Journal of Advanced Research in Applied Sciences and Engineering Technology 32, Issue 1 (2023) 120-138

SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Smart Campus 4.0: Digitalization of University Campus with Assimilation of Industry 4.0 for Innovation and Sustainability

Satish Kumar Mahariya[1], Awaneesh Kumar[2], Rajesh Singh[1,*], Anita Gehlot[1], Shaik Vaseem Akram[1], Bhekisipho Twala[3], Mohammed Ismail Iqbal[4], Neeraj Priyadarshi[5]

[1] Uttaranchal Institute of Technology, Uttaranchal University, Dehradun 248007, India
[2] School of Agricultural Science, Raffles University, Neemrana, Rajasthan, India
[3] Digital Transformation Portfolio, Tshwane University of Technology, Staatsartillerie Rd, Pretoria West, Pretoria 0183, South Africa
[4] University of Technology and Applied Sciences, Nizwa, Oman
[5] Department of Electrical Engineering, JIS College of Engineering, Kolkata, India

ARTICLE INFO

Article history:
Received 28 March 2023
Received in revised form 17 July 2023
Accepted 24 July 2023
Available online 30 August 2023

Keywords:
Smart Campus; Industry 4.0; education; sustainability; digitalization

ABSTRACT

According to the United Nations, global sustainability in terms of social, economic, and environmental issues must be achieved by 2030. SDGs 4 and 9 are related to education and strengthen the attainment of quality education and infrastructure innovation. Resilient infrastructure plays a significant role in strengthening the campus in terms of education, management, placement and environment. These all aspects come under the smart campus. Smart campus 4.0 is the amalgamation of multitude industry 4.0 enabling technologies for delivering smart and innovative facilities with the aspect of sustainability. The previous studies have proved that the sustainable development goals (SDGs) can be achieved with the amalgamation of industry 4.0 enabling technologies in the campus such as cloud computing, artificial intelligence (AI), Internet of things (IoT), edge/fog computing, blockchain, robot process automation (RPA), drones, augmented reality (AR), virtual reality (VR), big data, digital twin, and metaverse. The main objective of this study to provide the detailed discussion of all industry 4.0 enabling technologies in single research related to smart campus. The findings observed are IoT-Based Drone system is intended to ground patrolling, and a cloud server to develop a smart campus energy monitoring system. AI for campus placement prediction model; cloud and Edge computing architecture to build an intelligent air-quality monitoring system. The novelty of the study, it has discussed all industry 4.0 enabling technologies for a smart campus with challenges, recommendations, and future directions.

1. Introduction

The united nations' sustainable development goal 4 (Quality Education) and goal 9 (Industry, Innovation and Infrastructure) ensure inclusive and equitable quality education and promote lifelong learning opportunities for all and build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation [1,2].

* *Corresponding author.*
E-mail address: drrajeshsingh004@gmail.com

https://doi.org/10.37934/araset.32.1.120138

Following the pandemic of COVID-19, the higher education industry is consistently transforming and acclimatizing to multiple factors, where faculty, researchers, students were necessitated to implement communication methods, learning methods, and teaching styles [3]. Moreover, as the world anticipates a post-pandemic future, so it is essential to recognize that the amplification in the advancement of technological and also approaches for learning and working.

Universities campuses and colleges around the world are pioneering the path in highlighting the advantages of a collaborative approach of scientific work and industry knowledge in achieving sustainability [4]. University and colleges are the cornerstones of research formulation, development, and innovation, where researchers and professors work to solve many global challenges using unique methods and tools to achieve sustainability. Currently there many universities that are integrating the smart technologies for establishing the concept of “Smart Campus”. In 2022, the University of Birmingham (new campus in Dubai) introduced the smart campus concept with the goal of accomplishing university objectives such as living labs for research, net zero carbon, industry collaboration, and teaching [5]. Moreover, the smart campus empowers innovation for future generations with digitalized platforms and technologies [6,7]. The data generated from the digitalized platform assists to make intelligent decision making and also helps to create space for research collaboration.

In accordance with the technology advancements and global requirement, the universities are in the process to adapt the modern and digital technologies in the universities and campus with a vision of delivering a digital and innovative experience in teaching and learning [8,9]. Campus digitalization necessitates the deployment of digital technologies while enshrining environmental sustainability and cutting-edge user experiences. The real-time data collected empowers the interpretation of community requirements and the quick delivery of strategies [10]. The digital technologies of Industry 4.0 have enabled different domains to accomplish sustainable development goals with real-time monitoring, data analytics, virtual visualization with security and privacy [11,12].

With this motivation, the studies analysed previous studies that addressed the significance of smart campuses. Z. Y. Dong *et al.,* has emphasized the interdisciplinary view of smart campus by analysing the enabling technologies and also proposed human centric learning enabled smart campus [13]. Muhamad *et al.,* discussed the systematic literature review of smart campus features and seven technologies. Radio frequency identification (RFID), IoT, sensor technology, mobile technology, cloud computing, web service, 3D visualization and augmented reality [14]. Fernández-Caramés & Fraga-Lamas, has discussed the distinct communicating cloud and edge computing-based architectures for smart campus by studying blockchain as a tool to enhance transparency for smart campus applications [15]. Prandi *et al.,* proposed a smart campus concept for creating awareness in community with intelligent ecosystem by integrating sensors and web-based application [16]. Silva-da-Nóbrega *et al.,* intends to recognise the key components as well as the substantial shortcomings in the smart campus aspects and indicators from the participant's viewpoint in attempt to offer a list of goals for outcome [17]. Y. Zhang *et al.,* conducted and introduced a human-centred case study to assess the reliability and compliance of present study patterns to the necessities and preferences of decision makers [18]. From the previous studies, it has been concluded that the studies have discussed the significance of the smart campus concept in universities. However, the studies lack the discussion of all industry 4.0 enabling technologies including RPA, metaverse and digital twin. To overcome the previous studies limitations, the current study presents the role of industry 4.0 enabling technologies for smart campus with innovation and sustainability. The study presents the previous studies of industry 4.0 technologies for smart campus in detail. The contribution of study is as follows:

i. Overview of smart campus 4.0 with industry 4.0 enabling technology are discussed.
ii. The significance and application of the enabling technologies like Cloud computing, IoT, edge and fog computing, AI, Big data, Blockchain, RPA, Drones, AR, VR, Cyber security, digital twin, and Metaverse in campus 4.0 are discussed.
iii. The limitation and challenges are addressed as well as suggested vital recommendations such as IoT and Cloud computing for real-time monitoring and automatic attendance; Smart desk with IoT and AI; Digital progress report of student with Blockchain and AI; AR/VR, RPA and Digital twin for hybrid classroom for future enhancements.
iv. The organization of paper is as follows: Section 2 covers overview of smart campus 4.0; Section 3 covers technical integration in Smart Campus 4.0, where we have discussed different technologies implemented in previous studies for the realization of smart campus. Section 4 presents the recommendations, challenges and limitations where we have suggested recommendations for future enhancement.

2. Overview of Smart Campus 4.0

The industry revolution (Figure 1) initiated illustrates revolutions in campus from Late 18th to early 21st century [19]. In the late 18th to early 19th century (Campus 1.0) we use the natural resources on campus and also use calk and duster technology for teaching. In the late 19th to early 20th century (Campus 2.0) we use the induction and emergence for electricity in organization/ campus for utilities purpose. In the second half of 20th century (Campus 3.0) we have intervention of electronics, telecommunication and computers devices in campus for remote education [20]. Early 21st century (Campus 4.0) we implement Smart, interconnected cyber physical systems for class monitoring, feedback system, Attendance system, Virtual library management using Industry 4.0 enabling technologies like Cloud computing, IoT, edge and fog computing, AI/ML, Blockchain, Big data, RPA, Robots and Drones, Augmented reality, Virtual reality, Cyber security, digital twin, and Metaverse [21].

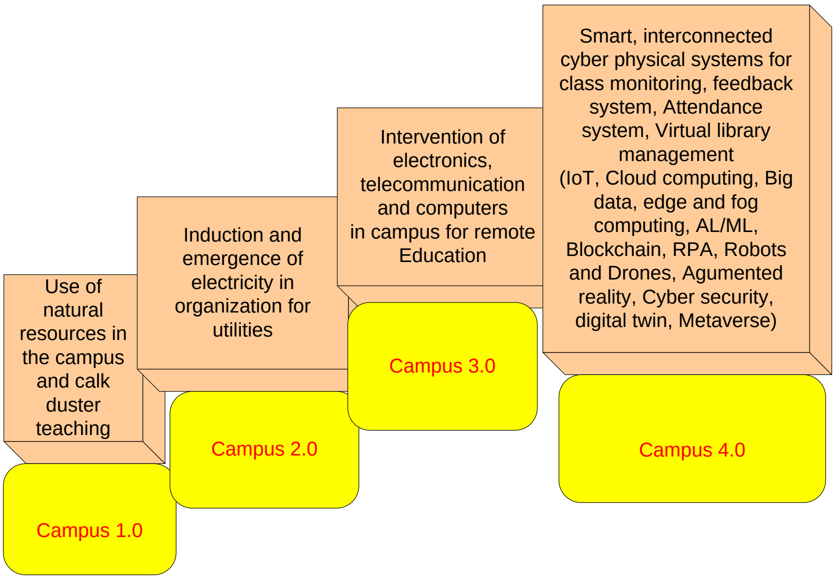

Fig. 1. Revolution in campus with inclination towards industry 4.0

Figure 2 explains various enabling technologies of Industry 4.0 like Cloud computing, Blockchain, edge and fog computing, AI, IoT, big data, RPA, Augmented reality, digital twin, Virtual reality, Cyber security, and Metaverse. IoT is evolving and continues to be the newest and most well-liked concept in IT sector. Over the past ten years, the term IoT has grown in popularity by conjuring the image of a global infrastructure of physically networked objects that would allow anytime, everywhere connection for anything and not just for anybody [19]. Another way to think of the Internet of Objects is as a global network that grants each and every object a distinct identity and facilitates communication between people, things, and anything else in the world [20]. Cloud computing is the only technology that seems to be able to analyse and store all the data effectively. It is a smart computing system that unites several servers into a single cloud platform to enable resource sharing that is available from any location and at any time [21].

To immerse in virtual worlds and interact with rich three-dimensional (3D) models of educational content using virtual reality (VR), augmented reality (AR), and other extended reality (XR) technologies. These models encompass anything from complicated protein structural biochemical models to representations of historical locales and artefacts. VR, AR and XR may improve design-based learning outcomes in disciplines like architecture and engineering, assist the growth of spatial cognitive abilities, and raise student engagement [22]. Using RPA technology, staff members of any business may programme a robot, modify data, and communicate with any other organisations. RPA technology is used across all digital settings. Humans carry out specialised, repetitive digital jobs in businesses. Robotic Process Automation technology can automate such repetitive activities or replicate human activity [23]. The Metaverse is a persistent multiuser environment where physical reality and digital virtuality coexist. It is post-reality universe. It is built on integration of technologies, like as AR and VR, that allow for multimodal interactions with digital items, virtual surroundings, and people [24].

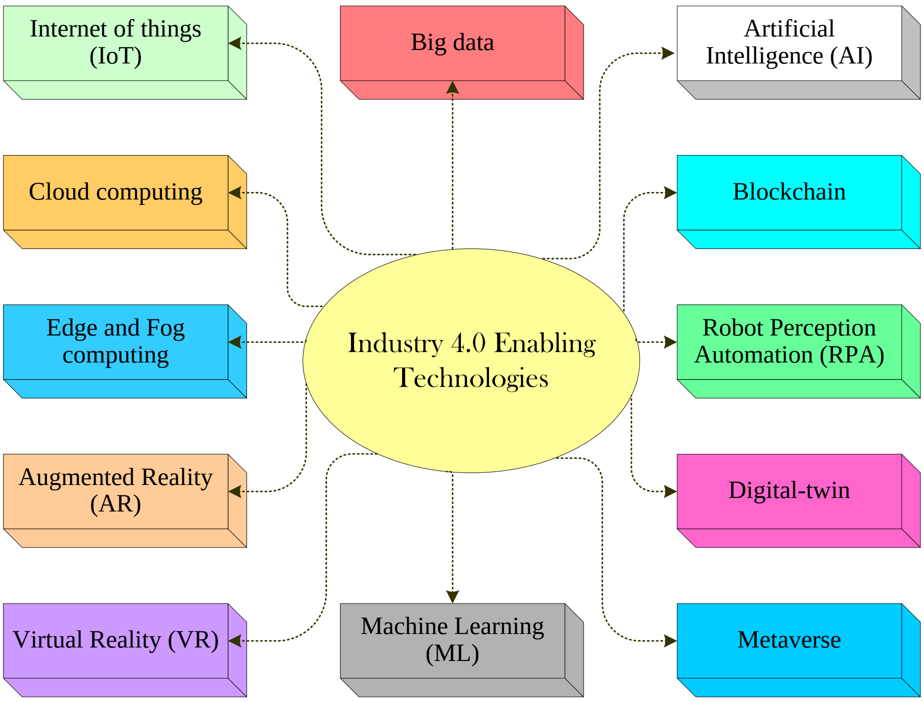

Fig. 2. Industry 4.0 Enabling Technologies

3. Technical Integration in Smart Campus 4.0

The section comprises of the latest technology intervention i.e., IoT, cloud computing, Edge/ Fog computing, Blockchain, AR/ VR, Digital twin, Metaverse for realization of smart campus.

3.1 IoT

IoT-Based Drone system is intended for ground patrolling on campus by using open source ArduPilot software, the Pixhawk flying controller, and the Drone Kit Python library are all loaded on a Raspberry Pi 4. The cellular technology used for drone communication is also more reliable and offers a potentially effective way to get over interference and low operation range. The drone has successfully used follow-me mode and autonomous navigation to reach the incident spot with an accuracy of 1 to 2 metres. The drone was able to sustain a 30-minute flight [25].

Deep Guiding, a thoughtful foundation for student guidance and care on campus using Internet of Things technologies, is built on deep learning and uses facial recognition. A campus student's dedicated video trajectory may be created using the DeepGuiding framework, and the recorded videos of Each learner may automatically be categorised to perform effective footprint reviews as needed [26]. An air quality monitoring system may be used to keep track of indoor air pollution. Data parameters for IAQ may be gathered from environment with the integration of the IoT [27].

Framework for a Campus Safety and Security System based on IoT. Until backup team arrived, this framework would operate as an immediate responder to occurrences on campus and monitor the offenders even outside the university [28]. Smart Classroom for a Sustainable and Smart Campus built on Cloud and IoT Integration. The intelligence system, maintenance system, unified campus portal services and security are all provided by IoT-based cloud computing technologies [29]. It is suggested to use a runtime model to manage wireless sensor networks on campuses that are intelligent. When compared to the conventional approach, this strategy is more successful at controlling campus facilities and uses 16.7% less energy [30]. The underutilization of classrooms on a genuine university campus, which results from a discrepancy between enrolment and attendance, is addressed in this work. To do this, we outfit classrooms with IoT sensors that can monitor current usage, AI based estimate attendance, and assign rooms to courses in the most efficient way possible to reduce wastage of space. The system's benefits in room expenses of 10% were achieved as a consequence, and the danger of room overflows was extremely low [31]. IoT-based facial recognition terminal hardware solutions, unified management in the system's background, calculations, and data analysis provide important campus big data that can be used by instructors and students to create more effective lesson plans and research proposals [32].

A Blynk App-based IoT-based parking management system that uses a Raspberry Pi i4B+ (RPi) integrated computer, GPS sensor, ultrasonic sensors, and Pi camera module to assist employees and students in finding parking spaces quickly and efficiently [33]. For the purpose of preserving campus safety and enhancing sustainability, IoT sensors are made to display accurate interior environmental data. Sensors connected for the smart campus environment, environmental data such as air temperature, light intensity, and humidity are collected using two Arduino microcontrollers. As a result of this framework's use of the system server, sensor readings may be recorded and shown in real time in the environment application and on the server platform [34].

The university campus's sustainability and security have been improved thanks to the use of IoT and data visualisation. The authors described general system design as well as interactive dashboard that makes managing campus facilities and timetabling easier [35]. CampusTalk, a collection of IoT apps created on the IoTtalk platform at National Chiao Tung University (NCTU) where the app integrates the ideas of automatically producing mirror device features and talkPal device features [36]. It is suggested to use a fog computing architecture based on LoRaWAN to connect IoT nodes placed throughout a campus and it has been validated by simulating the smart campus using a 3D Ray-Launching radio-planning simulator built [30]. For small hybrid renewable energy systems (HRES), which include wind turbine, solar system, battery storage system and diesel generator, this study suggests IoT-based design. Four levels make up the suggested architecture: application layers, the power, communication network, and data collection [33].

Employing machine learning techniques, the occupancy level of a campus area was determined by using a network of sensors to collect several environmental factors, including CO_2, total volatile organic compounds, carbon monoxide (CO), motion, acoustics, humidity, and temperature [33]. The study established the hardware models of three components, including the lighting system, environmental factors, and real-time image sensing, with the goal of producing smart lampposts with long range communication and Wi-Fi [37]. IoT and blockchain integration for the creation of a sustainable environment that aims for population and environmental cohesion in a means of making economic progress compatible with the environment. Integrating blockchain aims to meet two needs: security and process agility. Data is kept cryptographically private to prevent exposure [36]. Table 1 summarizes the comparative analysis of the preceding studies that focused on IoT for smart campus applications.

Table 1
IoT and cloud computing for smart campus

Ref	Hardware	Wireless connectivity	Cloud computing
[25]	ArduPilot software, Pixhawk flying controller, Drone Kit, Raspberry Pi 4	Wi-Fi/Bluetooth, cellular technologies	Yes
[26]	Camera, PC	Bluetooth, GPS, Wi-Fi/4G network interface	Yes
[27]	ESP-8266 Wi-Fi microcontroller, Raspberry, OLED screen, microSD card,	Wi-Fi	Yes
[28]	Raspberry Pi, 4G dongle, Drone structure, Sound and break glass Sensors, Camera	GPS, Wi-fi, 4G network interface	Yes
[29]	RFID, AC, IoT sensors, ARM Microcontroller, Camera	GPS, 5G network, gateways, routers, switches, WIFI router	Yes
[30]	Temperature and brightness sensors, location sensor, RFID device	RFID device, Wireless sensor device	No
[31]	IoT sensors	Bluetooth	No
[32]	Wireless Sensor Networks, RFID, library face recognition terminal hardware, dormitory face recognition terminal hardware	RFID wireless data communication	Yes
[33]	Raspberry Pi 4 *B*+ (RPi) embedded computer, Pi camera module, GPS sensor, and ultrasonic sensors	Wi-Fi	No
[34]	Mobile IoT devices, video camera,	Communication technologies	Yes
[35]	IoT devices, mobile	LTE, NB-IoT or WLAN	No
[36]	Raspberry Pi 3, A 0 dBi antenna, RHF4T002 bridge, LoRa Gateway v5.0.1, LoRa Packet Forwarder v4.0.1 and LoRaWAN-Server v0.6.0	Wi-Fi, and Bluetooth, LoRaWAN transceiver	Yes
[38]	intelligent electronic devices (IEDs) and remote terminal units (RTUs), IoT devices, Power devices (battery, solar, grid, generator etc.)	Wi-Fi, ZigBee, WiMAX, LoRa, Cellular etc.	No
[39]	Environmental, gas detection, temperature, relative humidity, light level, PIR based motion activity, and absolute sound sensors, Camera	Wi-Fi, Bluetooth	No
[40]	IoT devices	Wi-Fi	Yes

In Table 1, we discussed various IoT devices, wireless communication, and cloud platforms used by previous studies to realize the smart campus. Wi-Fi is a widely used wireless communication protocol that has been implemented in various studies for wireless connectivity, and in hardware, Raspberry Pi is widely implemented as a controller for the realization of smart campus applications with cloud computing.

3.2 Cloud Computing

In contrast to previous past IT paradigms, cloud computing places a greater emphasis on services than on technology. Here, technology (storage, CPU, networking hardware) serves as the foundation rather than the actual service. Consumers of the service are shielded from the technological intricacies. Self-service allows customers to request services, and they are only charged for what they utilise [37]. Open platform for cloud storage powered by cloud computing and big data technology model to overcome problem of large data analysis and cluster data security and suggests an optimization strategy by deploying system architecture for cloud storage using HDFS + HBase distributed storage in a Hadoop cluster [41].

Figure 3 illustrates the education cloud service in the campus for the multiple areas such as availability of more specialized computer software applications; human resources; university research and collaboration work; faculty content creates design and share; virtual library; students' online classes, and virtualisation. Create real-time energy monitoring system for smart campus using big data analysis and cloud computing. Monitoring platform gathers data about power use in campus buildings through smart metres and environmental sensors and uses big data processing techniques to analyse data enormous volume [42].

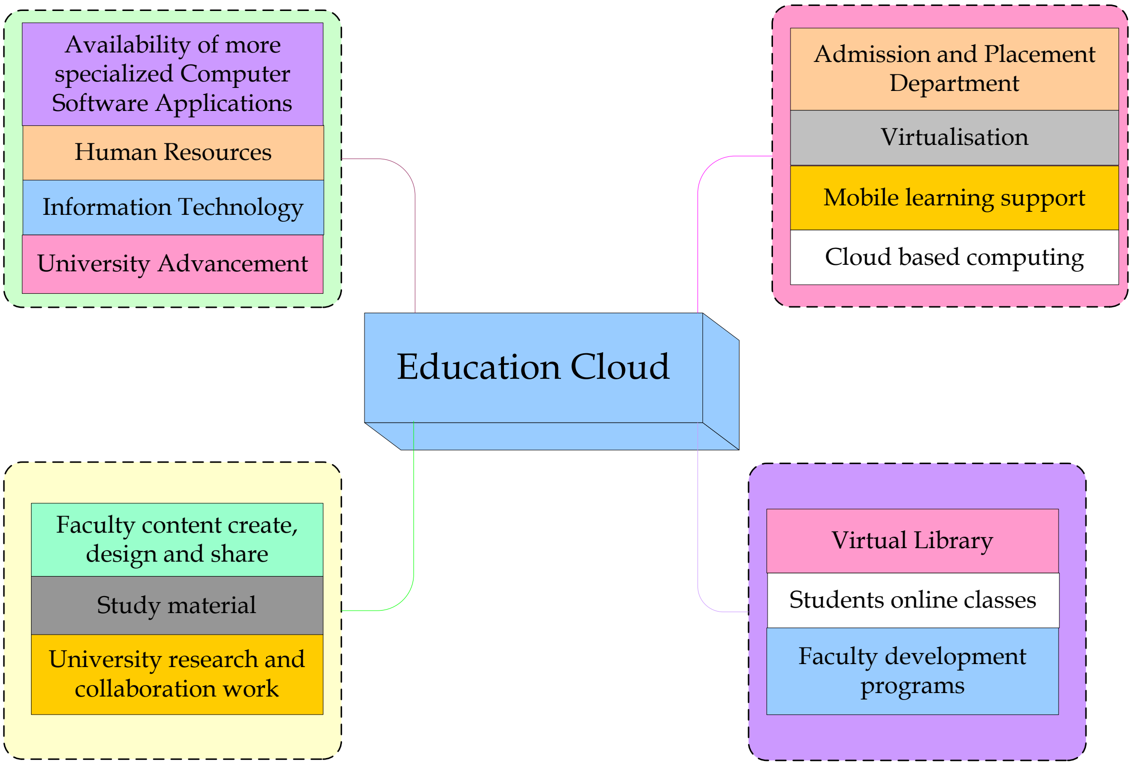

Fig. 3. Education Cloud Service for Campus 4.0

Figure 4 illustrates the services of implementing the cloud service platform such as campus user access and management, campus access department authority control system and user cluster data information management. It is suggested to use multi-source multimedia conference system, or MMCSACC, which has variable bandwidth architecture and two-tier data distribution structure. MMCSACC may offer a greater delivery ratio, better performance and better user experiences compared to standard multicasting technologies [43]. A specialised cost estimator and allocator is included into 3-axis auto-scaling framework for resource allocation and load balancing (on the z-axis). In the event that the vertical threshold is exceeded by new requests, cost estimation server builds log of the current load estimations of horizontal and vertical scales and servers demands from new users. Study simulates 1000 smart campus user requests, adopts a cutting-edge ensemble with bagging approach, and effectively manages a class imbalance scenario [44].

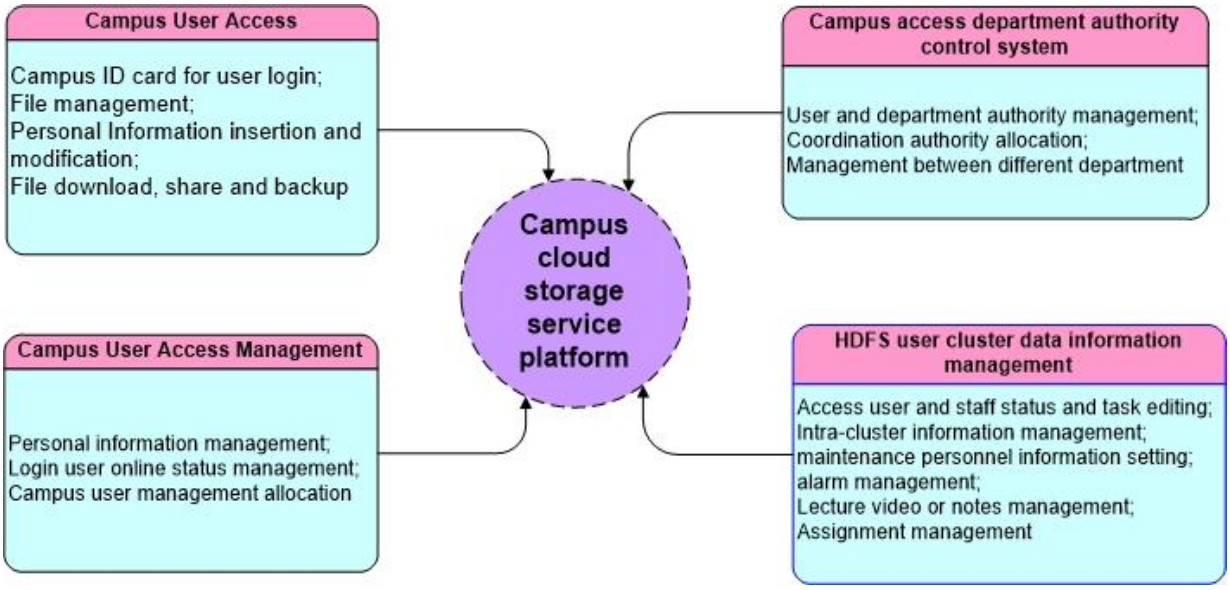

Fig. 4. Campus cloud storage service platform

3.3 Big Data

In order to provide guidance for security protection system of smart campuses in colleges and universities, ensure security and stability of higher vocational colleges' networks, and guide development of smart campuses, application of big data technology for information security and campus networks security was primarily studied [45]. A cloud storage construction scheme for discuss the application of virtualization, campus big data scenario, and streamlined configuration, storage optimization and other technologies in cloud storage. The cloud storage technology is applied in construction of digital campus, which strongly accelerates process of digital campus informatization [46]

Big data frameworks may analyse data in any format and offer practical, cost-effective solutions for any activity. The developed method is universal, making it appropriate for use in addressing smart campus needs [47]. Big Data framework for student behaviour analysis in Learning Management System (LMS) at Catholic University of Murcia, evaluating the data volume created by users in LMS (up to 70 GB), the tools used by students, and their related events, and reviewed in order to identify patterns and shortcomings in usage of the LMS by students [48]. Scheduling technique where the power inputs to energy storage systems (ESS) are chosen to minimise the cost of running the microgrid (MG). After being designed with operational economies in mind, the ESS model is incorporated into mixed integer linear programming (MILP). The method is tested in a campus MG and put into use with ESSs and PV arrays [44].

Big data for the administration and data analysis acquired through data centralization in proprietary infrastructure through IoT. Methods of distributed and multilayer analysis for putting in place a smart environment based on sustainability [49]. Prediction of career choice using campus big data mining of potential college student behaviour. Approach Cluster Centers Based on XGBOOST (ACCBOX) model to students' career choices prediction and show method superiority compared to current state-of-art techniques by evaluating on 4000 students thirteen M behavioural data, which is based on straightforward premise that most notable classes characteristics are reflected by category main samples [50]. In an effort to advance the growth of college football, this article examines the meaning and structure of the existing football culture in colleges and universities and proposes some remedies based on big data [47].

3.4 ML & AI

To learn how to study a bigger, efficient and concise, and excellent performing campus education information system, use Internet and AI technology. This system can meet students and teachers needs regardless of visits large number year, month, or day. Actively optimise and refine some of the system's construction-related issues. As a consequence, the system's reaction time was decreased by an average of 21.6%, and its overall power consumption was cut by an average of 1.43% [51]. By analysing the data that students produce in the academic systems that a smart campus controls, this study suggests the creation of an architectural model that incorporates variable identification and assessment. The outcomes of the data analysis are fed into an AI decision-making tool [52].

To thoroughly assess the campus sustainability and carbon emissions at Huazhong University of Science & Technology (HUST), ecological footprint assessment (EFE) and machine learning are used. Even though HUST has 72% forest cover, its Ecological Footprint Index was 12.52, strongly suggesting unsustainability [53]. Developing energy prediction models employing statistical analysis, including multiple linear regression (MLR) models, multivariate regression models, and relative relevance analyses in relation to steam (STM) and electricity (ELC) consumption. Which building characteristics are still crucial and relevant to campus action plans and building policy can be determined by the prediction models [54]

Campus Placement Analyzer obtained 78% in XGBoost and 78% in AdaBoost Classifier utilising Supervised ML Algorithms including Logistic, SVM, KNN, Random Forest, Decision Tree, and advanced approaches like Bagging, Boosting, and Voting Classifier [55]. The Campus Placement Prediction algorithm analyses student data from past years and used it to forecast the likelihood that current students will be placed. Regarding accuracy, precision, and recall, the model is also contrasted with other conventional classification methods like Decision tree and Random Forest [56]. Classroom occupancy measurement in big spaces with more than 100 occupants using image processing and support vector machines (SVM) [57].

To address the challenge of scheduling courses and allocating classrooms while taking into account a number of limitations, including lecturer availability and timing requirements for events. Classroom and course timetabling allocation problem including constraints variety , like lecturer and events availabilities timing requirement were captured in numerous optimization algorithms include genetic algorithm [58], simulated annealing [59], and tabu search [55]. Table 2 addresses the comparative analysis of the preceding studies, where it briefly discusses the AI/ML model for smart campus applications and identifies that the decision tree, support vector machine, random forest, genetic algorithm, k-neural network, and logistic regression are implemented in the previous studies for smart campus application in terms of campus placement, carbon emissions, etc.

Table 2
AI/ML for smart campus

Ref	ML/AI Model	Accuracy
[48]	Decision Tree Model	Average response time 21.6% less
[53]	Genetic Algorithm	22% more accuracy
[56]	Logistic Regression; Support Vector Machine; KNN; Decision Tree and Random Forest	58%; 69%; 63.22 %; 69% and 75.25%
[60]	Support Vector Machine	Accuracy increases by 20%

3.5 Edge/Fog computing

Network for campus edge computing using IoT street lighting nodes as compute nodes and workload prediction model. In context of hardware-software co-design process, this article suggests a campus edge computing network. Street lighting is used by the system as an IoT network communication node device. Network is analysed using neural network learning techniques, and a service for allocating resources throughout the whole network is provided. In comparison to the regression approach and TDNN, the suggested model makes superior predictions over a short period of time [37].

Dependable bandwidth allocation and edge caching for mobile users. Simulation findings demonstrate that suggested method may not only enhance mobile users' quality of experience (QoE) but can also shield against assaults from malicious edge nodes [61]. Over the course of three months, the edge computing infrastructure, which has 36 edge nodes and is based on wireless access point (AP), will serve 44 000 active end users throughout a 3.1 km2 region by offloading computation to more than 8500 wireless APs. When compared to cutting-edge techniques, CampEdge was found to reduce user latency by as much as 30% [62]. Dynamic cooperative caching approach for edge computing environments' time-sensitive applications. In terms of cache hit rate, server load, average latency, and average hops, cooperative cache algorithm outperforms benchmark cooperative cache algorithm method [63].

Tunghai University developed a series of sophisticated air-quality monitoring systems using cloud and edge computing architecture. For each service on the Edge side, we created container-based virtualization, which builds Kubernetes Minion (Nodes) in the Docker container service separately. In order to evaluate and assess the power consumption for Kubernetes Pods, Ganglia Monitoring System gathers pertinent data, including utilisation of the Protocol Data Unit (PDU), memory, network, and Central Processing Unit (CPU) [64]. For precise and effective pedestrian detection, use a lightweight multispectral network that is aware of temperature and illumination. The suggested IT-MN is an effective one-stage detector that can accommodate environmental effects and improve sensing accuracy by fusing thermal image data with visual pictures to supplement valuable information when the quality of the visual images is poor. The findings demonstrate that the suggested technique successfully reduces the miss rate and inference time to 14.19% and 0.03 seconds per picture pair on GPU, respectively [65].

3.6 Blockchain

SDN and blockchain technology for Industrial IoT ecosystem's security and privacy based on SC. We use blockchains as verifiable and immutable repository to store network manifests that are signed and verified via SC-based smart contracts by device maker or an industry authority. This authentication is designed into the IoT onboarding process [66]. A seven-tier system built on blockchain technology was used at universities to raise educational standards and evaluate academic supervision based on research findings [67]. For electric automobiles in smart campus parking lots, a blockchain-based energy trading architecture is suggested. It has two layers: a physical infrastructure layer and a cyber infrastructure layer, and it allows for local load balancing for the institution [68]. The comparative analysis of above studies is addressed in Table 3, where it briefly discusses the distinct types of blockchain implemented model for smart campus applications and identified that consortium blockchain, and permissioned blockchain for raise educational standards and evaluate academic supervision, and supervising the electric automobiles in smart campus parking lots.

Table 3
Blockchain For Smart Campus

Ref	Objective	Blockchain type
[66]	For managing the Industrial IoT ecosystem's security and privacy	Consortium Blockchain
[69]	For raise educational standards and evaluate academic supervision based on research findings	Permissioned blockchain
[68]	For electric automobiles in smart campus parking lots	Permissioned blockchain

3.7 AR/ VR

Developers, device producers, distribution platforms, and other parties participating in VR's production and dissemination need to take responsibility for accessibility within the scope of their individual responsibilities if VR is to become an accessible medium [70]. The campus tour system for cultural activities is implemented using augmented reality technology and smartphones with GPS, cameras, Wi-Fi, and digital compass built in. The findings demonstrate that our mobile campus touring system is more engaging and dynamic method for promoting and learning about campus cultural activity [71]. Interactive campus roaming AR system is designed combining with GPS module for locating outside the campus and utilizing deep learning technology to achieve locating the inside buildings of campus [72]. A process for building interactive cartographic VR environment and open-source software to explore urban landscapes for visitors to campus, like new geography/geomatics students trying to find their cartography lecturers [73]. MultiGen-Paradigm's MultiGen and Vega advanced software systems for VR model in 3D Web visualization developed rapidly. This technology allowed for the creation of VR walkthroughs on personal computers, even in multiplayer virtual worlds [74].

BIM + VR technology allows for creation of 3D digital smart campus and integration of campus-wide modelling and VR technology, which helps to some extent with the construction of educational information and offers more practical and user-friendly services for the faculty members and students across the entire university, including teaching activities, daily management, safety education, and other areas [75]. After the overall integration for the virtual campus roaming system, virtual reality technology and X3D technology with various techniques are used to design the numerous scenes on campus, construct 3D models of office buildings, libraries, science and technology buildings, and so forth [76]. Teaching strategy that incorporates virtual reality technology into lessons in the classroom and investigates the viability of using the SLOODLE platform to teach art design so that the platform may be widely used in art design education [77].

3.8 Robotic Process Automation (RPA) and Digital Twin

The two primary components of robotic process automation are hard automation and soft automation. Hard automation is the use of machines or robots to carry out tasks that are fixed or specialised but call for repeated actions. Soft automation, in contrast, is a sophisticated kind of hard automation that enables diverse jobs to be done in accordance with requirements. Soft automation includes robotic process automation (RPA) and can be a more effective alternative for a person since it can carry out time-consuming and important tasks more quickly. Create virtual text-to-speech assistant bot to help coordinator, teachers, and administrative staff who are in charge of controlling the inventory of things in addition to their many other responsibilities [78].

Intelligent Campus Digital Twin for Sustainable Comfort Monitoring and building information modelling tools using IoT-based wireless sensor networks in areas of environmental monitoring and emotion detection to give insights into comfort level in a smart campuses (SC) [67]. An O&M management system architecture based on digital twins (DTs) is being created to combine heterogeneous data sources, facilitate efficient data querying and analysis, and further bridge gap between human connections with buildings and classrooms [79].

3.9 Metaverse

A more engaging and enjoyable process will result from applying the metaverse architecture as an E-Learning environment framework [80]. Intelligent Technology Multiple Influences on College Students Network Behaviour as political and ideological education objects in universities by using the Metaverse technology. It has been deeply embedded in their learning, entertainment, social interaction, and consumption behaviours, presenting new times characteristics [81]. Viability of an extensive and ongoing augmented reality experience that all visitors to our university may share. By taking into account the characteristics of the various surroundings and the accessible sensor platforms, we develop integrated framework to allow first AR campus metaverse [82]. Imagine that Metaverse platform uses a collection of IoT devices to gather data on behalf of virtual service providers (VSPs). Self-interested device owners dynamically choose a VSP to increase benefits. Adopt hybrid evolutionary dynamics, where diverse populations of device owners can use various revision methods to upgrade their tactics. Numerous simulations show that a hybrid methodology can result in stable evolutionary states [83].

4. Recommendation, Challenges and Limitations

The section is categorized into two sub sections namely Recommendation, challenges and limitation.

4.1 Recommendations

In this section we have discussed the vital recommendations of the proposed study and in the below, the recommendations are discussed individually on the basis of the technology.

4.1.1 Hybrid architecture with multiple technologies for Campus 4.0

Figure 5 illustrates hybrid architecture implementation in the smart campus for digitalization and real-time monitoring with intelligent analytics and virtual representation. IoT based devices are used to capture data through sensors, actuators and vision nodes. This IoT based devices communicate data to the edge devices, fog devices and gateway through wireless communication. In the edge device and fog devices, the data is analysed and filtered and then communicated to the cloud server through gateway. Cloud computing, bigdata, and blockchain are used to handle and secure data with advanced security. Data available on the cloud server enables prediction through AI/ML. AR/VR, metaverse and digital twin for virtual reality of any application based on previous real-time IoT data. RPA with IoT data empowers to provide the chatbot and personal assistance system in the campus.

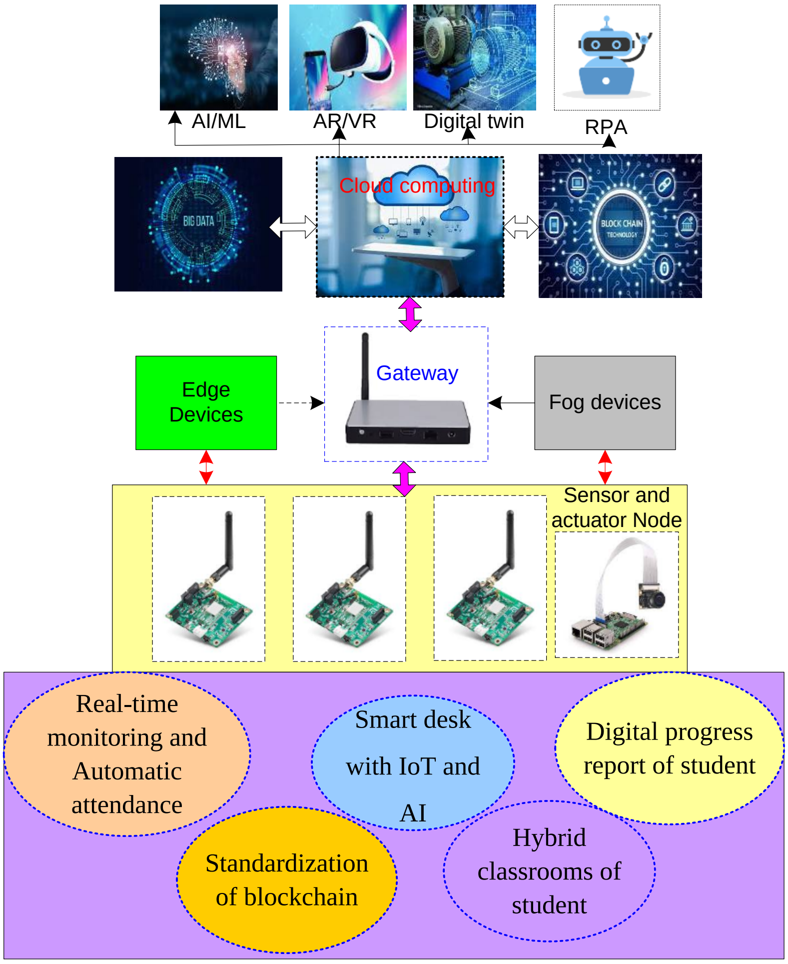

Fig. 5. Proposed architecture for data capturing, analysis and prediction

4.1.2 IoT and Cloud computing for real-time monitoring and automatic attendance

IoT based device for system monitoring for visualizing and marking the student's attendance in the classroom and also to monitor the student in college campus area through wireless connectivity. Id card will be inbuilt with GPS, and wireless devices communication protocol. So, when students enter or present in the classroom during the lecture or lab faculty can mark the attendance by single button press. The data will also be available on the university cloud server through wireless connectivity.

4.1.3 Smart desk with IoT and AI

Smart desk based on IoT with vision node enables to identify the student mental health. Vision node captures the emotion of the student and apply AI & ML to detect the depression and stress level and also find the reason of situation and share this data simultaneously to relevant class coordinator, HOD, counsellor and students' parent (if required) by using cloud sever and resolve the mental health problem.

4.1.4 Digital progress report of student with Blockchain and AI

Blockchain enables to secure the data in the distributed ledger network. Blockchain enables us to create a student progress monitor system. Encryption is eliminated to secure data share with authorized person like student, faculty, class-coordinator, management and parents. AI enables us to evaluate the progress of the student semester wise and identify which particular subject they are scoring.

4.1.5 Hybrid classrooms of students with AR/VR, RPA and digital twin

Hybrid classrooms enable to boost the transition of normal class into intelligent classroom in virtual environment. The amalgamation of AR or VR simulated learning experience, to explore system behaviour under different conditions, understand failure and develop understanding on system sensibilities. These technologies enable us to visualize the class in virtual reality mode for better development of the intelligent classroom.

4.1.6 Standardization of blockchain

For business collaboration on application development to share blockchain-based solutions and interface with current systems, standardisation is necessary. Blockchain and big data analytics might work well together, particularly in data management and analytics. for making safe and distributed use of the data from the storage. To eliminate vulnerability, privacy and security standards should be established at the beginning of Blockchain applications.

4.2 Challenges and Limitations

Every experience that is utilised is inaccessible, and even if there were a cure for it, it would be impossible to keep up with the regular modifications to hardware and software. Users with varied degrees of visual, hearing, movement, and neurological skills were not initially intended to use the current wave of immersive technology. Localized, one-time fixes cannot take the place of systemic reform. Plan for accessibility from the outset, lack of standards, the necessity of developer support, the significance of auditing and reporting, the fact that VR is not a form of instruction, and recognition of the limitations of VR accessibility are the main lessons that other institutions should take away as they implement accessibility thinking into their VR programmes.

Regarding the security and privacy of transactions, blockchain may be insecure (cybercrime). There is no set protocol that will enable communication and integration amongst various departments. Bitcoin network entire energy consumption rate also increased along with the cryptocurrency's value. The majority of higher education IT businesses lack the necessary expertise to manage risk and third-party service performance. In the business world, a lack of trust in the cloud is a result of subpar or non-existent service level agreements, inadequate risk management, a lack of vendor lock-in, a justification of ROI, management of change orders, and market immaturity.

The analysis and mining of big data is exceedingly difficult, though, because of its noisy, dynamic, diverse, interconnected, and unreliable characteristics. "Deep analysis" is needed to use large data to assist guide people's decisions rather of just providing simple report formats. It is challenging to represent this sort of complicated analysis in SQL and requires rely on complex analysis models. In order to take preventative action, people need to be aware of what is happening right now as well as be able to predict what will happen in the future by analysing data. Due to their limited expansibility, traditional relational database systems run into previously unheard-of challenges when used to manage these limitations of deep analysis on massive amounts of data. RPA carries considerable danger even though it is a technology that is often regarded as being beneficial. The following are a some of the risks: If a trivial logical error is discovered, RPA can err quicker and more reliably; When automating tasks, a human may not be present to monitor the status and RPA providers claim that their products are simple to use, don't need a specialist to deploy, and are very effective.

5. Conclusions

Smart campus empowers to implement intelligent environment with advanced technologies of Industry 4.0. Currently the world is progressing towards sustainability in terms of resilience infrastructure with digitalization. The digitalization of any field is achieved with the assimilation of Industry 4.0 technologies such as IoT, AI, big data, cloud computing, blockchain and robotics. There are various studies that has detailed presented the individual technologies for smart campus, however there are limited studies that has focused on presenting all technologies in single research for making understanding the role of these technologies for future smart campus. This study also empowers the researchers to understand the implementation of these technologies with the aspect of sustainability. In this study we have discussed the overview of the different various Industry 4.0 enabling technologies in smart campus. The study also discussed the significance and application of these technologies in the smart campus. The following are the few findings that has observed in this study, Wi-Fi is an extensively employed wireless communication protocol that has been employed in various studies for wireless connectivity, and Raspberry Pi is widely implemented in hardware as a controller for the realization of smart campus applications with cloud computing. Another finding is that, decision tree, support vector machine, random forest, genetic algorithm, k-neural network, and logistic regression are implemented in the previous studies for smart campus application in terms of campus placement, carbon emissions, etc. Consortium blockchain and permissioned blockchain have been employed to raise educational standards, evaluate academic supervision, and monitor electric vehicles in smart campus parking lots. The study also presented vital recommendation such as hybrid classrooms of students with AR/VR, RPA and Digital twin; digital progress report of student with Blockchain and AI; smart desk with IoT and AI; IoT and Cloud computing for real-time monitoring and automatic attendance and hybrid architecture with Multiple technologies for Campus 4.0.

Acknowledgement
This research was not funded by any grant.

References

[1] United Nations. "SDG 9: Industry, Innovation And Infrastructure." (2022).
[2] The Global Goals. "Goal 4: Quality education - The Global Goals." (2023).
[3] United Nations, “Creating a Smart Campus: A British University Develops a ‘Living Lab’ (2023).

[4] Awasthy, Richa, Shayne Flint, Ramesh Sankarnarayana, and Richard L. Jones. "A framework to improve university–industry collaboration." *Journal of Industry-University Collaboration* 2, no. 1 (2020): 49-62. https://doi.org/10.1108/JIUC-09-2019-0016
[5] University of Birmingham. "Delivering the world's Smartest Campus - University of Birmingham." (2023).
[6] Amran, Mohd Effendi, and Mohd Nabil Muhtazaruddin. "Renewable Energy Optimization Review: Variables towards Competitive Advantage in Green Building Development." *Progress in Energy and Environment* (2019): 1-15.
[7] Ha, Chin Yee, Terh Jing Khoo, and Jia Xuan Loh. "Barriers to green building implementation in Malaysia: A systematic review." *Progress in Energy and Environment* (2023): 11-21. https://doi.org/10.37934/progee.24.1.1121
[8] Sneesl, Radhwan, Yusmadi Yah Jusoh, Marzanah A. Jabar, Salfarina Abdullah, and Umar Ali Bukar. "Factors Affecting the Adoption of IoT-Based Smart Campus: An Investigation Using Analytical Hierarchical Process (AHP)." *Sustainability* 14, no. 14 (2022): 8359. https://doi.org/10.3390/su14148359
[9] Ferreira Jr, Divino, João Lucas Oliveira, Carlos Santos, Tércio Filho, Maria Ribeiro, Leandro Alexandre Freitas, Waldir Moreira, and Antonio Oliveira-Jr. "Planning and optimization of software-defined and virtualized IoT gateway deployment for smart campuses." *Sensors* 22, no. 13 (2022): 4710. https://doi.org/10.3390/s22134710
[10] Cheong, Pauline Hope, and Pratik Nyaupane. "Smart campus communication, Internet of Things, and data governance: Understanding student tensions and imaginaries." *Big Data & Society* 9, no. 1 (2022): 20539517221092656. https://doi.org/10.1177/20539517221092656
[11] Alblaihed, Munthir A., Usama M. Ibrahem, Ahmed B. Altamimi, Hind R. Alqirnas, and Magdy I. Salem. "Infosphere Is Reshaping: How the Internet of Things Leads Smart Campuses for Knowledge Management." *Sustainability* 14, no. 20 (2022): 13580. https://doi.org/10.3390/su142013580
[12] Paspatis, Alexandros, Konstantinos Fiorentzis, Yiannis Katsigiannis, and Emmanuel Karapidakis. "Smart Campus Microgrids towards a Sustainable Energy Transition—The Case Study of the Hellenic Mediterranean University in Crete." *Mathematics* 10, no. 7 (2022): 1065. https://doi.org/10.3390/math10071065
[13] Dong, Zhao Yang, Yuchen Zhang, Christine Yip, Sharon Swift, and Kim Beswick. "Smart campus: definition, framework, technologies, and services." *IET Smart Cities* 2, no. 1 (2020): 43-54. https://doi.org/10.1049/iet-smc.2019.0072
[14] Muhamad, Wardani, Novianto Budi Kurniawan, and Setiadi Yazid. "Smart campus features, technologies, and applications: A systematic literature review." In *2017 International conference on information technology systems and innovation (ICITSI)*, pp. 384-391. IEEE, 2017. https://doi.org/10.1109/ICITSI.2017.8267975
[15] Fernández-Caramés, Tiago M., and Paula Fraga-Lamas. "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." *Applied Sciences* 9, no. 21 (2019): 4479. https://doi.org/10.3390/app9214479
[16] Prandi, Catia, Lorenzo Monti, Chiara Ceccarini, and Paola Salomoni. "Smart campus: Fostering the community awareness through an intelligent environment." *Mobile Networks and Applications* 25 (2020): 945-952. https://doi.org/10.1007/s11036-019-01238-2
[17] Silva-da-Nóbrega, Pedro Ivo, Adriana Fumi Chim-Miki, and Marysol Castillo-Palacio. "A Smart Campus Framework: Challenges and Opportunities for Education Based on the Sustainable Development Goals." *Sustainability* 14, no. 15 (2022): 9640. https://doi.org/10.3390/su14159640
[18] Zhang, Yuchen, Christine Yip, Erwan Lu, and Zhao Yang Dong. "A Systematic Review on Technologies and Applications in Smart Campus: A Human-Centered Case Study." *IEEE Access* 10 (2022): 16134-16149. https://doi.org/10.1109/ACCESS.2022.3148735
[19] Lasi, Heiner, Peter Fettke, Hans-Georg Kemper, Thomas Feld, and Michael Hoffmann. "Industry 4.0." *Business & information systems engineering* 6 (2014): 239-242. https://doi.org/10.1007/s12599-014-0334-4
[20] Bai, Chunguang, Patrick Dallasega, Guido Orzes, and Joseph Sarkis. "Industry 4.0 technologies assessment: A sustainability perspective." *International journal of production economics* 229 (2020): 107776. https://doi.org/10.1016/j.ijpe.2020.107776
[21] Sigov, Alexander, Leonid Ratkin, Leonid A. Ivanov, and Li Da Xu. "Emerging enabling technologies for industry 4.0 and beyond." *Information Systems Frontiers* (2022): 1-11. https://doi.org/10.1007/s10796-021-10213-w
[22] Al Farsi, Ghaliya, Azmi bin Mohd Yusof, Awanis Romli, Ragad M. Tawafak, Sohail Iqbal Malik, Jasiya Jabbar, and Mohd Ezanee Bin Rsuli. "A Review of Virtual Reality Applications in an Educational Domain." *International Journal of Interactive Mobile Technologies* 15, no. 22 (2021). https://doi.org/10.3991/ijim.v15i22.25003
[23] Kowsalya, T., S. Pratheba, K. Punithavarshini, and S. Sakthiya Ram. "Robotic Process Automation in Social Innovation for Education System." *International Journal of Research in Engineering, Science and Management* (2020).
[24] Gorkhali, Anjee. "Industry 4.0 and enabling technologies: Integration framework and challenges." *Journal of Industrial Integration and Management* 7, no. 03 (2022): 311-348. https://doi.org/10.1142/S2424862222500075

[25] Gaber, Abdelrahman Mahmoud, Rozeha A. Rashid, Nazri Nasir, Ruzairi Abdul Rahim, M. Adib Sarijari, A. Shahidan Abdullah, Omar A. Aziz, Siti Zaleha A. Hamid, and Samura Ali. "Development of an Autonomous IoT-Based Drone for Campus Security." *ELEKTRIKA-Journal of Electrical Engineering* 20, no. 2-2 (2021): 70-76.

[26] Chen, Lien-Wu, Tsung-Ping Chen, Da-En Chen, Jun-Xian Liu, and Ming-Fong Tsai. "Smart campus care and guiding with dedicated video footprinting through Internet of Things technologies." *IEEE Access* 6 (2018): 43956-43966. https://doi.org/10.1109/ACCESS.2018.2856251

[27] Martín-Garín, A., J. A. Millán-García, A. Baïri, J. Millán-Medel, and J. M. Sala-Lizarraga. "Environmental monitoring system based on an Open Source Platform and the Internet of Things for a building energy retrofit." *Automation in Construction* 87 (2018): 201-214. https://doi.org/10.1016/j.autcon.2017.12.017

[28] Abdullah, Alghamdi, Mohammed Thanoon, and Anwar Alsulami. "Toward a smart campus using IoT: framework for safety and security system on a university campus." *Advances in Science, Technology and Engineering Systems Journal (ASTESJ)* 4, no. 5 (2019): 97-103. https://doi.org/10.25046/aj040512

[29] Revathi, R., M. Suganya, and Gladiss Merlin NR. "IoT based Cloud Integrated Smart Classroom for smart and a sustainable Campus." *Procedia Computer Science* 172 (2020): 77-81. https://doi.org/10.1016/j.procs.2020.05.012

[30] Zhang, Ping, and Jianzhong Wang. "Management of intelligent campus wireless sensor networks based on runtime model." *Journal of Computer and Communications* 3, no. 07 (2015): 22. https://doi.org/10.4236/jcc.2015.37003

[31] Sutjarittham, Thanchanok, Hassan Habibi Gharakheili, Salil S. Kanhere, and Vijay Sivaraman. "Experiences with IoT and AI in a smart campus for optimizing classroom usage." *IEEE Internet of Things Journal* 6, no. 5 (2019): 7595-7607. https://doi.org/10.1109/JIOT.2019.2902410

[32] Li, Weiguang. "Design of smart campus management system based on internet of things technology." *Journal of Intelligent & Fuzzy Systems* 40, no. 2 (2021): 3159-3168. https://doi.org/10.3233/JIFS-189354

[33] Jabbar, Waheb A., Chong Wen Wei, Nur Atiqah Ainaa M. Azmi, and Nur Aiman Haironnazli. "An IoT Raspberry Pi-based parking management system for smart campus." *Internet of Things* 14 (2021): 100387. https://doi.org/10.1016/j.iot.2021.100387

[34] Sungheetha, Akey. "Assimilation of IoT sensors for data visualization in a smart campus environment." *Journal of Ubiquitous Computing and Communication Technologies* 3, no. 4 (2022): 241-252. https://doi.org/10.36548/jucct.2021.4.001

[35] Ceccarini, Chiara, Silvia Mirri, Paola Salomoni, and Catia Prandi. "On exploiting data visualization and IoT for increasing sustainability and safety in a smart campus." *Mobile Networks and Applications* (2021): 1-10. https://doi.org/10.1007/s11036-021-01742-4

[36] Lin, Yi-Bing, Li-Kuan Chen, Min-Zheng Shieh, Yun-Wei Lin, and Tai-Hsiang Yen. "CampusTalk: IoT devices and their interesting features on campus applications." *IEEE Access* 6 (2018): 26036-26046. https://doi.org/10.1109/ACCESS.2018.2832222

[37] Chang, Yao-Chung, and Ying-Hsun Lai. "Campus edge computing network based on IoT street lighting nodes." *IEEE Systems Journal* 14, no. 1 (2018): 164-171. https://doi.org/10.1109/JSYST.2018.2873430

[38] Fraga-Lamas, Paula, Mikel Celaya-Echarri, Peio Lopez-Iturri, Luis Castedo, Leyre Azpilicueta, Erik Aguirre, Manuel Suárez-Albela, Francisco Falcone, and Tiago M. Fernández-Caramés. "Design and experimental validation of a LoRaWAN fog computing based architecture for IoT enabled smart campus applications." *Sensors* 19, no. 15 (2019): 3287. https://doi.org/10.3390/s19153287

[39] Eltamaly, Ali M., Majed A. Alotaibi, Abdulrahman I. Alolah, and Mohamed A. Ahmed. "IoT-based hybrid renewable energy system for smart campus." *Sustainability* 13, no. 15 (2021): 8555. https://doi.org/10.3390/su13158555

[40] Dong, Bing, Burton Andrews, Khee Poh Lam, Michael Höynck, Rui Zhang, Yun-Shang Chiou, and Diego Benitez. "An information technology enabled sustainability test-bed (ITEST) for occupancy detection through an environmental sensing network." *Energy and Buildings* 42, no. 7 (2010): 1038-1046. https://doi.org/10.1016/j.enbuild.2010.01.016

[41] Fuguang, Yao. "Research on campus network cloud storage open platform based on cloud computing and big data technology." *Journal of Intelligent & Fuzzy Systems* 38, no. 2 (2020): 1215-1223. https://doi.org/10.3233/JIFS-179483

[42] Yang, Chao-Tung, Shuo-Tsung Chen, Jung-Chun Liu, Ren-Hao Liu, and Ching-Lung Chang. "On construction of an energy monitoring service using big data technology for the smart campus." *Cluster Computing* 23 (2020): 265-288. https://doi.org/10.1007/s10586-019-02921-5

[43] Zhang, Wei, Xinchang Zhang, and Huiling Shi. "MMCSACC: A multi-source multimedia conference system assisted by cloud computing for smart campus." *IEEE Access* 6 (2018): 35879-35889. https://doi.org/10.1109/ACCESS.2018.2851956

[44] Razzaq, Mirza Abdur, Javed Ahmed Mahar, Muneer Ahmad, Ihsan Ali, Roobaea Alroobaea, Fahad Almansour, and Kumarmangal Roy. "The 3-axis scalable service-cloud resource modeling for burst prediction under smart campus scenario." *IEEE Access* 9 (2021): 116927-116941. https://doi.org/10.1109/ACCESS.2021.3105539

[45] Hang, Feilu, Linjiang Xie, Zhenhong Zhang, Wei Guo, and Hanruo Li. "Information Security Situation in Blockchain for Secure SDN Based on Big Data in Smart Communities: Research on Information Security Situation Awareness Based on Big Data and Artificial Intelligence." *International Journal of Information Security and Privacy (IJISP)* 16, no. 2 (2022): 1-19. https://doi.org/10.4018/IJISP.308315

[46] Huang, Chao. "Research on Cloud Storage Technology in Digital Campus Big Data Scenario." *Academic Journal of Science and Technology* 2, no. 2 (2022): 6-8. https://doi.org/10.54097/ajst.v2i2.1051

[47] Villegas-Ch, William, Jhoann Molina-Enriquez, Carlos Chicaiza-Tamayo, Iván Ortiz-Garcés, and Sergio Luján-Mora. "Application of a big data framework for data monitoring on a smart campus." *Sustainability* 11, no. 20 (2019): 5552. https://doi.org/10.3390/su11205552

[48] Cantabella, Magdalena, Raquel Martínez-España, Belén Ayuso, Juan Antonio Yáñez, and Andrés Muñoz. "Analysis of student behavior in learning management systems through a Big Data framework." *Future Generation Computer Systems* 90 (2019): 262-272. https://doi.org/10.1016/j.future.2018.08.003

[49] Villegas-Ch, William, Xavier Palacios-Pacheco, and Sergio Luján-Mora. "Application of a smart city model to a traditional university campus with a big data architecture: A sustainable smart campus." *Sustainability* 11, no. 10 (2019): 2857. https://doi.org/10.3390/su11102857

[50] Nie, Min, Zhaohui Xiong, Ruiyang Zhong, Wei Deng, and Guowu Yang. "Career choice prediction based on campus big data—mining the potential behavior of college students." *Applied Sciences* 10, no. 8 (2020): 2841. https://doi.org/10.3390/app10082841

[51] Hong, Hetiao. "Research on Campus Education Information System Based on Internet of Things and Artificial Intelligence Decision." *Wireless Communications and Mobile Computing* 2021 (2021): 1-17. https://doi.org/10.1155/2021/8626890

[52] Jeong, Byeong-Cheol, Dong-Hwan Shin, Jae-Beom Im, Jae-Young Park, and Young-Jin Kim. "Implementation of optimal two-stage scheduling of energy storage system based on big-data-driven forecasting—an actual case study in a campus microgrid." *Energies* 12, no. 6 (2019): 1124. https://doi.org/10.3390/en12061124

[53] Zheng, Niting, Sheng Li, Yunpeng Wang, Yuwen Huang, Pietro Bartoccid, Francesco Fantozzid, Junling Huang *et al.,* "Research on low-carbon campus based on ecological footprint evaluation and machine learning: A case study in China." *Journal of Cleaner Production* 323 (2021): 129181. https://doi.org/10.1016/j.jclepro.2021.129181

[54] Im, Haekyung, Ravi S. Srinivasan, Daniel Maxwell, Ruth L. Steiner, and Sayar Karmakar. "The Impact of Climate Change on a University Campus' Energy Use: Use of Machine Learning and Building Characteristics." *Buildings* 12, no. 2 (2022): 108. https://doi.org/10.3390/buildings12020108

[55] Khandale, Shubham, and Sachin Bhoite. "Campus placement analyzer: using supervised machine learning algorithms." *Int. J. Comput. Appl. Technol. Res* 8, no. 09 (2019): 379-384. https://doi.org/10.7753/IJCATR0809.1004

[56] Manvitha, Pothuganti, and Neelam Swaroopa. "Campus placement prediction using supervised machine learning techniques." *International Journal of Applied Engineering Research* 14, no. 9 (2019): 2188-2191.

[57] Paci, Francesco, Davide Brunelli, and Luca Benini. "0, 1, 2, many—A classroom occupancy monitoring system for smart public buildings." In *Proceedings of the 2014 Conference on Design and Architectures for Signal and Image Processing*, pp. 1-6. IEEE, 2014. https://doi.org/10.1109/DASIP.2014.7115644

[58] Abdelhalim, Esraa A., and Ghada A. El Khayat. "A utilization-based genetic algorithm for solving the university timetabling problem (uga)." *Alexandria Engineering Journal* 55, no. 2 (2016): 1395-1409. https://doi.org/10.1016/j.aej.2016.02.017

[59] Kostuch, Philipp. "The university course timetabling problem with a three-phase approach." In *International Conference on the Practice and Theory of Automated Timetabling*, pp. 109-125. Berlin, Heidelberg: Springer Berlin Heidelberg, 2004. https://doi.org/10.1007/11593577_7

[60] Villegas-Ch, William, Adrián Arias-Navarrete, and Xavier Palacios-Pacheco. "Proposal of an Architecture for the Integration of a Chatbot with Artificial Intelligence in a Smart Campus for the Improvement of Learning." *Sustainability* 12, no. 4 (2020): 1500. https://doi.org/10.3390/su12041500

[61] Xu, Qichao, Zhou Su, Yuntao Wang, and Minghui Dai. "A trustworthy content caching and bandwidth allocation scheme with edge computing for smart campus." *IEEE Access* 6 (2018): 63868-63879. https://doi.org/10.1109/ACCESS.2018.2872740

[62] Wang, Zhong, Guangtao Xue, Shiyou Qian, and Minglu Li. "CampEdge: Distributed computation offloading strategy under large-scale AP-based edge computing system for IoT applications." *IEEE internet of things journal* 8, no. 8 (2020): 6733-6745. https://doi.org/10.1109/JIOT.2020.3026862

[63] Chunlin, Li, and Jing Zhang. "Dynamic cooperative caching strategy for delay-sensitive applications in edge computing environment." *The Journal of Supercomputing* 76 (2020): 7594-7618. https://doi.org/10.1007/s11227-020-03191-4

[64] Kristiani, Endah, Chao-Tung Yang, Chin-Yin Huang, Yuan-Ting Wang, and Po-Cheng Ko. "The implementation of a cloud-edge computing architecture using OpenStack and Kubernetes for air quality monitoring application." *Mobile Networks and Applications* 26 (2021): 1070-1092. https://doi.org/10.1007/s11036-020-01620-5

[65] Zhuang, Yifan, Ziyuan Pu, Jia Hu, and Yinhai Wang. "Illumination and temperature-aware multispectral networks for edge-computing-enabled pedestrian detection." *IEEE Transactions on Network Science and Engineering* 9, no. 3 (2021): 1282-1295. https://doi.org/10.1109/TNSE.2021.3139335

[66] Krishnan, Prabhakar, Kurunandan Jain, Krishnashree Achuthan, and Rajkumar Buyya. "Software-defined security-by-contract for blockchain-enabled MUD-aware industrial IoT edge networks." *IEEE Transactions on Industrial Informatics* 18, no. 10 (2021): 7068-7076. https://doi.org/10.1109/TII.2021.3084341

[67] Zaballos, Agustín, Alan Briones, Alba Massa, Pol Centelles, and Víctor Caballero. "A smart campus' digital twin for sustainable comfort monitoring." *Sustainability* 12, no. 21 (2020): 9196. https://doi.org/10.3390/su12219196

[68] Silva, Felipe Condon, Mohamed A. Ahmed, José Manuel Martínez, and Young-Chon Kim. "Design and implementation of a blockchain-based energy trading platform for electric vehicles in smart campus parking lots." *Energies* 12, no. 24 (2019): 4814. https://doi.org/10.3390/en12244814

[69] Chatterjee, Kakali, and Ashish Singh. "A blockchain-enabled security framework for smart agriculture." *Computers and Electrical Engineering* 106 (2023): 108594. https://doi.org/10.1016/j.compeleceng.2023.108594

[70] Ludlow, Barbara L. "Virtual reality: Emerging applications and future directions." *Rural Special Education Quarterly* 34, no. 3 (2015): 3-10. https://doi.org/10.1177/875687051503400302

[71] Wong, L. H. "Mobile campus touring system based on AR and GPS: A case study of campus cultural activity." In *Proceedings of the 21st International Conference on Computers in Education. Asia-Pacific Society for Computers in Education, Indonesia*. 2013.

[72] Liu, Guoyang, and Ji Wu. "Design and implementation of virtual campus roaming system based on Unity3d." In *2019 International Conference on Machine Learning, Big Data and Business Intelligence (MLBDBI)*, pp. 147-150. IEEE, 2019. https://doi.org/10.1109/MLBDBI48998.2019.00034

[73] Edler, Dennis, Adalbert Husar, Julian Keil, Mark Vetter, and Frank Dickmann. "Virtual reality (VR) and open source software: a workflow for constructing an interactive cartographic VR environment to explore urban landscapes." *Kartographische Nachrichten* 68, no. 1 (2018): 3-11. https://doi.org/10.1007/BF03545339

[74] Sourin, Alexei. "Nanyang Technological University virtual campus [virtual reality project]." *IEEE Computer Graphics and Applications* 24, no. 6 (2004): 6-8. https://doi.org/10.1109/MCG.2004.57

[75] Wu, Bei, Yaning Wang, Ruiqi Liu, Shiye Tan, and Ruoyan Hao. "Research of intelligent campus design based on immersive bim+ vr technology." In *Journal of Physics: Conference Series*, vol. 1885, no. 5, p. 052053. IOP Publishing, 2021. https://doi.org/10.1088/1742-6596/1885/5/052053

[76] Liu, Li Ping, and Yu Jian Wang. "An Implement of Virtual Campus System Base on the X3D Technology." *Advanced Materials Research* 422 (2012): 551-554. https://doi.org/10.4028/www.scientific.net/AMR.422.551

[77] Wang, Qinghai, Zhang Zhe, and Yadan Xing. "Application and research of VR technology in art design teaching." In *Journal of Physics: Conference Series*, vol. 1345, no. 4, p. 042026. IOP Publishing, 2019. https://doi.org/10.1088/1742-6596/1345/4/042026

[78] Campus, Anantapur. "ROBOTIC PROCESS AUTOMATION-A VIRTUAL ASSISTANT FOR INVENTORY MANAGEMENT."

[79] Lu, Qiuchen, Ajith Kumar Parlikad, Philip Woodall, Gishan Don Ranasinghe, Xiang Xie, Zhenglin Liang, Eirini Konstantinou, James Heaton, and Jennifer Schooling. "Developing a digital twin at building and city levels: Case study of West Cambridge campus." *Journal of Management in Engineering* 36, no. 3 (2020): 05020004. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763

[80] Dahan, Neama A., Muna Al-Razgan, Ali Al-Laith, Muaadh A. Alsoufi, Mahfoudh S. Al-Asaly, and Taha Alfakih. "Metaverse framework: A case study on E-learning environment (ELEM)." *Electronics* 11, no. 10 (2022): 1616. https://doi.org/10.3390/electronics11101616

[81] Ge, Jiajia. "Multiple influences of intelligent technology on network behavior of college students in the metaverse age." *Journal of Environmental and Public Health* 2022 (2022). https://doi.org/10.1155/2022/2750712

[82] Braud, Tristan, Carlos Bermejo Fernández, and Pan Hui. "Scaling-up ar: University campus as a physical-digital metaverse." In *2022 ieee conference on virtual reality and 3d user interfaces abstracts and workshops (vrw)*, pp. 169-175. IEEE, 2022. https://doi.org/10.1109/VRW55335.2022.00044

[83] Han, Yue, Dusit Niyato, Cyril Leung, Chunyan Miao, and Dong In Kim. "A dynamic resource allocation framework for synchronizing metaverse with iot service and data." In *ICC 2022-IEEE International conference on Communications*, pp. 1196-1201. IEEE, 2022. https://doi.org/10.1109/ICC45855.2022.9838422