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Review

The Making of Smart Campus: A Review and Conceptual Framework

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Abstract: Smart campus is an emerging concept enabled by digital transformation opportunities in higher education. Smart campuses are often perceived as miniature replicas of smart cities and serve as living labs for smart technology research, development, and adoption, along with their traditional teaching, learning and research functions. There is currently a limited understanding of how the smart campus is conceptualized and practiced. This paper addresses this gap by using a systematic literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach. The study uses four major domains of the smart campus, i.e., society, economy, environment, and governance, to classify existing research. These domains are each aligned to the central smart campus concepts of digital technology and big data. The analysis found little evidence of a comprehensive real-world application of the smart campus towards addressing all four domains. This highlights the infancy of the current conceptualization and practice. The findings contribute to the development of a new conceptual foundation and research directions for the smart campus notion and informs its practice through a conceptual framework. The findings reported in this paper offer a firm basis for comprehensive smart campus conceptualization, and also provide directions for future research and development of smart campuses.

Keywords: artificial intelligence; big data; digital transformation; higher education institution; industry 4.0; internet-of-things; PRISMA; smart campus; smart city; smart university; smartization process

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1. Introduction

Recent technological advancement in this era has far-reaching development phases in cloud computing, big data, Internet-of-Things (IoT) and artificial intelligence (AI) [1]. Higher education institutions (HEI) have used these technologies in their campuses to reform teaching, learning and research experiences of university students and staff, including alternative modes of attendance and collaboration [2]. Today, more and more university administrations are embracing digital campus transformations [3].

The digitally transformed university campus is also referred to as 'smart campus' [4,5]. Smart campuses model the smart city ecosystem, and along with their traditional teaching, learning and research functions, they also promote lifelong learning, research, innovation, and entrepreneurship, and offer various Living Lab programs [6].

Some scholars argue that technological progress, and other issues pertaining to the environment, economics and social sector make it inevitable that all education processes will become 'smart' whereby campuses will become learning and living environments that are integrated with advanced technological infrastructures, such as sensors, IoT and artificial intelligence (AI) [7,8]. Some others see a campus as a place of convenience, safety, sustainability, leisure and learning, enhanced by diverse and advanced systems and technologies [9]. Nevertheless, there is a lack of explicit definition of a smart campus beyond its heavy dependence on big data and digital technology [4,10].

Existing definitions of smart campus often consider the smart campus as being a miniature model of a smart city [11]. Other definitions describe it as a dynamic learning

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environment for fostering intelligence and smart solutions using people, physical infrastructure and digital technologies [12]. It is an emerging development in the education sector and in the application of AI [13], creating a cultural paradigm [14] or a smartization process (that is a planned and organized process by which an organization adopts and implements smart technologies in their operations), where universities are opening up their boundaries [15].

While many definitions are based on smart campus functions, commonly accepted conceptualizations of how these functions align to its idealized purposes are less understood. Table 1 summarizes the key definitions of a smart campus.

Table 1. Definitions of a smart campus.

Theme	Definition	Source
Smart city development focused	"Considered a small smart city that acts within the context of smart cities, which offer intelligent services and applications to their citizens to improve their quality of life."	[16,17] (p. 6)
	"Acts within the context of smart cities, which offer intelligent services and applications to their citizens to improve their quality of life."	[17] (p. 6)
Advanced technology infrastructure focused	"Refers to the hardware and software required to provide advanced intelligent context-aware services and applications to university students and staff."	[18] (p. 3)
	"A data-oriented, networked, intelligent and collaborative teaching, management and scientific research system based on big data, internet-of-things, mobile internet and other advanced information technologies."	[19] (p. 204)
	"A collaboration of technologies such as big data, cloud computing, IoT, internet and high-performance computing, virtualization, mobile network and social network, sensors and common communication interfaces."	[20] (p. 2)
	"Intelligent infrastructure where smart sensors and actuators collaborate to collect information and interact with the machines, tools, and users of a university campus."	[21] (p. 1)
	"Utilizes and integrates smart physical and digital spaces to establish responsive, intelligent, and improved services for creating productive, creative, and sustainable environment."	[22] (p. 3)
	"Not only about deploying smart platforms to effectively perform campus-related services but it is a broad concept that includes many electronic and physical objects that communicate and interact with each other."	[23] (p. 255)
Enhanced education experience focused	"An educational environment that is penetrated with enabling technologies for smart services to enhance educational performance while meeting stakeholders' interests, with broad interactions with other interdisciplinary domains in the smart city context."	[24] (p. 4)
	"Is the high-end form of education systems."	[25] (p. 16145)
	"To integrate information technology into teaching and education to provide a teaching environment with network, data, integration, and intelligence."	[26] (p. 450)

This study aims to develop a clearer understanding of how a smart campus is conceptualized and practiced by employing the PRISMA approach technique [27,28].

Following this introduction, Section 2 covers research design, search strategy, inclusion and exclusion criteria, and data analysis. Section 3 describes the results under general observations, and the four domains of smart campus. Section 4 presents and discusses the findings and its proposed conceptual framework, and Section 5 concludes the paper.

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Concept

2. Materials and Methods

2.1. Research Design

This paper draws on recent studies reported in the academic literature related to smart campus, where they attempt to comprehend the concept relative to their pursuits in a defined plan or protocol [29]. The systematic literature review approach was applied to identify and analyze papers relating to the concept of smart campus to gauge how this notion is conceptualized and practiced. The PRISMA approach with its four stages of identification, screening, eligibility and inclusion was adopted to deal with the unknown stack of publications out there and also to provide a structured and targeted search to obtain the key literatures for the construction of the conceptual framework.

The PRISMA study included four primary phases as shown in Figure 1. Online search, using the Scopus database, was utilized for the research. The search was confined to journal articles published between 2017 and 2022 to capture recent studies, considering the rapid phase of transformation in digital technology development. Only articles published in English were considered to avoid difficulties in translation and interpretation.

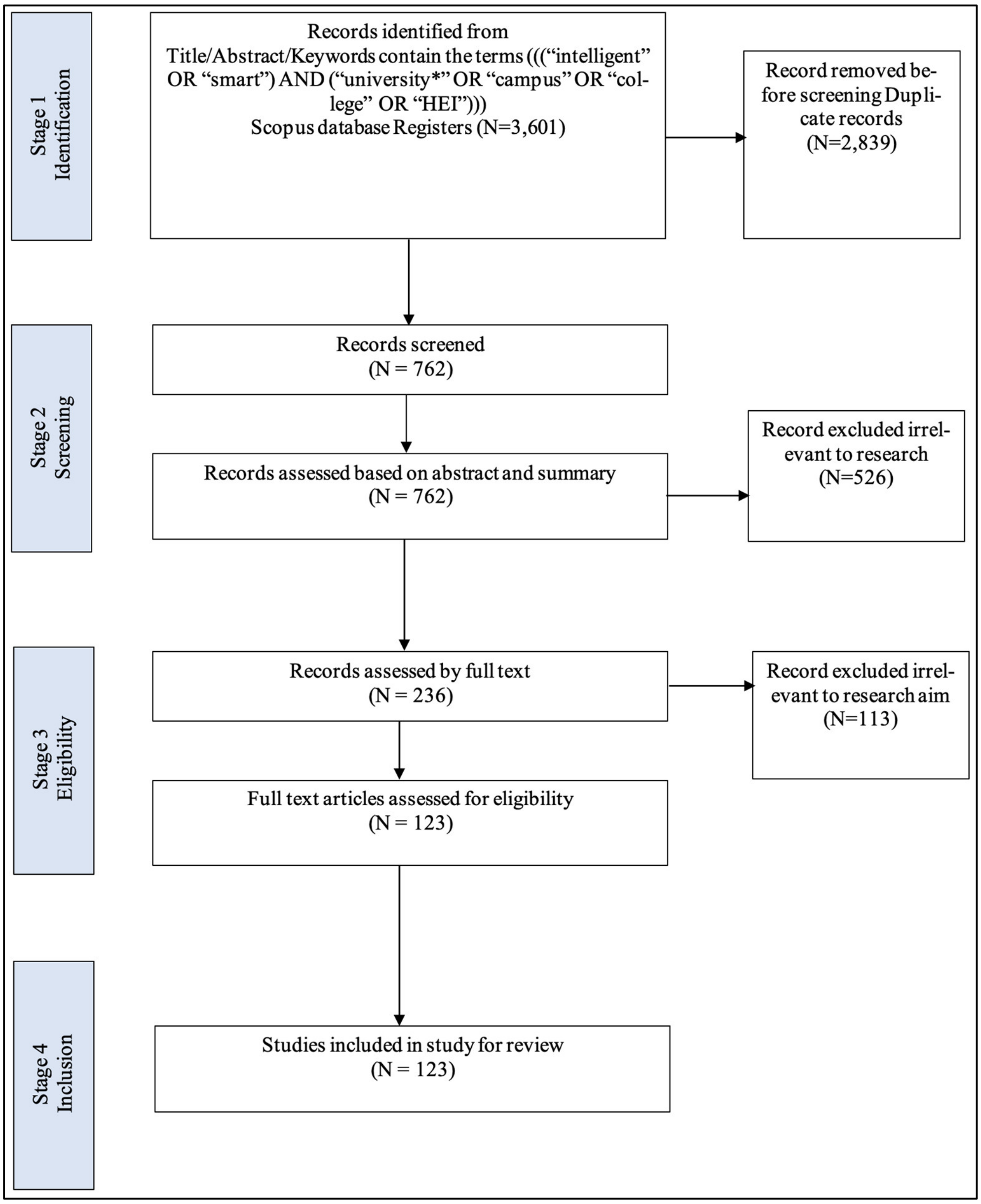

Figure 1. PRISMA review flow chart.

The first phase of identification in planning involved developing the research aim, research question, a list of keywords, and the criteria for the inclusion and exclusion of articles. The aim of the research was framed to generate insights into the application of the four domains in making smart campuses. The criteria for inclusion included peer-reviewed journal articles in English, available online, relevant to the research aim. The search was conducted using the query string of (((“smart” OR “intelligent”) AND (“campus” OR “universit*” OR “college” OR “higher education institution” OR “HEI”))) to search the titles and abstracts of available articles. The first stage of the search gathered 3601 journal articles. Further exclusions were applied on relevant subject areas, peer-review status, and online full-text availability, resulting in the selection of 762 articles.

The second phase of screening involved an assessment of the abstract and summaries of the articles, where 526 articles were removed, leaving 236 articles. The exclusion focused on the relevance of the articles to the objective of the paper on the four domains in the making of a smart campus. The third phase of eligibility evaluated full-texts of the articles where irrelevant articles were excluded, and 123 articles were retained, suggesting discussions related to the four smart campus domains. Finally, the fourth stage of inclusion focused on the reading of the full-text of the 123 articles, which met the research objectives. These articles provided sufficient grounding for the four smart campus domains. Figure 1 presents the PRISMA review flow chart, and the inclusion and exclusion criteria are listed in Table 2.

Table 2. Exclusion and inclusion criteria.

Primary Inclusionary Criteria	Primary Exclusionary Criteria	Secondary Inclusionary Criteria	Secondary Exclusionary Criteria
Academic journal articles	Duplicate records	Relevant to the smart campus notion	Irrelevant to the smart campus notion
Peer-reviewed	Books and chapters	Relevant to research objective	Irrelevant to research objective
Full-text available online	Industry reports		
Published in English	Government reports		

Relevant publications to the smart campus notion are those that cover the application of advanced AI in university campuses, focusing on capturing the recent developments in AI, IoT, Cloud Computing and Big Data. In addition, relevant publications to the research objective included those that contribute to the research aim to consolidate a clearer understanding of how the smart campus is conceptualized and practiced. They should address the array of smart campus definitions, demonstrate the latest technological development in smart campus, and finally, discuss the four domains for the conceptual framework of smart campus. On the other hand, any endeavor which does not suggest the application of AI, IoT, Cloud Computing and Big Data for university campuses are deemed irrelevant to the smart campus notion. Additionally, any endeavor which does not discuss smart campus definitions, smart technological development for campuses and the four domains are also deemed irrelevant to the research objective.

Out of 123 selected and reviewed papers, 81 relates to the smart campus domains (or categories) elaborated in the next section. The list of these papers is provided in Appendix A Table A1. These categorization criteria, or the analysis domains are elaborated in the following section. Selected 123 articles are read and following to the categorization, they are analyzed manually for their key aspects and contributions to address the research question of this study.

2.2. Category Formulation

Providing the review results in a structured way requires categorizing the literature on smart campus under widely accepted domains. For that purpose, the study adopted the four domains of economy, society, environment, and governance, with an overarching (digital) technology and (big) data perspective. These domains (illustrated in Figure 2) are widely used in urban research [30], and align with common understandings of sustainable development at the microlevel for an inclusive framework [31], which is generally a key rationale for the "smart" concept [32,33].

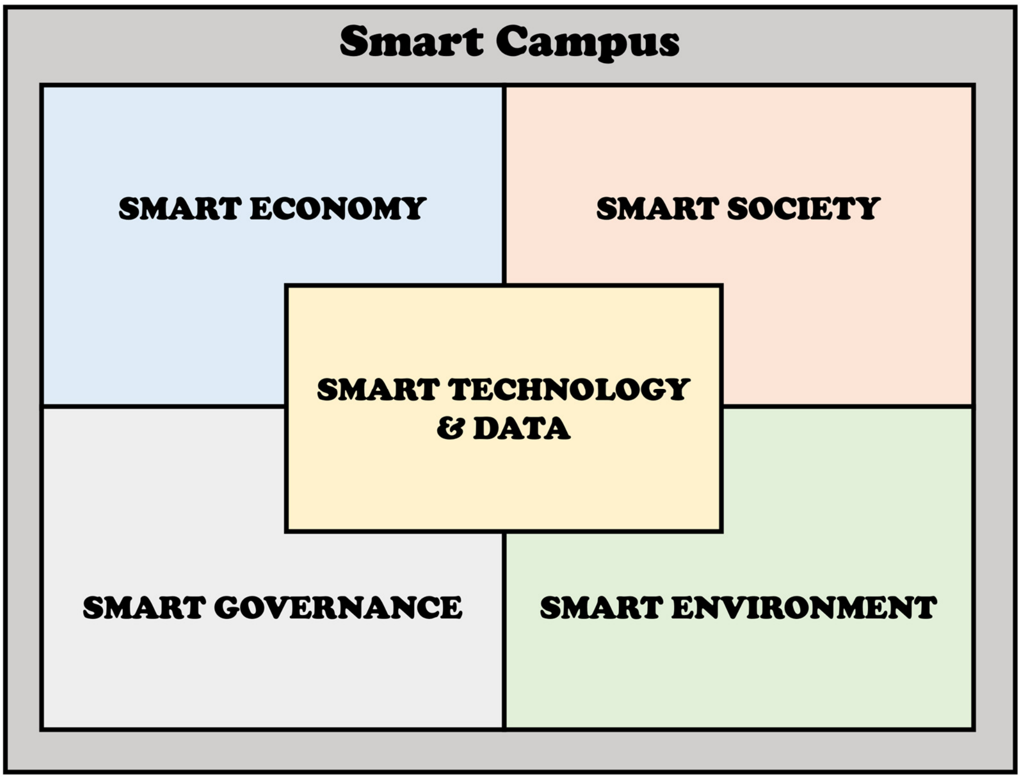

Figure 2. Smart campus domains.

The economy domain is concerned with business or capital investment activities, that are responsible for the efficient provision of services for the operation of organizations and citizens. Universities are expected to promote entrepreneurial activities, while serving their role in academic research [34].

The societal domain covers the social issues relating to the life of campus users [35]. It includes matters relating to safety, health, and equitable access to resources, opportunities, and services, with full allowance for cultural and spiritual needs. Normative social aspects also relate to deliberative processes that seek to empower campus citizens in the management and operation of the campus. As such, citizens are meaningfully engaged in any implementation of smart campus approaches [36].

The environmental domain is concerned with improving both the natural and built environments. It seeks to maintain species and habitats and ensure long-term sustainability, which also mean the sound integration of built and natural environments [37]. The environmental domain recognizes that the way natural resources are used and considered can influence the quality of campus life [38,39].

The governance domain is the enabler to achieve the smart campus as it involves strategic decision-making and implementation with the engagement of stakeholders. The emergence of the 'third mission' on universities induced the role of collaborative governance, shifting from public administration and political science in public policymaking to reach across the society through an inclusive approach to adopt specific public policies [40].

These four domains are supported by an overarching (digital) technology and (big) data perspective—that could be seen as the fifth category that has high interaction with the other four—in smart campuses [8,20,41]. For instance, big data handles the huge and heterogeneous information collected, stored, and sorted for the operations of the campus [42,43]. Digital technologies, such as sensors, IoT, AI, 5G, cloud computing and blockchain, sustain big data and provide the means to facilitate smart campus functions [44,45]. The results of the analysis under these domains are provided in the next section.

3. Results

3.1. General Observations

There is a body of evidence raised in recent research claiming that smart campus is currently being applied in universities. The application is mainly in smart architecture and smart applications but is limited in both functional span and in the number of universities. The research studies are primarily focused on the technological developments, including AI, IoT, cloud computing, big data, sensors, and blockchain and not the human aspect or the end-user. Researchers have, however, acknowledged this gap where studies are scant in relation to human issues and its significance for smart campus. The need for collaborative approaches involving the campus citizens has been raised in most recent research studies. This is significant throughout all the stages of smart campus from conceptualization to implementation. User integration has been considered to be crucial. It is demonstrated in recent research studies that smart campus is a tangible paradigm for capturing the surging development of information technology, AI, IoT, and cloud computing. It provides a means or framework to embrace the rapid technological advancements toward progressive solutions to improve quality, efficiency, waste reduction, cost reduction and overall sustainability.

A total of 123 relevant articles and conference papers were included for the PRISMA review, where 80 (65%) were discussed on the research on at least one of the four domains of smart campus, while 43 (35%) were discussed in the other sections of the paper in the introduction, and the materials and methods section. A total of 60 articles (75%) out of the 80 articles discussed the concepts of the domains while 20 (25%) discussed prototypes and case studies on the four domains. This indicated that more research was conducted on the concepts than on prototypes and case studies. Hence, the development of the conceptual framework is highly conceptual, which fulfills the aim of the study.

The number of domains covered by the 80 articles is shown in Appendix A Table A1. As shown, it is demonstrated that 30 (38%) articles covered research on at least one domain, 26 (33%) on two domains, 20 (25%) on three domains and 4 (5%) on all four domains. Therefore, it is evident that more than two-thirds of the research focused on a single domain, about a third on two, about a quarter on three and a very few on all the four domains. It is also demonstrated that smart campus research has so far been dominated by the focus on a single domain which was evident by the numerous discrete researches being conducted. This has a significant bearing on the development of the conceptual framework at this stage in not reaching its full development to cover all four domains. The desired outcome of focus on all four domains is, however, very small right now.

The reporting on each of the four domains is shown in Appendix A Table A1. As shown, about 70% (n = 56) covered the society domain, 50% (n = 40) covered the environment domain, 41% (n = 33) covered the economy domain, and 36% percent (n = 29) covered the governance domain. It should be noted that the coverage ratio for each of the domains is calculated from the total number of 80 articles focused on each domain separately to compare the degree of attention devoted to each of them. Hence, the total percentage does not necessarily add up to 100%. The study demonstrated that the society domain was given the most coverage, followed by environment, economy and the least coverage was that of governance.

3.2. Economy Domain of Smart Campus

The economy domain of the smart campus entails the entrepreneurial capacity of the campus [21,46]. This is reviewed further under four aspects: business opportunity, improved efficiency, innovation ecosystem, and utility cost saving. A total 33 articles discussed the economy domain, where 26 of them discussed the conceptual phase and 7 were focused on prototyping and case study investigations.

3.2.1. Business Services

Business services opportunity is created within the economy domain of smart campus using smart technology. The global agenda of Industry 4.0 has forced universities to transform to meet its requirements by modernizing existing programs, facilities, and infrastructure [47]. A knowledge economy is created through the growing global smart education market [24] for income generation [48]. Rich and diverse business systems are developed [26] spurring new organizational and business models [49]. This created connection between universities and industry [50] for economic benefits by maximizing funds and providing the best service to campus stakeholders with open business opportunities for web developers [51]. Dedicated smart systems are developed, including the "Blockchain Business Model for Higher Education" (BBM-HE) created to transform business model for tokenized education [52]. In addition, the control and energy management system to boost and sell energy to the grid [53], the smart waste management system which recycles solid wastes for circular economy [54], the BIM-based smart system in the saving of building stock for investment [55] and finally, a smart parking platform providing profits for participants through electric vehicles [56] to lower costs, improve user experience and maintain a certain level of revenue [57] are also developed. It is, therefore, demonstrated that there are very few attempts in the development of smart technology for business services.

3.2.2. Improved Efficiency

Improved efficiency benefits are created with smart technologies where smart campus provides advanced education systems using AI for information and communication to enhance efficiency [58]. There are opportunities for better experiences to improve campus efficiency [59] through internet-of-things, and community-based digital technology to enhance resource utilization in a university [60]. In addition, there is financial stability and entrepreneurial leadership [61], reduction in production costs [3], effective management of energy and other resources in a university [62,63]. Moreover, the emergence of technology enabled efficient resource control in university facilitates, improving information dissemination, and generating the organization income [48]. Finally, smart campus involves the development of a trading platform for optimizing resource allocation, [24] including Blockchain-based applications, to foster efficient production at low-cost in new business approaches [49]. Though it is demonstrated that there are few attempts in smart technology development for improving efficiency, it is, however, worth noting that efforts have begun.

3.2.3. Innovation Ecosystem

Innovative ecosystem comprises two main areas of sustainability and smart campus solutions. Sustainability innovations explored campuses as urban living labs (ULL) [64] for prototyping an open architecture for sustainable evolution [59]. These included the following developments: a platform for promoting sustainable campus [65], smart green campus [66] to reduce carbon footprint using solar photovoltaic (PV) power [67], mobility for promoting decarbonization and credit trading [68], and finally, a smart waste bin [54]. On the other hand, smart campus solutions uncovered significant resource efficiency gains, offering better experiences [57] which included, smart grid innovations for integrating power generation and infrastructures through digital technology networks [61]. In addition, pertinent innovations, including a hybrid renewable energy system [62,69], and several energy management systems (EMS) for distributed energy resources (DERs) [69], were developed.

Furthermore, a Blockchain-based energy trading platform [56] increasing sustainable energy by green energy suppliers [70], integrating automated distribution systems and energy storage technologies [71], and a Hybrid Firefly Lion Algorithm (FLA) [72] for optimizing energy management were also developed. Other innovations included a data governance platform [26], the (R)evoCampus [60], OnCampus mobile platform [73], and a Blockchain Business Model for Higher Education (BBM-HE) [52]. Additionally, smart parking innovations, such as an IoT Raspberry Pi-based parking management system

(IoT-PiPMS) [74], and a Cloud-based Automated Parking System [75], were developed. Finally, the human-centered learning-oriented smart campus (HCLSC) framework [24] for smart campus development was developed. Therefore, it is evident that there are already smart technology developments promoting innovation ecosystem in universities and such developments will continue in the future.

3.2.4. Utility Cost Savings

Utility cost saving is an economic benefit created by smart campus using smart technology in electrical energy reduction through the development of energy management systems, smart buildings, and smart parking. Smart campus facilitates electrical energy reduction [75] through the development of energy management systems minimizing grid electricity cost [69,70,72]. These were achieved through the application of smart technology in green energy production [66] where the hybrid renewable power distribution is supported through IoT [62]. In addition, there was reduction of operation cost, including electricity [60], water and energy in a self-sufficient university building [64]. Finally, a parking management system was developed to reduce management costs and save energy consumption [74]. Although the impact is not widespread at present, there has been a reduction in utility costs due to the use of smart technology and there are opportunities for further cost savings with smart technologies.

3.3. Society Domain of Smart Campus

The society domain of the smart campus addresses the crosscutting issues that affect the life of people which included strategies for community engagement, quality of campus life, social responsibility, and versatile learning. A total of 56 articles were found discussing the domain where 46 were conceptual and 10 were prototypes.

3.3.1. Community Engagement

Community engagement is a benefit offered by smart campus where the university community becomes an IoT integrated environment, [7] creating a digital campus using advanced information technologies in IoT, big data, network and AI [76]. The university campus becomes smarter by the inclusion and advancements of technology [77], increasing automation [78] where technology is adapted creating a connected and responsive campus [48]. In addition, a collective university experience is created with the focus on human citizens provided by the three elements of a smart campus comprising: (a) the influence by campus citizens, (b) networking of operations and businesses, and (c) emphasis on infrastructure and services development [11]. Moreover, higher education institutions (HEIs) provide technological solutions for a dynamic ecosystem created from students and academics in a digital community [79]. The smart solutions created include sensing, adaptation, inferring, and community contentment [59]. Finally, there is connectivity with everything forming an ecosystem of robust communications network [48]. However, these initiatives are limited to the concept of smart technology sustaining community engagement in universities. There are undoubtedly practical applications in universities which have not been documented.

3.3.2. Quality of Campus Life

Smart campus is a smaller version of a smart city [58], which has the potential of impacting the quality of life of its citizens [80]. In addition, smart campus is human-centered, and user-driven for value creation to improve the total university experience [57]. IoT is a revolutionary technology that has upgraded human lives through the smartization of services [81]. There is integration of new technologies focusing on enhancing the life of campus citizens [8,82]. It has smart features which improve quality and support the overall experience of its citizens, providing value-added services in developing a much better and more effective environment achieved through technological changes using smart devices through the internet [59].

There is a wide application of internet-on-community services and management [11] and smart living in smart transport, smart canteen, and smart navigation [58]. Moreover, expert systems are provided to improve the educational environment and quality [3], such as a dedicated smart campus solution architecture called RevoCampus developed to enhance room comfort control for a smart campus [60]. For ease of parking, a parking management system was developed to assist matching of individual drivers to vacant parking places [74,75]. Finally, there was a development of social systems to assist life on campus through a smart platform which forms social circles based on interests mining [73]. These are but few recent developments in smart campus improving quality of campus life which demonstrates the beginning of a large potential yet to be developed.

3.3.3. Social Responsibility

Smart campus is an emerging development in IoT technology [83] which provides the overall influence on campus citizens, including the development of digital systems to enhance services in a university [59]. In addition, a dynamic ecosystem is created by campus citizens in a digital community [79] forming a robust communications network [84]. Moreover, a community of human-centered and user-driven value creation to improve the total university experience is created [11], facilitated by a Wi-Fi hotspot-based mobile application to construct friendship networks [85]. In addition, a platform was developed to enable formation of teams for IoT application appropriate in a university context of academic groups [65]. Furthermore, external stakeholders are now able to participate in defining higher education institutions external interests [86]. Moreover, a new management system is developed to replace the present system, which has become obsolete [25]. On the other hand, robust systems technologies were developed, including a novel DMS (disaster management system) called the Named Data Networking Disaster Management (NDN-DM) [87], and a surveillance system for enabling safer space [88]. There is evidence on the emphasis in the social factor promoting stakeholders' participation which compliments the enhancement of social responsibility.

3.3.4. Versatile Learning

The rapid change in technology is transforming learning and teaching, evolving from basic e-learning to smart campuses and s-learning [89]. It is allowing education to be delivered anywhere and anytime through distance learning, growing and creating new programs dedicated for implementation [90]. In addition, learning opportunity is now accessible to all segments of society for geographical boundaries are no longer a barrier [91]. Moreover, digital transformation has created new learning using digital technology to provide high-quality resources to a wider audience and improved access to information which are physically inaccessible [92]. Online learning has is now encouraging students to become more participative and active learners [93]. Furthermore, continuous innovation in technology has created a high-end form of education system with remote, personalized, and ubiquitous features [58].

Learning efficiency can be promoted using wireless communication and virtual reality (VR) technology reforming college education and entering a stage of rapid development [94]. Moreover, smart classroom is implemented through mobile learning for modernizing and internationalizing education networks [95] as new learning approaches are developed through the integration of IT [96]. Furthermore, the intelligent classroom stimulates students' learning process and comprehension quality [97] as a smart learning environment [98]. However, online learning has shortcomings, including monotonous and uneven teaching quality, absence of interaction, inadequate teaching audit, and the lack of students' motivation in learning [99]. This might be due to that teaching and learning are innately human processes that simply work best with direct and interpersonal instruction and relationships. It has been demonstrated that the development of smart technology for learning has advanced and will continue to progress, thus increasing the versatility in learning.

3.4. Environment Domain of Smart Campus

The environment domain of the smart campus is concerned with the management of the natural environment and sustenance of resources [21]. They environment domain is reviewed under four aspects: environmentally friendly services, renewable energy, sustainable development, and zero waste, which are discussed below. A total of 40 articles were found to discuss the environment domain, where 30 focused on the conceptual phase, while 10 focused on prototyping and case study.

3.4.1. Environmentally Friendly Services

Environmentally friendly services are created in smart campus through smart technology by integrating technologies into a centralized environment for generating a sustainable relationship between people and the natural environment [100]. Moreover, environmental sustainability has been enhanced by reducing travel to and from campuses, minimizing use of facilities and curtailing energy demand. In addition, there is reduction of paper waste and tree harvests [101,102]. Finally, a wireless sensor network, IoT cyber-physical system, was developed in University of Malaga in Spain to mitigate environmental pollution, including noise by assisting campus managers in scheduling classes to avoid peaks and clusters [82]. The online learning promoting remote learning and reducing on-campus learning has created environmentally friendly services.

3.4.2. Renewable Energy

Renewable energy is created by incorporating green energy into smart system applications to minimize the environmental impact through a hybrid renewable energy system operated by an IoT-based architecture in a university campus [62]. Green IT (information technology) assists in reducing electrical power consumption [53] in a global move by universities towards energy-saving and carbon-emission mitigation thereby improving sustainability and stakeholders' participation [74]. An energy management system, involving development of smart grid and microgrid projects integration in sustainable energy generation, was pursued at the University of Genoa's Savona Campus. Its simulation was successful on the optimal management of heating, ventilation, and air condition systems and plant [103]. In addition, a proposed energy management system was developed to integrate renewable energy resources with campus microgrid for cost reduction [71]. Finally, energy management and efficiency are pursued in major universities demonstrated by the development of a first ICT-centered methodology and software toolchain [102]. Sustainable transport, relying on smart energy, is yet another key area for smart campuses [104]. The aspiration of integrating renewable energy resources, by using smart technology to promote green energy, however, is still at its infancy stage.

3.4.3. Sustainable Development

Industry 4.0 and sustainable development goals [47,48] were among the global agendas which triggered transformations in higher education institutions (HEIs) for influencing future generations to deal with global issues [52]. Therefore, HEIs have begun focusing on sustainability management throughout the globe [105] facilitated effectively by advanced technology for sustainable development [106]. Environmental specific factors were among the issues considered in the pursuit of IoT-based smart campus [77]. Smart campuses provide urban living labs (ULL) [64] and a testbed [107] designed to facilitate experimentation on sustainability solutions in energy production, water utilization and cleanliness, meeting the global SDGs [58].

Moreover, digital technology is used in treating water, environmentally friendly facilities, mobility and waste management [61], driven by smart solution systems [59] through the Long-Range Wide-Area Network infrastructure [21] and IoT platforms [65]. Additionally, integrative approaches to sustainability [63] promoting open and integrative participation of stakeholders [15] were adopted by HEIs. Finally, environmental sustainability is boosted by e-learning, because emissions go down due to a reduction in travel to campuses, as virtual classes can be attended from anywhere in the world [102]. There has been attempts to use smart technology to enhance the pursuit of sustainable development in campuses and it is expected to increase together with the rapid development of digital technology.

3.4.4. Zero Waste

Zero waste is about the reduction of waste in smart campus to improve the state of the natural environment addressed through waste management and green campus. Waste management systems developed included the following three prototypes: firstly, the smart waste bin for effective waste collection [108]; secondly, the Smartbottle Ecosystem developed as a means to eliminate single-use plastic water bottles to mitigate waste where the bottle communicates with a smart refilling station through IoT and ICT for refill [79]; and finally, the third is a smart waste management system for university campus operated by 5G to mitigate health and environmental problems. It is based on the premise of recycling materials reducing emissions from landfills and industrial sites to rectify environmental issues of water/air pollution and littering [54]. Green campus development, on the other hand, is demonstrated by two prototypes. Firstly, the reduction of carbon footprint of a university using solar photo volt system to save 31% of electrical energy and decrease the annual emissions from campus electricity use by 27% [67]. The second prototype is on smart agriculture through IoT to improve soil quality, water management and environmental sustainability [109]. The few prototypes demonstrated the beginning of tangible researches on zero waste and is expected to expand coinciding with the rapid development of digital technology.

3.5. Governance Domain of Smart Campus

The governance domain of the smart campus enables users to be involved in decision-making and in the use of public services [21]. This is elaborated further into cybersecurity, data governance, decision-making, and service management which facilitate the governance domain. A total of 29 articles were found on the governance domain where 19 were conceptual and 10 were prototypes and case studies.

3.5.1. Cybersecurity

Cybersecurity has emerged swiftly along with the surge in IoT prompting an urgent challenge for all institutions and business organizations and is growing [110]. Smart campus development involves significant informatization, emphasizing the need for effective cybersecurity [111]. Cybersecurity is demanded literally in networks due to their vulnerability to attacks and is thus becoming a focus of recent research [112]. Smart systems require machine learning (ML) and deep learning (DL) intelligence to detect attacks in IoT networks [113]. However, intrusion detection systems (IDS) using traditional machine-learning algorithms in online systems are becoming weak as they are shallow learning and cannot counter new attacks [114]. Shallow intelligent algorithms cannot process the voluminous amount of data now generated. Hence, deep learning algorithms are required and are gaining focus on recent research to address the emerging problem of cybersecurity in cloud computing architectures [115]. Finally, Blockchain frameworks also provide effective counter cyber-attack measures in quantum tools for large-scale quantum computers having cryptographic mechanisms [116]. Cybersecurity is developed at a fast phase with deep learning algorithm technologies to deal with the increasing trend in hacking.

3.5.2. Data Governance

Data governance emphasizes the significant role that data provides in facilitating the governance domain in smart campus, including a scientific information system framework required in smart campus [117] to create a system for managing information for data detection through the integration of IoT technology and intelligent computing model [118]. A main facet for governance in public organizations is information technology [119] and as such, smart campus requires data governance platform to manage and control education data resources objectively [26]. In addition, there is a need for effective systems to deal with the increasing challenges from student privacy, complex data, and the digital gap through smart campus innovation and social data governance [43].

Hence, universities are encouraged to fully implement measures to manage large amount of information through big data technology for decision-making and development. The research, therefore, suggests a focus on development of student management systems using big data technology in smart campus [25]. Finally, big data management is effectively managed by blockchain technology which is found to be vital for creating advanced solutions where university leaders are embracing as a robust solution [49]. Data governance facilitates enhance management of information through smart technology. Universities comprised operational facets which serve a wide spectrum of stakeholders beyond its traditional role in teaching and research.

3.5.3. Decision-Making

The robust decision-making created by smart campus facilitates its governance domain through smart decision-making based on objective principles [73]. University administrators, industry, and policymakers need to know the crucial issues of smart campus comprising specific technologies, organizational traits, environmental values and the end-user requirements to improve the adoption and utilization of IoT-based smart campus effectively [77]. Moreover, a university transition to smart campus in adopting smart technology is oriented to the improvement of processes outlining evolution paths and prioritize improvement measures, forming a roadmap that facilitates decision-making [120].

In addition, the making of smart campus emulates a smart city for improvement in administration, management, and decision-making [121]. As such, innovations in decision-making adopted the approach in making university campuses like smart cities having more centralized body in smart governance [61] for sustainability management and implementation [63] through an integrated management system to facilitate decision-making [3]. In addition, a mobile platform called "On Campus" was developed to address accurate context awareness, resource allocation and smart decision-making [73]. Finally, a smart platform for delivering smart university projects through an IT conceptual framework was developed to facilitate good governance for university strategic plan [80]. These developments have demonstrated the emergence of smart technology for decision-making in universities.

3.5.4. Service Management

Innovation in service management pursued open extensible architecture to support service integrations and create a dynamic digital ecosystem [59]. As such, artificial intelligence (AI) is used to enhance all educational processes and students' achievements in servicing the education function in a university [3]. In addition, the emergence of technology-enabled university is helping the management control resource utilization, and improve information dissemination [48] thereby increasing efficiency and facilitating better space utilization [74]. An architectural framework was developed for the integration of technologies to improve administrative and academic management where its versatility creates solutions for implementing the various services in the university [8]. Smart parking development addressed the problem of unauthorized visitors in the campus by enhancing the security service through the coordination of vehicle identification [75] and a novel optimal allocation framework developed to allow a campus manager to re-domain a car park for revenue generation through electric vehicles [57].

Moreover, the management of smart campus is enhanced by an ICT-centered methodology and software toolchain for monitoring and controlling infrastructure on energy management [122]. Finally, a smart fire evacuation system was developed based on building information modelling (BIM) to develop spatial building modeling plan for fire evacuation [55]. These are a few recent developments in smart technology assistance in service management which demonstrated a potential for more opportunities in the near future.

4. Discussion

This study investigated the making of smart campus through a framework of the four domains of society, economy, environment, and governance, where each are aligned closely with the central smart campus concepts of smart technology and big data. The domains were investigated further to determine the extent of their development where four subthemes for each were discovered to create the conceptual framework shown in Figure 3. Moreover, a profile of the spread of the recent research on the domains are shown in Appendix A Table A1. The study also gauged the level of development between the conceptual and prototype initiatives conducted so far, also shown in Appendix A Table A1.

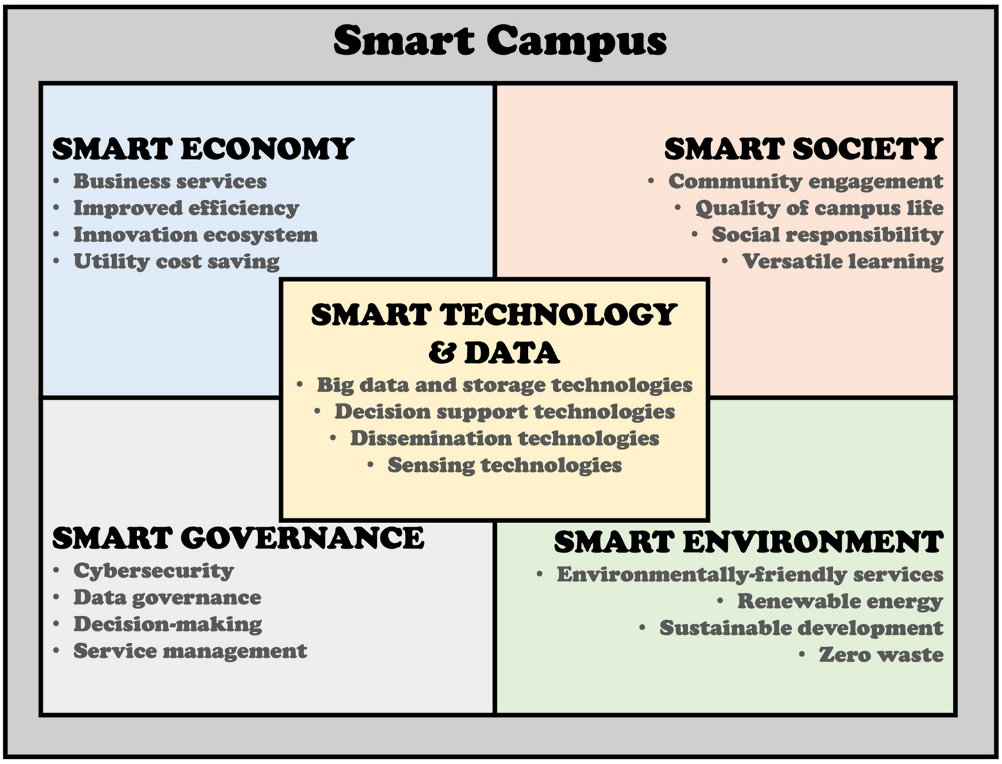

Figure 3. Conceptual framework of smart campus.

The study review results revealed a variation in the amount of research conducted on each domain. The society domain had more research followed by the environment, the economy, and lastly, the governance domain. These are based solely on the count of recent publications located in the search and did not take into account any other basis for differences in the outcome. Moreover, the count was completed on the content analysis of the reviewed literature where a spread on the coverage of each article on the domains was revealed, demonstrating that majority were devoted to a single domain followed by the coverage of two, then three, and lastly, all four domains. It was also revealed that more than half of the research was of conceptual nature and only a few are prototypes, indicating the level of research on smart campus to be more conceptual at this present stage.

The results revealed the economy domain with business opportunities provided by smart campus to be at its infancy stage where there is no evidence of expanded businesses established on campuses at present. Current research has only provided an overview of the business setting, such as meeting the global agenda of Industry 4.0 to modernize university operations which aims to create rich and diverse business systems [47]. Moreover, few discrete studies were completed on technology to sustain business, such as blockchain technology [52] to control the sales of energy [53], a circular economy created by recycling waste [54], building stock sustenance [55], and revenue generation using car parking spaces [56]. Research, to date, has only highlighted the possibility of improving efficiency through smart technology [49]. However, there is no evidence of widespread application. Again, there has only been a few discrete smart technology developments, such as a trading platform for efficient resource control [73]. Innovation ecosystem has so far been limited to sustainability and smart campus solutions where an urban living lab (ULL) [64] has been propagated predominantly to test for sustainability and green campus. Moreover, there has been limited studies focused on resource efficiency [57] and smart grid innovations [61] for optimizing energy management [69], blockchain technology [56], smart parking [74] and human-centered learning [24]. Finally, utility cost reduction research so far is limited and have only begun with electrical energy reduction [70] and cost reductions through smart buildings [64], and smart parking [75].

On the other hand, the results on the society domain revealed a rise in smart technology development with few discrete studies being conducted. Community engagement development addressed connectivity with building an ecosystem of integrated environments for a digital campus [7]. The campus becomes connected, responsive, and smarter when it comprises a collection of people, amenities, and assets in an atmosphere of advanced digital infrastructures and services. A group and community concept for social-level fulfillment is created [11]. Quality of campus life is influenced by the smart city concept which then impacts the citizens' quality of life [81]. The total university experience is human-centered, and user-driven for value creation to upgrade human lives through technological changes using smart devices [57]. Smart living is provided through expert systems, such as smart architecture [58] and a smart platform forming social circles [73].

Social responsibility is about the overall influence on campus citizens [59] influenced by the paradigm of the IoT [83] where friendship networks are facilitated by a mobile application [85], and work groups created by a platform [65]. Disaster management [87], and surveillance systems [88] were also created through smart technology development. In addition, versatile learning is characterized by its predominant benefit of borderless delivery providing learning opportunity to all societies' segments [91]. Moreover, a high-end form of education system with remote, personalized, and ubiquitous features is created [25], including smart classrooms for modernized learning integrating IT (information technology) [95]. However, online learning has certain disadvantages, such as monotonous delivery, lack of sharing knowledge, insufficient education evaluation standards, which leads to a decrease in motivational drive for students [99].

The study review results on the smart environment domain revealed the environmentally friendly services being created by generating sustainable environment to harmonize the integration between people and nature [100]. The use of smart technology mitigated the use of systems responsible for polluting the environment [102]. In addition, renewable energy was found to integrate green energy and smart system applications which mitigated ill-environmental impacts [62]. Moreover, the hybrid renewable energy systems in Green IT created savings in energy and reduced carbon emissions [30,53] through energy management systems [71]. Sustainable development is a global agenda [52] addressed by smart solutions through integrative approaches in favor of humanity and sustainability [106]. Finally, zero waste was found to involve the application of smart technology in waste management [79,108] and contribute to a green campus [67,109].

Finally, the review on the governance domain revealed that cybersecurity development is reaching a heightened level of complex dynamics [110] to counter advanced attacks through deep learning algorithms [115] and blockchain technology [116]. These technologies provide a robust security system needed to protect the data governance function for the information framework in a university [117]. In addition, big data information is required for decision-making and development [25] which is effectively managed by blockchain technology [49]. Moreover, there is an open extensible architecture to support service integration and creation [59]. Finally, smart technology is helping the management control resource utilization and information dissemination [48] for service provision in learning and other functions of a university [8,55,122].

5. Conclusions

This review study used four major domains of the smart campus—namely society, economy, environment, and governance—to classify existing academic knowledge on smart campuses. These domains are each aligned to the central smart campus concepts of digital technology and big data. The analysis revealed little evidence of a comprehensive real-world application of the smart campus towards addressing all four domains. This finding indicates the infancy of the current conceptualization and practice. The study contributes to the development of a new conceptual foundation and research directions for the smart campus notion and informs its practice through a conceptual framework, and lastly advocates further empirical studies on smart campus for discovering the recipes for successful practice. In other words, the study findings reported in this paper offer a firm basis for comprehensive smart campus conceptualization, and also provide directions for future research and development of smart campuses.

This study has the following limitations that should be noted: (a) The study did not engage any bibliometric or visualization software in the data analysis, which may result in some possible minor human errors. (b) The study did not undertake bibliometric [123], scientometric [124] or meta [125] analyses as the field is not advance enough to expand the review to that level. The study also did not employ an analysis or visualization software and instead conducted the tasks manually. (c) The study adopted the generic domains of economy, society, environment, governance and technology and data, and identified key indicators from the literature reviewed under these domains, where some other contextual domains might have existed. (d) The study focused on academic literature and only peer-reviewed journal articles; this might have resulted in neglecting some of the key developments reported in other academic or grey literature outlets. (e) The review is conducted manually, which might result in a reviewer bias. (f) There was no investigation on the technology and data domain of the framework. (g) The measurability of the 16 elements of the four domains is yet to be undertaken to add to the robustness of the framework. Lastly, our prospective research will focus on addressing these limitations and further expanding knowledge in these areas.

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Appendix A

Table A1. Reviewed articles, paper types, and domains.

No	Reference	Title	Paper Type		Domain Covered			
			Concept	Prototype	Economy	Society	Governance	Environment
1	[66]	Smart Green Campus: The Campus of Tomorrow	√		√	√		√
2	[91]	Studies in Computational Intelligence	√			√		√
3	[65]	Smart UTB: An IoT Platform for Smart Campus	√		√			√
4	[59]	Building Smart University Using Innovative Technology and Architecture	√		√	√	√	
5	[105]	Modifiable Campus-Wide Appraisal Model for Sustainability		√				√
6	[92]	Stakeholder's Perspective of Digital Technologies and Platforms Towards Smart Campus Transition	√			√		

Table A1. *Cont.*

No	Reference	Title	Paper Type		Domain Covered			
			Concept	Prototype	Economy	Society	Governance	Environment
7	[108]	Nature-Inspired Search Method and Custom Waste Object Detection and Classification Model		√				√
8	[78]	Internet-of-Things in Higher Education: A Study on Future Learning	√			√		
9	[87]	Named Data Networking for Efficient IoT-based Disaster Management	√			√		
10	[62]	IoT-Based Hybrid Renewable Energy System	√		√			√
11	[112]	Intelligent Techniques for Detecting Network Attacks: Review and Research Directions	√				√	
12	[93]	Modeling the Impact of Massive Open Online Courses Implementation Factors on Continuance Intention of Students	√			√		
13	[61]	Smart Campus and Microgrid	√		√		√	√
14	[3]	Review on Smart Universities and Artificial Intelligence	√		√	√		
15	[113]	Computational Intelligence Approaches in Developing Cyberattack Detection System		√			√	
16	[110]	Hybrid deep-learning model to detect botnet attacks over internet-of-things environments		√			√	
17	[63]	Lessons from unsuccessful energy and buildings sustainability actions	√		√		√	√
18	[88]	Challenges and Solutions of Surveillance Systems in IoT-Enabled Smart Campus	√			√		
19	[11]	Facilitating Successful Smart Campus Transitions: A Systems Thinking-SWOT Analysis Approach	√			√		√
20	[103]	A Building Energy Management System Based on an Equivalent Electric Circuit Model		√		√		√
21	[70]	Scheduling and Sizing of Campus Microgrid	√		√			
22	[117]	Promoting Digital Campus to Smart Campus Based on Artificial Intelligence	√			√		
23	[107]	On exploiting Data Visualization and IoT for Increasing Sustainability and Safety	√			√		√
24	[26]	Research and Construction of University Data Governance	√		√	√	√	
25	[111]	Statistical Analysis of threatening IP in Universities Based Automated Script	√				√	
26	[43]	Smart campus communication, Internet-of-Things, and data governance: Understanding student tensions and imaginaries	√			√	√	
27	[68]	A Win-Win Scheme for Improving the Environmental Sustainability of University Commuters' Mobility and Getting Environmental Credits	√		√	√		√
28	[79]	Joining Sustainable Design and Internet-of-Things Technologies on Campus: The IPVC Smartbottle		√		√		√
29	[60]	Improving the Environmental Sustainability	√		√	√		√
30	[84]	Education and Digital Transformation		√		√		
31	[48]	I-Campus: Towards the Information Integration	√		√	√	√	√
32	[73]	On Campus: a mobile platform towards a smart campus		√	√	√	√	√
33	[24]	Smart campus: definition, framework, technologies, and services	√		√	√		√
34	[116]	Quantum-Inspired Blockchain-Based Cybersecurity: Securing Smart Edge Utilities in IoT-Based Smart Cities		√			√	
35	[69]	Optimal Scheduling of Campus Microgrid Considering the Electric Vehicle Integration	√		√	√		
36	[102]	Exploring Sustainable E-Learning Platforms for Improved Universities' Faculty Engagement in the New World of Work	√			√		√
37	[50]	Adaptive Learning Supported by Learning Analytics for Student Teachers' Personalized Training during in-School Practices	√		√	√		√
38	[121]	The Campus as a Smart City: University of Málaga Environmental, Learning, and Research Approaches		√		√		√
39	[21]	Design and Experimental Validation of a LoRaWAN Fog Computing Based Architecture for IoT Enabled Smart Campus	√		√	√		√
40	[115]	Deep learning architectures in emerging cloud computing architectures	√				√	
41	[71]	Optimal Energy Management of a Campus Microgrid		√	√			√
42	[86]	Higher Education Institutions as Knowledge Brokers in Smart Specialization	√			√		
43	[114]	Hybrid Intrusion Detection using MapReduce based Black Widow Optimized Convolutional Long Short-Term Memory		√			√	
44	[49]	A Bibliometric Analysis of Blockchain Technology Research Using VOSviewer	√		√		√	
45	[118]	Design and Optimization of University Management Information System Based on Internet-of-Things and Intelligent Computing Model	√				√	
46	[94]	Methods of College Education Reform under the Background of Wireless Communication and VR Wireless	√			√		
47	[54]	A 5G-Enabled Smart Waste Management System		√	√	√	√	√
48	[64]	A Methodology for Designing Smart Urban Living Labs	√		√	√		√
49	[47]	Adapting Universities for Sustainability Education in Industry 4.0	√		√			√
50	[95]	Integrating mobile technologies in a smart classroom to improve the quality of the educational process: Synergy of technological and pedagogical tools	√			√		
51	[80]	Modelling and Implementing Smart Universities: An IT Conceptual Framework		√		√	√	
52	[83]	Study of Smart Campus Development Using Internet-of- Things	√			√		
53	[98]	A Blended Learning Model Based on Smart Learning Environment to Improve College Students' Information Literacy	√			√		√
54	[56]	Design and Implementation of a Blockchain-Based Energy Trading Platform for Electric Vehicles		√	√			

Table A1. *Cont.*

No	Reference	Title	Paper Type		Domain Covered			
			Concept	Prototype	Economy	Society	Governance	Environment
55	[122]	Software toolchain to enhance the management and integration of a sustainable campus		√	√		√	√
56	[15]	A Smart Campus Framework: Challenges and Opportunities for Education Based on the Sustainable Development Goals	√			√	√	√
57	[90]	Smart Academic and Professional Education	√			√		
58	[77]	Factors Affecting the Adoption of IoT-Based Smart Campus: An Investigation Using Analytical Hierarchical Process (AHP)	√			√	√	√
59	[51]	Smart Campus with A Learning Management System	√		√	√		
60	[52]	Fostering Equality in Education: The Blockchain Business Model for Higher Education (BBM-HE)	√		√	√		√
61	[57]	Modelling and Optimization of Resource Usage in an IoT Enabled Smart Campus		√	√	√	√	
62	[81]	A Smart Education Model for Future Learning and Teaching Using IoT Smart Innovation, Systems and Technologies	√			√		
63	[109]	Fostering Environmental Awareness with Smart IoT Planters		√		√		√
64	[96]	Integrating Entrepreneurship and Innovation Education into Higher Vocational Education Teaching Methods Based on Big Data Analysis	√			√		
65	[67]	Incorporating External Effects into Project Sustainability Assessments: The Case of a Green Campus Initiative Based on a Solar PV System	√		√		√	√
66	[119]	A Methodology for Creating a Macro Action Plan to Improve IT Use and Its Governance in Organizations	√				√	
67	[82]	A Low-Cost IoT Cyber-Physical System for Vehicle and Pedestrian Tracking	√			√		√
68	[72]	An Optimal Energy Management System for University Campus Using the Hybrid Firefly Lion Algorithm (FLA)	√		√	√		
69	[8]	Application of a Big Data Framework for Data Monitoring	√			√	√	√
70	[106]	Integration of IoT and Blockchain to in the Processes of a University Campus	√			√		√
71	[74]	An IoT Raspberry Pi-based parking management system	√		√	√	√	√
72	[76]	Application of Intelligent Algorithm Big Data Analysis in Smart Campus Construction	√			√		
73	[55]	A BIM-Based Smart System for Fire Evacuation		√	√		√	
74	[99]	Exploring the Innovative Blockchain-Based Application of Online Learning System in University	√			√		
75	[7]	Situational Awareness System	√			√		
76	[75]	A cloud-based automated parking system for smart campus	√		√	√	√	
77	[53]	Trends and Challenges of Internet-of-Things in the Educational Domain	√		√			√
78	[58]	A Systematic Review on Technologies and Applications in Smart Campus: A Human-Centered Case Study	√			√		√
79	[25]	Challenges and Strategies of Student Management in Universities in the Context of Big Data Mobile Information Systems	√			√	√	√
80	[85]	Explore the Ubiquitous Learning on Campus: A Friendship-Based Knowledge Diffusion Approach		√		√		
Total			60	21	34	58	29	39

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