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Trends in IoT applications in smart campuses : A topic modeling approach

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This article provides an in-depth examination of the emerging field of smart campuses and IoT by investigating the thematic landscape of existing literature. The study employs Latent Dirichlet Allocation (LDA) topic modeling to analyze the thematic landscape, identifying key research areas and themes. The dataset consists of 507 research articles retrieved from the Scopus database, covering the period from 2014 to 2023. The LDA model was optimized with $\alpha = 0.1$ and $\beta = 0.01$, and the number of topics (K) was determined as 8 based on the c_v coherence score (0.393), ensuring robust topic extraction. This analysis offers a comprehensive overview of the current state of smart campuses and IoT research, revealing diverse research themes such as "Comprehensive Technology Integration and Management," "Artificial Intelligence and Cloud-Based Systems," "Educational Technologies and Innovative Applications," "Low Power Networks," "Smart Education Environments," "Safe and Flexible Smart Campus Architecture," "Energy Efficient Smart Buildings," and "Sustainable Smart Education and Urban Development." These themes highlight the complexity and multidimensionality of the research in this field. While the study provides valuable insights, it is important to acknowledge certain limitations, such as potential biases in dataset selection and the interpretative nature of topic modeling. Moreover, the LDA model's dependence on predefined topic numbers might limit its ability to capture emerging research themes comprehensively. Future research could refine these findings by incorporating additional datasets, employing alternative modeling approaches such as Hierarchical Dirichlet Process (HDP), and integrating hybrid methodologies to enhance thematic robustness. The study's findings underscore the diversity and richness of research themes, offering valuable insights for researchers and practitioners, and facilitating more targeted and effective future research and innovation.

Keywords: *Smart campus, Internet of things, Topic modeling, Trend analysis.*

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Introduction

In recent years, rapid technological advancements have facilitated ongoing interaction between individuals and technological systems, which is crucial for resource optimization in both public and private sectors [1]. This transformation extends to universities, which are evolving to fulfill their roles in education, community service, and technological leadership more effectively by utilizing their resources efficiently [2]. A key aspect of this evolution is the emphasis on personalized learning experiences and enhancing university environments [1].

Smart campuses combine traditional educational settings with digital technologies, aiming to enrich learning experiences while optimizing the use of human labor, time, and resources [2]. They adapt to changing conditions, meeting the needs of students and academics efficiently while offering solutions in areas such as energy efficiency, sustainability, and transportation [3], [4]. By integrating IoT, smart campuses improve educational processes, making life more comfortable, secure, and practical for users, and shaping future educational paradigms [5]. Research in this field has grown, demonstrating IoT's role in creating interactive learning environments, optimizing energy consumption, and enhancing security systems [6], [7].

The use of IoT in smart campuses has become more prevalent, with systematic analyses highlighting its expanding applications. For instance, Nie [8] explored how smart campuses emerged through the integration of cloud computing and IoT, while Fernández-Caramés and Fraga-Lamas [9] outlined key characteristics, technologies, and applications of smart campuses, offering guidelines for planners and developers. Madyatmadja et al. [10] discussed how IoT could be implemented in a smart campus, and Anagnostopoulos et al. [11] addressed smart campus surveillance systems, positioning smart campuses as miniature versions of smart cities. Similarly, Luckyardi et al. [12] examined various theories and models of IoT in smart universities, and Polin et al. [13] discussed the impact of digital transformation on smart campuses. Recent studies have further explored how digital twins can simulate and enhance smart campus operations, reducing energy consumption and improving security protocols [14]. Additionally, blockchain-based IoT networks have been proposed for secure data sharing among smart campus infrastructures, mitigating cyber threats and enhancing interoperability [15].

Despite the growing body of research, existing studies tend to focus on specific case studies or technological implementations rather than providing a comprehensive overview of research trends in IoT applications for smart campuses. While bibliometric analyses have been used to study IoT trends in other domains (e.g., smart cities and industrial IoT), a systematic, data-driven examination of IoT research in smart campuses remains limited. Previous studies primarily employ qualitative approaches or small-scale bibliometric analyses, lacking a thematic exploration of large-scale academic literature. Additionally, there is a lack of research that tracks the evolution of research themes over time to identify emerging trends.

Bibliometric and content analyses are essential for understanding IoT research trends from a social sciences perspective. For example, Leong, Tajudeen, and Yeong [16] used these methods to identify trends in IoT research, emphasizing the importance of examining technology adoption behaviors in areas like smart homes. This indicates that IoT has the potential to revolutionize educational environments, with bibliometric analysis and topic modeling being critical for understanding research trends in this field. However, research on smart campuses has not yet applied advanced topic modeling techniques to uncover latent themes in the literature. This study addresses this gap by employing Latent Dirichlet Allocation (LDA) topic modeling to analyze IoT research in smart campuses, offering a structured and scalable approach to identifying key themes and research trends.

This study employs bibliometric analysis and topic modeling to analyze publications on smart campuses and IoT usage. Bibliometric analysis helps track the evolution of a scientific field [17], while topic modeling identifies hidden themes in large text collections [18]. This analysis reveals the key themes and trends in smart campus and IoT research over time, providing valuable insights into the role of smart campuses in education.

By systematically mapping the thematic landscape of IoT applications in smart campuses, this research offers a novel perspective on the field's development, highlighting key research gaps, and guiding future academic and practical advancements.

The research aims to uncover the dominant themes and their evolution, offering a complex understanding of IoT's role and strategies for integration in smart campuses. It focuses on three primary research questions:

1. What are the bibliometric characteristics of IoT research in smart campuses from 2014 to 2023?
2. What key topics have emerged in IoT research within smart campuses during this period?
3. How have research trends in IoT usage within smart campuses evolved?

The study addresses these questions using topic modeling to advance the understanding of IoT applications in smart campuses. The article is organized as follows: the next section outlines the methodology, followed by the presentation of empirical findings. The discussion and conclusion sections synthesize insights and practical applications, summarize outcomes, acknowledge limitations, and propose future research directions.

Method

In the relevant section of this study, the methods used, along with the data collection and analysis processes, are detailed extensively.

Data collection

In this study, the Scopus database was utilized for literature review and data collection processes. Scopus is a comprehensive database that includes over 7,000 publishers from 240 different disciplines, led by industry leaders such as Emerald, Taylor & Francis, Elsevier, Sage, Springer, IEEE, and Wiley Blackwell [19]. During the data collection phase of the research, a total of 507 studies published between 2014 and 2023 were accessed based on the keywords ("smart campus" OR "smart university") AND ("internet of things" OR "IoT") in English. These include articles, reviews, conference proceedings, conference reviews, books, and book chapters. Key bibliographic details—including article titles, keywords, abstracts, countries of origin, DOIs (Digital Object Identifiers), publication venues (journals or conferences), and publication years—were systematically extracted and organized into an Excel spreadsheet for further analysis. This dataset was used in the analysis process. Particularly, article abstracts were preferred for topic modeling analysis because they reflect the essence and key findings of the studies reported in the articles. This approach provides comprehensive information about the focus of the paper, the methodology adopted, and the contributions made. This method, based solely on examining abstracts, has been widely adopted among researchers, building on previous studies conducted across various fields [20], [21]. Software tools such as VOSviewer and MS Excel were used to assess the overall performance and development trends of the field, and the Gensim library within the Python programming language was utilized for topic modeling analysis.

Data analysis

Bibliometric analysis

Bibliometric analysis, a quantitative method for examining scientific publications, is widely regarded as a rigorous approach for analyzing large volumes of scientific data. Donthu et al. [22] offer a step-by-step guide to bibliometric techniques, demonstrating how to conduct these analyses reliably. This method is instrumental in identifying evolutionary nuances and new developments in a field. As Oliveira et al. [23] point out, bibliometric analysis is essential for mapping scientific knowledge and identifying research opportunities. It facilitates the quantitative assessment of articles, authors, institutions, countries, and journals, helping to classify scientific gaps and trends. According to Lazarides, Lazaridou, and Papanas [24], bibliometric analysis serves as a valuable tool for quantitatively evaluating the most influential articles, authors, and institutions in a given topic. Overall, bibliometric analysis is a powerful technique for understanding the structure, impact, and collaboration within scientific works, enabling researchers to identify influential trends and shape their research strategies accordingly.

Topic modeling

Topic Models refer to a sophisticated statistical language modeling approach designed to uncover latent structures within text-based datasets. This methodology is distinguished by its ability to facilitate the discovery of hidden data in the field of text mining and to analyze in detail the relationships between text documents [25]. Its versatility and effectiveness have attracted widespread interest in numerous disciplines, including but not limited to educational journals [26], management information systems [27], and cybersecurity [28]. Among the various topic modeling techniques—such as Latent Semantic Analysis/Indexing (LSA/LSI), Hierarchical Dirichlet Process (HDP), and Latent Dirichlet Allocation (LDA)—LDA has emerged as the most widely adopted method [29]. Its applications are extensive, with LDA-based approaches frequently employed across domains including natural language processing, text mining, and social media analysis [25]. Fundamentally, LDA is a probabilistic approach that assumes each document contains words that collectively express various thematic discussions or themes, originating from different distributions [30]. Initially, the model presupposes a predefined number of potential topics, leading to different word distributions within each topic. Latent Dirichlet Allocation (LDA) captures the core objective of topic modeling: uncovering latent thematic structures within large text corpora. Within this framework, documents are represented as probabilistic mixtures of topics, while each topic is characterized by a distinct distribution of words [18], [31]. LDA benefits from the clustering of semantically similar words together [18]. Clustering, a fundamental technique in machine learning, refers to the process of grouping data into a finite number of clusters based on similarity measures within the dataset [32]. In the context of LDA, the core assumption is that each topic is represented by a distinct probability distribution over words. Additionally, LDA posits that each document arises from a mixture of these latent topics and is associated with them in varying proportions [33]. Essentially, each document reflects a combination of these k latent dimensions by selecting a set of words that best capture the underlying thematic structure [25].

In this study, while performing topic modeling with Latent Dirichlet Allocation (LDA), parameter selection was performed based on common practices in the literature and a comprehensive sensitivity analysis. First of all, while determining the number of topics (K), the range of 5–15, which is frequently used in previous studies with similar data sizes and study areas (e.g. Blei, Ng, and Jordan [34]), was taken as the starting point.

Then, the coherence measure c_v was calculated for each of the K values (according to the method described by Röder, Both, and Hinneburg [35]) to test which model provided the most thematically consistent content. In addition, the hyperparameters α and β of the LDA model were tested with different combinations (e.g. α=0.01, 0.1, 0.5; β=0.01, 0.1, 0.5) to observe the stability of the model performance. The sensitivity analysis performed in this way revealed which parameter settings provided a consistent topic set. As a result of the examinations, the model containing 8 topics reached the highest value in terms of c_v score (0.393) and provided the most significant separation when the obtained topic headings were evaluated with content analysis.

Although a threshold of c_v of 0.7 is recommended in the literature, it is emphasized that this value may vary depending on the structure of the dataset, homogeneity of the documents and the study area [35]. Therefore, it is stated that c_v values in the range of 0.4–0.6 can also reflect sufficient thematic consistency in different types of datasets in the literature [36]. In our study, 0.393 was determined as the model parameter that produced the most consistent results considering the wide variety of terms and topics included in the examined dataset.

In exploring the optimal number of topics (K) for topic modeling, the research encompassed a K value range of 5 to 15. The 'c_v coherence criterion' proposed by Blei et al. [18] was used as an evaluation criterion, targeting a benchmark value of 0.7, indicative of a well-structured topic model. This methodological approach found that a model containing 8 topics (K=8), considering specific alpha (α) and beta (β) parameters, reached the peak of c_v coherence scores. Consequently, it was concluded that 8 topics offered a distribution that comprehensively and effectively represented the thematic content of the dataset, achieving an optimal topic number with a c_v score of 0.393.

Subsequent stages of the analysis involved measuring the proportion of each topic within individual documents, mapping the distribution of terms across topics, and assessing the overall prevalence of topics across the dataset. Such detailed examinations paved the way for temporal trend analyses of topics through the calculation of slope metrics. This rigorous analytical approach resulted in the compilation of a list detailing the top thirty terms ranked by their frequencies of occurrence, thus summarizing the essence of each identified topic.

Findings

This section addresses the research question: What are the prominent themes in Internet of Things (IoT) research within smart campuses? Our analysis provides a structured understanding of the evolving landscape by integrating bibliometric insights with topic modeling results. The findings not only illustrate trends in publication outputs and citations but also highlight how emerging research themes align with broader technological advancements and societal needs.

Bibliometric analysis findings

The data in Table 1 presents a consolidated overview of 507 publications between January 2014 and December 2023. The findings indicate a significant rise in research interest in smart campuses and IoT, particularly from 2019 onwards, as 80.9% of publications were produced during this period. Additionally, the highest citation count was recorded in 2019, while the average number of citations per publication peaked in 2017, suggesting that earlier foundational studies had a lasting impact on the field. To enhance clarity and avoid redundancy, overlapping details on publication trends and citations have been consolidated, emphasizing the most critical insights.

Table 1

Publication year, citations and average citations

Year	# Publications	% of Total Publications	Citations	Average Citations
2023	83	16,37%	49	0.59
2022	89	17,55%	221	2.48
2021	95	18,74%	603	6.35
2020	75	14,79%	794	10.59
2019	68	13,41%	1118	16.44
2018	47	9,27%	907	19.30
2017	32	6,31%	1014	31.69
2016	9	1,78%	177	19.67
2015	4	0,79%	67	16.75
2014	5	0,99%	119	23.8
Total	507	100,00%	5069	10.0

The steady increase in the number of publications highlights the growing research interest in smart campus technologies. Notably, research output between 2019 and 2023 accounts for the majority of contributions, reflecting a shift toward digital transformation and IoT adoption in higher education institutions. The citation trend further supports this observation, as foundational studies published before 2019 received higher citations, emphasizing their impact on the domain.

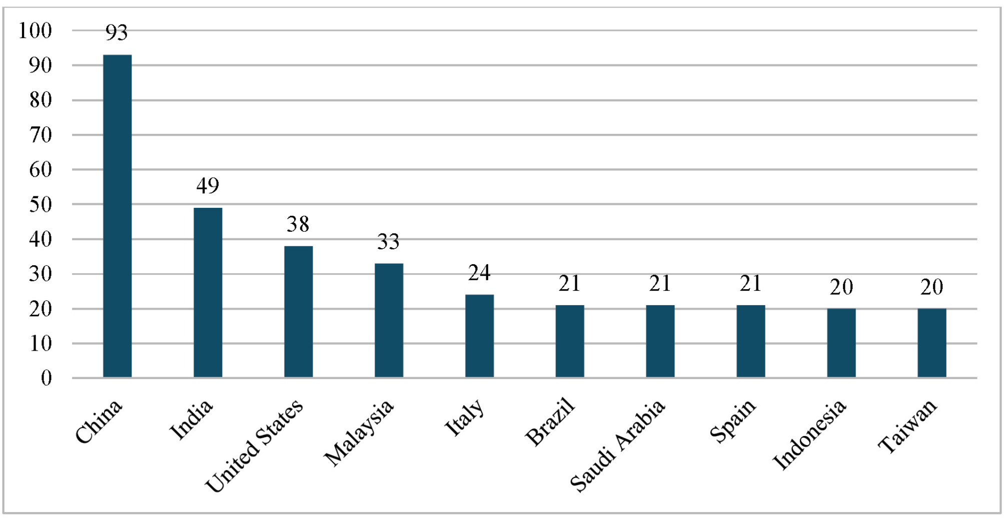

Figure 1

Top Countries

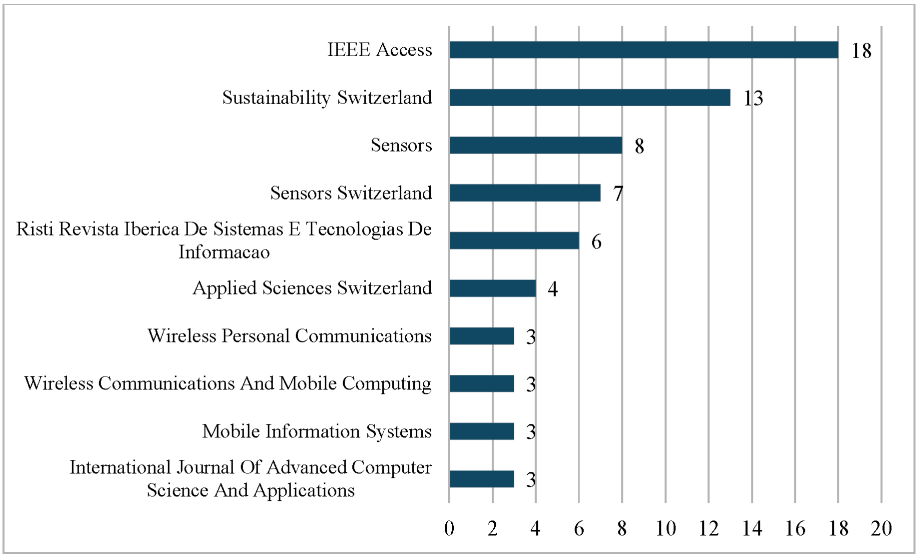

Figure 2

Top Journals

Figure 1 presents an overview of the top ten countries contributing to smart campus and IoT research. The global distribution of research output is heavily influenced by factors such as technological infrastructure, national funding programs, and collaborations between academia and industry. China's leadership (18.34%) in research is driven by strong government-backed initiatives, smart city projects, and extensive IoT investments. Similarly, India's rapid technological adoption and partnerships between universities and technology firms have fostered a dynamic research ecosystem. The United States maintains significant contributions due to university-industry collaborations and sustained funding from technology firms. Meanwhile, Malaysia and Italy have seen increased contributions due to policy-driven digital transformation strategies and institutional support for IoT-driven educational frameworks. These insights demonstrate how regional policies and funding priorities shape the development of smart campus research worldwide.

The compilation consists of contributions from both journals and conference proceedings, with Figure 2 identifying the top ten journals that serve as primary sources of literature on smart campuses and IoT. This publication model underscores the increasing interest in technological advancements and ecosystem studies within smart campuses. The presence of leading interdisciplinary journals highlights the expanding scope of IoT applications in education, sustainability, and digital infrastructure management.

Topic modeling findings

An analysis using Latent Dirichlet Allocation (LDA) was conducted to explore emerging themes in research on smart campuses and the Internet of Things, resulting in the

Table 2

8 Topics Discovered by LDA

Topics	Terms	%
Comprehensive Technology Integration and Management	data | system | technology | application | service | management | network | information | environment | device	56,21
Artificial Intelligence and Cloud Based Systems	system | model | network | service | learning | data | application | computing | machine | cloud	12,82
Educational Technologies and Innovative Applications	education | technology | learning | system | student | parking | data | model | higher | adoption	10,26
Low Power Networks	network | system | technology | lora | communication | monitoring | sensor | wireless | lorawan | low	5,33
Smart Education Environments	system | teaching | classroom | technology | information | management | model | development | intelligent | construction	4,93
Safe and Flexible Smart Campus Architecture	architecture | data | middleware | network | software | security | device | cloud | application | service	4,14
Energy Efficient Smart Buildings	energy | building | system | management | control | consumption | indoor | air | data | use	3,55
Sustainable Smart Education and Urban Development	learning | city | technology | student | system | sustainable | environment | development | time | real	2,76

identification of eight distinct topics. The effectiveness of topic classification using LDA models is highly contingent upon the selection of an appropriate number of topics, as this parameter critically influences the coherence and interpretability of the resulting thematic structures. A balance between specificity and generalizability was achieved by selecting K=8, based on coherence scores and prior studies. Overly narrow selection can lead to broad thematic categories, while too many topics may result in excessive clustering and redundancy. To strengthen the rationale behind topic selection, the significance of each theme has been explicitly tied to broader technological and educational trends.

The topic "Comprehensive Technology Integration and Management" (56.21%) emerged as the most dominant theme, aligning with the broader trend of digital transformation in higher education. This theme reflects the increasing demand for seamless integration of IoT solutions across various campus operations, supporting real-time data exchange, security enhancements, and resource optimization. The high prevalence of this topic can be attributed to the growing need for interoperability among smart campus subsystems, ensuring efficiency and sustainability.

Table 3

Distribution of th Publications on the Topics by Years

Topics	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Comprehensive Technology Integration and Management	4	3	6	21	28	40	43	53	44	43	285
Artificial Intelligence and Cloud Based Systems	1	1	2	5	4	10	6	10	13	13	65
Educational Technologies and Innovative Applications	0	0	0	2	3	6	8	10	11	12	52
Low Power Networks	0	0	0	1	4	5	4	6	5	2	27
Smart Education Environments	0	0	0	0	1	2	4	8	7	3	25
Safe and Flexible Smart Campus Architecture	0	0	1	1	5	1	5	1	2	5	21
Energy Efficient Smart Buildings	0	0	0	1	2	2	3	3	5	2	18
Sustainable Smart Education and Urban Development	0	0	0	1	0	2	2	4	2	3	14
Total	5	4	9	32	47	68	75	95	89	83	507

On the other hand, the relatively lower prevalence of topics such as “Energy Efficient Smart Buildings” (3.55%) can be explained by the nascent stage of energy management applications in smart campuses. While energy-efficient solutions are critical for sustainability, the integration of such technologies has been slower due to cost, regulatory constraints, and the complexity of retrofitting existing infrastructure. However, the upward trend in this research area suggests a growing recognition of its importance.

Table 3 illustrates noticeable changes in research interest over time. The peak of 285 publications in “Comprehensive Technology Integration and Management” underscores the significance of Internet of Things usage in smart campuses research. “Educational Technologies and Innovative Applications,” initially garnering minimal interest, experienced a notable increase, especially since 2017, demonstrating a growing interest in innovative applications of IoT for education. Similarly, “Artificial Intelligence and Cloud-Based Systems” has gained momentum, highlighting the increasing role of AI-driven automation, predictive analytics, and cloud solutions. Conversely, “Low Power Networks” and “Safe and Flexible Smart Campus Architecture” exhibit slower momentum, potentially due to limited technological adoption and infrastructure challenges. However, these areas remain crucial for developing efficient and secure smart campus solutions.

The topic of “Comprehensive Technology Integration and Management” topic dominates in terms of volume (56.21%) and exhibits significant momentum (5.76%), emphasizing the ongoing and increasing scientific focus on this topic. Following closely is “Artificial Intelligence and Cloud-Based Systems” with substantial volume (12.82%) and momentum (1.46%), indicating the growing interest in its impact on technological innovations. While ranking third in terms of volume (10.26%), “Educational Technologies

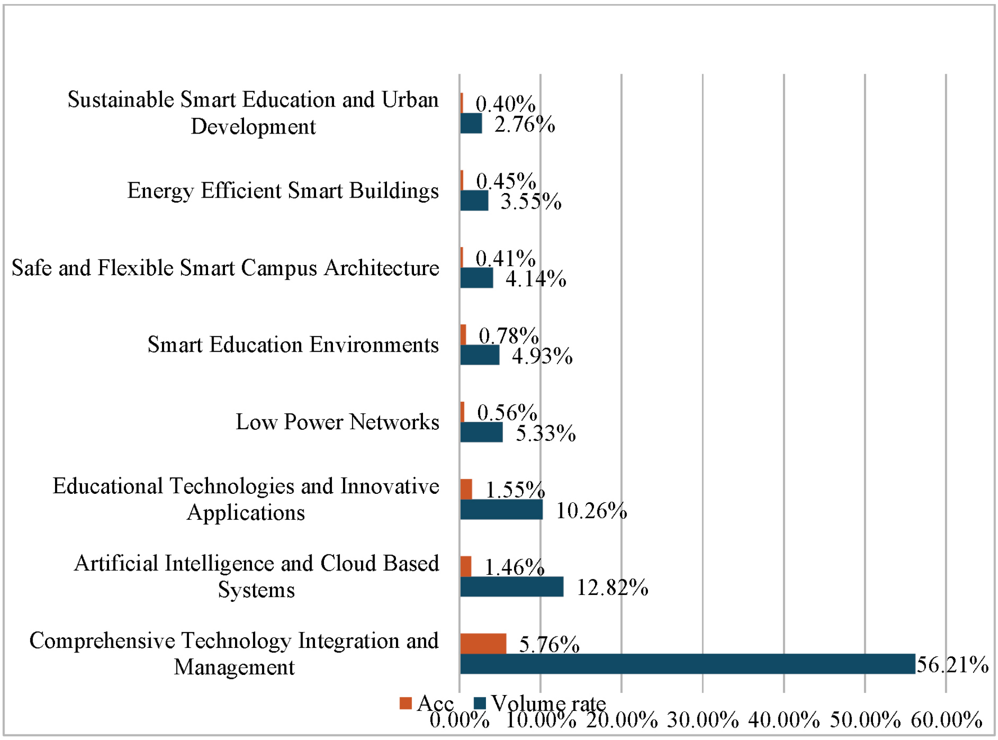

Figure 3

Volume and accelerations

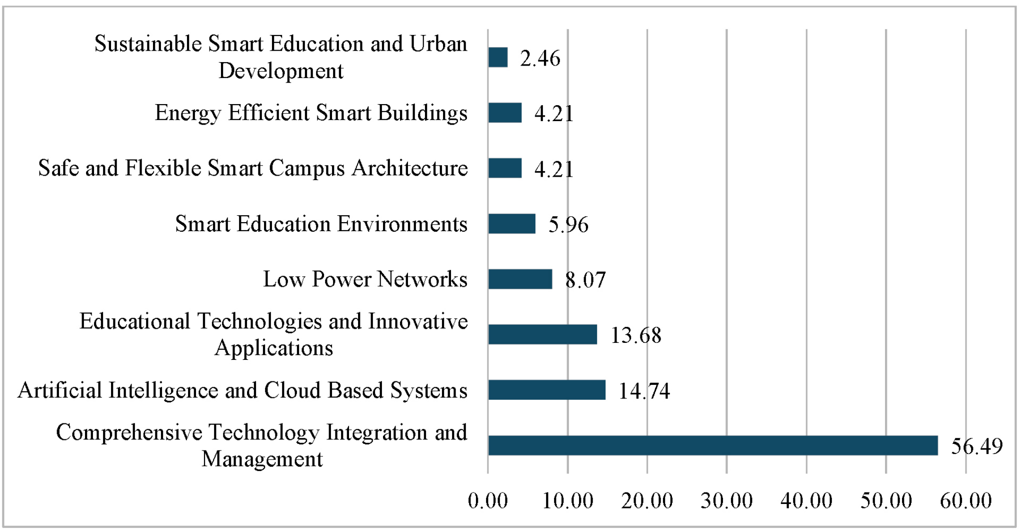

Figure 4

The accelaration of the topics within themselves

and Innovative Applications" ranks second in momentum (1.55%), reflecting intense research efforts in this area. The topic of "Low Power Networks" ranks fourth in volume (5.33%) but shows slower momentum (0.56%), indicating an established yet moderately growing research area.

"Smart Education Environments" ranks fifth in volume (4.93%) but fourth in momentum (0.78%), signaling an active and expanding research field. The momentum rate (0.41%) for "Safe and Flexible Smart Campus Architecture" underscores the increasing importance of regulatory frameworks in micromobility research. Figure 4 explains the growth trends in each topic area; the slope value represents the rate of increase or growth rate over time. A high slope value indicates a rapid increase in research volume for a topic, while a low value indicates a slower growth rate or stagnation.

In Figure 4, "Comprehensive Technology Integration and Management," "Artificial Intelligence and Cloud-Based Systems," and "Educational Technologies and Innovative Applications" are identified as having the most significant growth trends. In contrast, "Sustainable Smart Education and Urban Development" exhibits the lowest slope, shedding light on areas where research focus and efforts are concentrated and forecasting future scientific interest. Figure 5 represents comparative growth rates by ranking topic trends against each other, showing how interest in each topic has evolved over time relative to others. Positive values indicate increasing interest, while negative values indicate a decline.

The negative accelerations in "Comprehensive Technology Integration and Management" suggest a waning interest in other areas, possibly indicating research saturation or a shift towards emerging trends. While "Artificial Intelligence and Cloud-Based Systems" maintains its importance, its relative growth rate is decreasing. "Safe and Flexible Smart Campus Architecture" exhibits minor negative trends, indicating slower

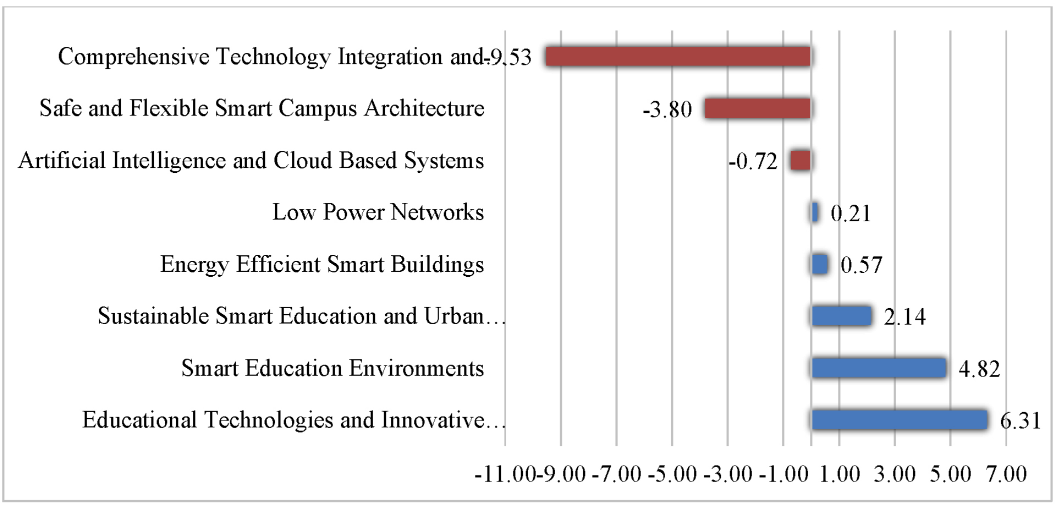

Figure 5

The accelerations of the topics compared to other topics

growth compared to other topics. “Energy Efficient Smart Buildings” and “Low Power Networks” show slight increases in interest levels. “Sustainable Smart Education and Urban Development” maintains its significance, experiencing a notable increase in interest. “Smart Education Environments” demonstrates significant growth rates, emphasizing the importance of technology in smart educational settings. With the highest positive slope, “Educational Technologies and Innovative Applications” emerges as the fastest-growing area, signaling increasing scientific interest in innovative applications of IoT in education technologies on smart campuses, potentially positioning it as a significant research focus in the future.

Discussion

Bibliometric features of internet of things in smart campuses (RQ1)

The relationship between the total number of publications and citations in the context of IoT in smart campuses provides insights into the field’s academic impact. From 2014 to 2021, there has been a noticeable increase in both publications and citations, indicating growing interest and maturity in IoT research for smart campuses. The average citations per publication peaked in 2017 (31.69), then gradually declined, suggesting a saturation in groundbreaking topics or a delay in citation accumulation for newer articles. A decrease in publications and citations from 2020 onwards, likely due to the COVID-19 pandemic, highlights the disruption’s impact on research outputs.

Notably, China, India, and the United States are the top contributors, with significant input from Malaysia, Italy, Brazil, Saudi Arabia, Spain, Indonesia, and Taiwan. This global distribution reflects the widespread recognition of IoT benefits in enhancing campus management and educational quality. Differences in publication numbers may be due to varying technology adoption rates, government support, financial resources, and educational technology priorities.

IEEE Access is the leading journal in this field, emphasizing an interdisciplinary approach covering sustainability, sensor technology, wireless communication, and information systems. The focus on sustainability and sensors highlights their importance in creating efficient, responsive, and environmentally friendly educational environments. This analysis helps researchers identify key journals and trends in IoT applications for smart campuses, guiding future research and innovation efforts.

Prominent topics of internet of things in smart campuses (RQ2)

The topic modeling analysis of 507 articles on the Internet of Things (IoT) in smart campuses identified eight main themes. The most researched topic, “Comprehensive Technology Integration and Management,” highlights the role of IoT in integrated road network monitoring and security services, emphasizing the need for inter-departmental collaboration and comprehensive management systems [37]. IoT is crucial for enhancing both educational and administrative functions in smart campuses by improving infrastructure, information services, and overall management [38]. Combining IoT with big data technologies facilitates effective campus operations, resource management, and sustainability [3].

The second major topic, "Artificial Intelligence and Cloud-Based Systems," reveals how integrating AI and cloud systems through IoT has transformed educational environments, enabling efficient resource allocation, smart classrooms, and context-aware services [39]. These technologies support real-time data management, operational efficiency, and sustainability goals [40].

"Educational Technologies and Innovative Applications," the third topic, shows how IoT technology enhances smart learning environments by connecting various campus facilities, leading to improved resource management and secure educational experiences [41]. Smart campuses use IoT for innovative learning experiences, offering interactive smart classrooms and laboratories [42].

The topic "Low Power Networks" focuses on efficient data transmission and environmental monitoring through IoT devices [43]. Studies compared low-power wireless technologies for reliable, flexible communication, such as LoRaWAN networks for smart lighting systems [44].

"Smart Education Environments" and "Safe and Flexible Smart Campus Architecture" explore the integration of control networks to provide comprehensive information services and security solutions [45]. Analyses indicate the need for improved security technologies, with blockchain-based systems offering potential solutions for certification processes [46].

The themes "Energy Efficient Smart Buildings" and "Sustainable Smart Education and Urban Development" underscore the role of IoT and big data in managing energy consumption efficiently[47]. IoT technologies predict and manage energy use, contributing to sustainable urban development [48]. These technologies also improve the Smart Readiness Indicator (SRI) for campus buildings, demonstrating the IoT's role in enhancing sustainability and quality of life [49].

In summary, the analysis demonstrates IoT's critical role in smart campuses, enabling technology integration, operational efficiency, sustainability, and enriched educational experiences.

Emerging trends in internet of things in smart campuses research (RQ3)

The prominent trends of the eight topics emerging in the context of the Internet of Things (IoT) in smart campuses have been evaluated in this section. The most accelerating topics are respectively "Educational Technologies and Innovative Applications," "Smart Education Environments," and "Sustainable Smart Education and Urban Development." Digitization and technological advancements are revolutionizing the processes of learning and teaching. The growth in this area has become even more pronounced, particularly with the rise of remote learning and hybrid learning models during the pandemic period. Studies show that educational technologies enhance student participation and success, as well as facilitate access to learning materials [50]. Smart education environments, equipped with technologies such as IoT, artificial intelligence, and cloud computing, enhance personalization and interaction in education through smart classrooms. A study Zaballos et al. [49] demonstrates that smart education environments improve student interaction and learning experiences. Smart campuses play a significant role in sustainable urban development. The integration of smart technologies supports energy efficiency, resource management, and environmental sustainability, thereby helping educational institutions become greener and more efficient [48].

Conclusion

Summary of Findings

Interest in the Internet of Things (IoT) for smart campuses has surged recently, prompting comprehensive studies to explore this area. This research, spanning from 2014 to 2023, used the Scopus database and Latent Dirichlet Allocation (LDA) to analyze 507 publications. The study identified eight interconnected themes, highlighting key research directions: Comprehensive Technology Integration and Management, Artificial Intelligence and Cloud-Based Systems, Educational Technologies and Innovative Applications, Low Power Networks, Smart Education Environments, Safe and Flexible Smart Campus Architecture, Energy Efficient Smart Buildings, and Sustainable Smart Education and Urban Development. These themes reflect ongoing advancements in smart campus ecosystems, emphasizing areas such as AI-driven automation, cloud-based learning environments, and energy-efficient infrastructures. Additionally, the study underscores the disparity in research attention across themes, indicating opportunities for further investigation into underrepresented areas such as energy-efficient smart buildings and sustainable education models.

Real-World Applications and Policy Implications

The findings also hold significant policy and practical implications. Universities seeking to integrate IoT and AI-driven technologies into their campuses should consider long-term sustainability strategies, including investment in energy-efficient infrastructure and secure data-sharing mechanisms. The emergence of smart education environments suggests that policymakers should encourage adaptive learning technologies that improve student engagement and personalized learning experiences.

From an industry perspective, the growing interest in AI-driven campus solutions and low-power IoT networks indicates a shift towards more efficient and cost-effective implementations. Universities and educational institutions can leverage these insights to develop strategic partnerships with tech providers, ensuring that future smart campus solutions align with academic needs. Additionally, integrating blockchain-based cybersecurity measures can significantly enhance data privacy and protection, mitigating potential cyber threats.

Contributions

This research significantly enriches the understanding of IoT applications in smart campuses, offering theoretical, methodological, and practical contributions. Theoretically, the study maps key themes in existing research, providing a structured foundation for future investigations into smart campus innovation. Methodologically, this study adopts a broad article selection strategy, avoiding journal bias and minimizing researcher subjectivity through text-mining techniques. Practically, the study identifies priority areas for campus digitalization, offering a guiding framework for stakeholders to optimize educational, operational, and sustainability efforts.

Limitations and Future Research

This study acknowledges several limitations. Firstly, the analysis was confined to the Scopus database, potentially omitting relevant research from Web of Science, IEEE Xplore, and Google Scholar. Expanding future studies to include multiple databases would broaden the scope of insights. Secondly, the study analyzed only titles, keywords, and abstracts, which may have overlooked deeper contextual meanings present in full-text articles. Incorporating full-text analysis through natural language processing (NLP) techniques could enhance depth and accuracy. Finally, while LDA is a widely used topic modeling technique, it has inherent limitations in capturing nuanced relationships between topics. Future research could combine LDA with deep learning approaches, such as BERT-based topic modeling, to improve thematic precision.

To address these limitations and expand upon the findings, future research could explore how technological integration evolves within smart campuses by expanding upon the identified themes and examining their intersections with broader educational innovations. Comparative analyses with more recent literature could validate this study's findings and highlight emerging trends. Additionally, adopting a hybrid approach to content analysis, combining automated techniques with manual review of foundational or highly cited articles, may uncover deeper insights and latent themes, enhancing the overall understanding of smart campus developments. Investigating emerging IoT applications in newly developed smart campuses would help track the real-world impact of digital transformation in education. Furthermore, exploring AI-driven smart campus frameworks, leveraging machine learning and predictive analytics, could assess the evolution of technology adoption. Finally, assessing the role of policy and funding in shaping smart campus innovations would help identify key governmental and institutional drivers behind research trends.

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