目前智慧校園文獻評論分兩類:

1. 技術 : 這些研究著重在資訊與通訊技術（ICT）、人工智慧（AI）、物聯網（IoT）、虛擬實境（VR）與擴增實境（AR）等前沿科技的應用。例如：
物聯網與雲端運算在智慧校園的應用（[4], [5]）
5G 背景下的智慧校園技術（[6]）
AR 在教育中的應用（[7], [8]）
推薦系統與智慧協同學習平台（[9], [10]）

2. 教育理念導向 :智慧教室、智慧學習環境、智慧遠距教學、混合式學習、泛在學習等，探討智慧學習如何與智慧城市的發展互動（[1]）

IET Smart Cities

Research Article

Smart campus: definition, framework, technologies, and services

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容易著眼於創新的教育理念，卻缺乏兩者之間的深度融合觀點，忽略了智慧校園對其他智慧城市領域的潛在影響

Abstract: As the high-end form of a smart education system, the smart campus has received increasing research attention over the world. Owing to the multidisciplinary nature of the smart campus, the existing research is mostly one-ended on either the state-or-the-art technologies or the innovative education concepts but lacks a deep fusion view on them and omits the smart campus implication on other smart city domains. This study highlights the interdisciplinary view on smart campus. Based on an integral review on the supporting technologies and existing smart campus propositions, a human-centred learning-oriented smart campus is envisaged, defined and framed up, primarily aiming at meeting stakeholders' interests and elevating educational performance in pace of the technology development, as well as discussing the interdisciplinary factors that either promote or constrain the smart campus revolution. The expected contribution throughout this study is to provide a benchmark reference of a smart campus for international educational providers, government, and technological companies providing such services.

以人為本，以學習為導向的智慧校園

本研究的預期貢獻是，為國際教育機構、政府單位以及提供智慧校園相關服務的科技公司，提供一個智慧校園的基準參考模型

1 Introduction 智慧校園使市民轉化為智慧型勞動力

Along with technology development, people's lifestyles and working habits have undergone a tremendous transformation as well as the ways of learning. The gradual change of the learning environment and the increasing demand for personalised and adaptive learning have pushed the reform and development in the field of education. As the high-end form of a smart education system, smart campus came into reality and has received more and more attention over the world. Smart campus creates a smart learning environment to the citizens in transforming them into smart workforce, making it an integral part of the smart city framework [1, 2]. The development and popularity of smart campus also support knowledge economy. The global smart education market is forecast to grow at a compound annual growth rate of 15.96% during the period between 2018 and 2022 [3]. In such a fast-changing domain, there is a pressing need to perform active research and obtain a clear understanding of the smart campus and its attributes.

Considering the multi-disciplinary nature of smart campus research, there have been diversified literature reviews related to this area. On the one hand, the recent emergence and advance in information and communication technologies (ICT), artificial intelligence (AI), smart devices, and variable reality technologies (e.g. augmented reality (AR), virtual reality etc.) create unprecedented and prospective opportunities for educational institutions to pursue higher education standards and achievements. Some review articles in the technology domain emphasise the state-of-the-art technologies and seek their potential applications in the smart campus. To name a few, the applications of internet of things (IoT) and cloud computing technologies in smart campus are reviewed in [4, 5], respectively. The smart campus technologies under the background of 5G network are reviewed in [6]. The potential applications of AR technology in the education domain are reviewed in [7, 8]. The current progress and future research directions of the recommender systems in the smart campus are summarised in [9]. The key technologies involved in the adaptive and intelligent systems for computer-aided collaborative learning are reviewed in [10]. The propositions in these reviews are technology-driven whereas the primary entity of education, students, and teachers, are not necessarily centric in such technological smart campus. Fig. 1 shows the typical structure of a smart campus with key technologies supporting the operations.

On the other hand, the development in technology calls for a revolution from the traditional education strategy with predominantly face-to-face teaching/learning into a smarter way that promotes new education paradigms [11]. A series of terminologies to conceptually describe the innovative education have been raised, such as smart classroom, smart learning environment, smart e-learning, blended learning, ubiquitous learning etc. There is literature defining and envisaging the smart campus with respect to the smart education revolution. For instance, a vision for the development of the intelligent campus is provided in [2]. The design and development of a smart learning environment are explored in [11]. The blended learning concept and its applications in the smart campus are covered in [12, 13]. How smart learning interacts with the development of smart cities is investigated in [1]. This research focuses on the innovative educational concepts, but lack justifications on how emerging technologies could give support. 教育理念的缺乏技術如何導入等具體說明

As above, due to the multi-disciplinary nature of the smart campus, the existing reviews on the smart campus are mostly one-ended on either the state-or-the-art technologies or the innovative educational concepts. However, the success of the smart campus requires a deep fusion of technology and education. Moreover, as an essential scope in the smart city framework, the development of the smart campus must interplay with other smart city domains, such as economy, society, and legislation/regulation. The analysis of such interdisciplinary implications of the smart campus is limited in the literature. This study highlights the interdisciplinary view of smart campus. Based on an integral review of the supporting technologies and existing smart campus propositions, we envision, define and frame up a human-centred learning-oriented smart campus (HLSC) that primarily aims at elevating students' learning experience and institutions' education quality in the pace of the technological development. Besides, the interdisciplinary factors that either promote or constrain the smart campus revolution are also discussed. The expected outcome of this work is to provide a benchmark reference of the smart campus for international education providers, government, and technological companies providing such services.

本研究強調跨領域觀點，並基於現有技術與智慧校園架構進行整合性回顧，提出一個以人為本、以學習為導向的智慧校園（HLSC）模型，旨在提升學習體驗與教育品質，並深入討論推動或限制智慧校園革命的跨領域因素。

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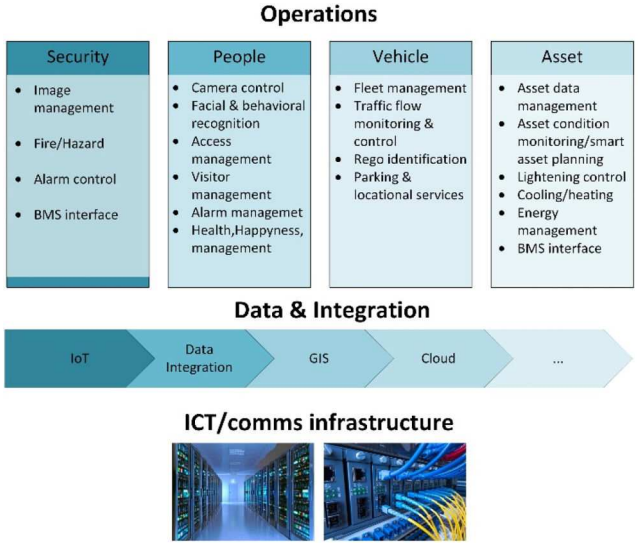

Fig. 1 *Typical technology-driven smart campus structure*

The rest of the paper is organised as follows. The supporting technologies in the smart campus are reviewed in Section 2; the vision on human-centred learning-oriented smart campus is provided in Section 3; the potential smart services are explored in Section 4; the interdisciplinary implications of the smart campus are discussed in Section 5; and Section 6 concludes the paper.

2 Smart campus technologies

The development of the smart campus would not be possible without the innovation in technology. In the literature, the main technologies supporting the smart campus revolution include cloud computing, IoT, AR, and AI. The principle of those technologies and their benefits to smart campus are reviewed in this section.

2.1 Cloud computing

Cloud computing is a distributed computation model that enables convenient, on-demand network access to a shared pool of configurable computing resources (such as networks, storage, and applications) that can be rapidly scaled, provided, and released upon user's request with a minimum interaction with the supplier [5, 14]. The popularisation of the cloud-based platform has been identified as a key trend in the technology-enhanced smart learning domain. Compared to the conventional computational infrastructure where both hardware and software are owned and kept by organisations at their premises, cloud computing enables learning activities in an unstructured environment. It allows the learners to gain fast access to online learning resources and services at anytime and anywhere, with infinite scalability, improved convenience, and lower cost [15]. By using a cloud-based learning platform in the smart campus, virtual learning materials could be created and seamlessly shared, which expands time and space dimension of teaching and learning and facilitates collaborative learning activities among instructors and students [16].

2.2 Internet-of-things (IoT)

Embedded with electronics, smart sensing devices, internet, and advanced communication technologies, IoT extends the internet connectivity onto physical devices and everyday objects. It is envisaged that the future computing paradigm will go beyond traditional mobile mode based on smart phones and portables, and evolve into an environment surrounded by intelligent and networked objects [17].

The prospective benefits of deploying IoT technology in smart campus mainly lie in three aspects. First, IoT provides the information platform for instructors to track students' learning progress and take informed actions. Second, IoT automates the smart campus operation and smooth's the teaching/learning process. Such convenience means that the stakeholders can put more focus on the learning activities rather than the routine management/administration tasks. Third, emotion or psychological recognition based on the IoT technology, if adopted in a smart campus, can track students' cognitivity in their learning activities and correspondingly redirect students' attention based on their mental conditions.

2.3 Augmented reality (AR)

AR is an emerging form of experience in which the real world is augmented by the virtual content from a computer, which allows seamless overlay and mix between computer-generated content and our real-world perceptions [7, 18]. Serving as a next-generation interface, AR provides a different way of interaction and gain experience to reinforce the teaching/learning environment. In a smart campus with AR technology, the students tend to gain better knowledge and understanding of what is going on around them, which elevates their learning experiences. As reviewed in the literature, AR technology could bring the following benefits to education:

- Motivate students to explore class materials from different angles [19].
- Facilitate teaching the subjects where students could not feasibly gain real-world first-hand experience [20].
- Enhance collaborative learning among students and instructors [21].
- Enhance students' cognition and concentration on their learning tasks [22].
- Enhance student creativity and imagination [23].
- Help students take control of their learning at their own pace and on their own path [18].
- Create an authentic learning environment suitable for various learning styles [18].

2.4 Artificial intelligence (AI)

AI is a computation science of making machines or systems to learn from experience, adapt to new inputs, and perform human-like tasks, which would be a suitable technique to solve problems where solution can be hardly generated through analytical analysis. Based on the perceived environment, the applied AI algorithm should be able to maximise the chance of the agent to successfully achieve its goal through interaction with the environment or extracting critical information from statistical data. AI has recently gained significant success in many real-world applications, such as pattern recognition [24], forecasting [25], translation [26], control [27], games [28] etc.

In a smart campus, as cloud computing and IoT has provided the platform for intelligent solutions, AI is then the technique that adds intelligence attributes to the devices and systems. To nominate a few, AI brings the following benefits to smart campus:

- Automatically customise the learning content [29].
- Virtually tutor students on a one-on-one basis [30].
- Context awareness of instructors' and students' psychological conditions [31].
- Predict future conditions [2].

3 Related works

The world is currently experiencing a smart revolution in various sectors in light of pervasive technologies. According to some dictionaries, the term 'smart' is broadly considered as very good at learning things, showing intelligent judgment, and fast reaction in handling problems. When a system can autonomously provide services in line with the dynamic user needs, it could be considered as 'smart' [2]. In today's education industry, the smart campus has been widely recognised as the smart form of the educational system. This section aims to provide a brief review of the worldwide efforts on smart campus development. The inadequacies in existing smart campus proposals are also analysed.

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In recent years, many researchers have attempted to characterise the concept of smart campus and provided a guideline on its development. An intelligent campus (iCampus) framework is proposed in [32], which characterises a smart campus into six intelligence pillars: iLearning, iGovernance, iGreen, iHealth, iSocial, and iManagement. Based on this framework, a review is further provided in [33] that summarises the characteristics, supporting technologies, and applications built on the smart campus. Although the six pillars are all important viewpoints to evaluate a community, most of them (e.g. iGovernance, iGreen, iHealth, iSocial, and iManagement) are not unique to the campus since other communities under smart city scope might have similar concerns. Focusing on tertiary education, a smart university taxonomy is identified in [34] where its main features, components, technologies, and systems are provided. Moreover, the smooth transition from a traditional to a smart campus is concerned in [35], which designs a methodology for the conscious and coherent choices of strategies to develop a smart campus.

There are some other research studies investigating how to integrate emerging technologies to realise campus smartness. IoT and cloud computing are integrated to provide web-based learning platform for smart campus as investigated in [36]. A technological smart campus architecture is proposed in [37] to provide both basic and value-added smart services. The mixed reality technologies are deployed in [38, 39] to reflect the synergy of virtual environment and real campus in educational intelligence. In [40], AI is deployed in a smart campus under a three-level machine learning framework where the embedded intelligent agents can learn from the smart campus data to perform the best actions based on the perceived context. These smart campus approaches are technology-driven which mostly lack identification on the requirements of the people (e.g. students and teachers) involved in various educational situations.

Practically, many educational institutions over the world have been augmented with emerging technologies to embrace the idea of a smart campus. For instance, an increasing number of educational institutions in the US and UK have implemented cloud computing-based smart campuses to provide more efficient and convenient educational services [16]. A smart learning system based on advanced ICT is established in Korea to promote ubiquitous learning and social learning [41]. A smart campus project is carried out at Lancaster University [42], mainly focusing on energy management and environmental sustainability. In the University of Malaga [43], advanced communication technologies are adopted in the IoT infrastructure to build a smart university campus that is able to support efficient environment management as well as innovative education and research activities. The University of New South Wales in Australia has also implemented a pilot IoT project for four smart campus use cases: classroom attendance, student study space usage, parking lot occupancy, and bus-stop waiting management [44]. It is noticeable that most educational institutions develop their smart campuses as an expanded form of smart buildings, targeting similar areas such as energy efficiency, waste management, and environment sustainability. However, seldom they emphasise the elevation of teaching/learning experiences through smart transformation.

4 Human-centred learning-oriented smart campus (HLSC)

As smart campus acts as a key field of smart city, they are often under a similar socio-economic, environmental, and geographical context, meaning they share similar infrastructures, communication channels, services, transport networks, and even challenges and needs. As reviewed in Section 3, the smart implementation of a campus can partially learn experience from other smart city domains, which ends up with some smart applications that can be universally required, such as energy management, waste management, health management, sustainability etc. However, as a campus is a place to provide education services with students and instructors as the mainstay, it would be more sensible to bring the students' and instructors' voices into the smart campus design and focus on the growth and development of students and the enhancement of the education quality.

Accordingly, the vision of the education transition should primarily target on reinforcing the students' learning experience based on their needs and elevating the educational performance of institutions. Therefore, in this section, we envisage the HLSC, with identified definition, framework as well as main features.

4.1 Design criteria

Based on the review of existing works, we summarise the following criteria that should be reflected when deploying the emerging technologies on the smart campus.

4.1.1 Human-centred: The primary role of a smart campus is a smart learning environment that provides smart education services to cultivate innovative talents. In a smart learning environment, although technology must play an important role, the deployment of smart devices and technologies should not be the sole focus. As suggested in [45], a smart learning environment is a physical environment that is enriched with advanced devices and technologies to promote higher learning performance. It is found that the learner is always raised as the heart in smart learning environment design [46]. This learner-centric concept has been recognised in many research studies on smart learning. One example is the learner-centric smart learning environment built in [47] that is based on semantic web and ubiquitous computing. As reflected by this learner-centric concept, we should re-examine the role of technology in the smart campus revolution, and make sure the provision of intelligent services is centred on human factors. The smart campus is not only a technology system but also a new form of an education system based on new technologies. From the systematic point of view, the smartness of future campus needs to be shifted from technology-led to learner-centric and further into human-centred, highlighting the educational needs of all the people involved in the education system.

Human-centred design is defined as an approach to system design and development that aims to make interactive systems more useful by focusing on the use of the system and the needs of the users within a collaborative environment [48]. This approach emphasises the human experience, satisfaction, and performance, which enhances the effectiveness and efficiency of the system on human-related tasks while counteracts possible adverse effects on human health, safety, and performance. From an integral point of view, a smart campus is an educational institution involving various stakeholders. The main stakeholders of the smart campus typically include students, instructors, parents, and management teams, which all take different roles. Based on their responsibilities and obligations, the stakeholders' expectations on campus smartness will also be deviated [2]. The human-centred criterion means that the smart campus development should not only be centric on students but also need to consider the interests of other stakeholders and try to satisfy their needs in a coordinated way.

4.1.2 Learning-oriented: Smart campus can be seen as a simplified version of the smart city that covers multiple areas, such as the six intelligence pillars proposed in [32]. According to the survey results provided in [49], the education institutions prefer to invest the most on smart learning solutions rather than other aspects such as health, social, energy, management or governance. This need for the education institutions encourages the technology deployment and education innovation in the smart campus should be learning-oriented.

It is evidenced that the integration of emerging technologies in a smart campus can provide great opportunities for the students to learn in a substantially different way rather than in traditional educational institutions. For example, the network-based technologies allow the students to learn autonomously at home and/or via a virtual platform, which offers interaction with both the real world and digital world with sufficient learning support. The popularity of mobile devices offers great convenience to gain information anytime and anywhere, which supports ubiquitous learning. Some research reports that some activities that were

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一種滲透各項賦能科技（enabling technologies）的教育環境，透過提供智慧服務，以提升教育表現並滿足利害關係人的需求，且在智慧城市脈絡中，能與其他跨領域構面廣泛互動。

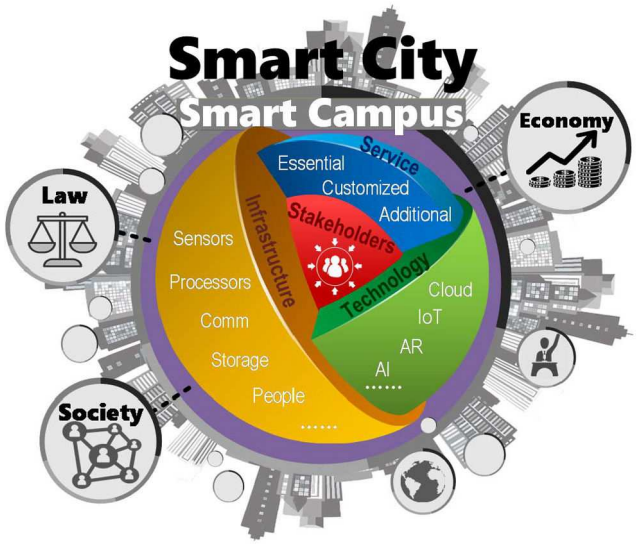

Fig. 2 *Proposed framework for HLSC*

traditionally deemed as recreation, such as playing games, social networking, and movie watching, are nowadays also educational methods to guide students' development [50].

Moreover, along with the rapid technological development, innovative pedagogical approaches, namely smart pedagogy, have been developed recently to enhance the learning experience for students. For instance, personalised learning emphasises tailoring the learning processes according to students' learning needs that include background, interests, preferences, requirements etc. [51]. Compared to a unified learning goal and process for each student in a traditional classroom, personalised learning can meet the interests of each individual student, enhance their information and technology literacy, and help inspire their creativity. Moreover, problem-based learning (PBL), as a type of smart pedagogies, allows students to learn the subject through identifying problems and solving problems, which projects student-centric learning and promotes lifelong learning [52]. The PBL approach helps students deeply understand the subject and develop suitable skills for self-directed learning. Above features means PBL is an appropriate pedagogical approach for tackling complicated problems that require multidisciplinary approach. The prospective smart pedagogies to be adopted in universities are summarised in [34]. In [46], a four-tier architecture is proposed to model smart pedagogies, where smart pedagogies are classified into four categories: mass-based generative learning, individual-based personalised learning, group-based collaborative learning, and class-based differential instruction.

Based on the above review, it is essential that the smart campus leverages advanced technology to create a learning-oriented environment that aims to elevate the learning experience of students and the teaching quality of educational institutions.

4.1.3 Interdisciplinarity: A smart campus is not an isolated system, but an essential part of a smart city. The smart city development plan is usually multi-dimensional, covering the multiple disciplines that support citizens' life. The widely accepted taxonomy of smart city dimensions is provided in [53] as a smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. Since the development and quality of smart people in a city highly depends on the education they received, smart campus, as an institution to provide educational services, serves as the foundation of smart people dimension.

Nevertheless, it would be noticed that there exists high interoperability between other dimensions and smart campus. The development of smart campus must more or less interact with and has an effect on other domains in smart cities. For instance, by supplying innovative talents to the city, smart campus gives birth to an innovative environment to facilitate the self-development of the smart city, which will contribute to the development of other smart city dimensions. The smart campus transition may also be slowed down by the pressure from other smart city domains, such as the regulatory requirements on data security and privacy. Therefore, a smart campus should be constructed with consideration on these interdisciplinary implications and developed at a compatible pace with other smart city dimensions.

4.2 Definition establishment

Although the concept of the smart campus was raised decades ago, there has not been a universal and clear definition of it. The development of a smart campus may not be concentrated without a common understanding of what exactly a smart campus is. The existing proposals on smart campus are mainly technology-led and omit the interdisciplinary factors. Bearing the design criteria in mind, we envisage the future campus as the HLSC, which is defined as

> An educational environment that is penetrated with enabling technologies for smart services to enhance educational performance while meeting stakeholders' interests, with broad interactions with other interdisciplinary domains in the smart city context.

4.3 Framework design

The framework of the HLSC is shown in Fig. 2 where smart campus acts as an important part in the context of a smart city to provide education service to the young generation. It is also connected to other domains within a smart city, such as economy, society, legislation, environment, politics etc., in a way that the interdisciplinary factors may either constrain or promote the development of a smart campus. This reflects the interdisciplinary nature of the smart campus. The main body of a smart campus consists of three layers surrounding the stakeholders: infrastructure layer, technology layer, and service layer. The outmost layer serves as the underlying infrastructure of a smart campus while the innermost layer includes the elements that can be directly applied and take effect on the stakeholders. The framework takes the stakeholders at the centre, indicating that the activities in all the smart campus layers, although some of them are not directly connected to the stakeholders, should be centric on the stakeholders' interests. The stakeholder needs and the three layers of smart campus are further described as follows:

4.3.1 Smart campus stakeholders: The planning, construction, maintenance, and use of smart campuses involve the participation and commitment of multiple stakeholders including students, academic staff, non-academic staff, parents, and management team. Therefore, the feedback from these stakeholders is of great significance to the development of the HLSC. Generally, due to the different roles of the stakeholders, their needs and contribution on campus smartness deviate, so fully understanding these stakeholders is essential for maximising the value of the HLSC. The campus smartness needs and contributions of each type of stakeholder are summarised in Table 1.

4.3.2 Infrastructure layer: A good supporting infrastructure is important in smart campus development since it is portrayed as the foundation for the other layers. It should not only include the ICT elements that are supportive of the new technologies and in agreement with the smart concept but also involves people as part of the infrastructure. The essential ICT elements include but not limited to information sensing devices, information processing equipment, storage, and wired and wireless communication network. The people here mainly refer to the staff that design, construct, and maintain the infrastructure and system. As the smart campus is deeply penetrated with new technologies, only the people with technological qualifications are competent for handling such infrastructure reinforcement. Without them, the campus systems would not be able to work effectively and efficiently as they should be.

The required infrastructure of the smart campus could be achieved through either completely new construction or an upgrade from the existing infrastructure. On the one hand, in new campus

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Table 1 Needs and contributions of different stakeholders in smart campus

Stakeholders	Needs	Contributions
students	• convenient campus life	• feedback the user experience
	• interesting, personalised, informative, efficient, and highly engaged education experiences	• provide suggestions for the smart campus improvement
	• obtain guidance to get into a better educational institution or workplace for their next stage	• develop the technology and concepts of smart campus into more fields in their future work
academic staff	• updated knowledge of student learning progress and the latest development in the subject matter	• feedback the user experience
	• optimise the students' learning performance	• improve the shortcomings of smart campus
		• act as a coordinator rather than instructor
		• apply smart pedagogies
		• improve teaching quality
non-academic staff	• adopt advanced intelligent methods for daily campus maintenance and support	• participate in the construction and subsequent maintenance of the smart campus
	• an efficient way to handle the heavy administrative burden	• provide technical support for users
		• analyse user needs
		• feedback the user experience
		• optimise the operation of the smart campus
parents	• close track on child's learning progress	• handle students' extra-curricular activities
	• notice of the child's abnormal learning behaviour	• provide suggestion to help academic staff understand the status of students
	• receive an early warning on potential risky events	• feedback the user experience
management team	• comprehensive campus monitoring	• coordinate various school departments
	• easier school management	• coordinate school and external communication
	• timely performance data of students and staff	• manage funds
	• timely ranking data compared with other competitive institutions	• make decisions on smart campus construction

construction, the campus smartness can be comprehensively considered since the start of the new campus master planning and design so as to reap the full benefits of smart solutions. On the other hand, for an existing campus, it is usually impossible to start everything from the sketch but can only construct the infrastructure upon existing systems. There would not be a fast track to move from a traditional campus to a smart campus, and the infrastructure upgrade must consider the balance between the benefits of achieving a certain level of smartness and the investment on this project.

4.3.3 Technology layer: Technology represents the mediate layer in the smart campus framework as shown in Fig. 2. Although it is not connected to learning directly, this technology layer relies on the infrastructure to create the environment for smart learning to happen, and also functions as an educational catalyst that enables the transformation from traditional learning to smart learning, which overcomes traditional education obstacles, such as the time and space constraints and the monotonous education mode that could hinder the development of individual talent and potential.

The emerging technologies that are supportive of the development of smart campuses have been reviewed in Section 2. However, in practice, the actual deployment of new technologies is concerned with the specific campus environment and practical education needs, meaning their penetration levels can be different across buildings and campuses. For example, due to the financial budget limit, it would not be possible to install the smart sensing devices everywhere to realise global observability, which requires optimal planning of device locations depending on the services demanded by stakeholders, the building construction plan, the campus geographic information, the security and privacy requirements etc.

4.3.4 Service layer: The service layer consists of the smart campus applications that can be directly applied to the stakeholders. In the HLSC, these provided services should be able to meet the various stakeholders' needs (i.e. human-centred criterion), with the objective to enhance education performance (i.e. learning-oriented criterion). The human-centred concept of smart campus requires the service provider to understand and suit the intelligence needs of different stakeholders. The knowledge of stakeholder's needs could be gained from an anonymous survey on each type of stakeholder to define the user cases which will form a standard database to guide HLSC development. To truly reflect the deviated user case information, the survey should be designed multi-dimensionally to differentiate the education levels (e.g. primary, secondary, and tertiary education institutions) and geographical information (e.g. countries, states, cities, and campus wise), and updated on a time regular basis (e.g. every year). In the meantime, regular reviews on existing smart services are also necessary to keep track of stakeholders' needs.

Moreover, the sole aim of the HLSC is to enhance education performance. Keeping the stakeholders' needs in mind, the human-centred services must also be adjusted or tailored to be learning-oriented, i.e. directly or indirectly contribute to improving students' learning outcomes and/or stimulating students' learning talent and potential. This normally involves an analysis of the learning-oriented benefits and risks of each candidate service. In the literature, the smart campus services can be divided into three categories: essential services, personalised services, and additional services. The potential services in each category are explored in Section 5.

4.4 Main features of smart campus

Based on the framework in Fig. 2, the HLSC is expected to have the following features:

(1) *Context-aware*: Smart campus is often equipped with a pack of smart sensing devices that monitors a wide physical area, which provides the foundation for context awareness. Context is often defined as an aggregate of various aspects that describe the current status of smart campus, and context awareness mainly refers to the ability to observe and become aware of the environment condition and user behaviour within the campus and provide tailored services to satisfy individual needs [54]. Context awareness is mainly supported by IoT technology and is seen as a basic feature of smart campus to enable a series of personalised services [47].

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(2) *Data-driven*: The smart campus data are automatically collected in real-time from various sources including sensing devices, teaching/learning processes, performance assessment, extra-curricular activities etc. [2]. With the aid of cloud service and IoT, a large amount of data would be accumulated and reasonably shared with minimal intrusion to users' privacy. Data-driven is an important feature in achieving the smartness of a campus in the sense that the majority of the smart functions offered by the campus are based upon big data analytics. In a learning-oriented smart campus, the data-driven applications should primarily focus on extracting descriptive evidence from the data to support learning performance enhancement.

(3) *Forecasting*: The enormous educational data generated from the information system offers opportunities to learn from the historical observations and forecast future conditions. This forecasting feature not only refers to anticipating what will happen in the near future but also involves decision-making in response to future events at its earliest opportunity. The forecast ability of a smart campus can provide a more manageable learning environment and promote forward-looking ability.

(4) *Immersive*: The immersive feature of the smart campus allows a mixture of virtual and real world environments for learning, which provides the students a sense of 'being there' and thus enriches the learning experience [55, 56]. We actually live in the real world, but the knowledge that can be acquired from the real world is usually limited. It will be challenging for students to observe and understand some phenomena that exist but are rarely experienced in the real world. In these situations, students could seek assistance from a virtual environment to achieve a greater understanding. The immersive learning also improves the students' concentration and motivation in their learning activities.

(5) *Collaborative*: A shift from individual to collaborative learning is happening in the education domain, which transforms the teacher-centred instruction into learner-centred interaction. Collaborative learning can encourage knowledge sharing among students and between instructors and students. In a collaborative learning environment, new knowledge can be created by interacting between services and people, meaning the students can actively create knowledge based on experience rather than passively receiving knowledge from the teacher. The students could act as various roles including a teacher to instruct others, which would redefine the role of the teacher in the new education environment. Statistics have shown that collaborative learning brings several benefits to students, including a higher level of engagement, increased confidence, and improved learning outcome [57]. Supported by cloud-based technologies, online collaboration could be efficiently achieved within the education community, either on-campus or off-campus, through a web-based platform.

(6) *Ubiquitous*: Thanks to the universal deployment of wireless communication and mobile technologies, people can now learn everywhere, not only formal learning in physical classrooms but also informal learning in a virtual and mobile environment. Ubiquitous learning, also known as u-learning, is defined in [58] as a learning paradigm that takes place in a ubiquitous computing environment that enables learning the right thing at the right place and time in the right way. The smart campus is expected to expand time and space dimension of teaching/learning and provide a ubiquitous learning environment to students. In the new environment, learners can learn at any time, any place, anyway, and at any pace, which promotes autonomous adaptive learning for individual students with a seamless learning experience.

4.5 Acceptability and feasibility

Although the HLSC has shown to be beneficial to the education community, its acceptability and feasibility among educational institutions and populace needs to be discussed. Over the last decade, the construction of digital campuses has been implemented in many institutions over the world, which has laid the foundation for the realisation of smart campuses. However, some of the new technologies required for smart campuses are still immature at the current stage, which may hinder the practical development of smart campuses. We look forward to new technological breakthroughs in the near future.

In recent years, the new technologies deployed on the smart campus are also embedded with risks that have been questioned and disputed by the populace. For example, to implement an IoT environment, sensing devices have to widely install in classrooms to capture the facial expressions and movements of students to track the teaching/learning condition and progress in real time. The original intention is to help perform effective learning and improve teaching quality. However, a privacy concern is that it will infringe on the privacy of students and may even cause depression in students, and thereby deteriorate the learning experience and affect the learning performance. In fact, the monitoring system only feeds back the abstracted data, not the original video footage, and the collected information can be stored on the local server instead of the cloud for preventing leakage. Moreover, a series of technical measures to mitigate cybersecurity also need to be applied, which should to some extent relief the privacy concerns from users.

Another example is that people are reluctant to new technologies or pedagogies because they are sophisticated with the traditional system. This may decrease the acceptability of the new smart campus system. Historically, the acceptance of emerging things often requires an adaptation process. As long as the human-centred principle is adhered to, we can expect an increase in smart campus acceptability by educational institutions and the populace in the near future.

To seek mitigation for the concerns from the populace, good practice in the HLSC is to conduct a survey to hear populace voice first, and then further efforts can be made based on the survey results to adjust the system aiming to relieve populace concerns. In doing so, the human-centred criterion would be met.

5 HLSC services

In the HLSC, the provision of smart campus services should directly or indirectly influence student learning outcomes. The learning-oriented services in smart campus can be divided into three categories based on their importance, functionalities, and target users, which are essential services, personalised services, and additional services. The services that could potentially be provided in each category are elaborated in this section.

5.1 Essential services

Essential services refer to the fundamental smart functions provided by the campus, which is generally applied to every students and staff member. The prospective essential services are summarised as follows:

5.1.1 Physical environment service: The physical environment condition at a place will directly affect the comfort, cognition, and health of the persons involved. The physical environment service refers to the real-time calibration of key physical environmental factors including lighting, temperature, and humidity to create a comfortable and ecological environment using IoT technologies. This physical environment service not only ensures the building's internal learning and living comfort but also focuses on restricting carbon emissions and contributes to energy efficiency and environmental sustainability [59]. Moreover, the physical environment could be optimised in a context-aware manner in terms of the conditions of the persons at the place, so as to help elevate students' learning experience.

5.1.2 Security service: As a cyber–physical system, smart campus requires security services from both physical and cyber perspective. The physical security service typically refers to automatically analysing the video from surveillance cameras located in public areas within a campus (e.g. corridors, stairs, classroom, laboratory, parking area etc.), tracking moving objects in real-time and extracting the key information using AI techniques. Once potential security risks are speculated, an early warning should be alarmed which timely triggers the security control measures to be carried out by the security staff. By

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applying physical security service, security incidents could be prevented in advance and false alarm caused by human intervention is eliminated, which provides a safe and secure physical environment for teaching/learning [2].

Moreover, the smart campus is exposed to various cybersecurity issues that should be detected and prevented via smart cybersecurity services. A cyber-secure campus can provide a peace-of-mind cyber environment for the students and staff when they use the virtual teaching/learning facilities, This means they are free to use online materials based on their needs, without worrying about the disruption of services or leakage of sensitive data. The main cybersecurity concerns in a cloud-IoT-based smart campus are related to data insecurity. For example, the communication networks of smart campus are easy to be unsafe because the cyber system of the campus is usually open, so it is easy for intruders to get access to the campus data and perform attacks. A solution approach for the attack issues could be increasing the data redundancy and protection against denial-of-service attacks [60]. Moreover, since a large number of sensory devices and wireless communication technologies are widely deployed over the campus cyber system, there will be an increasing chance of sensitive data being leaked or destroyed during transmission. In this situation, sensitive data transmission in smart campuses needs to upgraded to meet the requirements of confidentiality, authenticity, integrity, and availability.

5.1.3 Management service: Under the IoT-based infrastructure, the personalised information (e.g. schedules, learning activities, extra-curricular activities etc.) and the physical resource information (time, location, learning participants, learning tasks etc.) would be both collectable within the campus. Based on such multimodal data, the management service is designed to change the way the stakeholders interact with campus resources mainly in three aspects. The first is to intelligently allocate space resources such as classrooms, offices, meeting rooms, and accommodation [29]. The second is to manage the provision and usage of energy resources (e.g. water, heating, and electricity) in real-time to satisfy personal needs and optimise the energy savings on the campus. The third is to manage the time resources, which refers to appropriately scheduling the campus activities to optimise the learning/working efficiency of stakeholders.

5.1.4 Navigation service: The smart campus is equipped with surveillance cameras originally for security reasons. In the meantime, it provides a large amount of data indicating the people's locations over time, which offers the opportunity to identify specific persons from the video and track their footprints using face recognition technology. Based on personal footprint, a navigation service for personnel within campus could provide seamless indoor and outdoor navigation and quickly locate the place where the events occur and the people who need care [61]. It tries to provide peace of mind service to the individuals on campus so that they can put more focus on their teaching/learning activities.

5.1.5 AR service: As mentioned earlier, AR technology can provide a seamless connection between virtual content and real-world environment. The next question is: what forms of service should AR provide in the smart campus to improve the teaching/learning experience?

Five forms of AR-based service are identified in [18] that are AR books, AR gaming, AR objects modelling, and AR laboratory.

When the AR technology is integrated into books, an entirely new interface with 3D and interactive presentation of learning contents would be available to students. An AR e-book about insect life-cycle was designed and experimented on the science class students at an elementary school in Taiwan, which verifies the ability of AR-based e-book to inspire students' imagination capability and further improve their learning motivation [22].

Games have been utilised by instructors to assist students in an easier understanding of learning content. AR game empowers the instructors to augment the real world with virtual data for a highly visual and interactive form of learning. However, the negative impact of digital games, such as distraction, self-alienating behaviours, and mindless repetition, has also been concerned by instructors [62, 63]. How to balance students' game engagement to optimise the game-based learning performance in education is still an open research area for further investigation.

AR could also be applied to create location-based contents that are usually used for outdoor field trips with handheld devices. The location-based contents generally refer to relevant information to places such as historical sites, buildings, and artefacts, and could be placed somewhere in the world as virtual objects [7]. The outdoor field trip then becomes a game-based virtual object hunting activity that encourages the students to discovery new knowledge about different locations.

AR object modelling refers to translating the objects or theories into 3D objects for the students to play with. By doing so, it is more intuitive and interactive for the students to explore the physical properties of objects and relationships between objects, especially when the objects are difficult to be statically presented.

AR technology could also be embedded in laboratory equipment, such as the AR goggles that can display the experiment steps, identify the associated tools, and include textual user instructions. The AR condition in the laboratory allows the students to more quickly locate the tasks and focus on the tasks with less head movement, which helps improve the learning efficiency in laboratory activities.

5.1.6 Laboratory service: With the aid of IoT-based lab environment and AI-based lab instruments, it is expected that the future laboratories are equipped with smart labware that can proactively interact with students. One example is that the labware can automatically give feedback about students' lab operations in real time and guides students to complete the lab tasks. In doing so, students can gain intuitive experience of human–computer interaction in forms of audio, video, and AR, allowing them to fully concentrate on the lab activities and to achieve optimal lab experience. Moreover, virtual and remote laboratories would be a cost-effective and efficient solution to support experience teaching on subjects constrained by expensive equipment and heavy time burden [64]. The innovative laboratory services can significantly enhance the efficiency of lab practice and also largely prevent potential safety issues.

5.1.7 Ubiquitous learning service: Ubiquitous learning service mines the most appropriate learning materials from a globally sharing platform based on students' real-time knowledge, learning records, and learning preference, and then pushes the learning materials to students' mobile terminal devices (i.e. smart phone, tablet, portables etc.). It builds a good connection between learners, instructors, experts, and other education partners all around the world and forms a dynamic learning circle to achieve faster and easier knowledge obtaining. Ubiquitous learning service creates a 4A (anyone, anytime, anywhere, and any device) environment for students [65], completely unrestricting the learning barriers and truly realises 'learning in life'.

5.2 Personalised services

Personalised services include tailored services for individual persons. In personalised services, the delivered contents would be different for everyone within the campus. Based on the existing technologies, the following personalised services are envisaged.

5.2.1 Smart card service: Smart card service provides each stakeholder one card to replace various school-related cards (student ID, building access card, library card, medical card, pass card, parking permit etc.), which brings personalised efficiency, convenience, and security to stakeholders and promotes management standardisation of all the school departments [66]. Smart card service mainly functions in four areas: personal identification, financial management, public information provision, and consumption monitoring [66].

5.2.2 Social media service: The popularity of mobile networks has accelerated the development of social media for information

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dissemination and sharing among students and staff. Through mining, the social media data, the activities, opinions, and preferences of user groups could be extracted in a non-intrusive way. Such knowledge is important for smart campus context awareness in the sense it contributes to more accurately identify the features and conditions of key individual or small groups, more efficiently manage the activities of instructors and students in the virtual network, and more precisely determines the services provided to each people, so as to improve the personalised education performance.

The provision of social media service requires proficient data mining technology. In the literature, some data mining tools targeting on social media have been developed. For example, in [67], a deep topic modelling method is proposed to detect topics from personal micro-blogs based on the multi-modal data containing texts, images, and videos. In [68], a real-time monitoring system is proposed to monitor and analyse the Weibo public opinion sent by students on the major events.

5.2.3 Personalised teaching/learning service: Based on digital records throughout the students' learning activities, the smart campus system can provide a personalised concept map for each student. The concept map is a visual roadmap that is updated in real-time to depict how the students acquire new knowledge and synthesise it into their existing knowledge, which is crucial in tackling the problem of knowledge personalisation [69]. Such data could be used to identify the students' fine-grained learning outcomes with circulated feedback from the instructors. By analysing the personalised learning experience of each student, the system could create and update students' knowledge map [69], evaluate and predict students' learning achievements [70], recommend appropriate learning materials and resources [9], and optimise the learning routine of individual students [29].

From the perspective of instructors, the system could perform a multi-dimensional assessment of instructors' teaching performance [71], suggest the optimal teaching strategy [71], provide personalised online training [72], and encourage cross-disciplinary collaborations [73].

5.2.4 Psychological service: Psychological condition, such as emotion, is another factor that impacts the teaching/learning performance of instructors and students. The psychological conditions of individuals within campus could be potentially captured by analysing their physiological information using AI-based emotion recognition technology. The methodologies for emotion recognition have been rapidly developed in recent years, such as speech emotional recognition [31], facial emotion recognition [74], and multimodal emotion recognition [75]. By applying the emotion recognition recursively in real-time, the psychological condition of instructors and students could be tracked, which should provide sufficient evidence to explain how the psychological factor affects the teaching/learning performance within the smart campus.

Based on the tracked psychological condition, it is also prospective to perform timely social–psychological interventions on specific students where necessary. In the education domain, social–psychological interventions refer to some brief exercises that target students' feelings and motivation in and about the learning tasks, which can significantly enhance student learning achievement and reduce achievement gaps even after a long time period such as several months or years [76]. Compared to the academic class where academic contents are taught, these social–psychological interventions focus on improving students' psychological conditions, such as their belief of the potential to improve their intelligence or that they belong to and are valued in school [76].

5.3 Additional services

Additional services are some extra options that could be added on top of the essential or personalised services, which could also serve as a good interface for campus service reinforcement and new technology adaption. Some examples are provided as follows:

5.3.1 Reminder service: Reminder service monitors the schedule of personal and campus activities and adaptively pushes reminders to the users before the events. It can also provide health-friendly reminders according to people's conditions, such as reminding people to get up and take a rest after a long time sitting or laboratory work. The reminder service is usually provided as an option that could be switched off by the users if they are confident in their schedule and health condition.

5.3.2 Extra-curricular activity service: Participating in extra-curricular activities is additional to the learning activities and it offers significant opportunities for students to develop social engagement, discover new interests, and inspire creativity. The extra-curricular activity aims to customise off-campus activities for different groups of students. The students are grouped based on their availability, background, and preferences, while the activity details including themes, destinations, routes, and schedules are designed with the aid of IoT and social media. During the activities, smart activities service could also monitor the activity condition and dynamically adjust plans to control the activity process in order to optimise participants' satisfaction while ensuring personnel safety and security.

5.3.3 Robotic service: Robotics, as a physical presentation of AI, becomes increasingly pervasive and is potentially applicable to many aspects of life. In situations where a constant human companion is not always available, robotics can provide task-related feedback and motivational learning support to elevate students' learning experience [77]. The robotics serves as an additional function to the personalised learning service.

5.4 Accessibility, universality, and usability

Owing to the requirement of advanced technologies, smart campus services may not be easily accessible to everyone and everywhere with education needs. Some examples are the developing countries with limited technological capabilities, people with physical/mental disabilities, and students with low financial support. The efforts that the HLSC can make to achieve its accessibility, universality, and usability need to be discussed.

In order to promote the universality of smart campus and allow more individuals of different nationalities, backgrounds, and identities to gain the benefits of smart campus, the construction of smart campus can be implemented in multiple stages according to the actual conditions of the campus. A universal smart campus construction procedure could be: analysing and evaluating the needs and capabilities of different educational institutions, formulating a reasonable implementation plan for each independent campus, monitoring the construction process of smart campus, progressively evaluating the smart capability of campus, and updating with feasible alternatives in case of limited capability.

Regarding the accessibility of smart campus, an open cloud platform can be established to encourage information sharing and online teaching communication between campuses. People can independently publish free courses and teaching resources on the platform to help others with limited smart campus access. In addition, based on AI technology, the smart campus is able to improve accessibility from visual, hearing, mobility, and cognition, and thereby provide the greatest possible convenience for users with special needs (e.g. people with disabilities). For example, AI-based voice-text conversion technology provides convenience for hearing-impaired users.

It is also important to equip the smart campus with a seamless and unified network environment. By using IoT and situational awareness technology, related device or systems can provide smart services for users autonomously with significantly enhanced usability and efficiency. For instance, the emergency early-warning system can autonomously ensure the safety of students and timely push related information to the parent's devices.

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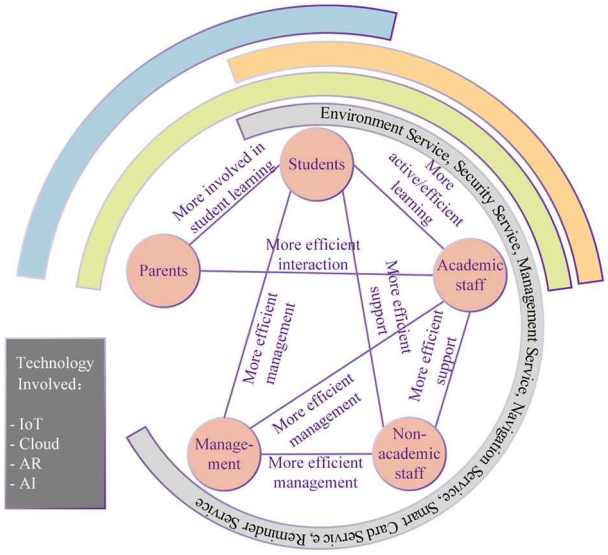

Fig. 3 *Interactions among smart campus stakeholders and services*

5.5 Stakeholder-service interactions

In the HLSC, besides summarising the potential smart services, how are the various services linked with the stakeholders also needed to be analysed. We aim to answer the following questions:

- Which stakeholders can gain benefit from using each service?
- How do the stakeholders interact in the smart campus system?
- How are the services improving the interaction between stakeholders?

The interactions among the smart campus stakeholders and services are illustrated in Fig. 3 where each partial ring shape covers the stakeholders who would potentially gain benefits from using the included services. The links between stakeholders denote how their interactions can be improved by using smart services. For example, the services included in the grey partial ring shape could be effective on four types of stakeholders, including students, academic staff, non-academic staff, and management team. Since parents are the external stakeholder of smart campus, they may not be able to use those services and thereby not covered by the grey partial ring. The contributions of those services on the four relevant stakeholders involve more efficient learning, management, and support within the campus. The four technologies (i.e. IoT, Cloud, AR, and AI) are also necessary for the system to enable the required services.

6 Interdisciplinary factors

This section discusses some interdisciplinary factors that either promote or constrain the smart campus revolution under the scope of smart city, including its economic incentives, social impacts, legal/regulatory constraints, and sustainability awareness.

6.1 Economic incentives

As the educational institutions at various levels are also businesses, their executives should also think about attracting and retaining students, cutting operating costs, improving workflows, and other financial considerations. There are several economic incentives that drive the development of the smart campus. The first incentive is the lower capital and operating expenditure costs. The leverage of new technologies enhances information and workflow automation and energy management, which minimises the reliance on the human workforce for education and management jobs and thereby reduces the labour costs. For example, the context-aware feature of campus enables automatic security control that could significantly lower the need for security guards compared to traditional campuses with human-based security management [78]. Moreover, as the energy within the campus is to be managed in a more efficient and sustainable way using renewable energy sources, IoT, and AI-based techniques, this would result in a significant saving on energy cost. Compared to traditional face-to-face education, most education activities are expected to be implemented via web-based platforms under the new education paradigms, which provide opportunities for the educational institutions to transform their education businesses from business-to-user to business-to-business mode. Such a transformation not only benefits the education industry but also generates more opportunities for technology companies.

Another economic incentive for building a smart campus is its potential to generate new income streams. Along with the enhanced students' learning experience in smart campus, a new set of education and management capabilities are also enabled. By doing so, the smart campus solution offers a multifaceted methodology to address the stakeholders' needs, which helps attract new students, increase productivity, drive collaborations, and extend their reach for better business opportunities with minimal constraints.

From the economic perspective, the main constraint on smart campus development would be the cost associated with the infrastructure upgrade and new technology deployment. This requires a large amount of initial investment as well as subsequent maintenance expenses. Although the overall capital and operating costs are expected to reduce in the long run, the educational institutions usually need a rigorous cost–benefit analysis before making any decision on smart campus solutions.

6.2 Social impacts

The primary role of a smart campus in a smart city is to cultivate young talents for the society. In the process of transforming the students into the future labour force, the smart learning environment provided by the smart campus makes the students adapt to the smart revolution at their early age so they can quickly get used to the smart working environment after they graduate. This continuous delivery of smart generations to society would gradually change the citizens' concept and habit of learning, working, and living, which contributes to the 'smart people' dimension of smart city and can significantly elevate the city sustainability and competitiveness [79].

Besides, a smart campus could also bring the following benefits to society. First, the forecasting and context-aware feature of smart campus provides early warning on potential hazards and reinforces the campus security protection, which would effectively reduce crime rate and minimise the reliance on public resources, such as fire control, ambulance, police etc. Second, the data shared through social media by the students and staff promotes the collaboration and interaction from different sectors in the society. Third, the data sharing platform of smart campus can be regarded as a huge and reliable resource. The data shared by smart campus improves the understanding of the young generation by society and provides guidance on other social services, such as catering, medical, psychological etc.

Although we generally regard a smart campus as an institution that provides education service on young people, the concept of smart campus could be expanded to realise a social learning system where the whole learning activities take place in every aspect of the society and throughout the life cycle of citizens. For example, smart learning systems could be penetrated in industries other than education, such as the transportation industry and financial industry, to provide continuous educational or training service to enterprise employees throughout their employment [1]. Such a social learning system is supportive of all kinds of education within a city and functions as a social service that meets citizens' learning expectations at both individual and collective levels.

The transformation from traditional to smart campus also poses new social concerns. The students, as young generations, usually grasp technologies much faster than the instructors, while the instructors, especially those more sophisticated in face-to-face teaching, will have a hard time adapting their daily work to the new learning environment. In the smart learning environment, teaching materials that are traditionally prepared by teachers will be easily

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obtained by students from various online sources, which poses new challenges for instructors to change their roles from merely an information provider to a learning facilitator [2]. The new environment forces the instructors to discover new ways of teaching/learning to maintain their values in the education industry. Therefore, a social concern would be how to manage the instructors and other staff to quickly get used to the new environment while minimising the unfavoured social impacts such as unemployment.

6.3 Legal/regulatory constraints

Although smart campus could bring benefits to the economic and social domains, the legal/regulatory domain acts as a big barrier that slows down the development of the smart campus, with concerns mainly from the following areas.

6.3.1 Cybersecurity and data privacy: Cybersecurity and data privacy are always critical concerns when dealing with cyber systems and sensitive human-related data. These systems and data must be handled according to the legal/regulatory requirements. As the realisation of system smartness highly relies on the availability of high-dimensional data, in particular personal data with the subjective opinion, protecting the data for students and staff would be a great challenge in smart campus development, especially on an information platform based on emerging technologies such as cloud computing and IoT [42]. In an IoT-based smart campus, the placement of sensing devices is generally authority-operated where the students and staff have few alternatives to the surveillance technologies deployed all over the places. In today's data-driven context, on the one hand, there is an increasing responsibility for the school leaders and executives to invest more in cybersecurity and avoid intruding user privacy [80]. On the other hand, a new law, policies, and regulations need to be established to protect personal data while supporting an appropriate level of context awareness.

6.3.2 Standardisation: In today's education transformation, standardisation is expected to play a pivotal role in promoting the principle of system interoperability in technology deployment for allowing the education industry to move in a smarter direction. However, it is usually challenging to align the established standards with practical needs throughout the era of change [81]. Although a large amount of data can be generated from various sources, there still lacks standards on how to appropriately exploit the data to plan, monitor, analyse, and manage the people within the campus. It is also important that education authorities at different levels define and establish data-related standards according to their respective requirements. Without such standards, it would be difficult for developers to achieve data interoperability in the new information system. Moreover, new education paradigms are promoted in smart campus, but the existing education-related standards are still mainly designed on the old education framework, showing a gap between the smart education research and the education standardisation [81]. There is a pressing need on a series of standards from a higher authority in supporting the development of the smart campus, preferably as part of the smart city plan, to assure the success of smart campus as well as direct the rapid, healthy and ordered smart education innovation.

6.4 Sustainability awareness

The term ‘sustainable’ refers to the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Owing to the recent concerns on climate change and the environment, it is essential to be aware of how the smart campus interacts with the environment field and how to achieve sustainability in its development. This could be realised in three ways.

First, campus sustainability can be improved via more efficient energy and waste management. In an IoT context, the use of resources on campus can be monitored in real-time through specific systems. This enables smart energy management in order to maximise energy saving and minimise carbon footprint generated by the daily campus activities. Moreover, waste management also contributes to the environmental impacts and sustainability of the smart campus. With sensors placed at bins and waste trucks, real-time data can be collected for waste management analysis. This provides clues to decide the optimal waste cleaning schedule with the objective of maximising the economic benefits while minimising the harm to the environment.

Second, the increasing use of renewable energy, such as solar energy and wind energy, also adds great value to campus sustainability. Rooftop photovoltaic systems and wind turbines are the main devices that harvest solar and wind energy to support energy use within the campus. The excessive energy can also be sent back to the grid, which also contributes to sustainability in other areas of a smart city.

Third, as the smart campus is a place that provides education services, educational activities, such as courses and workshops, can be carried out frequently to improve students’ awareness of sustainability. Moreover, a cloud-based forum could also be established to share sustainability knowledge and information. Considering the students will eventually contribute to society after graduation, this education also helps elevate the social sustainability awareness in the long run.

7 Conclusion

As the high-end form of a smart education system, the smart campus has received increasing research attention over the world. Based on an integral review on the supporting technologies and the related smart campus works, this study envisages, defines, and frames up the HLSC, which is defined as an educational environment that is penetrated with enabling technologies for smart services to enhance educational performance while meeting stakeholders’ interests, with broad interactions with other interdisciplinary domains in the smart city context. The infrastructure, technology, and service are identified as the three essential layers in the smart campus framework, all of which should be centric on the interests of the involved stakeholder. Context-aware, data-driven, forecasting, immersive, collaborative, and ubiquitous are identified as the six main features of the smart campus. The potential smart services to be provided in the campus have been explored, and the interdisciplinary factors that either promote or constrain the development of smart campuses have also been discussed.

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