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Application of a Smart City Model to a Traditional University Campus with a Big Data Architecture: A Sustainable Smart Campus

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Abstract: Currently, the integration of technologies such as the Internet of Things and big data seeks to cover the needs of an increasingly demanding society that consumes more resources. The massification of these technologies fosters the transformation of cities into smart cities. Smart cities improve the comfort of people in areas such as security, mobility, energy consumption and so forth. However, this transformation requires a high investment in both socioeconomic and technical resources. To make the most of the resources, it is important to make prototypes capable of simulating urban environments and for the results to set the standard for implementation in real environments. The search for an environment that represents the socioeconomic organization of a city led us to consider universities as a perfect environment for small-scale testing. The proposal integrates these technologies in a traditional university campus, mainly through the acquisition of data through the Internet of Things, the centralization of data in proprietary infrastructure and the use of big data for the management and analysis of data. The mechanisms of distributed and multilevel analysis proposed here could be a powerful starting point to find a reliable and efficient solution for the implementation of an intelligent environment based on sustainability.

Keywords: sustainability; IoT; big data; smart cities; smart campus; Hadoop

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1. Introduction

The population of cities is growing through birth as well as migration from rural areas. It is expected that the proportion of the population living in cities and towns will "rise from 54 percent in 2015 to 60 percent by 2030, and to 66 percent by 2050" [1]. This unstoppable growth poses many environmental concerns, mainly an increase in the consumption of natural resources. The consumption of resources has been studied for several years, where its orientation has been based on the sustainability of the environments where people perform their different activities. Conducting a study and a proposal for sustainability supported by the use of information and communication technologies (ICT) is a heavy task for the extensive areas covered by a city, as well as the variations in society. This study addresses sustainability from a technological point of view, developed in a scaled environment such as a university campus. University campuses can be as large as cities and represent environments that are normally difficult to reproduce in another ecosystem. The idea is conceptualized by converting a traditional campus into a smart campus based on the concepts and experiences of smart cities where the integration of systems satisfies the needs of citizens with control over the consumption of resources.

Smart cities are partly the result of advances in the field of ICT where, thanks to the Internet of Things (IoT), multiple devices can connect to the internet and generate information that allows them to interact effectively with other members [2]. However, moving from a traditional city to an intelligent city entails a great technical and socio-cultural effort, in addition to a high investment in physical and economic resources. The questions to answer, before considering a smart city environment, are broad and require specialists in different areas to work together under the objective of optimizing resources [3].

A university campus conforms to the previous definition, so having this type of ecosystem is an ideal starting point for this study. The geographical distribution, administration and the number of people who frequent them constitute ideal environments for the demonstration of techniques or processes of a smart campus [4]. However, the question of what a "smart and sustainable campus" is and of what it comprises remains. From this initial question, other more specific questions arise: is ICT able to solve sustainability issues in a smart campus? What improvements does a smart campus offer over a traditional campus in terms of sustainability? Moreover, do traditional campuses meet, at least partially, the requirements of smart and sustainable campuses? Not all these questions can be answered based on a single experience; therefore, they should be addressed in cooperation with the different areas that make up the administrative and academic part of a university campus and based on experiences of related works. Several of these works do not cover a study like the one proposed, where the objective of creating a smart campus goes hand in hand with the sustainability of the campus with the environment.

Related research proposes policies or reviews on how to educate students to encourage good use of resources. This is different from the proposed work, because the basis is the use of ICT to provide the necessary means to meet the needs of students with the adequate use of resources. This study begins by defining university campuses as places where hundreds or thousands of people study or work, and their work depends on the infrastructure to house them. This infrastructure is a network of communications, transport and services that are required for the management of university life [5]. As a result, the processing of each activity generates large volumes of information. This information is stored with the purpose of consulting it later and generating knowledge that is useful for the user. Among the systems and devices that generate information within a university campus are security systems, biometric access devices or card readers, wireless systems, automatic dispensers, domotic buildings, academic management systems, financial systems and so forth [6]. In traditional university campuses, these systems are independent and do not have processes that centralize the information in such a way that they can be used to optimize resources and take advantage of knowledge to improve student learning.

The integration of these different systems is the basis for a better interpretation of why things happen within a university environment. For example, the latest generation of wireless systems provide relevant information about the places that students prefer in certain seasons [7]. In the same way, automatic dispensers can reveal information about consumables that teachers prefer in their free time [8]. The access sensors provide important information with which to determine the time a person stays on campus [9]. The application of domotic systems allows the adequate management of the consumption of energy. These are several of the systems that can be found on a university campus, and that allow the supposition that the transformation to a smart campus is feasible [10]. The IoT concept provides the necessary support for all devices to connect to the Internet, and the data they generate is stored in centralized places such as the cloud. At the university campus level, there are technological advantages, since most have private data centers that would replace a public cloud, reducing the costs of external services and ensuring the high availability of the data [11].

The centralization and analysis of data are important in a smart campus for their contribution to the processes of identification of events and needs, considering that universities make decisions based on the data they have about students and their administrative structures. However, current decision making requires improving methods of data analysis and results in shorter periods. The problem is that the volume of data greatly exceeds the processing capabilities of the classic analysis platforms [12]. Having techniques that detect the needs of the university population and generate results based on trends is the basis of a smart campus. Therefore, the alternative, which currently represents a trend in data science for its superior results, is the use of big data. These platforms offer alternatives for the management of data and obtaining knowledge about students that are flexible, with lower costs and in shorter periods. Traditional techniques such as business intelligence (BI) and data mining can perform data analysis. However, due to their nature and the limitations of the data, many of these are omitted or eliminated in the preparation process; in a smart campus, it is important to keep most of the data while looking for alternative techniques for cleaning, so that it does not affect the efficiency of the decision making [13].

This work proposes, taking as a guide, the smart cities and moving from a traditional campus to a smart campus that works with three fundamental axes: the acquisition of data through the IoT, the centralization of data in a proprietary infrastructure and the management and analysis of data with the use of big data. This integration allows proper management of the information that is generated within the campus. The sensors are responsible for monitoring all the events that arise in their environment and sending the information to a storage system. The system stores the information in a private cloud where all the data are processed and transformed to present quality data for the next phase. The big data architecture is in charge of selecting the data and, through data analysis processes, it gives the campus the knowledge necessary to make decisions. For example, on a hot day, the sensor system monitors the temperature and the environment of each of the classrooms. According to this information, the management systems determine what action they should take, such as opening windows or turning on the air conditioning system. Being able to manage the different devices, by means of a previous analysis of the acquired data of the environment, allows the adequate use of the resources in a sustainable environment [14]. The results of this work allow the generation of comfortable environments where the students, teachers and administrative staff have their needs met in total harmony with the environment. The depth of the analysis should make it possible to determine exactly the places most frequented by students through the data obtained from the wireless system. Knowing the exact location of students makes it possible to take advantage of these spaces to generate awareness campaigns about the use of resources.

This work is divided as follows: Section 2 presents the concepts used for the development of the method; Section 3 contains the method, where the different phases to be considered for the implementation of a big data platform are established; and Section 4 presents the conclusions found in the development of this work.

2. Preliminary Concepts

2.1. Big Data

Big data is massive data analysis, referring to an amount of data so large that traditional data processing applications are not able to capture process and present the results in a reasonable period. Big data was born with the aim of covering needs not met by existing technologies [15]. In education, it can have an important impact on teachers, school systems, students and curricula. The analysis of big data can identify students at risk, ensure that students are making adequate progress, and can support the implementation of a better system for the evaluation and support of teachers and principals [16]. To comply with this process, big data techniques work around the storage and processing of data that have specific characteristics, such as:

- The content format;
- The type of data;
- The frequency with which the data is made available;
- The intention: how the data should be processed (ad hoc query in the data, for example);
- Volume: the size of the data that can come from multiple sources;

- Velocity: the speed with which data arrives using units such as terabytes, petabytes or exabytes;
- Variety: structured, semi-structured, and unstructured.

2.2. Smart Campus

Technological advances modify the immediate future and create new paradigms on human interactivity with things. The integration between technologies and their applications in social environments promotes the generation of intelligent environments, which support the automation of processes, remote control, and decision making in their environment. University campuses are places where thousands of people study or work daily. The university campuses are in communication with the cities in which they are located on tangible issues related to infrastructure, and on intangible issues such as social relations or innovation [17]. The use of ICT, as in cities, improves educational campuses and the quality of life of the inhabitants [18]. It allows areas of educational control to monitor their students and those involved in university education. A smart campus allows a better coexistence between the university population and its surroundings, adequately manages the resources within the campus, and provides favorable places for learning.

2.3. Smart Cities

An intelligent city is able to take advantage of the data it produces in its daily operations to generate new information that allows its management to be improved and to be more sustainable, more competitive, and offer a better quality of life, thanks to the participation and collaboration of all the citizen actors. A smart city detects the needs of its members and reacts to these demands by transforming the interactions of citizens with public knowledge systems and elements of knowledge [19]. The intelligent city bases its actions and its management on this knowledge, in real time, or even anticipating what may happen.

2.4. Internet of Things

There is data everywhere in the home, at work, and in practice in all facets of life. Communication devices generate large volumes of data that allow managers or data scientists to establish research on user trends, as well as the status of machines and their products. The connection of physical things to the internet makes it possible to access data from remote sensors and control the physical world remotely. The combination of captured data and data retrieved from other sources, for example data on the Web, results in new synergistic services that go beyond the services that an isolated integrated system can provide. This technological innovation aims to connect the items we use daily to the internet, with the aim of bringing the physical world closer to the digital world [20].

2.5. Hadoop

Hadoop is an open-source framework for storing data and running applications in basic hardware clusters. It provides massive storage for any type of data, as well as enormous processing power and the ability to handle virtually unlimited tasks or work. Hadoop applied in technological environments is not only able to acquire and manage large volumes of data, but it does so regardless of its format. Hadoop can store all kinds of data: structured, unstructured, and semi-structured; log files, images, video, audio, communication, and more. Hadoop stands out for presenting an architecture capable of ensuring high availability and recovery of the data it ingests [21].

The large volumes of data generated in the systems included in this study require a platform that allows their processing, guaranteeing speed, effectiveness, and data quality. In this proposal, the Hadoop architecture is used as a platform due to the advantages it offers in the distribution of nodes for all sub processes. Hadoop allows improvement of the processing without punishing the use of the infrastructure that the campus has. Another advantage is the versatility that it presents in the processing of data that is in different formats. An example of this is the events generated by the personnel access systems; these systems send the data in plain text files or .xml files.

In a campus, as well as in a smart city, finding a diversity of sources forces us to look for solutions that go beyond the traditional BI platform. Hadoop assigns massive collections of data across multiple nodes within a cluster of servers, while indexing and keeping track of the data and preparing it for the analytical process. It is necessary for the implementation of a smart campus to integrate several data sources and apply a process of analysis on these, because the behavior and the patterns that a person presents depend on many variables, unlike any other process of data analysis.

For example, if a student consistently fails a multiple-choice exam, it is important to recognize why he has this difficulty. The data that is available in the different computer systems of the university campus contain substantial information that, by means of preprocessing and analysis, can explain the factors relevant to why the student fails. These factors often do not depend on a linear analysis, since the variables are many and depend on one another. In the case that is presented, a socio-academic analysis of the student, whereby applying a regression of the data, it is possible to detect whether the student is carrying this problem from the high school, may be necessary. If this process is satisfactory, it will not be necessary to include more variables. Otherwise the analysis is extended where systems are added and thus there are more variables. This example gives a simple output if it is considered that there are cases where the analysis process needs to include the data of all the systems, with the volume of data, as well as the processing, increasing exponentially. For this reason, it is important to select a big data architecture that provides enough resources for the process, both in memory and in storage. Hadoop adapts to the aforementioned needs for the analysis of data, which collects information from IoT systems, systems with transactional as well as non-transactional databases, plain text files, and so forth.

2.6. Definition of the Problem

The continual growth of the university population forces the expansion of university campuses both physically and in the expansion of resources as they need to cover the needs of their members [22]. To cover these needs, it is important to establish a structured plan that allows students to live with the environment where issues of global interest, such as sustainability, are raised. University campuses that do not have a defined plan, which includes guidelines and policies that allow the proper management of economic, social and natural resources, affect the development of learning. To solve these problems, university campuses look for alternatives supported by ICT. The consideration that is made is that university campuses generally have their own computer infrastructures that allow them to generate and store large volumes of data, which in most cases is used. Having a platform that takes advantage of all the systems in charge of acquiring data and analyzing them in a private cloud environment helps the management of learning and the interaction of the university population with ICT. This process, in addition to guaranteeing improvement in educational processes, allows the university population to interact with the environment and improve situations of comfort, safety and decision-making. The challenge for data scientists is to unify all the data generated in academic systems, financial systems, enterprise resource planning, learning management systems, security systems, sensor systems and actuators, among others.

The experience of studies carried out in the field of smart cities allows systems to be integrated, applying IoT and big data concepts to transform a traditional campus into a smart campus. This option has great value in educational management because it improves the interaction of students, teachers and administrators in a sustainable environment. It generates comfortable environments where the needs of each individual are covered in a personalized way, based on a projection of their tendencies. This ecosystem integrates concepts, technologies, data and individuals to guarantee a knowledgeable society where the development of learning is guaranteed by new technological trends [17].

Another important aspect of the definition of the problem is the importance of the security and privacy of the data. The ability to extract and analyze the data that big data achieves will probably generate controversies and negatives in the campus population. To solve these problems, it is important to have clear security and privacy policies in the handling of data [23].

3. Related Work

The process of the selection of related works was made by taking the model proposed by Barbara Kitchenham as a guide [24]. This method details the steps to follow to obtain a review with research value. In the process, we searched and classified more than six thousand articles from four sources related to smart cities and smart campuses. The scientific bases considered for the search were Scopus, Springer, Elsevier and IEEE. The process of inclusion and selection is detailed in Figure 1. The figure shows the phases used for the filtering of the articles and the number of works reviewed. In the first stage, a search was made on scientific bases, simply relating to works in the smart cities and smart campus area published between 2014 and 2018 and which have open access, with the result that six thousand and seventy-five works were found.

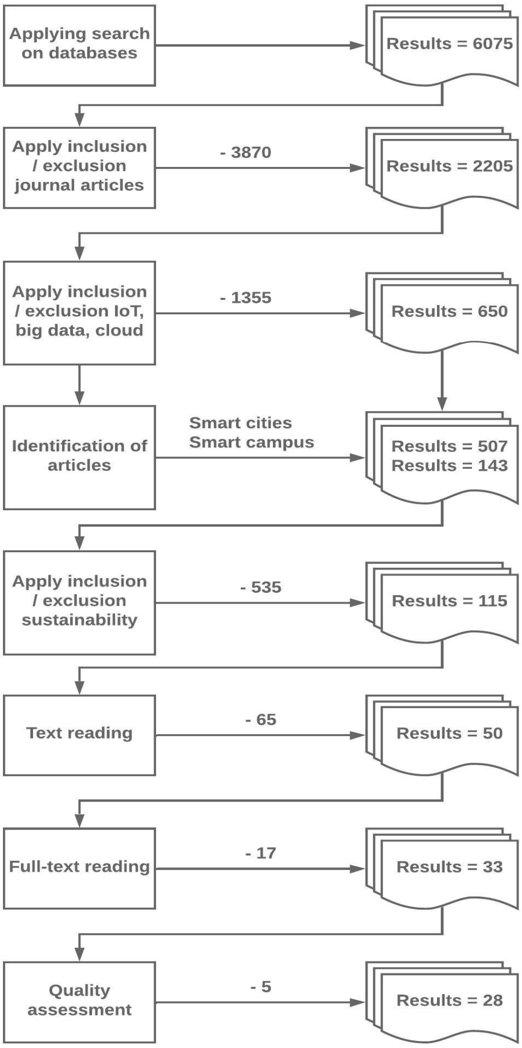

Figure 1. Process of the selection of previous works. Source: authors.

In the second stage, the works were filtered and only journal articles were considered, resulting in two thousand two hundred and five articles. In the third phase, the works that were related to the use of IoT, big data and cloud computing were filtered, resulting in six hundred and fifty articles. These articles were processed to identify those that deal with smart cities, obtaining five hundred and seven results and those that deal with smart campuses, obtaining one hundred and forty-three articles. The articles were processed to identify those that addressed issues such as sustainability, resulting in one hundred and fifteen related articles. The next stage was to make a reading of the summary, introduction and conclusions focused on verifying the guidelines of the articles with the proposed work, of which sixty-five articles were excluded. Of the fifty remaining articles, seventeen dealt with the issue of system integration in a smart campus or smart city environment in a superficial manner, so they were excluded by selecting thirty-three articles for the next stage. The thirty-three selected articles went through a new review where the quality of the article was evaluated specifically within the proposed method and the relevance that it represented for this work and five articles were excluded. The twenty-eight articles included in this study contribute directly to the objective of this work that seeks to establish an intelligent campus, integrating innovative technologies that guarantee the coexistence of the population with the environment in a sustainable model.

Table 1 describes the twenty-eight works considered, the type of research, and the type of contribution. These works were reviewed in detail, since they were those that directly influenced the research.

Table 1. Distribution of publications by type of research. Source: authors.

REF	Title	Type of Research	Type of Contribution
[25]	A smart campus prototype for demonstrating the semantic integration of heterogeneous data	Proposed solution	Process
[26]	From the university to smart cities—how engineers can construct better cities in BRIC's countries: a real case from smart campus FACENS	Evaluation research	Model
[27]	Social activities recommendation system for students in smart campus	Proposed solution	Tool
[28]	OnCampus: a mobile platform towards a smart campus	Proposed solution	Process
[4]	What smart campuses can teach us about smart cities: user experiences and open data	Evaluation research	Model
[29]	Data acquisition and analysis of smart campus based on wireless sensor	Proposed solution	Process
[17]	Learning analytics for smart campus: data on academic performances of engineering undergraduates in Nigerian private university	Evaluation research	Model
[30]	The construction of smart campus in universities and the practical innovation of student work	Proposed solution	Process
[31]	Evaluation of the smart campus information portal	Evaluation research	Model
[32]	Intelligent campus (ICampus) impact study	Evaluation research	Model
[33]	A study on association algorithm of smart campus mining platform based on big data	Evaluation research	Model
[34]	The development of a smart campus—African universities point of view	Proposed solution	Process
[35]	Composite indicators for smart campus: data analysis method	Proposed solution	Model
[36]	Student perception of smart campus: a case study of Czech republic and Thailand	Evaluation research	Process
[37]	Building a smart campus to support ubiquitous learning	Evaluation research	Model
[38]	Smart campus: fostering the community awareness through an intelligent environment	Evaluation research	Process
[5]	Constructing smart campus based on the cloud computing platform and the internet of things	Evaluation research	Process
[39]	A smart, caring, interactive chair designed for improving emotional support and parent–child interactions to promote sustainable relationships between elderly and other family members	Evaluation research	Process
[40]	E-Learning and Its Effects on Teaching and Learning in a Global Age	Evaluation research	Process
[41]	Adding the "e-" to learning for sustainable development: challenges and innovation	Proposed solution	Model
[42]	Corporate attitudes towards big data and its impact on performance management: a qualitative study	Proposed solution	Model
[14]	Designing an efficient cloud management architecture for sustainable online lifelong education	Evaluation research	Process
[43]	Sustainability and energy efficiency research implications from an academic	Proposed solution	Model
[44]	Exploring factors, and indicators for measuring students' sustainable engagement in e-learning	Evaluation research	Process
[45]	Operating charging infrastructure in China to achieve sustainable transportation: the choice between company-owned and franchised structures	Proposed solution	Model
[46]	Systematic review of education for sustainable development at an early stage: cornerstones and pedagogical approaches for teacher professional development	Evaluation research	Process
[47]	Definitions and frameworks for environmental sustainability in higher education	Proposed solution	Model
[48]	The impact of modern markets on the performance of micro, small and medium enterprises	Proposed solution	Model

The first consideration was that the works related to smart cities addressed the problem from an urbanistic point of view; the variables that were part of the studies represented the care of the environment and the proper use of energy resources. Another factor of analysis was mobility and security; these factors include geographic problems and video surveillance systems [5,29,37]. Here, domotics and the IoT are considered stronger, as the objective they focus on is to implement models that allow the use of energy and the proper use of energy. The IoT, for its part, manages the deployment of sensors and devices that generate information that is stored in the cloud through the internet. For the process to be complete, the information stored must generate knowledge. Big data is responsible for the analysis through the processing of data, and the results respond to the needs of people in real time. Figure 2 shows the basic pillars of an intelligent city that contribute to competitiveness and safeguard a sustainable future in the symbiotic link of networks of people, companies, technologies, infrastructure, consumption, energy, and space [49].

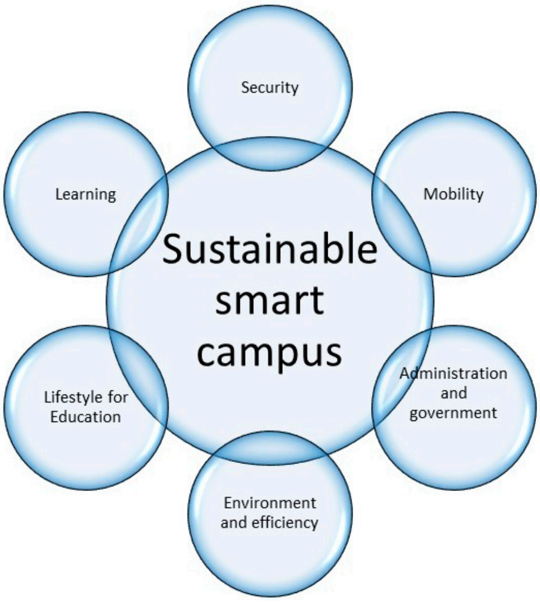

Figure 2. Pillars of a sustainable smart campus. Adapted from: [50].

Secondly, the works related to smart campuses are considered and 85% were studies that recommend the use of different models of smart cities applied to a university campus. They performed an analysis of the characteristic features of these environments, focused mainly on the management of services through mobile or desktop applications [51]. The main objective was to exploit the information generated by the different systems responsible for academic management. For example, through applications users could know exactly where they were, or easily find an office or person. Other applications focused on a specific area of the campus, such as a faculty or a building. The purpose was to centralize the largest number of devices and sensors that provided relevant data on the activities developed in that area. The ten works considered as the main ones to address the sustainability issue were directly related to specific areas that were included in the study, for example, a sustainable environment which supports improvement to the learning or the administration of the cloud in an efficient way [14,40]. These works guaranteed the functioning of the architecture proposed in this investigation. The guideline that was carried out with these works was to take the experiences and proposed designs and compare them, in certain cases, with the architecture of this work and to improve the design of sustainability in a campus.

4. Method

The concept of smart campuses is not new; however, the conception and integration of new technologies make it truly innovative. The results of the analysis of related works determined that in the field of smart campuses, there are still many topics to be addressed, and problems that require scientific contributions. The method of this research establishes a process that includes all the components that contribute to the transformation of a traditional campus into a smart campus. The existing models and processes in smart cities act as a guide for this work. Based on this, several pillars that are part of smart cities are included in the analysis of university campuses, maintaining the difference in scales as a reference [37]. Therefore, a university campus is considered a controlled representation at the scale of a city. University campuses have always displayed a recurrent ambivalence. On the one hand, they have acted as a powerful exchanger of knowledge and opportunity for collaboration; while on the other hand, they have provoked conflicts and isolation in students with academic problems. The explanation of these phenomena is complex and there are different understandings, depending on the point of view of the analysis. From a social point of view, university campuses are a place of crisis for certain populations [52]. Their complex and concentrated socio-academic activities often give rise to problems of exclusion, segregation, and educational polarization. However, learning generates wealth and well-being for those involved. In fact, university campuses are a space of coexistence and connection for individuals and social groups, which stimulates and facilitates the development of learning and knowledge [53].

In summary, a university campus is a generator of social problems and, at the same time, an institution that provides solutions. However, student agglomerations produce important negative externalities, such as greater responsibilities and a lack of resources, which reduce academic efficiency. Solving these negatives requires considerable effort towards their correction [54]. From the point of view of innovation, university campuses are excellent places to generate inventions, develop new technologies and disseminate knowledge. From an environmental point of view, the artifacts and physical devices incorporated in the university campuses transform and model the natural environment where it is located. The transformation of the physical environment has to do with the construction of infrastructure and buildings that can generate significant environmental impacts [55].

4.1. Characteristic Features of University Campuses

By thinking of a university campus as a small city, it serves as a test bed for the integration of techniques that make up a smart campus. This concept allows identification of the characteristic features of a campus based on those of a city [56]. For example:

- Complexity: One of the main challenges facing university campuses is the level of complexity of the processes that take place within their limits, and in their area of closest influence. So-called "complexity science" is understood as a set of ideas about the self-organizational capacity and the adaptive nature of some complex systems. Complex systems include the climate, natural ecosystems, the economy, and in this case, university campuses.
- Diversity: The campuses differ among themselves because of their geographical location, their academic vocations, or their socio-economic structure. At the same time, very different spaces coexist within each campus. The more sophisticated and disparate the functions of a campus, the more diverse the agents involved in them will be. If the dimension factor is added to this condition, then the greater the size and functional complexity, the greater the number of agents that will have to be counted when formulating policies.
- Uncertainty: For planners, the uncertainty that surrounds the future of university campuses is a constant consideration. Any projection is faced with the task of foreseeing the future of a campus in ten or twenty years. The current limitations of forecasting tools have greater weight in situations that worsen if one operates in a constantly changing environment.
- Sustainability: A university campus generates a significant change in an environment, the installed infrastructure; the consumption of energy, the interaction of people with the environment must be controlled through institutional policies. New technologies provide sufficient means and processes to find a balance between the environment and the consumption of natural resources [43]. Sustainable development must be included in the design of smart campuses, where the needs

of all its stakeholders are met without compromising the development of new generations and natural resources.

The characteristic features of a university campus allow identification of the key points that support a smart campus. The structure of a smart campus must be flexible, scalable and evolutionary, where processes are evaluated constantly and the level of reaction to external events is efficient [57]. The controls and audits, considering the characteristics of the campus, must guarantee that its components are adequate and include all factors of influence in the daily life of the campus.

4.2. Components of a Smart Campus

This research is carried out in a university campus that chose to participate in the study. In Figure 3, the components that are considered for the development of the method are presented. These components internally govern diverse systems that comply with a specific process, and the integration of these and the general components results in a smart campus. A smart campus aims to improve the quality of life of its community by applying ICTs in a sustainable manner [35]. For this purpose, the components included in this work are related to three main axes: the IoT, in charge of generating and obtaining environmental data; cloud computing, which centralizes data in internal or external infrastructure; and big data, which comes with the analysis and management of data [58].

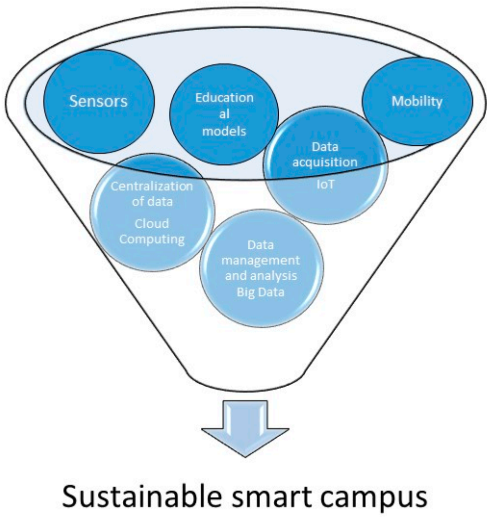

Figure 3. Components considered for a sustainable smart campus. Source: authors.

4.2.1. IoT Data Acquisition

The IoT allows information to be stored on the internet, thanks to the connectivity that different devices and sensors have. This information is processed, and the results allow measurements or control of different environments. Within a smart campus, this concept is maintained but on a small scale. This feature has advantages with respect to the handling and control of information [59]. In this work, the data of all the identified components of the campus is part of an internal network and are stored in a data center infrastructure where the best physical characteristics for the storage and processing of information are provided [60]. The campus has integrated several systems considered as part of the IoT, and these systems acquire information on activities and events that are a daily part of university life. Among these are:

- Access control systems: Biometric sensors or RFID readers control the security of the university campus. When detecting any event, the sensors activate the different actuators located strategically in the smart campus [29].
- Automation systems: The university infrastructure is complemented directly with autonomous systems. These systems seek to reduce energy waste, as well as improve the quality of life of the

university population. Several of these systems are integrated into the data analysis architecture that helps manage resources efficiently [42].

- Security systems: Security is vital in a university campus, and for this, there are systems of sensors or video surveillance systems that generate information about any event 24 h a day. The potential of these systems allows their data to be used for other activities, such as detecting trends or identifying special needs of the population. The monitoring capacity added to the analysis process allows autonomous control of the services offered by the university.
- Automatic dispensing system: Automatic dispensers are widely used in university campuses and are devices that have relevant information on the trends of the population that consumes these products. The analysis of these data can reveal which product is the most consumed in different periods.

The way in which sensors interact with the environment and people contributes to creating a knowledge society. The sensors are responsible for collecting information from the environment and sending it to the cloud, where interested parties can consume it. Information converted into knowledge helps decisions to be made quickly and accurately. This contribution is ideal for the development of smart cities; however, in an environment of scale, the results are measurable and quantifiable in much shorter periods. The aforementioned does not imply a leap in the processes or in the architecture of an IoT system. The technology proposed by Kamilaris and Pitsillides [61] gives this proposal greater validity, since implementing an ecosystem based on the Internet of Things will ensure that students and teachers make sound decisions in relation to their environment. This ecosystem contributes to managing hours of classroom use and managing virtual environments with interactive learning devices. The decision-making system can automatically detect which equipment or system is not in use and put it in standby or turn off as appropriate. In the area of academic management, this technology contributes to the allocation of physical spaces that meet the needs of each subject, as well as the number of participants.

The system, with the use of IoT, reduces the consumption of energy resources by generating friendly environments. These environments are based on the automation of events such as opening blinds, turning lights on or off, etc. Controlling a large number of events has greater advantages and encompasses a set of systems that allow for the control of more complex and susceptible environments such as a data center [47].

With the security that the integration of cameras will bring to the system, the teacher will be able to verify that each student is who they say they are. In addition, tasks assigned to the teacher are automated, which, in traditional education models, are still practiced manually, such as taking attendance. With this technology, acting through cameras, facial recognition that determines which student is present or not, is possible. Having technology as the main assistant in the educational environment breaks the paradigms of learning and opens greater possibilities to generate knowledge.

Another important point is the acquisition of data where the protection of personal data of the individuals that make up the smart campus is considered. On this subject, there are works [62] that study the regulatory framework applicable to the use of personal data in smart cities that serves as a reference for the development of a smart campus. The controlled ecosystem where this work is carried out allows the total availability of the data. However, access to them is done with the appropriate permission of the population. Another measure of control is the ability to persuade the university community to participate in the use of the data that, through its analysis, seeks to satisfy its own needs.

4.2.2. Cloud Computing and Centralization of Data

Previously, the systems that are part of the data acquisition were described; the objective is to improve the management of the information. For this, it is necessary to store the data in a centralized place with access to all the systems that are part of the university campus. For example, smart cities upload and store data to the cloud in order to manage the data in an adequate and fast way [63]. Using the cloud in the architecture of smart cities does not represent major inconvenience due to the management capacity, as well as the availability of greater economic resources. In a smart campus, storage becomes an infrastructure problem and a cost-benefit analysis. To solve these problems, the use of internal data centers that are part of the university infrastructure is considered, essentially transforming its intranet into a private cloud [64].

The ability to manage data internally improves control by implementing quality processes in storage and high availability when consuming data. This research uses a data center architecture that allows the generation of a private cloud to provide secure data storage. Figure 4 details the topology within the data center. This topology provides the capacity to store 60 terabytes of information. It also has redundancy systems and backup equipment that guarantee the availability and quality of the data. In addition, energy backup systems are available in case of any electrical failure. The devices that comprise this private cloud architecture guarantee availability on the proposed platform. The VNX3200 is responsible for storage in solid-state disks. It is connected to the management and processing unit via fiber optics that allow high-speed data transmission. It is composed of two internal controllers that, in addition to managing the storage system and meeting the requests of the processing unit, allow high availability and redundancy of the data. The second element is a Cisco UCS MINI chassis that integrates eight blade servers that allow the creation, administration and distribution of virtual machines. In addition to these tasks, the servers also handle computer processes, attends to customer requests, and are responsible for processes such as load balancing and virtualization tasks. There are elements of redundancy that allow the system to guarantee availability in case of any incident. Finally, the N3K-DC devices are three-layer switches; each one integrates 48 fiber optic ports that are connected in a redundant architecture which guarantees communication. Through this equipment it is possible to communicate with the campus intranet, and the services can even be published to the internet.

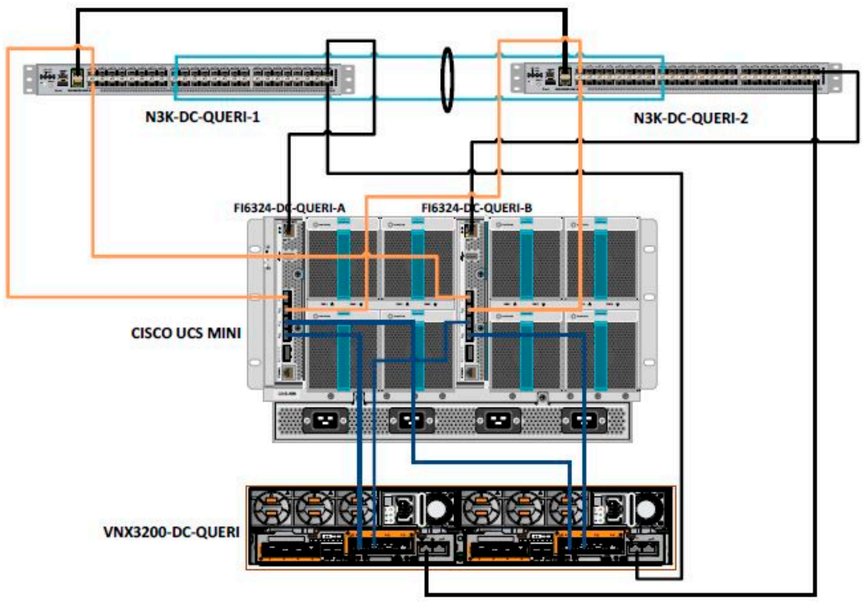

Figure 4. Topology of a private cloud. Source: authors.

All systems are connected directly to the computing center, which is the intelligent part and is responsible for processing tasks. The data center is connected through two-network equipment, that works in layer three, to the data network of the entire campus. This part of the topology guarantees high availability and redundancy in case of an accident in one of the pieces of equipment. This architecture allows the creation and management of different virtual servers, facilitating management in the processing of information according to the concept of big data.

4.2.3. Data Management and Analysis of Big Data

Before starting the process of data analysis and management, work must be aligned to the regulatory framework that applies to the use of data in the smart campus. A specific framework, which applies to environments as proposed, has not been possible to locate in the analysis of previous works; however, at this level the laws generated by each state also govern. These problems are better known in the use of the internet as new factors undermining the right to privacy generate serious problems of personal and commercial security. For the development of this work, the right to privacy for each person has been considered due to the law established by the country where the study originates [65]. In addition, the data is duly protected during the process and is used only for educational analysis, maintaining the right to privacy of the individual protected by the legal tradition that protects and preserves the inviolability of the home, papers and documents. This ensures that others can use none of these elements without the consent of the individual to whom they belong. During the execution of the method, sensitive data thats affect the most intimate details of a person's privacy have not been used, eliminating the possibility of creating an ideological, racial, sexual, health, economic or any other profile that becomes a threat to the individual. Therefore, the regulations on data protection will not apply to information such as files kept by individuals in the exercise of exclusively personal or domestic activities, nor those data made anonymous in such a way that it is no longer possible to identify the interested party [66]. In a smart campus like the one proposed, there are processes where the identification of individuals is not necessary. The opposite happens in ecosystems such as medicine where the application of big data requires identifying each individual to associate an illness or disease. In this phase, it is important that the data of each person can be associated as belonging to him or her.

The existing data sources in a smart campus directly influence data management. For this reason, it is important to use tools capable of performing a quality process in the extraction, transformation and loading of data (ETL), considering adequate processing times. Studies on educational data analysis use BI techniques applied to educational data in order to discover patterns in students that allow the detection how they learn [67]. The results are used to make corrective decisions in teaching methods, as well as to make projections and anticipate a possible event such as student desertion [68]. These studies use ETL processes, the processed data is stored in a data warehouse, where data is queried through data mining algorithms and a conclusion is reached. These techniques generally take as a guide the application of the processes of data analysis of a company and, when passing them to a wider environment, they present certain technical and knowledge difficulties. On the one hand, a BI system is developed in an environment where the analysis objective is unique and, in many cases, can focus on a part of the business, for example, the detection of variables affecting sales in certain quarters. If the study needs more scalability, it is necessary to go back to the design process, add the variables to generate cubes of online analytical processing (OLAP) and design the dashboards to present the information. For the development of processes, both commercial and open source tools can be used. The decision to use commercial or open source tools depends on the economic limitations of the organizations and knowledge level of the tools.

Another important factor that intervenes in the use of BI platforms is the data sources they can handle and which are usually structured databases [69]. When processed by the ETL they are stored in a multi-relational database. The management of these platforms is increasingly versatile and staff with the required knowledge are not difficult to find. If we compare the needs in the aforementioned environment vs. what a smart campus implies, good results are not expected immediately in the volume of data. The first comparison is because, in the extraction of data from the different sources, an ETL does so on an individual basis based on the variables that it needs for the analysis, which means that if these variables change, it will be necessary to create a new connection to the correct source and start the process again. In a smart campus model, the idea is to consider all sources and that the platform in charge of data analysis manages the variables regardless of the sources. Having a large number of variables exponentially increases the volume of data considered for the analysis.

Another point to consider is the ability to use data that is not precisely in a specific format: an ETL has the ability to work with several formats, extract them and convert them to a specific one. This task, although it seems an advantage when we talk about a large volume of data and variety in the formats of the data, can become a problem when consuming many storage and processing resources. In a smart campus, the management of several systems is considered both in structured databases as well as in unstructured sources.

The analysis of the possible usefulness of a data analysis tool based on BI platforms confirms that the conditions of the data in an intelligent campus exceed its functionalities. In an environment such as the one proposed, it is necessary to have processing and storage that guarantees high availability, safety and quality in the data. For this reason, in a smart campus, it is important to think about platforms that have been used in large companies that work with large volumes of data like Hadoop [70]. Companies of the scope of Google, Yahoo, Amazon, and so forth, have used this tool, and this guarantees the treatment of the data at the required level within the guidelines established in the study. Another advantage of Hadoop is the ease it has to skillfully manage any type of file or format; something that is very difficult to obtain with a traditional BI approach [71]. Other architectures such as Apache Spark apply to big data platforms. This architecture in relation to Hadoop presents better response time in processing and is used in real-time analysis. Apache Spark is more expensive than Hadoop for the deployment of infrastructure that it needs. Although this architecture is novel and has been put on par in the market with Hadoop, it does not meet the conditions presented in this study [72].

The method we used based on cost and the availability of the infrastructure is Hadoop, which is an open-source framework for storing data and running applications in clusters [73]. Hadoop provides massive storage for any type of data, has an enormous processing capacity, and is able to process virtually unlimited concurrent tasks or work.

The architecture of Hadoop allows an effective analysis of large volumes of data, and the results can strengthen decision-making and improve educational processes. This architecture also allows monitoring of the opinions of students, as well as the ability to draw conclusions about learning problems presented by certain groups of students. With Hadoop, universities can exploit complex data, analyze it, and customize results by adapting the process to the needs of the university and the students.

Hadoop is composed of three fundamental pillars: versatility, flexibility, and fault tolerance. Among the components that allow the execution of the architecture is the distributed file system (HDFS). The Hadoop engine consists of a MapReduce work scheduler, as well as a series of nodes responsible for executing it [74]. These characteristics are presented as a set of utilities that enable the integration of subprojects. It is important to consider that MapReduce also provides retrospective and complex analysis capabilities that can touch most or all of the data [75]. MapReduce provides a method of data analysis that is complementary to the functions provided by SQL.

The main problems that are resolved in Hadoop are

- Data capture;
- Storage;
- Filtering out;
- Transfer;
- Analysis;
- Presentation.

These problems are classic in a traditional campus, and the way to solve them is through client-server storage methods where the user interacts with the application, which in turn controls the storage and analysis through relational databases. This method works well with applications that do not generate a large volume of data and that are processed by traditional servers, or that do not exceed the limit of their processor. In summary, this method depends on the applications and available computing resources. An example of this is the process used by BI. However, when it comes to dealing with huge amounts of scalable data, processing the data through a single database is a frantic task, which makes the process a bottleneck.

MapReduce divides the task into small parts and assigns them too many teams, collects the results, and forms the resulting data set. Figure 5 shows the traditional method of data analysis in a university campus, where the user interacts with an application and the data is stored in relational BDD. On the other hand, MapReduce manages the data generated in several processes; the centralization system processes this data and interacts with the user when presenting the results.

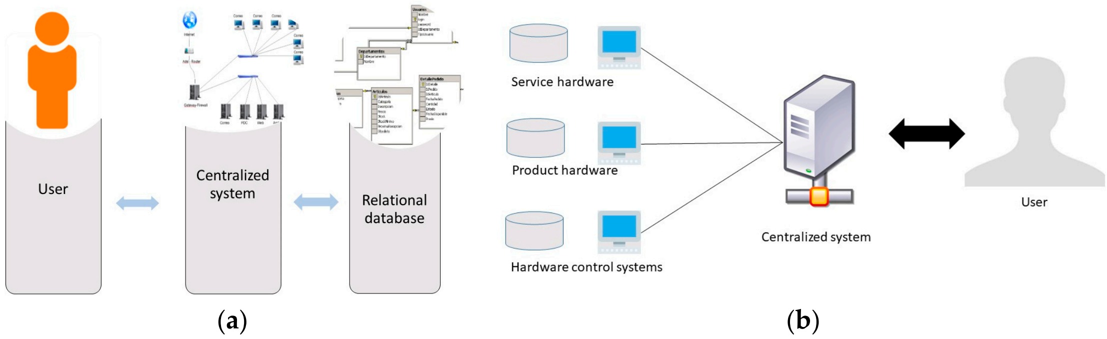

Figure 5. (**a**) Traditional analysis system vs. (**b**) MapReduce. Source: authors.

The architecture shown in the previous figure represents an improvement in the management and processing of the data; Hadoop integrates the MapReduce algorithm, which is responsible for the processing of the data in parallel [76]. Figure 6 presents the architecture of Hadoop, which in its core has two main layers; the first is responsible for the computation, and the second is responsible for distributed storage. Thus, the base apache Hadoop framework is composed of the module of Hadoop common that contains libraries and utilities needed by other Hadoop modules. There are Java libraries and utilities required by different Hadoop modules. These libraries provide file systems and OS level abstractions and contain the necessary Java files and scrips required to start Hadoop. The next module is the Yarn framework that is a resource-management platform responsible for managing computing resources in clusters, providing very high aggregate bandwidth across the cluster.

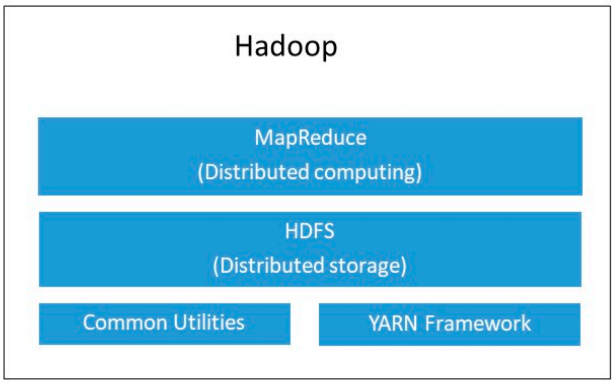

Figure 6. Hadoop architecture. Source: authors.

According to the characteristics and needs presented in a smart campus, Hadoop has the best architecture when applied in a fully distributed mode [77]. This mode of operation requires that a defined number of clusters be deployed that are responsible for processing all assigned work. The management cluster carries out the assignment of tasks, and both the management and the processing are virtual machines assigned in the data center of the campus. The advantage of having the architecture in the intranet is network management, which leads to the best use of resources. Being integrated with the internal network, the communication is transparent and there are no critical problems, as can be the case when creating the clusters in an external cloud [78].

The installation of the architecture is done on a Linux platform then the functionality in the workflows is checked. MapReduce plans the tasks through a JobTracker that is responsible for sending the works to the nodes. MapReduce sends the incoming workflow to the available TaskTracker nodes in the cluster, handling the map functions and reducing them in each node [79]. The planner keeps tasks as close to the machine that has issued that information as possible. If the work cannot be located in the current node in which the information resides, the nodes in the same rack are given priority. This allocation reduces network traffic on the cluster's core network. If a TaskTracker fails or suffers a timeout, that part of the work is rescheduled. Hadoop responds to a master–slave structure, where the JobTracker is located in the master and there is a TaskTracker for each slave machine, as shown in Figure 7. The JobTracker records the pending works that reside in the file system. When a JobTracker starts, it looks for that information, in such a way that it can start the work again from the point where it was left [80].

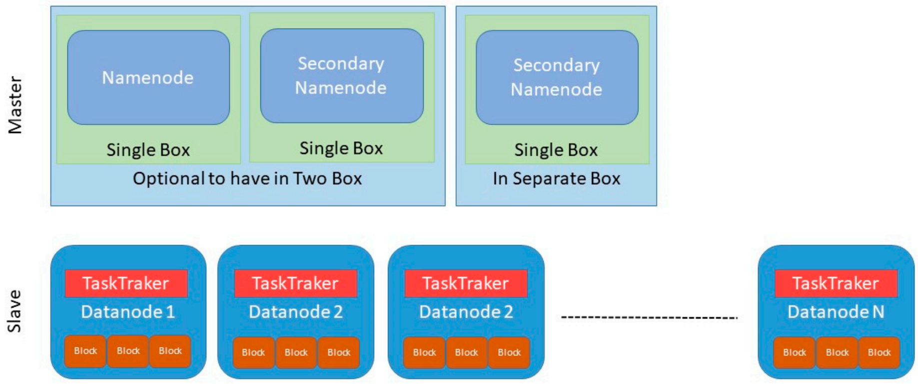

Figure 7. Hadoop master–slave structure. Adapted from: [81].

The HDFS handles two fundamental elements in the architecture: the NameNode and the DataNode [82]. The NameNode is only found in the master node and is responsible for keeping all the stored data indexed. That is, it informs the application where the searched data is found. The NameNodes are found on the computers of the slaves and are responsible for storing the information.

With the architecture mounted and with the data acquisition process executed, it starts its analysis. This is done through Hadoop, which allows visualization of the different nodes in a graphical interface. In the analysis of the data, the project is divided into several subprojects, which facilitates obtaining information for each system included in Hadoop. For example, it is possible to analyze the drinks that have the highest consumption at certain dates or seasons. The skill of the data scientist is in posing the right questions to help to control the parameters of a specific event.

The Hadoop interface contains all the works that are in process and stores the corresponding information in files. To verify the functioning of the architecture in this research, the following conditions for the analysis are presented:

- Which are the beverages that present the higher indices of consumption in examination seasons in the campus?
- Which are the places in the campus with the highest population density in winter and summer?
- What are the activities that generate greater knowledge in students in the campus?

These questions seek to solve common problems in a university and help improve the use of resources and the understanding of university trends. For the first question, the information generated by the automatic dispensing system enters the analysis process. The information is sent from the dispensing machine to a virtual server. Figure 8 details the architecture of the data acquisition of the different sensor and actuator systems. In the specific case of the dispensers, they contain different sensors that allow the actuators to generate a specific event that is translated into data, which is sent to the information layer. In this layer, the data is stored in relational or non-relational BDD, depending on the application. The communication protocol of the sensors and actuators at the commercial level is varied. However, the university that participated in the study, with the purpose of designing a scalable architecture and guaranteeing communication, standardized the use of the technologies and with them the protocol of communication within the smart campus using the TCP protocol. In the knowledge layer, the data sent by the dispensing machines is acquired through the different data mining processes, or what is defined within the big data platform. The knowledge generated is applied in the good use of resources for the first case, and the improvement of services. Hadoop stores the data and the administration cluster assigns small analysis processes to the 120 nodes implemented within the architecture. The storage format of the data is simple and contains fields such as date, time, type of beverage, location within the campus, and its identifier. This data arrives in plain text and in real time; therefore, the analysis process has accurate information. The Hadoop analysis is based on applications developed in Java, where the Hadoop libraries are imported and a .jar file is generated that, when executed, starts the analysis process.

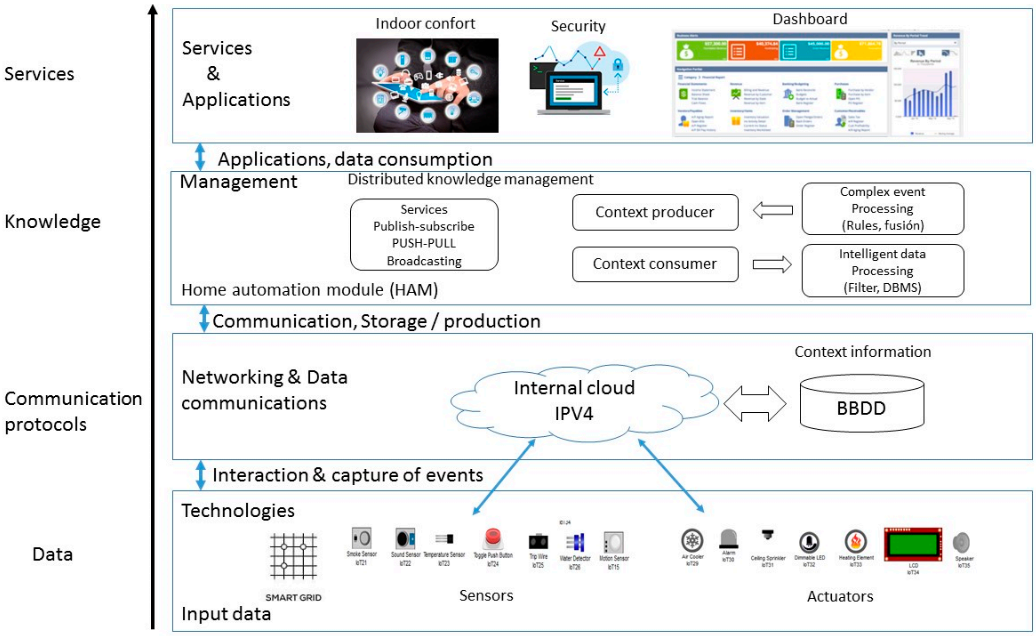

Figure 8. Internet of Things (IoT) architecture within a sustainable smart campus. Source: authors.

Table 2 presents the results of the first analysis, where the study period consisted of 2 weeks, which is the usual period of exams. Samples were taken every four hours, and drinks available in each machine were classified into four classes. The percentage is related to the amount shipped and the total amount of beverages owned by a vending machine of 288 units capacity. The table shows a high consumption of coffee, followed by coca cola drinks, which in one way or another contain caffeine. With the results obtained, several adjustments can be made within the optimization of resources. On the one hand, it has the capacity to project the number of beverages required according to their classification in different seasons. On the other hand, with the results of the analysis, it is possible to complement a study on stress in students when performing an exam. The study makes it possible to create awareness campaigns on the dependence on caffeine, and the treatment of stress in the student population.

The analysis of the places with the highest population density within the campus requires accurate information on the location of the students. In order to comply with the requirements of the analysis, the data generated by the wireless local area network (WLAN) is considered. The university campus has an integrated WLAN system that handles load balancing device identification, enabling this type of study. Access-point (AP) devices provide information about the number of hosts that are connected, and the controller that manages the APs can emit traces of these hosts that include information of the time they connected to the network, as well as the identification of the AP to which they are connected [83]. The potential of wireless systems promotes the use of information to the inhabitants of the smart campus, based on the conditions of the environment. This consideration is applicable according to work that has been done in urban sectors, and that can be adapted to the needs presented in this study [84]. This monitoring is continuous; therefore, the volume of data is high, and the consequence is that the processing of the file takes more time. To reduce the processing time, we work with algorithms developed in Java that perform a pre-filtering, whereby the sample is segmented from months to weeks or days.

Table 2. Consumption of drinks in examination seasons. Source: authors.

Period	Type of Drink	Percentage
07:00–11:00	Coffee	60%
07:00–11:00	Coca-cola	25%
07:00–11:00	Juices	10%
07:00–11:00	Others	5%
11:00–15:00	Coffee	53%
11:00–15:00	Coca-cola	30%
11:00–15:00	Juices	11%
11:00–15:00	Others	6%
15:00–19:00	Coffee	42%
15:00–19:00	Coca-cola	39%
15:00–19:00	Juices	15%
15:00–19:00	Others	4%

Table 3 shows the results obtained in the density analysis, in which the gross data in of four random weeks of both the summer period and the winter period are considered. The distribution of the AP within the smart campus is by area, and the amount of equipment assigned depends on the analysis of the population density and the optimization methods that the wireless system allows. The APs, in addition to providing access to the network, generate important information such as the amount and detail of the hosts that connect to the network in a specific period. This information is useful to determine in which areas more infrastructure resources or bandwidths are needed, with the objective of optimizing these resources. Another derivative of this analysis is that academic authorities can provide relevant information about the university at the points where students usually meet. Chatting or informative activities can be held by academics taking advantage of the places preferred by the students. The results shown in the table are as expected; however, the tool allows a quantitative analysis, which allows the use of resources to be improved and generates objectivity in its use.

Table 3. Areas with the highest population density in a smart campus. Source: authors.

	Number of Users in Summer per Week				Number of Users in Summer per Week			
Areas	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**
Playground	6450	6098	5493	4536	4839	3927	2983	1826
Green areas	2983	4997	5382	6113	5487	4387	3762	2873
Coffee shops	502	493	650	528	638	936	1182	1382
Laboratories	392	182	293	387	508	1029	1603	2083
Libraries	932	670	398	732	736	1283	1893	3072
Buildings	1982	805	1038	963	973	1562	1793	1923
Total	13,241	13,245	13,254	13,259	13,181	13,124	13,216	13,159

The implementation of a data analysis architecture such as Hadoop allows for better decision making regarding the management of natural resources. Through information on places where there are a greater concentration of students, it is possible to carry information about the proper use of resources. Generating awareness campaigns becomes a way of education and even more so when the smart campus has a system that learns from the data generated by each user. For the deployment of network equipment or AP, sectors that do not have a minimum number of users are restructured immediately to take advantage of resources and promote use in the places that need it.

To respond to the academic activities that generate learning in students, the structure of a single system that provides data to multiple systems is changed. This coupling of more data sources is required because analyzing performance in people requires greater effort, as well as a greater number of variables. The variables contain the student's socio-academic information, academic record, financial situation, interaction with learning management tools, and so forth. There are several methods through which the analysis can be focused; one is to create a sub process that filters the information of each system, and then unites it in one to present the information. Another method is to perform the sequential analysis of each system, where the results are stored in variables and then presented as a common result.

When creating sub processes in charge of analyzing each system, the processing time is optimized. This functionality is found in the capacity of Hadoop when assigning and coupling a certain number of cores to each task. The inclusion of data mining algorithms allows deepening of the analysis to create clusters and identify the patterns in each student. This analysis allows determination of how students learn, as well as evaluation of the teaching methods of each teacher. This type of study is a true contribution to a smart campus, since it allows the improvement of learning, which is the main objective of a university. By improving the quality of learning, the results of the environment improve, as this conveys a vision of excellence internally and externally. A good image as a university helps improve student income rates, and this goes hand in hand with the economic growth of the campus. Therefore, economic well-being improves the quality of life of those involved, and budgets are increased in all areas.

Mobility is another important point that directly affects sustainability within the smart campus and one of the objectives of this architecture is to reduce the CO2 emission that this causes. In order to meet this objective, it is important to analyze the information that exists within the campus and why the problem arises. As a starting point, we must consider that a university campus can be geographically as large as a small city, therefore, mobility must be considered in a sustainable environment. To solve the problem there are options, such as implementing an internal transport system that carries out the tours every so often. This option solves the problem, to a certain extent, of the inhabitants of the campus not using their vehicles and therefore reducing the emission of gases. However, it is not an optimal solution because its implementation is based on the experience of the administrative staff of that area.

The architecture proposed in this work covers these needs by defining the times, units and routes of each transport based on the analysis of the students' existing data. Figure 9 shows the flow diagram under which the process to solve this problem is conceived. The first stage is responsible for collecting the data that comes from systems such as the location system through the wireless, video surveillance systems and academic management systems. If the data exist and are appropriate, the big data architecture assigns the necessary nodes to perform the processing of the information. The following flow leads to the storage of the data and its analyses through Hadoop that performs the process based on the research parameters. For example, when identifying patterns in students, the most frequent places are determined, even the big data process takes data from previous processes such as the location of students through the wireless system. This information is selected according to the students who have traveled the greatest distance, in this way it is possible to determine if the students move over short or long distances. As a fixed variable, the system detects students who travel more than two kilometers, with this data, there is enough information to define the places to which, and times in which buses should be sent.

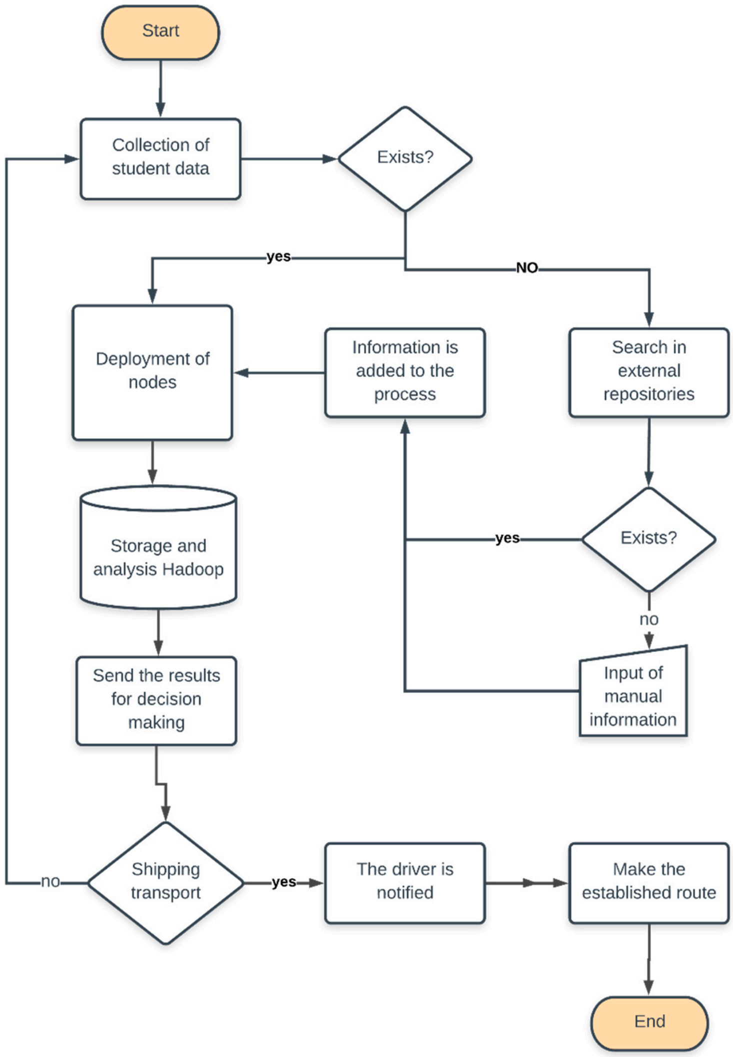

Figure 9. Flow diagram of an internal transport process by means of big data. Source: authors.

The video surveillance systems, as an integral part of the proposal, send information about bus stop points. If there is saturation; the analysis system detects and alerts the administrator to send buses. Academic management systems provide information about student schedules so that big data identifies all the variables that contribute to solve the problem. Once the transport administrator is notified, they arrange the driver and the route. If the transported shipment is not made, the cycle returns to the data collection phase and the process is repeated. If the data does not exist or is not sufficient for the analysis, the process stops and looks for information that helps to solve the problem in external sources such as alternative systems or spreadsheets. If the data found is sufficient, the data is added to the process and the Hadoop nodes are implemented according to the request made. Otherwise, the data is entered manually, this corresponds to scenarios where the system does not find enough data to make a decision and an operator has to join the process to verify or correct it if it is the case.

5. Discussion

Transforming traditional campuses into smart campuses not only improves the management of processes that contribute positively to student learning, but the approach carried out in this work also allows the integration of state-of-the-art technologies to solve problems related to the use of resources, as well as to improve the environment where learning takes place. The use of technologies, such as IoT, allows the automation of different environments within the campus, enabling the interaction of individuals directly with the environment. This technology, taken from smart cities, allows the campuses to acquire information on all the events that each student, teacher or member of the administrative staff performs [47]. At the same time, it is capable of executing actions that improve the lives of people, no matter how basic they may seem. For example, the use of dispensers that send data on the preferred choice of individuals at each time of the year show the population trends with the possibility of generating healthy eating habits in individuals.

The wireless service, when implemented, allows us to measure the population density in each area of the campus, offering even detailed information about the movement of each device and therefore of each person. This ability can be exploited, in addition, to offset charges in the AP and opens the possibility of detecting these places and bringing important information to the university, such as waste management, services provided by the university, etc. All this is possible with the proper use of resources and the most important thing that these technologies allow is the reuse of the devices that the campus has to take advantage of the technological and economic resources [43]. These possibilities, which are framed in these systems, directly support the sustainability within the environment. In the work developed, the systems, through the information acquired, processed and analyzed, are able to execute actions that align with the proper use of resources. For example, in the energy part, the smart campus acts directly on areas or stations that do not require energy by directly turning off any device that is located in it. Additionally, the interactive equipment that has been integrated into the system shows whether a teacher uses it or not, in such a way that, at a certain time of inactivity, the device generates an event and it enters into energy saving mode.

In terms of security, the smart campus architecture allows integration of all the means used for perimeter security, turning them into the eyes of the campus, where each event is monitored in real time. Internally, the architecture is able to recognize people through intelligent services implemented as an additional component of big data. This service improves the management of each class by eliminating processes that a teacher is used to doing, such as taking a register. With facial recognition, the smart campus is responsible for this task, becoming the assistant in each class. Another factor that is possible to improve is the mobility within the campus. This study has been developed in a campus that has more than thirty hectares and there are several disadvantages when trying to move from one faculty to another. The use of vehicles has been restricted and emphasis is placed on the use of internal transport, reducing the pollution emitted by private vehicles [44]. However, how is it possible to cover the mobility needs of each student? The responsibility rests again with the monitoring systems, but especially with the results obtained from Hadoop. Data analysis allows the system to improve the allocation of schedules for both teachers and students so that students with similar schedules are classified and located in specific areas. These results reduce the students' needs to move long distances within the campus. However, the analysis goes further and has the ability to identify the trends of each student, for example, the hours and places he usually visits during his/her free time. By identifying this trend, Hadoop classifies and effectively issues the number of buses, their capacity and hours that these must travel through the different areas.

The combination of technologies demonstrates that generating ecosystems, where people, technology and the environment can coexist, is possible and that their results can be applied to larger environments. Smart campus is the ideal test bench where new technologies can be evaluated and their architectures can be replicated in cities, improving the way of life for individuals.

The use of data can become a topic of discussion in the application of big data within a smart campus; however, it is necessary to motivate the population about their participation in this process. The objective of this project is to improve the wellbeing of the people who are in this environment, for which the use of data is indispensable. With this method, it has been explained about their use and how they are protected. However, there are processes where identifying people will be essential, specifically in the analysis of the data that determines how students learn. This process, which is specific to identifying patterns and classifying students, recommends activities that help improve student learning. Another point is security. The smart campus has several systems that are able to identify who enters or leaves each of the facilities, guaranteeing the trust of each person in the system.

In this work, it has been considered as an internal policy of the smart campus that not all information is published and the current law of the country where it carries out its activities governs the use of the data.

Another necessary aspect to consider is technological acceptance. This issue directly involves the population who are part of the study, because, in the design of the smart campus, the changes to the different areas of the campus are considered. At this stage, it is possible to detect negatives to the implementation due to ignorance or to a technological change, which brings with it a rejection of new processes. To counteract this, a model capable of mediating between technology and people is required. The technology acceptance model (TAM) will be considered as a model in future work and provides the correct path for the population to accept a technological change that adds new concepts and automation of processes [85]. In many cases, people consider new technologies as a direct competitor, arguing that many of these technologies can replace people in their activities. Awareness and education are the keys to this process and those people who will be responsible for motivating others to accept the technologies in their environment and, even more so, the proposals in this work that interact with the university population. The importance of the TAM makes it possible to prepare students to live in societies that support good communities, living with nature and generating sustainable environments such as smart cities.

6. Conclusions

The main question stated at the beginning of this work was what makes a university campus a smart campus? To address the issue, it has been necessary to perform a specific analysis of the characteristics they present. A university campus is a set of infrastructures such as classrooms, libraries, laboratories, faculties and computer systems where the university community can develop activities for their learning. This concept is broadened by Sections 2 and 3 of this work. A university campus should not focus solely on infrastructure, it needs to interact more with its community. This interaction helps to guarantee learning by offering services that guarantee the comfort and safety of each person. In addition, our proposal aims to facilitate management in all areas of a traditional campus through data analysis processes that have been described in this method.

The next question that was addressed in the study was to define what problems traditional university campuses are facing; the answer is part of the definition of the problem. However, it is important to mention the experience that large companies have gone through, where all those that have not evolved and integrated ICT in their processes are destined to disappear. This same concept applies to university campuses, which generally assume that learning is linear. This perception has changed and it is the duty of its authorities to improve learning methods using ICT. It is not enough to maintain large buildings and the best computer systems if each of these works individually. The integration of data that seeks to discover how a student learns and generate completely suitable environments that adapt to those needs is the key in education. Once it is defined that each student has specific needs and that these can be measurable in variables, a smart campus can be created that learns about their needs and supports the management of those involved.

A smart campus brings several improvements to the management of a traditional campus, this is in response to the third question raised in the development of this work. However, it is important to consider the depth of the idea; this improvement is not simply based on an organizational guideline. On the contrary, the response covers topics such as security, the discovery of trends in the university population, improvement of learning and, above all, that systems and services are used to improve the condition of their community. In several works that have been the subject of analysis for this proposal, it has been possible to show that the improvements on a traditional campus are many, but the continuing work of all the sectors that support this evolution is important. If we consider technical issues, it is important to mention that independently a university campus through a BI platform can analyze the academic data of students and make decisions that contribute to learning. However, an analysis on this scale is often not enough, since an analysis of behavior includes many variables that range through sociological, academic and financial aspects. The inclusion of variables sacrifices storage and processing, so applying technologies such as big data are presented as a solution that guarantees the inclusion of diverse sources and effective processing which considerably improves decision-making.

Traditional campuses have certain components that have been detailed in Section 4 and serve as a platform to create a smart campus. The fundamental component when implementing this solution is the technological reuse that gives greater value to the capacity of the platform that allows integrating the data generated by all the systems. The university campus where the study was developed has a diverse infrastructure; there are systems and devices of the last generation as well as not so new technology. The benefit in this evolution to a smart campus is given by three main components that are obtaining data through IoT-based technologies, its storage in a private cloud and finally its treatment using a robust platform such as Hadoop. By detailing these components as the main basis of this work, the requirements that a traditional campus has to meet can be divided into two parts. In the first place, there are the technical aspects that integrate the aforementioned, such as, for example, video surveillance systems, personnel access systems, computer systems, and so forth. The second part is the qualified personnel, this implementation needs a great knowledge in different areas, and the study to focus on a university defines that researchers, teachers, technical, administrative, and so forth, will support it. That guarantee the applicability of the proposal.

Converting a traditional campus to a smart campus is the obligatory step that universities must undergo, as the results are clearly positive and the resources in these environments exist. In this work, Hadoop is implemented as the big data architecture that supports the current needs of a smart campus. For the implementation, it is important to know the different tools that allow the inclusion and analysis of the variables that need to be evaluated in a smart campus. Considering smart campuses as test banks for smart cities is completely valid, as demonstrated in this study.

For a transformation of this type, it is necessary to prioritize the work in common with the different areas that contribute to the success of the data analysis. Generating knowledge from light and critical data contributes to the optimization of resources. In the three cases of analysis that have been presented in this study, it is found that each time a result is obtained it affects different areas, which directly compromises the effectiveness and efficiency of the decision making.

A critical point of a smart campus is to create optimal learning environments with tools and academic methods that match the needs of students. With a big data architecture, this is possible through having the ability to analyze a huge amount of data from different sources, and then correlating the data and presenting it to the interested parties so that they can take preventive and corrective measures as appropriate. The optimization of energy resources is another controllable area because; by having an integrated system where sensors and actuators generate information, big data analyzes the data and based on these applications can regulate consumption. An example of this is the results generated by the analysis of the places with the highest university population.

With these results, it is possible to determine the need and establish priorities for these places and others, to put them in waiting for an event to happen so that they can shift into an active mode. On the other hand, access control systems allow improved security and reduced human resources. This is thanks to the security systems that can track individuals through cameras and facial recognition applications. These allow a person in any area of the campus to be located in the same way, as the person's access is analyzed each period, generating reports of the activity of each person.

The contribution of this work is the improvement of learning through the integration and analysis of data in a smart campus. All the systems of a university campus generate data that is available in different repositories. The acquisition mode is based on the IoT systems, which, in this work, connect to a private cloud. The implemented distribution presents the essential processing capabilities for the production workflow to establish metrics that promote the availability, scalability, and reliability of the services. The availability of information converted into knowledge helps detect patterns in the way students learn, and what their needs are. Once these needs are met, all those involved in learning within the smart campus assume their role with effectiveness, thanks to an environment that is adapted to their needs.

Sustainability in a traditional university campus requires a great deal of effort and even generates more consumption of resources when looking at students' awareness of the environment. Our proposal includes a process of transformation to a smart campus that has many advantages with respect to the responsible management of resources, considering that each action follows a process of analysis and that each decision depends on the integration of many variables. At the beginning, it can be considered that it is a system that requires many trained personnel; however, the implemented method is scalable and it is possible to create scenarios where the results can be measurable and compared with traditional models. The potential advantages compared with a traditional model focus on the development of learning and generate comfortable ecosystems, which are friendly to the environment.

The big data architecture deployed contributes to the treatment and analysis of data to such an extent that it is possible to determine the needs of each person and customize the services to suit their needs. In specific cases, where the academic activities proposed by the teachers do not conform to the student learning model, the analysis of the data allows for identifying and recommending the best activities for each student, improving learning in the community. This process, simple as it seems, is more important since, by improving learning, student dropout rates are reduced and the academic effectiveness indexes known as the graduation rate are improved.

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