisticated e-learning and m-learning tools, recognizing their pivotal role in educational institutions. E-learning involves the sharing of knowledge and skills through web-based technology, while m-learning pertains to the same sharing process through mobile-based technology. Kumar Basak *et al.* [91] conducted a comprehensive analysis of the literature (examining the definition of concepts, terminology, distinctions, fundamental perspectives, advantages, drawbacks, similarities, and differences) among e-learning (electronic learning), m-learning (mobile learning), and d-learning (digital learning). They concluded that e-learning and m-learning are subsets of d-learning, and in some cases, specific learning tools can be categorized as both m-learning and e-learning. Amad *et al.* [92] investigated the effects of implementing the flipped classroom pedagogical approach through the M-learning model on learners' motivation and engagement in the learning process. The results revealed that the experimental group exhibited enhanced learning outcomes and notable motivation, as assessed by the ARCS model.

Incorporating IoT technology with advanced pedagogical approaches such as flipped classrooms and gamification can significantly enhance learning outcomes by making education more interactive and engaging. The flipped classroom model, when paired with IoT tools like Cisco networking academy, shifts the focus from traditional lectures to student-centered learning, allowing students to engage with content outside of class and use class time for interactive, hands-on activities. This model has shown improvements in student performance, with approximately a 20% increase in attendance, lab participation, and exam results. Additionally, the use of gamification can further drive engagement by introducing elements of competition, rewards, and real-time feedback, motivating students to actively participate in their learning process. The integration of IoT into e-learning and m-learning platforms provides a more personalized and accessible learning experience, allowing students to learn at their own pace and according to their individual needs. E-learning platforms utilize web-based technologies to facilitate knowledge sharing, while m-learning uses mobile-based tools for greater flexibility and on-the-go learning. Both platforms benefit from IoT integration by enabling real-time feedback, data tracking, and adaptive learning pathways that cater to different learning styles. Studies have shown that incorporating these technologies leads to improved student engagement and higher motivation, with learners experiencing enhanced outcomes, including better academic performance and increased participation in the learning process. By fostering a more interactive and personalized learning environment, IoT-supported educational tools not only improve academic results but also encourage students to take a more active role in their education.

C) An Assessment, Evaluation, and Feedback System Enhanced by IoT Technology

Farhan *et al.* [93] created an IoT-based interaction framework for the analysis of student experiences in electronic learning (eLearning) that involved evaluating the learning behaviors of students participating in remote video lectures by logging their activities and analyzing the multimedia data generated through machine learning algorithms. The development included an attention-scoring algorithm along with its workflow and a mathematical formulation designed for the intelligent assessment of the student learning experience. In a separate investigation, Farhan *et al.* [94] suggested the creation of an interaction framework grounded in development and conducted an analysis of students' experiences in electronic learning (eLearning). This analysis focused on measuring student attention, recognized as a crucial aspect of educational assessment related to student interaction.

To enhance assessment, evaluation, and feedback systems, IoT technology is utilized to monitor student behaviors and interactions during remote learning. Tools such as machine learning algorithms and attention-scoring systems are applied to analyze multimedia data from eLearning activities. The expected outcomes include more accurate assessments of student engagement and learning experiences, allowing for real-time feedback and tailored instructional adjustments, ultimately improving overall educational effectiveness. These IoT-based frameworks enable educators to gather detailed insights into student attention and participation, leading to more personalized learning experiences.

D) STEM (Science, Technology, Engineering, and Mathematics) Education Incorporating IoT Technology

Abichandani *et al.* [95] conducted an analysis of curriculum, pedagogy, and assessment strategies within the framework of the sensing, networking, services, and interface layers of the IoT technology paradigm. The review highlights optimal educational practices and amalgamates practical strategies for educators to foster impactful IoT learning experiences for students. These strategies involve the use of budget-friendly IoT hardware, open-source IoT software, active learning-oriented instructional methods, and direct/indirect assessment techniques. Nikitina and Ishchenko [96] explored the significance of integrating "Smart-systems" technologies into STEM education, emphasizing their role in preparing students for the future through hands-on experiences, the cultivation of critical thinking, and the enhancement of problem-solving skills. The research explored a range of technologies linked to "Smart-systems," including robotics, IoT, AI, and data analytics, providing a detailed understanding of how these technologies can be applied in the field of STEM education. Balaji *et al.* [97] outlined the advantages of utilizing a teaching methodology grounded in Artificial Intelligence, the Internet of Things, and STEM Social Enterprise Learning to inspire innovative thinking among students pursuing engineering education. Benita *et al.* [98] investigated an ecosystem based on IoT devices that can be utilized to offer STEM educational activities for students. The goal is to foster the development of specific STEM skills, including problem identification and solving, cognitive and analytical thinking, spatial skills, mental manipulation of objects, organization, leadership, management, and more. Burbaitė and Gudonienė [99] proposed a model and IoT concepts designed for educators in STEAM, outlining how to practically incorporate IoT concepts into Computer Science Education through processes such as modeling, construction, programming functionality, implementation, and realization within the STEAM framework. Habib *et al.* [100] created an intelligent toolkit in conjunction with a Teaching and Learning (T&L) module to impart STEM knowledge to students. The toolkit includes an Input/Output (I/O) test board capable of conducting both analog and digital data acquisition. At the core of this toolkit is the Raspberry Pi, responsible for processing and transferring the gathered data to a cloud platform called ThingsSentral™ for systematic storage, analysis, and graphical representation of data.

Integrating IoT technology into STEM education enhances teaching and learning by providing hands-on experiences that foster critical thinking and problem-solving skills. Practical strategies for educators include using cost-effective IoT hardware and open-source software, alongside active learning techniques and diverse assessment methods. The use of IoT, AI, and robotics in STEM curricula helps students develop essential skills such as creativity, innovation, and technical proficiency. IoT ecosystems can be employed to support skill development in areas like cognitive and analytical thinking, leadership, and organization. Additionally, IoT tools and models in education allow for interactive learning experiences, such as data acquisition and cloud-based analysis, that make complex STEM concepts more accessible and engaging. This approach equips students with the knowledge and skills necessary for the rapidly evolving technological landscape.

5. CONCLUSIONS

This study provides a comprehensive analysis of IoT integration within university environments, emphasizing how smart management systems can enhance operational efficiencies, improve student engagement, and optimize educational outcomes. Through case studies, including those from The Technical University of Cluj-Napoca, the research demonstrates the significant potential of IoT in streamlining functions such as energy management, campus security, and personalized learning experiences. The study highlights several critical findings: IoT can optimize operational efficiency by reducing energy consumption and waste, improve student engagement through personalized learning tools, and enhance campus security with advanced monitoring systems. However, challenges such as high deployment costs, maintenance requirements, data privacy concerns, and system interoperability issues need to be addressed for effective IoT adoption. These findings have direct implications for real-world applications. University administrators can use this research to guide IoT implementation strategies, focusing on cost-effective, scalable solutions that align with sustainability goals. Policymakers can develop frameworks for smart campus policies, emphasizing data security, privacy protections, and equitable access to technology. Furthermore, the study underscores the need for universities to tailor IoT solutions to their unique institutional needs, considering factors such as infrastructure, budget, and stakeholder acceptance. While this study offers valuable insights, it has limitations, such as the limited geographical scope and a focus on specific case studies. Further exploration is needed to include a broader range of institutions, especially in developing regions where IoT infrastructure may be less advanced. Additionally, emerging IoT technologies not covered in this study, such as 5G applications or advanced AI-driven systems, could provide new perspectives on the future of smart universities. Future research should explore the evolving security challenges associated with IoT in educational settings, including privacy risks and data breaches. There is also a need for further investigation into the long-term impacts of IoT on educational outcomes, particularly in terms of student learning and academic success. As IoT technologies continue to develop, studying their integration with next-gen learning tools and pedagogies will be crucial for shaping the future of education. The ethical implications of IoT in education cannot be overlooked. Privacy concerns related to the collection and use of student data, as well as the potential for biased algorithms in adaptive learning systems, must be carefully managed. Universities must prioritize transparency in data usage and ensure that systems are designed to protect students' rights. A balance must be struck between technological advancement and human-centered approaches that promote fairness, accessibility, and inclusion. This study aligns with current trends in educational technology and reflects the growing emphasis on smart campuses globally. As institutions increasingly adopt IoT solutions, the findings of this research are timely and relevant for stakeholders involved in smart university planning, including technologists, educators, and policymakers. In conclusion, while IoT offers transformative potential for higher education, its successful implementation requires careful planning, ethical consideration, and a commitment to equitable access. The recommendations provided in this study should serve as a roadmap for universities looking to harness IoT to create smarter, more sustainable, and effective educational environments.

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