IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received January 17, 2022, accepted January 30, 2022, date of publication February 2, 2022, date of current version February 14, 2022.

Digital Object Identifier 10.1109/ACCESS.2022.3148735

A Systematic Review on Technologies and Applications in Smart Campus: A Human-Centered Case Study

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This work was supported by the UNSW Digital Grid Futures Institute, University of New South Wales (UNSW), Sydney, under a cross disciplinary fund scheme.

ABSTRACT The smart revolution has penetrated in a wide range of applications. Smart campus, as the high-end form of education systems, deploys cutting-edge information and communication technologies to enhance the effectiveness and efficiency of campus services. Under the pandemic of COVID-19, smart campus has shown unprecedented importance owing to its remote, personalized, and ubiquitous features. All these factors have made smart campus an ongoing intense research topic in recent years, whereas existing reviews on smart campus were conducted in earlier years and thus an update is imperatively needed to investigate and summarize the emerging knowledge, technologies, and applications in this context. This paper conducts a systematic review on smart campus technologies and applications, and then strategically classifying them into different domains to investigate the current research pattern. Moreover, adhering to the human-centered principle of smart campus development, a human-centered case study has been carried out and presented in this paper to evaluate the consistency and adherence of current research trend to the stakeholders needs and interests.

INDEX TERMS Smart campus, systematic review, human-centered, information and communication technologies, smart applications.

I. INTRODUCTION

The continuous innovation in technology has been transforming our way of living, where "smart" has been recently raised as a key word in this transformation. The "smart" concept penetrates in a wide range of applications, including single devices such as smart phones and smart meters, integrated systems such as smart home and smart buildings, and even industrial sectors such as smart energy and smart manufacturing, etc. [1]. In the education sector, campus, as the core place to provide educational services, has also been given the concept of "smart", mainly referring to deploying advanced information and communication (ICT) technologies to enhance the effectiveness and efficiency of campus activities. In recent years, smart campuses have received increasingly research attention around the world and its essential role in smart cities have been widely recognized [2], [3]. Many regions in the world have established a new round of plan to implement and develop smart campus based on deepened applications of ICT technologies, such as the National Education Technology Plan by the U.S. department of Education [4], the "i-Japan Strategy 2015" [5], the Fourth Strategy on ICT in Education by the Hong Kong Education Bureau [6], and the Digital Education Revolution in Australia [7].

Under the pandemic of the COVID-19, campus closure has been intermittently implemented across 188 countries (as of April 2020) around the world, which has affected the well-being of hundreds of millions of learners [8]. To cope with the impact and challenges of the long-term school closure on the global education systems, emerging ICT technologies has been deeply researched, promoted and applied in the field of education, and the smartness in education has shown unprecedented importance during the pandemic.

The associate editor coordinating the review of this manuscript and approving it for publication was Liang-Bi Chen.

In recent years, there have been a number of review articles related to smart campus. Reference [9] provided a systematic review on real-life implementations of smart campus. Reference [10] reviewed the smart campus terminology and high-level framework. These articles put more focuses on the real-life smart campus projects, but lacks the review and taxonomy of the research outputs on smart campus technologies and their applications. From the research perspective, [11] is the article that systematically reviewed the technologies and applications in smart campus research. Its reviewed technologies include radio-frequency identification, Internet of Things (IoT), cloud computing, augmented reality (AR), sensor technology, mobile technology, and web services. This review was published in 2017, but the research related to smart campus has boosted after 2017 (as shown in Fig. 1), where many new technologies and applications have been developed and widely incorporated, such as edge computing, blockchain, deep learning, virtual reality, and 5G. This calls for a new review to update the knowledge and scope of smart campus technologies and applications. Moreover, some other technological reviews focus on the specific type of technologies for smart campus, such as the review on Internet of Things (IoT) and cloud computing in [12] and [13], the review on Augmented Reality (AR) in [14], and the review on recommender systems in [15]. These reviews are based on subareas of smart campus technology, but lack the systematic vision on smart campus research.

Although technological upgrade takes an important role in the smart revolution, most of the existing smart campus research are technology driven, with available technologies trying to find applications. These bottom-up approaches are technically sound, but lack the considerations on human factors. As the primary function of a school campus is to provide educational services and cultivate innovative talents, the main stakeholders in schools, i.e. teachers and students, must serve as the mainstay when new technologies are deployed, thus the human-centered concept of smart campus has been raised and recognized in many researches [16]–[18]. The human-centered principle aims to bring the voices of teachers and students into the smart campus research so that the new technologies can be appropriately applied in smart campus to meet stakeholders' needs and interests. However, despite its importance, human-centered research is rarely seen in the literature related to smart campus.

Considering the inadequacy and outdating of existing reviews on smart campus technologies and applications [9]–[15], as well as the lack of human-centered considerations, this paper provides a systematic literature review to summarize and categorize the enabling technologies and applications in the context of smart campus, together with a case study to provide a human-centered investigation on current trend of smart campus research and development. The main contributions of the paper are as follows:

- The smart campus research articles published up to 2020 are reviewed using a systematic review method, from which the enabling technologies and the applications in smart campus are summarized and taxonomized into different domains. As compared to the existing review articles, this review paper updates and consolidates the research outputs on smart campus technologies and applications, which could serve as the newest reference for smart campus related research and development.
- A human-centered case study is conducted to collect the research focuses from school teachers and students in terms of the technologies and applications in smart campus. Based on the human-centered investigation, the consistency and adherence of current smart campus research trend to the stakeholders' needs and interests are evaluated, and recommendations on future smart campus research and development are also given accordingly. This human-centered study is innovatively used to supplement the literature review, which can incorporate stakeholders' needs and interests into referencing and guiding the research in smart campus community.

The rest of the paper is organized as follows: Section 2 elaborates the methodologies adopted for systematic review; Section 3 presents the review and classification results on smart campus technologies and applications; Section 4 presents the human-centered case study and performs comparative analysis and discussion; Section 5 concludes the paper.

II. REVIEW METHODOLOGIES

The review on smart campus is carried out following the systematic review method in [19]. This method was originally developed for software engineering area, but has been spread to other research areas including smart campus [11], [20].

A. RESEARCH QUESTIONS

The following research questions are designed to guide the study.

1) RESEARCH QUESTION 1 (RQ1)

What are the key technologies that enable campus smartness?

In the past, the education systems over the world have experienced dramatic transformation from traditional campus to digital campus, and future transition towards smart campus expected. Along these transformations, technology has played a key role and there have been extensive technologies that influence campus development. New technologies are still emerging and are being incorporated in campus construction and operation. In the continuous technological development and expansion, some technologies, such as Internet, have shown their strength in achieving campus digitalization, but not necessarily the core technology in enabling campus smartness. Therefore, it is important to be clear what the enabling technologies for smart campus are and how the different technologies are classified. This review aims to answer these questions by providing a systematic categorization and organization of the reported technologies in the smart campus literature, which is expected to provide a reference for future technology deployment in smart campus.

2) RESEARCH QUESTION 2 (RQ2)

What are the application domains in smart campus?

Technologies cannot be smart by itself. They must be incorporated into various campus applications to realize smartness. A smart campus is an indispensable part of a smart city, many applications in smart cities can be reflected in the smart campus context. In this review, based on the exploration of the specific applications in smart campus, the main domains of these applications can be summarized, from which the recent research interests on each domain is evaluated.

B. SEARCHING METHOD

An automatic search on popular digital libraries is carried out from August 16, 2021 to August 20, 2021. To target on the technologies and applications in smart campus, we apply the following query string in the search: ("smart" AND "campus" in title) OR ("smart campus" in abstract) OR ("smart campus" in index terms). The searched digital libraries include IEEEXplore, Scopus, Web of Science, and SpringerLink, ACM Digital Library, and PubMed, all of which are considered most relevant to cover the scope of this review. The types of articles are restricted to peer-reviewed articles, including book chapters, conference proceedings, and journal papers. The more recent articles are more relevant to this study, so we only search the articles published between 2010 and 2020. The search only focuses on publications in English language. This initial search phase results in a set of 1,601 articles. The number of articles found in each library is listed in Table 1.

TABLE 1. Number of smart campus articles found in each digital library.

Resources	No of Articles
IEEEXplore	523
Scopus	351
Web of Science	606
SpringerLink	121
ACM Digital Library	21
PubMed	57
Total	1,679

C. SELECTION CRITERIA

Among the 1,679 articles, we first remove the duplicated papers or preliminary versions of publications, resulting in 1,078 articles.

Moreover, to target on answering the RQs, the inclusion and exclusion criteria in Table 2 are applied to accurately select the relevant publications. Firstly, the selected publications must present the new use or incorporation of one or more technologies to enhance applications in smart campus, which meets the scope of this review. Publications barely on technological innovations without application-oriented justification or merely re-arrangement of existing applications without technology involvement are excluded. Secondly, this review focuses on new smart campus approaches, so the review articles on approaches in the past are not considered. Thirdly, to investigate the research interests in different technology and application domains, the articles on the systematic modelling and planning of smart campus are not included.

TABLE 2. Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
- Publications with new use or incorporation of technologies on smart campus applications	- Publications on campus-like locations other than education institutes - Publications on technological aspects without mentioning the impact on smart campus applications - Publications on smart campus applications without technology involvement - Review articles on smart campus - Publications on systematic smart campus modelling and/or planning

After applying the inclusion and exclusion criteria, 109 articles are finally selected to complete the review. The number of publications in each media is listed in Table 3, and the number of articles in each publication year is presented in Figure 1. It can be seen that the number of publications in smart campus topic has dramatically increased since 2018, which motivates the conduction of this review for an updated exploration of the literature in this field.

TABLE 3. Number of articles in each publication media.

Types	No of Articles
Book chapters	6
Conference proceedings	55
Journals	48
Total	109

III. REVIEW RESULTS

Based on the selected articles, this section aims to summarize and categorize the enabling technologies and the potential smart campus applications that most frequently appear in the literature. The analysis and discussion of the results are reported in the discussion section.

The concept of smart is considered as the feature of autonomously providing services in line with the dynamic user needs [21]. This definition of smart is also applicable to the context of smart campus. As technologies are widely deployed in smart campus, this review only highlights the key

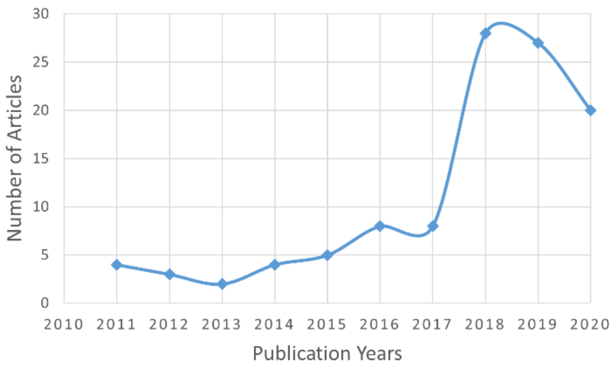

FIGURE 1. Number of selected articles in each publication year.

technology and application domains that contribute to above features to achieve campus smartness.

A. TECHNOLOGY DOMAINS

In the literature, the reported enabling technologies for smart campus include cloud computing, IoT, virtual reality (VR), AR, artificial intelligence (AI), mobile devices, etc. Based on the physical field and the enabled features of these technologies, we categorized them into 5 domains, namely data computing and storage technologies, IoT technologies, intelligent technologies, immersive technologies, and mobile technologies. The number and references of articles where technologies in each domain are used are summarized in Table 4. Note that many applications in smart campus requires the overlapping and interactions over multiple domains, which promotes the technology fusion towards the common smart development goal. The concept and scope of each domain is introduced below.

1) DATA COMPUTING AND STORAGE TECHNOLOGIES

In the context of smart campus, massive data are generated from time to time by sensing devices and components, which poses issues such as the costs of latency, storage, and energy consumption for communication. This requires the cyber platform to be able to handle big data in an effective and efficient manner. Distributed data computing and storage technologies have been rapidly advanced in recent years, showing great potential to satisfy smart campus needs. The key technologies falling in this domain include:

- Cloud computing: Cloud service enables convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly scaled, provided, and released upon user's request with a minimum interaction with the supplier. Cloud-based platform has been identified as a key trend in technology-enhanced smart campus. Compared to conventional computational infrastructure where both hardware and software are owned and kept by organizations at their premises, cloud computing enables learning activities in an unstructured environment, which allows users to gain fast data access at anytime and anywhere, with infinite scalability, improved convenience and lower cost. Reference [22] proposed a two-factor protection mechanism for cloud service, which can securely storage and processing of public data in smart campus. Reference [23] proposed the concept of mobile cloud education to enable smart anytime-anywhere learning in smart campus environment.
- Fog and edge computing: Although fog and edge computing technologies present different concepts and specific characteristics, they have a common principle of bringing the data processing and storage agents closer to the distributed devices, enabling the execution of highly demanding applications while meeting strict delay requirements. Fog computing focuses on processing data at the local area network level in a distributed architecture, while edge computing aims to push the intelligence, processing power and communication capabilities of an edge gateway directly into the end devices. As compared to cloud computing, fog and edge computing can better handle latency-sensitive distributed tasks and applications in smart campus, such as distributed control of devices and emergency decision-making on safety/security issues. For example, a trustworthy edge caching and bandwidth allocation scheme is proposed in [24] to protect the security of contents and mobile users in smart campus.
- Blockchain: Blockchain is a peer-to-peer distributed ledger technology that implements transactions with a decentralized digital database, which allows parties to directly exchange assets in real time without the need of intermediaries. Blockchain technology has received great interests in various sectors, such as financial and energy industry. However, the integration of blockchain into education institutes is still in its early stages. One application in the literature is a blockchain-based energy trading platform for electric vehicles in smart campus parking system [25].

2) IOT TECHNOLOGIES

IoT is a communication paradigm referring to the idea of connecting the objects of everyday life to the Internet. Embedded with electronics, sensors, internet and advanced communication technologies, the devices in an IoT environment can communicate with each other and interact with human over the Internet in a remote mode. Smart connectivity of existing objects and context-aware network resources is an indispensable part of IoT. which requires more affordable wireless technologies that consume less power and adaptable to almost all types of devices. Several low-power communication technologies are widely used for IoT connection, such as ZigBee, Bluetooth, Wi-Fi and Radio Frequency Identification (RFID). Three aspects are crucial for implementing seamless IoT system:

- Hardware: This refers to the essential hardware to build up the IoT environment. The main hardware components in the smart campus context include cameras, scanners, environment sensors, routers, gateway, RFID tags, etc.

- Middleware: The role of IoT middleware is to facilitate the interaction between a multitude of diverse devices and data, with a single core working on different kinds of devices or data formats. The main functional components for IoT middleware include the interface protocol for device interoperability and resolving the syntax and semantics, the central management for device discovery ad context management, the application abstraction to provide the interface with local and remote applications.
- Presentation: This refers to the visualization and interpretation interface which can be widely accessed on different platforms and designed for different applications. Presentation is critical for an IoT application as it allows the interaction between the user and the environment. This part of IoT is highly coupled with other technology domains, such as mobile technologies as smart tablets and mobile phones have become interfaces widely used for convenient and intuitive IoT presentation.

In recent years, IoT technologies have been widely used in smart campus and integrated in various applications. Some examples in the literature are given below. Reference [26] proposed an IoT-based automatic attendance checking system with photo face recognition capability. Reference [27] proposed a IoT-ready classroom device for screen streaming and management. Reference [28] discussed the possible roles of IoT in e-learning, including facilitating knowledge sharing among teachers and students, enhancing communications in virtual classroom, benefiting blended and collaborative learning. [29] presented an IoT-based platform for environment monitoring in university campus. In [30], an IoT-based system was proposed for fire alarming and disaster management within smart campus.

3) INTELLIGENT TECHNOLOGIES

Intelligence is a key enabling attribute of a campus to be identified as "smart", not only in educational services, but also in the multi-model development of smart campus. This requires the integration of intelligent technologies into an IoT environment with advanced big data processing and storage. The global market for intelligent education is expected to exceed $3.6 billion by 2023, with a compound annual growth rate of about 47% [31]. Intelligent technologies in smart campus generally refer to the following two types of technologies.

- AI: AI is commonly defined as "a system's ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goad and tasks through flexible adaptation" [32]. It would be a suitable technology to solve problems where analytical mathematical relationships cannot be precisely or rapidly established between cause and effect. Various feature engineering and machine learning algorithms can be incorporated in a AI system to map and model the relationship from the big data in a machine understandable way. In real-time applications, the AI system is able to maximize the chance of the intelligent engine to successfully achieve the goal of the task based on the perceived environment. AI has been widely used in smart campus applications involving human factor and uncertainties, such as personalized learning, virtual tutoring, decision-making, quantative evaluation, and future condition prediction. In the literature, the commonly used AI techniques include but not limited to facial recognition [26], emotion recognition [33], speech recognition [33], computer vision [34], [35], unsupervised learning [36], recommender system [37], [38], and anomaly detection [36], [39].
- Robotics: As the physical presentation of AI, robots are machines that are able to autonomously carrying out task-performing actions. In recent years, robotic systems have become smaller in size, consume lower power, and inexpensive, making them become increasingly pervasive and potentially applicable to smart education. The role of robotics in education can be categorised as 1) learning objects, which focuses on integrating robotic-related topics, such as AI and machine learning, as learning subjects for students; 2) learning tools, which sees robots as a tools to teach STEM subjects; and 3) learning aids, which mainly refers to the social robots, such as Robot-Tutor, for teaching activities with human interactions [40].

4) IMMERSIVE TECHNOLOGIES

Immersive technologies, mainly referring to VR and AR technologies, have been increasingly applied in smart campus. These technologies aim to provide seamless connection between virtual and real-world environments. The features and applications of VR and AR in smart campus are presented below:

- VR: VR is a technology that allows the users to immerse themselves in a programmed environment which can be an entirely imaginary universe or only the simulation of real world. The immersion is realized by using wearable equipment, such as visualization goggles, haptic gloves, and VR headsets, that place users a stereoscopic 3D display system through sighting, touching, and hearing. The values of adopting VR in smart campus lie in two parts: 1) this technology can help make abstract concepts and knowledge more tangible so as to improve and facilitate learning, increase memory capacity and make better decisions while working in entertaining and stimulating conditions, and 2) VR enables 3D modelling of various physical facilities on campus based on the space and the attribute data, assisting in more comprehensive analysis, management, and decision-making. In the literature, an "In Your Eyes" game was developed using VR technology in [41] to support the acquisition and the consolidation of the spatial perspective taking skill in young adults with mild intellectual disabilities. A 3D modelling software named Vega was developed in [42] to achieve VR smart simulation campus. VR is incorporated with IoT technologies in [43] to create a smart campus system model for efficient education and management.

- AR: AR is a form of experience in which the real environment in which people live is overlayed the virtual information from computer, which allows synchronization of computer-generated content and real-world perceptions, so that AR increases the amount of information that the users can take from the environment. As compared to VR, AR only provides partial immersion into the virtual world since the users can always perceive the real world around them. AR commonly requires a device interface, such as a smartphone, a tablet, or any other on-screen display system, to films the real world and inverts live virtual objects. AR technology provides a different way of interaction with information, which makes it an effective tool to enrich learning. The positive effects of VR on learning include encouraging participation and interactivity, and increasing motivation and attention of students. For example, by integrating AR in handheld devices, [44] proposes a model for better understanding the features of mobile collaborative AR in supporting social interactions in collaborative learning. Besides, AR has also been used in other areas in smart campus, such campus navigation and touring [45]–[47], and parking space finding [48].

5) MOBILE TECHNOLOGIES

Mobile technology is the technological fusion of wireless devices and the communication networking that connects them. It uses the code-division multiple access (CDMA) platform that allows the data sent from many users to be transmitted on a single frequency. With the advancement in cellular communication, handheld devices, and mobile APPs, the mobile technology has now improved from a simple device used for phone call and messaging into a multi-tasking device for indispensable activities in people's daily lives, such as GPS navigation, internet browsing, photographing, gaming, and social networking. In the context of smart campus, mobile technologies have been widely deployed in almost all dimensions of campus activities.

- Mobile Devices: Also known as handheld devices, mobile devices include any type of small portable digital mechanisms that usually has a small display screen, touch input, or a small keyboard. Recently, mobile devices (e.g., tablets, e-readers, smartphones and wearables) are increasingly popular due to their powerful functions comparable to desktops or laptops, and the wireless advantages which enables users to access a variety of information in anytime and at anywhere. Findings in research reveal that using mobile devices for campus activities facilitates students with ubiquitous functions to learn information, collaborate with peers, and view feedback from teachers [49]. Mobile devices have already been widely used in many educational institutions for web access and e-learning. For example, [50] presents an approach to detecting perceived stress in students using data collected from smartphones.
- Mobile APPs: This is short for mobile application, which is a portable third-party computer program or software application specifically designed to run on a mobile device rather than desktop or laptop computers. With the advancement in mobile devices and mobile Internet together with the emergence of smart operating systems such as iOS and Android, the development in mobile APPs have been boosted, mainly in five areas: tools, social networking, life services, entertainment, and industry expertise. The design of mobile APPs keeps track on user experience, which is in line with the human-centered principle of smart campuses. Recently, mobile APPs have begun to penetrate in campus activities, bringing benefits of convenient, efficient and humanized. For examples, [46] used an AR-based mobile APP to provide environment information in a real university, giving freshmen instant assistance if they have gotten lost. Reference [51] developed a system enabling users to locate bus on a digital mapping from Google Maps using their smartphone APPs. Reference [52] proposed a mobile APP for a meeting room booking and arrangement.
- 5G: 5G refers to the fifth generation of digital cellular networks, which is a new global wireless standard after 1G, 2G, 3G, and 4G networks. To compare with the previous standards, the main advantage of the 5G networks is that the data transmission rate can reach up to 10 Gbit/s, which is approximately 100 times faster than the previous 4G LTE cellular network. Higher performance and improved efficiency of 5G networks enable a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices. Smart campuses are densely populated, and its smart devices and services require high-density interaction. In this case, deployment of 5G networks can support the smooth transition towards smart campuses. For example, [53] discussed the communication barriers of smart campus e-learning platform, and thus established an upgraded platform in the context of 5G network.

B. APPLICATION DOMAINS

The enabling technologies have been integrated into many applications in smart campus. These applications are numerous and complicated, covering all kinds of services to form an integrated system with cooperative and self-adaptive features [132]. Since a smart campus can be seen a miniscopic version of a smart city, the way of identifying the domains in a smart city [2] is used in this review, with appropriate justifications to fit smart campus context. As a result, the smart applications in smart campus are categorized into 4 domains, namely smart learning, smart living, smart environment, and smart management. The number and references of articles

TABLE 4. Number and references of articles in each technology domain.

Technology Domains	No of Articles	References
Data computing and storage technologies	23 (21.10%)	[22-25, 49, 54-71]
IoT technologies	47 (43.12%)	[26-30, 34, 36, 53, 54, 58, 62, 69, 72-98]
Intelligent technologies	36 (33.03%)	[26, 33-39, 58, 61, 62, 81, 83, 87, 94, 99-116]
Immersive technologies	10 (9.17%)	[41-44, 46-48, 117, 118]
Mobile technologies	37 (33.94%)	[23, 24, 44-47, 50-52, 55, 57, 60, 63, 71, 80, 89, 92, 93, 100, 112, 119-131]

that cover applications in each domain are summarized in Table 5. Each application domain is elaborated below.

1) SMART LEARNING

Researchers have long been committed to using technology in education and are looking for ways to integrate different scientific advances into the learning environment. The current crisis caused by the COVID-19 pandemic has pushed a further boost to technological developments to ensure pervasive remote access to education. Smart learning is a process in which learners use advanced technologies to obtain learning resources, carry out learning activities, and build knowledge networks, and develop interpersonal networks. Its ultimate goal is to develop the learning and innovative ability of learners, so as to achieve better learning results. The literature focuses on the following applications in this domain.

- Smart Pedagogy: In technology-enhanced learning, smart pedagogy provides a synergy between technology and pedagogy in the context of existing learning theories, which can help educators find out how to support learning in the process of transformational education, how to integrate technology into learning to support metacognitive development, how to facilitate knowledge building and how to support digital capability development. Smart pedagogical competence can be seen as a driving wheel that ensures that the use of technologies in learning activities has pedagogical value. Smart pedagogy can be divided into the different types according to the learning characteristics, including personalized learning [127], collaborative learning [71], immersive learning [41], [44], and ubiquitous learning [60].
- Smart Classroom: A new type of classroom built with cutting edge technologies including Internet of Things, cloud computing, AR, VR, etc. Various intelligent equipment are used to assist the teaching presentation, facilitate the acquisition of learning resources, promote classroom interaction, and realize situational awareness and environmental management. Smart classroom aims to provide a humanized and intelligent interactive space for teaching activities. Through the combination of physical space and digital space, smart classroom would make learners compatible with the real world, thereby bring an atmosphere of "being there" to enrich the teaching and learning experience and facilitate the effective implementation of various smart pedagogies [11]. Some applications in the literature are give below. Reference [79] presents an ontology for an IoT-enabled smart classroom to deal with semantic interoperability issues. Reference [109] studied instrument smart campus with monitoring sensors to measure classroom attendance without endangering student privacy. Reference [133] used AI to predict attendance, and performing optimal allocation of rooms to courses so as to minimize space wastage.
- Smart Library: On top of the traditional library, the smart library is an intelligent building formed by applying smart technologies to the construction of the library. Smart library has been supported by IoT, with the characteristics of knowledge sharing, convenience of use and service efficiency. Reference [132] showed an advanced smart library which use a wireless system - radio frequency identification (RFID) to locate the position of books to shelves, and RFID electronic tags are used to store information of shelves, books, and book carts. Reference [120] developed a mobile application to assist students for finding free seats, as well as keeping bags safe by automating a locker.
- Smart Laboratory: A new technology-enhanced laboratory environment that aims to simplify or automate the data management and processes in the laboratory. The teaching platform is usually collaborated with the smart laboratory for docking and unified management of laboratory resources, and realizing a series of real-time services such as information update, online course adjustment and laboratory appointment, etc. Mobile devices are also involved for information release and acquisition accordingly. For example, [73] developed a smart laboratory system based on IoT and mobile application technologies to monitor the lab activities through sensors, including energy consumption, equipment usage and environmental parameters.

2) SMART LIVING

A smart campus is like a small city. Individuals on campus often encounter similar problems as in a city such as insufficient parking spaces, high crowded people, high pressure, and even getting lost in a large campus. Research shows that academic institutions are trying to promote campus informatization in order to provide more smart living services and experiences to allow students and teachers to grasp the benefits of big data on campus faster and more conveniently, and to participate more deeply in campus life. These changes can be found in the following applications:

- Smart transport: Campus transport system in a smart version seamlessly connects various vehicles including campus buses, cars and bicycles, and provides real-time location and arrival information based on IoT technologies, thereby to alleviate traffic problems as well as facilitate parking activities such as finding parking spaces, reserving parking spaces and paying parking fees. Reference [77] investigated the underlying communication networks for remote monitoring of electric vehicles charging stations. Reference [34] proposed a deep convolutional network architecture to automate the parking system in smart campus with modified Single-shot Multibox Detector (SSD) approach.
- Smart canteen: This system enables multiple smart services such as smart ordering, restocking, and sales and inventory management, which effectively improves teachers' and students' dining experience and economically benefits canteen in terms of attracting orders, increasing earnings, and reducing operating costs. Reference [99] discussed a smart canteen platform which aims at reducing queuing time when ordering food and present estimated crowd density in real-time.
- Smart health: Health system smartness is significant for improving the overall health level in a smart campus, especially during the COVID-19 pandemic. Through techniques such as remote healthcare, telemedicine, smart bioinformatics, ehealth records, health monitoring, pandemic alert platform, smart health system provides "anytime-anywhere" health care services to individuals on campus and seamless links internal and external health systems. For example, [113] contributed to mental health of students, and discovered key determinants of student mental health through big data analysis.
- Smart navigation: This is a geographic-based services for guiding users within the campus by determining the location of campus facilities and recommending optimal paths for users to reach their destination. Notifications and warning messages will also be provided to keep the users from hazards. In the literature, [119] developed a smart navigation system that suggests shortest/fastest routes based on all transportation methods in a campus. Reference [122] developed a system which helps visually impaired persons navigate in university campus. Reference [87] proposed a care and guiding system to provide seamless indoor and outdoor navigation with the function of quickly identify the place where incident occurred and the individuals need care and assistance.

3) SMART ENVIRONMENT

Facing the climate threats, a smart campus should be able to develop on an environmentally sustainable basis in the fields of energy, water resources, and cleanliness, which is guided by the global Sustainable Development Goals [134]. In this context, the "green campus" initiative, as a critical part of smart campus, has received widespread interests, and researchers have actively established smart environment strategies for campus in a series of eco-friendly practices. The smart environment on campus can be achieved from three aspects:

- Smart energy: Energy waste as well as unsustainable production and consumption of energy will significantly impact the environment and greatly increase operating costs in campuses. With the deployment of renewable energy sources, such as roof top PV systems, together with IoT and AI technologies on campus, energy can be harvested from sustainable resources and the use of energy can be monitored and controlled in real-time, which further enables smart energy management. This can be achieved by an integrated system that provides users a comprehensive understanding of the energy prosuming condition, forecasts future energy variations, and explores the energy saving potentials, so as to maximize renewable energy usage and minimize energy carbon footprints. In the literature, [36] presented a multi-agent-based unsupervised anomaly detection method to detect abnormal energy consumption in a smart campus. Reference [68] combined cloud computing with big data processing techniques to build a real-time energy monitoring system for smart campus.
- Smart waste: Waste is another area with considerable carbon footprint on campus. Cutting-edge technologies such as IoT and AI can be integrated to manage waste in a smarter way, where real-time data collected from sensors, detectors, and actuators is analysed for achieving efficient and optimal waste collecting, recycling, and disposal. For the smart bin application, bins on campus are equipped with sensor network to measure the weight and the level of waste inside the bins and the real-time data is shared with related departments or individuals with the aim to cut off the carbon footprint while maximize economic benefits. Moreover, real-time data can be also shared with waste-related companies to arrange reasonable garbage collection time or help cleaners set up cleaning schedules on demand.
- Smart water: Water system is supported by various smart sensors and devices to provide strategies for water use on campus. Its tasks involve water saving planning and scheduling, water quality control, emergency water cutoff, and data analytics. Toilet consumes the largest amount of water on campus. One smart application on toilet is the smart toilet system [135] that exploits IoT sensors (e.g., smell sensor, IR sensor, sonic sensor, RFID reader) to read water level, observe water quality, and track unintentional events (e.g. toilet blockage, toilet out of service). The sensor data will be transmitted to mobile management terminals for real-time monitoring and further analysis.
- Smart air conditioning: Air condition can largely affect students' learning performance in classrooms and buildings. Smart air conditioning on campus refers to monitoring and automatically regulating outdoor/indoor air quality, temperature, and humidity based on the

environment and comfort needs, which helps improve energy efficiency and environmental sustainability, and in the meantime provide the optimal physical environment for campus activities. Reference [97] reported an air quality monitoring experience in smart campus and discussed its implications. Reference [91] proposed an application to analyze harmful gas data collected by sensors and generate recommendations and alerts.

4) SMART MANAGEMENT

With the remarkable informatization advancement of educational institutions, campus management has ushered in new challenges. Strong campus management should be able to guarantee the normal operation of the campus, the on-demand supply of various services, and the integrity and full utilization of campus assets. On the contrary, management deficit is a key source of adverse effects on the interaction between stakeholders and campus resources. In the literature, smart campus management mainly focuses on the following aspects:

- Smart security management: This refers to campus security-related supervision and control with novel technologies such as IoT, cloud computing and big data, process and feedback various information in real time, and build a comprehensive management and control platform with the mobile Internet as the carrier, so as to improve campus safety through smart services such as safety inspection, disasters emergency response and school clinic management. It is to prevent and respond to disasters and criminal acts in or around campuses, to conduct comprehensive, real-time, efficient and accurate security monitoring, and to locate victims and respond faster to the related incidents. In the context of COVID-19, effective campus public health measures, such as automatic body temperature measurement, door lock automation and smart hand wash equipment, are additionally implemented to reduce the negative impact of the epidemic and protect the personnel's health and safety. Reference [123] proposed a mobile application that will let users send alerts along with their real-time location directly from their mobile phones. Reference [136] employed distributed fiber optic acoustic sensing technology (DAS) as the monitoring method to enhance detection accuracy of campus security incidents.
- Smart asset management: Asset management refers to the procurement, registration, maintenance, update and other activities of various materials and equipment, which is a dispensable part of campus operation. Smart asset management should be context-aware and adaptive to the actual situations, with the aims of satisfying the needs of stakeholders. With the integration of IoT, cloud computing and big data, campus assets can be more reasonably purchased, allocated, and used to ensure supply, save costs and improve efficiency. In the literature, [67] proposed a framework based on RFID and cloud computing technologies to overcome the managerial bodies concerned about valuable assets in the campus.
- Smart time and space management: The infusion of the environment, resources and applications of cutting-edge technologies in the smart campus breaks the limitations in traditional campuses, and the time and space dimensions have been greatly expanded. To manage the time and space resources in a smart way refers to appropriately scheduling campus activities and allocating space resources (e.g. classrooms, laboratories, offices, meeting rooms, and accommodation) based on IoT and AI technologies to optimize the learning/working efficiency of stakeholders. The room occupancy rates can be measured in real time through sensor instrumentation, and the attendance rates can be estimated by AI agents, so that optimal allocation can be performed. Smart time and space management is highly related to the division and synchronization of the various departments across campus, and in the meantime, it is the key to ensure the effective and efficient campus operation and minimize wastage. For example, [133] proposed a solution based on IoT and AI to address classroom under-utilization in a real university campus. Reference [83] developed new ways to distinguish and filter out WiFi-connected users outside of the lecture room, so as to estimate attendance.
- Smart learning management: A web-based platform that allows users to create, manage, deliver and track online learning, and provide services that facilitates communications and interactions between teachers and students. Learning management system (LMS) plays an important role in the success of e-learning, where on the one hand, students can find various resources related to courses or training and communicate with teachers and peers, and on the other hand, teachers can create and manage teaching content, follow up on students' learning progress, assess students' assignments, and provide feedbacks. Reference [72] introduced several examples of technical infrastructure deployed for implementing LMS, including one-to-one video after class conversations, fingerprint sensor simplifying the attendance process, and cloud-based data storage and sharing.

IV. A HUMAN-CENTERED CASE STUDY

A Young Talent Smart City Forum [138] was established in Hong Kong, which is used as a data source for human-centered studies in this paper. This forum is a unique platform aiming to collect innovative smart city ideas from school students. These ideas are submitted to the forum in the form of articles and forum proceedings are regularly updated. The students involved in an article must have at least one schoolteacher as their supervisor. The articles are accepted following a review and revise process imitating the review process for standard publications. All submitted articles are reviewed by the reviewer board of domain experts, and then the articles of interest are sent back to the authors for revision until the quality of article is qualified for the forum

TABLE 5. Number and references of articles in each application domain.

Technology Domains	No of Articles	References
Smart learning	44 (40.37%)	[23, 26-28, 33, 37, 38, 41, 44, 49, 50, 53, 56, 59, 60, 63-65, 69-73, 79, 81, 83, 90, 94, 97, 103, 105, 106, 108, 113, 115, 116, 120, 121, 124, 126, 127]
Smart living	42 (38.53%)	[24, 25, 35, 37, 42, 45-48, 51, 52, 54, 55, 57, 58, 75, 77, 78, 80, 81, 84, 86-89, 95, 101, 102, 111, 114, 117-120, 122, 123, 128, 131]
Smart environment	18 (16.51%)	[29, 36, 42, 43, 66, 73, 74, 82, 91, 96, 104, 112, 125, 130]
Smart management	30 (27.52%)	[22, 25, 26, 30, 34-36, 39, 61, 62, 67, 68, 72, 75, 76, 81, 83-85, 92, 93, 98-100, 107, 109-112, 126, 129, 137]

establishment. Based on above characteristics, this forum creates research opportunities for young talents in schools. In the meantime, students and teachers, as the main stakeholders of smart campus, are directly engaged, which allows the new ideas to be inspired in a human-centered manner. In this section, articles that are relevant to smart campus are selected from the forum proceedings as human-centered research data, from which to investigate the adherence of existing smart campus research on stakeholders' needs and interests.

A. DATASET DESCRIPTION

The collected human-centered dataset consists of 25 articles from 10 secondary schools in Hong Kong. More than 120 students and teachers are involved as authors and/or supervisors of the articles. These articles present innovative ideas by integrating cutting-edge technologies in various smart campus applications. The technologies include IoT, cloud computing, VR, Mobile devices, AI, 5G, etc. Some articles incorporate more than one technologies to achieve their objectives. The involved topics cover a wide range of smart campus applications, including teaching and learning, examination, canteen, waste management, pollution issues, toilet, health, parking, security. One finding from this review is that the existing literatures mostly focus on smart campus in university and other tertiary education institutes, but very rarely on campus in primary and secondary education levels. This human-centered data is collected from secondary schools, which can help fill the above gap by reflecting the adherence of existing research on the needs and interests of secondary school teachers and students.

B. TECHNOLOGY AND APPLICATION STATISTICS

The technologies and applications in the selected articles are statistically analyzed. We again categorized the technologies into 5 domains: data computing and storage technologies, IoT technologies, intelligent technologies, immersive technologies, and mobile technologies. The smart applications are categorized into 4 domains: smart learning, smart living, smart environment, and smart management. Some articles involve more than one technology and application domains. The number of articles related to each technology and application domain is summarized in Table 6.

TABLE 6. Number of human-centered study articles related to each technology and applications domain.

Technology Domains	No of Articles	Application Domains	No of Articles
Data computing and storage technologies	5	Smart learning	15
IoT technologies	19	Smart living	10
Intelligent technologies	14	Smart environment	11
Immersive technologies	3	Smart management	7
Mobile technologies	7		

The following conclusions can be made from Table 6:

- In terms of enabling technologies, teachers and students, as stakeholders, put the most weights on IoT and AI as their interests to realize campus smartness. In comparison, technologies such as cloud, AR, VR, and mobile APPs, are less attractive.
- In terms of smart campus applications, teachers and students raise learning as the domain mostly needed for smart revolution. Living and environment are also important domains with smart needing. By contrast, they show much less interests in smart management domain.

C. COMPARATIVE ANALYSIS

To compare results of the literature review and the human-centered case study, research weight on each technology and application domain is calculated using the data in Table 4 -VI:

$$w_i = \frac{n_i}{\sum_{i=1}^{D} n_i} \quad (1)$$

where w_i is the research weight on domain i, n_i is the number of articles categorized in domain i, and D is the total number of domains.

The research weights derived from the systematic review and the human-centered case study are shown in Figure 2.

In terms of technology domains, it is shown that the IoT and intelligent technology domains are outstanding from

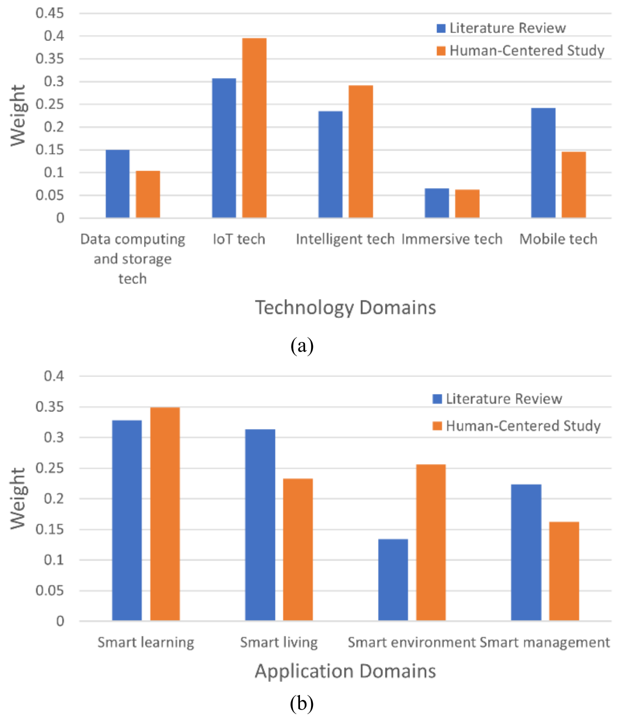

FIGURE 2. Research weights from literature review and human-centered case study on each (a) technology domain and (b) application domain.

both the literature and the human-centered perspectives, confirming their dominant roles in enabling campus smartness. Weights on data computing and storage technologies, such as cloud, fog, and edge computing techniques, are lower, showing the lighter needs to upgrade these technologies. A reason of this phenomenon could be that cloud technology is rather mature and sufficient to support the current needs in the context of smart campus. Mobile technology shows weights that are largely deviated between literature review and human-centered case study. Although there are large number of new mobile functions, APPs, and devices in the field of smart campus, users have not shown sufficient needs and interests on using them. This phenomenon indicates the existing mobile technologies can to a large extent satisfy the general campus needs of teachers and students, and the influences of new mobile technologies on their campus lives are insignificant. Immersive technology domain, such as AR and VR, are at their incipient stage to the smart campus stakeholders and industry, and their applications are rather limited, which results in their lowest weights in both approaches.

In terms of applications, smart learning is the only application domain showing consistently high weights in both literature review and human-centered case study, highlighting the prioritized needs and efforts in enhancing campus education quality. However, the statistical patterns in other application domains show significant deviation in the two approaches. The deviated weights on smart living and smart management could be caused by the inherent differences between universities and secondary schools. As compared to secondary schools, universities involve more comprehensive and complicated physical facilities, resulting in the higher weights on living and management presented in literature review. The weight on smart environment is high in human-centered case study, but much lower in literature review. This phenomenon indicates that students and teachers are highly aware of the environment deterioration, but the current research momentum shown in existing literature is still lacking behind.

D. DISCUSSION AND RECOMMENDATIONS

Based on the systematic review and human-centered study on smart campus technologies and applications, the following recommendations can be drawn for future research and development references.

For technology domains that are in well progress, IoT and intelligent technologies continue their dominance to support the future needs in smart campus while data computing and storage technologies maintain innovation and steady development to serve as the infrastructural resource for the data-rich environment. One critical challenge in these domains is the privacy issue raised by pervasive sensing environment and the sensitive human-related data. To protect the personal privacy and maintain data security, on the one hand, there is an imperative need to develop privacy-aware technologies and enhance cybersecurity; on the other hand, related regulations and laws [139] need to be on track to standardize the use of these technologies. The deviated weights shown in mobile technology domain indicates that there are still rooms for improvements whereas current stakeholders are not showing enough interests to further innovate these technologies. The challenge here is to let the stakeholders see the practical necessity of using these technologies on campus. Immersive technology domain is entering vigorous development stage to drive a range of future smart campus applications. Although it currently has the lowest weight in the systematic review, the increasing use of AR/VR technologies in schools could transform the way of education in the future. A survey shows that 90% of educators agree that immersive learning is an effective way of providing differentiated and personalized learning experiences for students [140]. Following this trend, the adaptation of related policy formulation would be a challenge to facilitate the practical implementation of immersive learning. For example, in order to provide immersive experience, AR/VR devices may require vast amounts of private and location information. In these situations, regulations and policies related to data security and environmental security become key factors to facilitate the applications [141].

In the smart application domains, smart learning is given the highest priority, the technical challenges are progressively being solved and the smart learning systems start to be able to provide more refined personalized experience. In this situation, educators' capability to handle these new forms of learning and pedagogy would be a potential issue. It is necessary to make more efforts on teacher training, improve their relevant abilities, and find approaches for teachers to adapt quickly to the smart environment while minimizing the unfavored social impacts such as unemployment. Smart living and smart management domains in schools are not as "smart" as in universities. This shows the infancy of smartness in primary and secondary schools, which calls for the future needs of adapting smart campus facilities to suit the needs of these schools. Climate change has shown huge impacts for years, disrupting the world economy and affecting people's lives. Sustainable Development Goals 13 urges to take action to combat climate change and its impacts [142]. As smart campus takes a significant role in smart city with considerable energy consumption, future research would need the expert collaboration across different disciplines to reduce campus carbon emission, which would also see great contributions in enhancing smart city sustainability.

Moreover, the human-centered integration of smart technologies and applications would be essential for healthy smart campus development. Technology innovation supports new applications, and applications are designed to suit the needs of stakeholders, this internal connection should be taken into account in future research to raise the practical value of technological advancement.

V. CONCLUSION

Smart campus, as the high-end form of education systems, has attracted undergoing intense research in recent years. Considering the inadequacy and outdating of existing reviews on smart campus and the need of human-centered visions on current smart campus research, this paper provides a systematic review on smart campus technologies and applications, and then performs a human-centered case study to evaluate the consistency and adherence of current research trend to the stakeholders needs and interests. The reviewed enabling technologies in smart campus are categorized into 5 domains that are data computing and storage technologies, IoT technologies, intelligent technologies, immersive technologies, and mobile technologies, while the applications in smart campus are categorized into 4 domains that are smart learning, smart living, smart environment, and smart management. Although the systematic review and human-centered case study have shown consistent research trends on most of the domains, the research weights on mobile technologies and smart environment applications are significantly deviated. These phenomena indicate firstly that the existing mobile technology applications to a large extent satisfy the needs of teachers and students, and secondly the lack of research momentum shown in existing literature to be in line with the environmental awareness among stakeholders.

Based on these findings, the researcher would give more consideration to stakeholders' needs to improve the practical values of their technical innovations. At the current stage, there shows needs in the improvement of personal privacy and data security, as this would escort the realization and progress of novel technologies. With the escalated legal and regulatory framework, new technologies would get more trust and support, which facilitates and smoothens the smartness transformation process of existing campuses.

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