Towards Next Generation Teaching, Learning, and Context-Aware Applications for Higher Education: A Review on Blockchain, IoT, Fog and Edge Computing Enabled Smart Campuses and Universities

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Abstract: Smart campuses and smart universities make use of IT infrastructure that is similar to the one required by smart cities, which take advantage of Internet of Things (IoT) and cloud computing solutions to monitor and actuate on the multiple systems of a university. As a consequence, smart campuses and universities need to provide connectivity to IoT nodes and gateways, and deploy architectures that allow for offering not only a good communications range through the latest wireless and wired technologies, but also reduced energy consumption to maximize IoT node battery life. In addition, such architectures have to consider the use of technologies like blockchain, which are able to deliver accountability, transparency, cyber-security and redundancy to the processes and data managed by a university. This article reviews the state of the start on the application of the latest key technologies for the development of smart campuses and universities. After defining the essential characteristics of a smart campus/university, the latest communications architectures and technologies are detailed and the most relevant smart campus deployments are analyzed. Moreover, the use of blockchain in higher education applications is studied. Therefore, this article provides useful guidelines to the university planners, IoT vendors and developers that will be responsible for creating the next generation of smart campuses and universities.

Keywords: IoT; blockchain; smart campus; smart university; teaching and learning; smart cities; fog computing; edge computing; higher education; context-aware applications

1. Introduction

Smart campuses and universities require an IT infrastructure similar to the one needed by smart cities, smart buildings, or smart homes, which make use of Internet of Things (IoT) solutions [1–4] to interact with the sensor and actuation systems of a university. Similarly to smart cities, but in contrast to most smart homes and buildings, smart campuses must provide long-distance communications, as many university campuses cover an area that can reach thousands of square meters. For instance, the campus of the authors of this article (Campus of Elviña, University of A Coruña, Spain) occupies a $26,000\,m^2$ area. Nonetheless, such an area can be considered small when compared with the largest university campuses in the world: Berry College (Floyd County, Georgia, United States) covers 109.26 km^2 of land [5], Duke University campuses (Durham, North Carolina, United States) are deployed on $37.83\,km^2$ [6], and the campus of Stanford University (Stanford, California, United States) occupies 8180

acres (33 km^2) [7]. These figures mean that smart campuses should make use of specific long-distance communications infrastructure that provides indoor and outdoor connectivity to the deployed IoT gateways, sensors and actuators, while guaranteeing reduced energy consumption and thus optimized IoT node battery life.

A smart campus and university is managed according to its strategic plan (a framework of its main priorities and commitments). As a result, universities devote financial resources to implement a broad range of actions (e.g., related to digital transformation, services, applications, events, facilities, human resources, governance, educational programs, or innovation) that are fundamentally designed to meet their institutional objectives. The strategic plan is driven by the university mission, vision, and core values (further detailed in Section 2). For instance, a number of universities around the world has committed to make tangible contributions to the United Nations Sustainable Development Goals (SDGs). Note that the provided smart campus services may be similar to the ones of a smart city, but adapted to the needs of a university (e.g., mobility/transport services, energy/grid monitoring, resource consumption efficiency, user behavior monitoring, or guidance applications). However, there are other services that are specific for a university environment, such as the services for analyzing the behavior of students in certain outdoor activities or their attendance to lectures.

In addition, there are other relevant differences with respect to smart cities regarding the architectures and technologies that can be applied to smart campuses and universities:

- Smaller size. Although, as it has been previously mentioned, there are really large campuses, most of them are not as large as cities and, in fact, there are many urban universities with buildings inside a city. Such a smaller size enables using certain communications technologies that do not need to reach very long distances. In addition, since often less devices require to be deployed than in a smart city, architectures can be less complex and need less routing layer devices, what usually reduces response time and infrastructure deployment cost.
- Infrastructure management. Frequently, in a smart campus/university all buildings and related infrastructure are managed by the same organization (i.e., the university), often making it easier to take certain measures to ease the deployment of the required infrastructure communications and architecture than in a smart city. In contrast, in a city most space is occupied with private buildings that are managed by people that do not work for the city council, so certain infrastructure deployments can be difficult when having to deal with the different necessities of multiple people.
- Homogeneity. A smart university can enforce the use of certain technologies and specific architectures, while a smart city in general will have to deal with a greater heterogeneity in such areas, which usually require complex solutions to integrate the numerous previously existing computational systems.

Due to the previously mentioned differences, it is essential to study specifically the most appropriate architectures and technologies for developing smart campuses and universities.

In contrast to previous reviews and surveys on smart campuses/universities, which are presented as systematic literature reviews [8,9], are focused on defining certain generic concepts/applications [10], or are centered on specific technologies [11–16], this article provides a holistic review that analyzes the application of the latest key technologies and architectures for the development of smart campuses and universities, including the following contributions, which have not been found together in the previous literature.

- After defining the essential characteristics of a smart campus and a smart university, the most common communications architectures are detailed together with their evolution: from traditional cloud-based to the latest ones based on edge computing.
- The application of blockchain to such architectures is studied as a tool to create a distributed immutable log that provides transparency and cybersecurity to higher education and smart campus applications.

- The characteristics of the most relevant smart campus deployments and initiatives are analyzed.
- The latest smart campus deployments are enumerated and multiple examples of their applications are described.
- The most recent communications technologies for outdoor and indoor smart campus applications are studied.
- The main challenges that will be faced by university planners, IoT vendors, and developers are listed.

The rest of this paper is structured as follows. Section 2 defines the concept of smart campus and its main features. Section 3 details the latest communications architectures for smart campuses and smart universities. Section 4 analyzes the potential applications of blockchain for deploying higher education and smart campus applications. Section 5 describes the most relevant smart campuses that have been already deployed, emphasizing their main applications and communications technologies. Finally, Section 6 indicates the main challenges for university planners, IoT vendors, and developers, and Section 7 is devoted to the conclusions.

2. Definitions of Smart Campus and Smart University

It must be first clarified that the term "smart campus" has been used in the past to refer to digital online platforms that manage university content [17,18] or to the set of techniques aimed at increasing university student smartness [19–21]. However, in this article, the concept of smart campus refers to the hardware and software required to provide advanced intelligent context-aware services and applications to university students and staff. In addition, the term smart university refers to the hardware and software used to develop tools to fulfill the key dimensions of the university mission:

- Improve the teaching, learning, and assessment processes involved in higher education.
- Foster research and innovation.
- Empower community-based knowledge transfer and a shared vision among the various university stakeholders (e.g., teachers, students, administration, non-profit organizations, research institutions, citizens, industries, and governments).

Such characteristics make smart campus and universities unique and enable differentiating from other concepts like smart cities. Nonetheless, smart campuses/universities are similar to smart cities in the way they are organized, which revolves around six smart areas [22]:

- Smart governance. It allows university staff and students to take part in different decisions that need to be made on a university or on a specific campus.
- Smart people. It is related to the engagement of the university users in teaching and learning processes or their attendance to certain events.
- Smart mobility. In the case of a smart campus, this field deals with the different issues related to the available transport systems, which should be efficient, green, safe, and may provide intelligent services.
- Smart environment. This field is related to smart solutions able to monitor, protect, and actuate on the environment while also managing the available resources in a sustainable way. For instance, smart environment systems provide solutions for monitoring waste, water consumption, or air quality. In addition, this field is usually related to the deployment of systems to control and monitor the energy consumed, generated and distributed throughout a campus.
- Smart living. It is responsible for monitoring the multiple living factors involved in the daily campus activities, including the ones related to health, safety or user behavior. Thus, smart living services can perform the following [23,24]:

  - Estimate room occupation and determine student classroom attendance.

- – Control the access to classroom/lab equipment.
- – Provide teaching interaction services and context-aware applications.

- Smart economy. This smart field deals with the productivity of a campus in relation to concepts like entrepreneurship or innovation.

As a summary, Figure 1 illustrates the main fields and technologies related to the deployment of a smart campus/university. The inner circle contains the six previously mentioned smart fields. The contiguous outer circle references some of the most relevant technologies required to provide solutions for such six smart fields, including IoT, Augmented Reality (AR), Cyber-Physical Systems (CPSs), or UAVs (Unmanned Aerial Vehicles). Note that some of such technologies are the same as the ones proposed by Industry 4.0 [25], so commercial and industrial deployments are already available in other fields outside smart campuses [26,27]. Moreover, there are also vertical fields like cybersecurity that affect several of the cited technologies, since their contribution is key to avoid potential issues [28]. Finally, the most external circle of Figure 1 indicates specific smart areas that are usually involved in the daily activities carried out in a smart campus/university. For example, smart plug-and-play objects [29] may be involved in many university activities, whereas certain environmental sensors are essential for actuating on smart buildings [30]. There are also other fields, like smart agriculture, that may be specific for smart campuses that include in their premises areas for growing certain crops that may require the use of autonomous decision-support systems [31].

Figure 1. Main fields and technologies of a smart campus.

3. Smart Campus/University Communications Architectures

Several authors have previously proposed different smart campus architectures, but it can be stated that, in general, they can be classified as Service-Oriented Architecture (SOA)

architectures [32,33] that revolve around two main paradigms (IoT and cloud computing [34]), which are usually helped by Big Data when processing and analyzing the collected information.

An example of smart campus architecture based on cloud computing is presented in [35], where the authors deployed a smart campus platform in three months by using Commercial Off-The-Shelf (COTS) hardware and Microsoft Azure cloud services. With respect to IoT, its use has been proposed for easing the deployment of architectures that allow for implementing learning, access control, or resource water management applications [10,36].

Some researchers have also proposed alternative paradigms for creating smart campuses. For instance, the authors of [37] propose an opportunistic communications architecture that allows for sharing data through infrastructure-less services. The main novelty behind the proposed architecture is the concept of Floating Content node, which is a computing device that produces data that can be shared among users located in nearby areas. Similar architectures have been proposed, but they have been focused on improving certain aspects like security [38].

Some of the latest smart campus architectures have suggested the use of the different types of the edge computing paradigm (e.g., mobile edge computing or fog computing), which have already been successfully applied to other smart fields [39]. The main advantage of edge computing is its ability to offload part of the processing tasks from the cloud, delegating such tasks to the so-called edge devices, which are physically located close to the IoT nodes. Thanks to this approach, the amount of communications transactions with the cloud and latency response are reduced, while also being able to provide location-aware services [40,41].

For example, the authors of [42] make use of edge computing devices to improve their smart campus architecture. Such devices are focused on delivering services related to content caching and bandwidth allocation. A similar approach is presented in [43], where the researchers provide smart campus services through edge computing devices embedded into street lights. In the case of the work detailed in [44], the authors propose a smart campus platform called WiCloud that is based in mobile edge computing, which allows for accessing the platform servers through mobile phone base stations or wireless access points. Finally, it is worth mentioning the smart campus system presented in [45], which makes use of fog computing nodes to enhance user experience.

To clarify the previously mentioned architectures, Figure 2 illustrates their evolution. In this figure, at the top, the traditional cloud-based architecture is depicted, which is composed by two main layers:

- Node layer: it consists of multiple IoT nodes and computing devices, whose data are collected through IoT gateways and routers in order to send them to the cloud where they are stored.
- Cloud layer: it is essentially a central server or a group of servers where the main processing tasks are carried out. In addition, the cloud allows for interacting with third parties, it presents the stored data to remote users and enables interconnecting the multiple IoT networks that may be scattered through different physical locations.

The architecture depicted at the bottom of Figure 2 on the left represents a fog computing architecture. In this case, besides the node layer and the cloud, there is a third layer (the fog layer), which is made of fog devices. Such devices provide different local fog services to the IoT nodes and are also able to exchange data among them to collaborate in certain tasks. A fog computing device is usually implemented on a Single-Board Computer (SBC), which is essentially a reduced-size low-cost computer (e.g., Raspberry Pi and Orange Pi PC) that can be easily deployed in the campus facilities.

Finally, the third and more evolved architecture of Figure 2 is the one at the bottom, on the right, which illustrates a typical edge computing smart campus architecture. Such an architecture is basically an enhanced version of the previously mentioned fog computing-based architecture, but through its edge computing layer it provides more computing power, thanks to the use of cloudlets. A cloudlet is often a high-end computer that is able to perform compute-intensive tasks, like the ones related to complex data processing or image rendering.
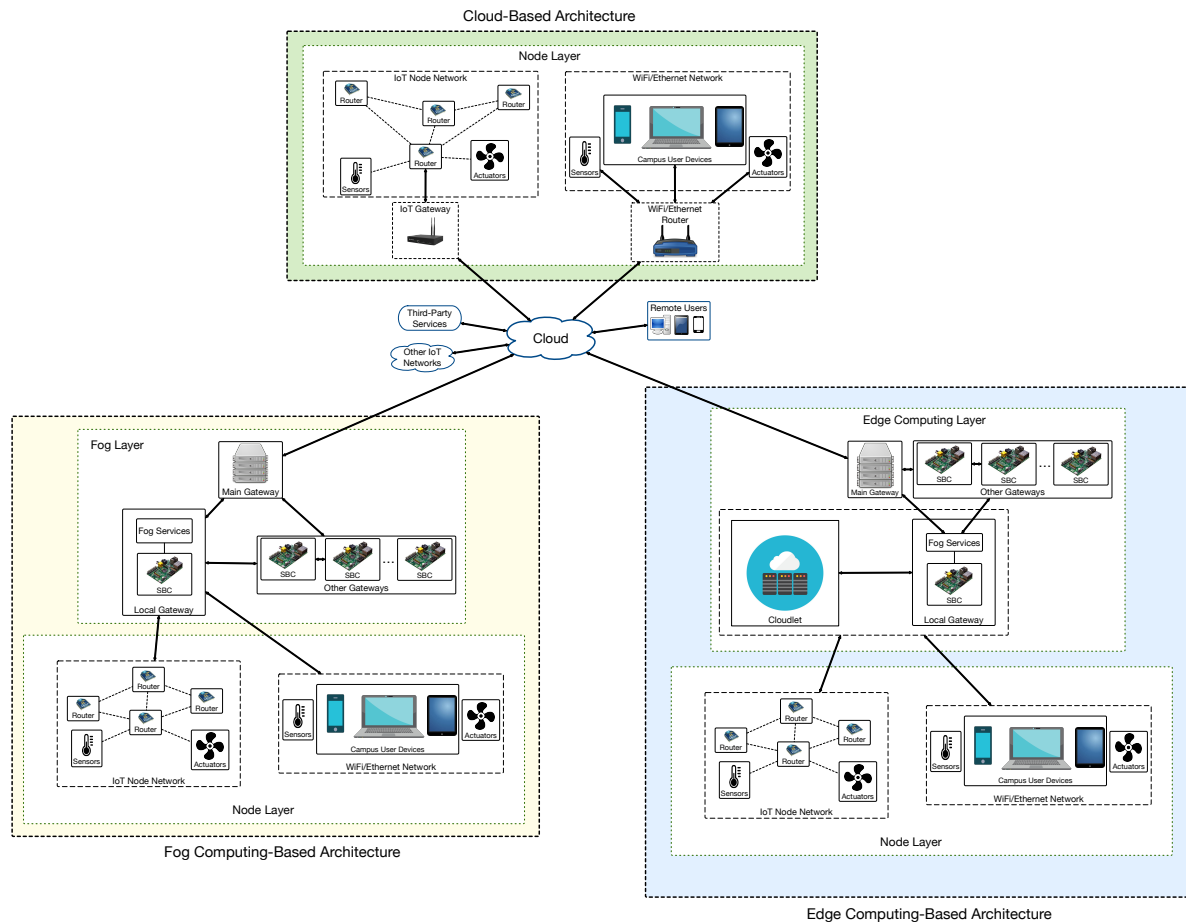
Figure 2. Smart campus architecture evolution.

4. Blockchain for Smart Campuses and Universities

Both academia [11–13] and public entities like the European Commission [46] have recently considered the improvement of the architectures described in the previous section by using Distributed Ledger Technologies (DLTs) like blockchain. Such a technology can be used for implementing higher education and smart campus applications, due to their ability to provide data exchanges among entities that do not necessarily trust each other [47]. In addition, the use of blockchain enhance smart campus applications that need transparency, data immutability, privacy, and security. Furthermore, blockchain allows for developing Decentralized Apps (DApps) based on Peer-to-Peer (P2P) transactions whose processes can be automated through the use of smart contracts, which can execute pieces of code in an autonomous way [48].

Nowadays, there are many blockchain platforms, like Ethereum [49], Hyperledger Fabric [50], or the popular Bitcoin [51], that can be used in multiple practical applications [52–55]. However, it is important to emphasize that blockchain is not the best technology for every application that needs to perform trustworthy data exchanges. For example, in many cases where smart campus applications are deployed in a private network, a traditional database is powerful enough and usually provides faster transactions than a blockchain. Therefore, to decide whether a blockchain is necessary, smart campus developers may use a decision framework [56] and, thus, detect certain necessary features, like the need for decentralization, transaction transparency, cybersecurity (e.g., data redundancy and protection against Denial-of-Service (DoS) attacks), or the lack of trust among entities (including respect to government agencies and banks).

Due to the previously mentioned benefits, different authors have proposed the use of blockchain and other DLTs for developing applications for smart campuses and universities. Specifically,

blockchain has been suggested for guaranteeing education certificate authenticity [57,58], managing digital copyright information [59], verifying learning outcomes [60,61], or enhancing e-learning interaction [62]. More potential smart campus applications and a deeper analysis on their characteristics can be found in [11–13,46].

5. Analysis of Recent Smart Campus and University Deployments

5.1. Relevant Deployments

In the literature, there only a few papers that present descriptions on actual smart campuses. An example of such a paper is [63], where the authors detail the development of the smart campus of Toulouse III Paul Sabatier university (France). Specifically, the smart campus is called neOCampus and involves multiple projects able to run on an open data platform that, for instance, can use collaborative WiFi. Similarly, in [64], the authors describe a smart campus based on cloud computing, SOA, and IoT that has been deployed in the Moncloa Campus of International Excellence of the Universidad Politécnica de Madrid (Spain). In the mentioned article, two applications are detailed: one for monitoring diverse environmental parameters, and another for determining people flows inside the campus. A similar smart campus is described in [65], where the authors propose an IoT and cloud computing based architecture for the Wuhan University of Technology smart campus (China) that is aimed at supporting diverse applications.

IoT is also key in the West Texas A&M University smart campus [66], which is deployed in a 176-acre land that includes 42 different buildings. Such a smart campus is focused on providing IoT-related and secure services, and has tested systems for smart parking or environmental monitoring. Another interesting work can be found in [33], where it is detailed the Birmingham City University smart campus (United Kingdom). The aim of the proposed smart campus is essentially to create a scalable and flexible SOA architecture where service integration and orchestration can be carried out easily through the use of an Enterprise Service Bus (ESB).

Finally, it is worth mentioning the work presented in [67], where it is described from a theoretical point of view the smart campus of Sapienza (Rome, Italy), including the author's approach for providing services in a scalable way.

As a summary, Table 1 shows the main characteristics of the most relevant smart campus deployments, including details on their location, size, used hardware, and their explicit support for advanced architectures (fog and edge computing enabled architectures) and blockchain-enabled applications.

Table 1. Characteristics of the most relevant smart campuses initiatives.

Reference	University	Smart Campus	Location	Size	Sensors and Actuators	IoT Hardware Platform	Cloud Platform	Applications	Fog/Edge Computing Support	Blockchain Support
[32]	Northwestern Polytechnical University	-	Xi'an (China)	-	Built-in smartphone sensors	-	-	Where2Study, I-Sensing (participatory sensing), BlueShare (media sharing application)	No	No
[33]	Birmingham City University	-	Birmingham (United Kingdom)	Two campuses of roughly 18,000 and 24,000 m^2	-	-	Microsoft's BizTalk Server as ESB	Business systems, smart buildings	No	No
[35]	University of Washington Bothell	School of STEM	Bothell (Washington, United States)	-	Accelerometer, magnetometer, gyroscope, light, humidity object and ambient temperature, microphone	Arduino	Amazon AWS and Microsoft Azure	-	No	No
[36]	University of Business and Technology	QA Higher Education (QAHE)	Birmingham (United Kingdom)	-	NFC and RFID tags, QR codes	IoT Wearables	Cisco Physical Access Control technology	Learning applications, access control systems	No	No
[37]	-	IMDEA Networks Institute	Leganés (Madrid, Spain)		-	-	-	Mobility modelling	No, but it is proposed the use of a similar paradigm (opportunistic Floating Content)	No
[38]	University of Oradea	-	Oradea (Romania)	-	RFID labels, mobile devices, sensor equipment	-	Private/public cloud with steganography	No (it only describes the architecture design)	No	No
[64]	Universidad Politécnica de Madrid	Smart CEI Moncloa	Madrid (Spain)	5.5 km^2, 144 buildings	Smart Citizen Kit	Raspberry Pi, Arduino	-	Smart emergency management and traffic restriction	No	No
[65]	Wuhan University of Technology	-	Wuhan (China)	-	RFID tags, cameras and diverse sensors	-	-	Smart learning and living	No	No
[66]	West Texas A&M University	-	College Station (Texas, United States)	0.71 km^2 with 42 buildings and a 9.68 km^2 working ranch	Temperature, air pressure, relative humidity and partial concentrations	Arduino	-	Connect cattle across the feed yard; environmental monitoring; water irrigation; smart parking	No	No
[67]	University of Rome	Sapienza smart campus	Rome (Italy)	-	-	-	N/A (it is only a theoretical proposal)	Smart living, economy, energy, environment, and mobility applications	No	No

Table 1. *Cont.*

Reference	University	Smart Campus	Location	Size	Sensors and Actuators	IoT Hardware Platform	Cloud Platform	Applications	Fog/Edge Computing Support	Blockchain Support
[68]	Soochow University	Wisdom Campus	Suzhou (China)	16.42 km^2	-	-	-	Automatic vehicle access, parking guidance, bus tracking, and bicycle rental	No	No
[69]	-	Indian Institute of Science campus	Bangalore (India)	2 km × 1 km	Water level sensors	TI MSP432P401R microcontroller	-	Water management	No	No
[70]	University of A Coruña	Campus de Elviña	A Coruña (Spain)	26,000 m^2	-	IoT nodes based on RisingHF RHF76-052 modules and IoT gateways based on Raspberry Pi 3	-	Outdoor applications (Crowdsensing, irrigation, and traffic monitoring)	Yes	No

5.2. Smart Campus and University Applications

Both indoor and outdoor applications can be deployed in a smart campus/university [8], but such smart applications differ in their requirements. The most relevant difference is that, in indoor environments, IoT nodes can be usually powered through the electrical grid and can make use of fixed communications infrastructure (e.g., Ethernet, WiFi access points). In contrast, outdoors, IoT nodes usually depend on batteries and need to exchange data at relatively long distances (at least several hundred meters, up to 2 kilometers). The following are some of the most relevant applications for both scenarios:

- Smart mobility and intelligent transport services. This kind of applications require outdoor communications coverage from traditional Wireless Local Area Networks (WLANs) or specific vehicular networks [71,72]. For instance, researchers of Soochow University proposed to use in their campus an automatic gate access system and diverse services for smart parking, bus positioning or for renting bicycles [68]. Similar services have been suggested by other universities for providing a smart parking service [73], electric mobility [74,75], smart electric charging [76], the use of autonomous vehicles [77], or for locating the campus buses [78,79].

- Smart energy and smart grid monitoring. These applications are used for controlling and monitoring the generation, distribution, and consumption of the campus energy sources (e.g., photovoltaic systems or wind generators). Specifically, in the last years, multiple authors focused their research on the study of smart campus microgrids [80–82], smart grids [83,84], and smart energy systems [85,86].

- Resource consumption efficiency. The use of the resources of a campus can be monitored through specific systems for garbage collection [87], water management [69], power consumption monitoring [88,89], and other solutions aimed at preserving sustainability [16].

- Infrastructure and building control and monitoring. The state of certain buildings and assets that are scattered throughout the campus can be monitored and controlled remotely. For instance, solutions have been suggested for monitoring campus greenhouses [90], for controlling the Heating, Ventilation, and Air Conditioning (HVAC) systems of the campus buildings [91] or for automating critical infrastructure supervision through Unmanned Aerial Vehicles (UAVs) [92].

- Green area monitoring. The health of the trees of campus can be monitored remotely through IoT sensor-based systems [93].

- User pattern and behavior monitoring. The smart campus services and infrastructure can be optimized thanks to the analysis of the user patterns and behaviors. For instance, mobility patterns, user activities, or social interactions can be determined through smartphone apps [94,95], by monitoring WiFi communications [96,97] or by collecting data from smartphone sensors [98], wearables, or even garments [99].

- Guidance and context-aware applications. These applications often depend on sensors and actuators spread across the campus and can help people by giving useful contextual information and indications on how to reach their destination. For instance, there is interesting research on guidance systems to aid hearing and visually impaired people [100] or for navigating the campus paths [101,102]. There are also augmented reality applications that provide relevant contextual information on the campus or that are able to guide the users through it [103–105].

- Classroom attendance. Different student monitoring systems have been proposed, which make use of IoT and artificial intelligence to control student classroom attendance [106] and their access to sport facilities [107].

- Remote health monitoring. Some of the latest smart campus applications are aimed at monitoring the health of certain campus users in real-time [108] or at measuring student stress [109] and health consciousness [110].

- Smart card applications. Although smart cards have been used for a long time by universities [111], they can still provide useful services for a smart campus, like information retrieval, mobile payments, library usage, access control, or e-learning [112–114]. Instead of a smart card, the latest developments suggested the use of the Near-Field Communications (NFC) interface of a smartphone to provide the mentioned smart campus applications [115]. Due to the multiple potential applications of smart cards, some authors also proposed to mine the data collected from the student transactions to infer their behavior [116,117].

- Teaching and Learning applications. The technologies embedded into a smart campus/university can also help students to learn through their mobile phones [118] or have an ubiquitous user-centered personalized learning and training experience with advanced analytics [119,120]. These technologies also allow teachers to make use of specific learning services (e.g., online programming contests [121]), sophisticated online teaching platforms [122], and to implement novel teaching paradigms like Flipped Classroom [123] or amplification [124].

- Research and innovation activities. Smart campus/university technologies can be used to encourage collaboration and cooperation among people (e.g., international networks of living labs). For instance, crowdsourcing can be used to collect data of people with different profiles (e.g., students, teachers, researchers, and administrative staff) and create large-scale datasets for further research and novel applications [125].

- Community-based knowledge transfer applications. Smart campus and university technologies can be explored to benefit the global community [126], either by increasing their awareness about sustainability issues [127] or by making citizens actively involved as central players of smart environments [128].

- Location-aware applications. In many situations the information given to smart campus users depends on their location. Such a location-aware data may include information on content, activities, projects, services, tools, knowledge, or events [129–132].

- Security services. Smart campus managers can make use of the multiple sensors and recording devices to monitor the campus status and increase physical security through video surveillance [133] and location-aware applications [134]. In addition, it is essential to protect the privacy of campus user data when making use of wireless communications [135] and preventing cyber-attacks [66].

5.3. Communications Technologies

In the past, researchers have used diverse technologies for connecting remote outdoor IoT nodes with smart campus platforms. Note that such technologies may differ a great deal from one scenario to another, as the distance to be covered and the kind obstacles found in the environment (especially, metallic objects [136]), severely condition signal propagation.

For instance, in [35], the authors propose the design of an IoT-based smart campus that makes use of BLE and ZigBee for providing short and medium-range communications. Nonetheless, note that ZigBee nodes can act as relays in a ZigBee mesh, so that the exchanged information can reach long distances [137].

WiFi (i.e., the IEEE 802.11 a/b/g/n/ac standards) is another popular technology that has already been suggested for providing indoor connectivity for smart campuses [64]. Bluetooth beacons can be also used in smart campus applications [138,139], but they usually are restricted to indoor environments, as their outdoor use requires the deployment of dense networks whose management is complicated [140].

Due to the popularity of mobile phones, the main cell phone communications technologies (i.e., 2G/3G/4G) have been suggested for providing smart campus services [141,142]. 5G technologies are still being deployed worldwide, but their use has already been proposed due to their ability to provide fast communications and reduce response latency in smart campus applications [122].

Despite the good perspectives of 5G for the next decade, nowadays, Low-Power Wide Area Network (LPWAN) technologies are arguably one of the best alternatives for smart campus applications that require low-power and long-distance IoT communications [143]. Some of the most popular LPWAN technologies are SigFox [144], LoRaWAN [145], and NB-IoT [146], existing other emerging technologies like Ingenu Random Phase Multiple Access (RPMA) [147], Weightless-P [148], or NB-Fi [149].

LoRaWAN defines the communication protocol and the system architecture for the network and uses LoRa as the physical layer. Although there are several recent works on the application of LoRa/LoRaWAN to multiple scenarios [150], only a few of them are focused on the deployment of smart campuses services [66,70,151–153]. For example, the authors of [152] analyze the indoor and outdoor performance of LoRaWAN on a French smart campus. In addition, other researchers [153] proposed a smart campus air quality system whose communications were carried out by LoRaWAN nodes. Another example can be found in [70], where the authors make use of a radio planning simulator to determine the optimal location of LoRaWaN nodes that provide smart campus services in outdoor applications.

There are also short-distance communications technologies that can be useful in smart campus applications. For instance, ANT+ transceivers are often embedded into chest straps to monitor performance and health in sports. Another example of popular short-distance communications technology is Radio Frequency IDentification (RFID), which is commonly used in university access control and payment systems [28].

Table 2 summarizes the main characteristics of the latest and most popular communications technologies for smart campus applications. Moreover, Table 3 compares the communications technologies of the most relevant smart campus solutions. Such a Table also indicates whether the provided references detail the network planning of the proposed solution and, as it can be observed, only a couple of works give details about it.

Table 2. Main characteristics of the latest and most popular communications technologies for smart campus applications.

Technology	Frequency Band	Typical Maximum Range	Data rate	Main Features	Typical Smart Campus Applications
ANT+	2.4 GHz	30 m	20 kbit/s	Very low power consumption, up to 65,533 nodes	Health and sport performance monitoring
Bluetooth 5 LE	2.4 GHz	<400 m	1360 kbit/s	Low power (batteries last from days to weeks)	User flow monitoring, guidance, positioning, telemetry
DASH7/ISO 18000-7	315–915 MHz	<10 km	27.8 kbit/s	Very low power (batteries last from months to years)	Item, vehicle and user tracking
HF RFID	3–30 MHz (13.56 MHz)	a few meters	<640 kbit/s	Low cost, in general it needs no batteries	User and asset identification for access control and payments
IQRF	868 MHz	hundreds of meters	100 kbit/s	Low power, long range	IoT applications
LF RFID	30–300 KHz (125 KHz)	<10 cm	<640 kbit/s	Low cost, it needs no batteries	Access control systems, asset tracking
NB-IoT	LTE frequencies	<35 km	<250 kbit/s	Low power, long range	IoT applications
NFC	13.56 MHz	<20 cm	424 kbit/s	Low cost, it needs no batteries	User access control and payments
LoRa, LoRaWAN	Different Industrial Scientific Medical bands	kilometers	0.25−50 kbit/s	Low consumption, long range	IoT applications
SigFox	868–902 MHz	50 km	100 kbit/s	It makes uses of private cellular networks	IoT and M2M applications
UHF RFID	30 MHz–3 GHz	tens of meters	<640 kbit/s	Low cost, it usually needs no batteries	Asset tracking, logistics, vehicle access control
Weightless-P	License-exempt sub-GHz	15 Km	100 kbit/s	Low power	IoT applications
Wi-Fi (IEEE 802.11b/g/n/ac)	2.4–5 GHz	<150 m	up to 433 Mbit/s (one stream)	High power (batteries usually last hours), high-speed, ubiquity	Internet broadband access
Wi-Fi HaLow/IEEE 802.11ah	868–915 MHz	<1 km	100 kbit/s per channel	Low power	IoT applications
WirelessHART	2.4 GHz	<10 m	250 kbit/s	Compatibility with the HART protocol	IoT sensing applications
ZigBee	868–915 MHz, 2.4 GHz	<100 m	20−250 kbit/s	Very low power (batteries last months to years), up to 65,536 nodes	Wireless sensor network applications, home automation and smart building applications

Table 3. Communications technologies of the most relevant smart campuses solutions.

Reference	Smart Campus	Communications Technologies	Network Planning
[32]	Northwestern Polytechnical University	Wi-Fi, Bluetooth	No
[33]	Birmingham City University	-	No
[35]	University of Washington Bothell	Zigbee, BLE, 6LowPAN	No
[36]	University of Business and Technology of Birmingham	-	No
[10]	Tennessee State University	-	No
[37]	IMDEA Networks Institute Wi-Fi, Bluetooth	No	
[38]	University of Oradea	4G, Zigbee	No
[43]	-	MESH Wi-Fi	No
[44]	-	Wi-Fi	No
[45]	-	3G/4G/5G, Wi-Fi	No
[64]	Smart CEI Moncloa	Wi-Fi, Ethernet	No
[65]	Wuhan University of Technology	Cable, wireless, 3G/4G	No
[66]	West Texas A&M University	LoRAWAN, 4G/LTE	No
[67]	Sapienza smart campus	-	No
[68]	Wisdom Campus, Soochow University	-	No
[69]	Indian Institute of Science	sub-GHz radios	No
[70]	University of A Coruña	LoRaWAN	Yes (based on 3D-ray launching)
[154]	Universitas Indonesia	800 MHz, 2.3 GHz, and 38 GHz	Based on ray-tracing and physical optic near-to-far field

6. Future Challenges

Despite the evolution of smart campuses and universities in the last years thanks to the technological advances achieved in fields like IoT, cloud computing, and certain communications paradigms, future university planners, IoT vendors, and developers will still face relevant challenges in the following areas.

- Scalability. As a campus can cover a large area, where a large number of users can request smart services, it is essential for applications to be easily scalable in order to adapt its performance to the number of simultaneous users.
- Service flexibility. A smart campus/university should be able to provide multiple services, which may differ depending on the physical area where they are provided (e.g., depending on the faculty), on the specific user that request them (e.g., access privileges may differ between a student and a professor), or on the specific goal (e.g., advancing to more effective teaching and learning services may differ substantially from the design of smart environment applications).
- Long-distance low-power communications. Since campuses usually cover areas of thousands of square meters that often involve monitoring outdoor smart IoT objects (e.g., street lights, irrigation systems), it is key to consider in the smart campus architecture the use of long-distance

wireless communications technologies whose energy consumption should be as low as possible to maximize IoT node battery life.

- New communications technologies. Although this article has analyzed the currently most relevant communications technologies, smart campus designers should be aware of the latest advances on communications in order to include them in the designed architecture. For instance, some authors are already suggesting potential applications for 6G technologies [155,156].

- Blockchain integration. DLTs like blockchain can be really useful to guarantee operational efficiency, data transparency, authenticity, and security. This aspect is a key enabler to develop novel decentralized smart applications (i.e., DApps) and to leverage new artificial intelligence paradigms such as big data, machine learning, or deep learning. These paradigms need to rely on trustworthy datasets in order to reach their full potential and produce new data model-based applications. Nevertheless, smart campus designers have to use blockchain with caution, considering their advantages and disadvantages. In addition, the incorrect use of smart contracts can be a problem, since they are able to trigger certain automatic behaviors that can have serious economic or personal consequences.

- Lack of smart campus standards and public initiatives. Although, in the last years, smart city initiatives have proliferated worldwide, there are only a few specifically related to smart campuses and universities. In addition, there is not a common framework for designing or deploying them, so future developers will have to keep compatibility and interoperability issues in mind.

- Seamless integration of outdoor and indoor smart campus applications. Due to their communications needs, outdoor and indoor applications may differ in the underlying technologies, so it is necessary to design architectures and devices that allow for switching between communications transceivers. This means that, although the lower layers of the communications protocol may differ, the upper layers are compatible so that they are able to provide seamless communications among users, IoT objects, and the computing devices scattered throughout a campus.

7. Conclusions

This article examined how higher education can leverage the opportunities created by the latest and most relevant IT technologies. After analyzing the basics on smart campuses and universities, this work has focused on studying the potential of IoT, blockchain, and the most recent communications architectures and paradigms (e.g., fog/edge computing) for developing novel smart campus and smart university applications. In addition, the latest key deployments as well as their communications technologies have been detailed and analyzed. Finally, the main future challenges are listed in order to allow future university planners, IoT vendors, and developers to create a roadmap for the design and deployment of the next generation of smart campuses and universities.

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