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Development of smart universities worldwide: practices and experiences

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ABSTRACT

This article presents the implementation process of the smart university model at Metropolia University of Applied Sciences (Scotland), University of Sydney (Australia), National University of Singapore, Stanford University (American), and the University of Tokyo (Japan). The article highlights the similarities, differences, and issues encountered during the implementation of the smart university model in different countries. The research shows that all universities have implemented smart campus elements, while other elements are implemented uniquely by each university. These campuses integrate smart technologies to monitor and analyze energy consumption, emissions, and more. Real-time data about the campus informs what is happening within the university, thereby facilitating easier management, administration, security, and environmental protection.

Keywords*: experiences, model , practices, smart university*

1. Introduction

Since the social distancing measures of the Covid-19 pandemic, the smart university model has become indispensable for many major universities worldwide. Many universities have been applying this model in various activities. For example, many universities have gradually shifted from face-to-face learning to online and virtual reality learning. Some universities have also installed smart sensors to detect body temperature,

enabling timely isolation of individuals showing signs of fever or coughing when entering the campus. In Vietnam, many researchers and university administrators have analyzed the theoretical framework of the smart university model, identifying the necessary elements of a smart university (Nguyen Huu Duc et al., 2019; Nguyen Huu Duc et al., 2020) and implementing it in Vietnamese universities. However, there is limited research on the practical application of the smart university model globally and no comparative studies between universities. Many questions remain unanswered regarding how to apply the smart university model appropriately to the specific context of each university, whether to implement some or all of the smart university technologies, and which aspects of the smart university model should be prioritized first.

Therefore, this paper focuses on the development of the smart university model at major universities worldwide, delving into the practical application of the model at these universities, comparing similarities and differences, and identifying characteristics of the smart university model development process. The paper will first analyze the elements of the smart university model as a foundation for subsequent analysis.

2. Typical Smart University Models

2.1. Metropolia University of Applied Sciences (Metropolia UAS, Scotland)

Metropolia UAS is one of the largest universities of applied sciences in Scotland. Its four main fields of education are Culture, Business, Healthcare and Social Services, and Technology. Metropolia UAS offers bachelor's and master's degrees but does not offer doctoral programs. The university has a student population of 16,200 and employs over 1,000 experts in various fields. In 2020, the university had 2,680 bachelor’s and 485 master’s graduates. It is the top university in terms of student applications among the universities of applied sciences in Scotland. The smart education aspect at Metropolia UAS is prominently featured through its phenomenon-based innovation hubs, while the smart campus element is demonstrated through the digitalization of the university campus. (Metropolia UAS, 2023a)

P*henomenon-based Innovation Hubs*

Educational activities at Metropolia UAS aim to train learners to work in teams, coordinate technology use, and utilize data to address challenges posed by social issues/phenomena.

Common societal phenomena include climate change, environmental pollution, industrial revolution, and health care. These evolving social phenomena pose numerous challenges for teaching, learning, and practice. Hence, to understand and address the challenges posed by social phenomena, the curriculum cannot follow traditional paths or be confined to a specific subject; instead, it must integrate multiple disciplines to address a particular social phenomenon.

The phenomenon-based innovation hubs were established as spaces for learners to freely create and develop new methods to solve problems. At these innovation hubs, learners acquire knowledge, skills, and methods for using smart technologies to solve economic, social, cultural, environmental, and technological/engineering issues. The smart aspect of this educational method lies in the collaboration between learners, learners and instructors, and learners and smart technologies to address the challenges presented.

The phenomenon-based innovation hubs represent a breakthrough in higher education in Finland. Currently, Metropolia UAS has established five such hubs, focusing on clean and sustainable solutions, smart mobility, functional cities for citizens, data-driven construction, and customer-oriented health and welfare services (Metropolia UAS, 2023b).

Figure 1. Phenomenon-based innovation hubs

Digitalization

One of the fundamental requirements for most universities transitioning to a smart model is the design of a smart campus. Metropolia UAS has four campuses: Arabia Campus, Myllypuro Campus, Karamalmi Campus, and Myyrmäki Campus. The university's digitalization efforts focus on improving the working and learning environments on these campuses to be modern and energy-efficient. Investments in smart campuses are carried out through RDI (Research, Development, and Innovation) projects (Antti Tikka, 2013).

With the Smart Campus project aimed at significantly reducing energy consumption, Metropolia UAS has installed sensor technologies in its buildings. Technologies such as big data, artificial intelligence, and machine learning are integrated into the existing energy management systems of the university's buildings, providing guidance to help shift user behavior towards more energy-efficient practices (Metropolia UAS, 2022b).

Figure 2. Karamalmi campus, one of the four main campuses of the university

The Smart Campus project at Metropolia UAS has replaced old technologies with modern eco-technologies, developed the Smart Energy Management System Integration, which allows dynamic monitoring of the buildings' environmental conditions and user interactions. It provides real-time information on energy consumption and building environmental conditions, engages users (faculty and students) to interact actively with the smart energy management system, and changes user behavior towards more energy-efficient and safer practices. Currently, smart campus-related projects are still being implemented at Metropolia UAS campuses. Due to the impact of the Covid-19 pandemic, the university is accelerating the adoption of technologies such as e-learning systems, developing digital solutions, artificial intelligence (AI) technologies, and remote analysis technologies (Metropolia UAS, 2022b).

2.2. University of Sydney (USYD, Australia)

Founded in 1850, USYD is one of Australia's oldest universities. Today, USYD is one of the eight elite universities in Australia and ranks among the top 40 universities globally for research and teaching, according to several rankings. The university has a total enrollment of over 45,000 students. It offers more than 400 programs, with many ranked in the top 50 globally (QS 2019 Subject Rankings) in fields such as law, healthcare, architecture, education, and finance (USYD, 2022).

The university's mission is to educate leaders who will improve the world around them, equipping students with the necessary leadership qualities to serve the community at all levels. Its values include Courage and Creativity; Respect and Integrity; Diversity and Inclusion; Openness and Courtesy (USYD, 2022).

To achieve its goal of being a leader in research and teaching, integrating smart technologies into teaching and learning activities is indispensable. Due to the Covid-19 pandemic, the university's digital transformation has accelerated rapidly. The following section delves into the application of virtual classrooms as a solution for teaching and learning during social distancing.

Online and Virtual Classrooms

During the Covid-19 pandemic, given the university's large international student body and multiple campuses spread far apart, in-person learning became extremely difficult. USYD had to establish an e-learning system to meet students' learning needs. Currently, USYD has developed an e-learning system with over 205 courses, allowing students to continue their studies from home. Students also participate in online classes through software such as Google Meeting, WebEx, or Zoom. Students can attend online classes from home, dormitories, or even from other countries (USYD, 2022).

For courses requiring practical work, some faculties have developed virtual classrooms. Virtual classrooms are a part of the smart classroom concept. In these classes, students are equipped with virtual reality (VR) headsets and VR controllers to interact within the virtual classroom. These virtual classrooms are designed flexibly, providing experiences that traditional classrooms cannot offer.

Figure 3. A virtual classroom at the University

In a virtual classroom for a psychology course, the class is designed as skyscrapers in 3D graphics. Each student experiences the feeling of looking down from the top of a building to understand acrophobia, or the fear of heights. Virtual classrooms are also applied in the university's medical faculty, with many virtual classes simulating operating rooms to conduct virtual surgeries with virtual patient models. The classes are also simulated as treatment and counseling rooms, allowing students to experience working in a hospital

environment (USYD, 2023). A standout feature of virtual classrooms is their ability to instantly store data from both teachers and students during the learning process. Any interactions by teachers or students are recorded by the computer system, allowing stakeholders (school administrators, teachers, families) to review and use the data for various purposes as needed.

Smart Campus USYD also aims to develop its campuses into smart campuses, with the Camperdown/Darlington campus, which has a long history, being the university's main campus covering over 72 hectares.

Figure 4. Camperdown/Darlington campus

The infrastructure of the Camperdown/Darlington campus is mostly fixed. IoT applications primarily consist of easily installable and removable technologies such as motion detectors, indoor/outdoor environmental sensors (temperature, air quality, sound, and humidity), thermal cameras, energy-monitoring power plugs, smartphone apps, drones equipped with smart sensors, and smart technology-integrated vehicles (cameras, lidar, GPS, IMU, wheel encoders, steering angles), among others. These smart technologies bring significant convenience and efficiency to the services provided on a smart campus, such as reducing unnecessary energy use and providing guidance to students (The National IoT Testbeds, 2021). For newly constructed campuses like the Westmead campus, the infrastructure is integrated with smart technologies to monitor and record energy flow within the buildings. Technologies include energy-efficient lighting systems, improved indoor air quality, rooftop photovoltaic systems, promotion of sustainable transportation, and landscape designs aimed at reducing surface heat (USYD, 2022).

Figure 5. Environmental sensors and motion detectors

Figure 6. Power plugs recording energy consumption and sensor-equipped drones

2.3. National University of Singapore (NUS)

NUS consistently ranks high in the QS World and The Asia university rankings, serving as a major hub for attracting and training talent for Singapore. Currently, NUS has three campuses, 12 global centers, and over 55,000 students and staff (NUS, 2023).

As a leading university, NUS aims to be a global leader shaping the future. Its mission is to educate, inspire, and reform. The values it pursues are innovation, perseverance, excellence, responsibility, and integrity.

The eight key research areas of NUS include Materials Science, Maritime, Integrative Sustainability Solutions, Finance and Risk Management, Biomedical Science and Translational Medicine, Asian Studies, and Smart Nation. The Smart Nation area focuses on developing strategic capabilities in data science, analytics and optimization, and cybersecurity.

Investment in Smart Technology Research

The university houses numerous centers, institutes, and laboratories dedicated to artificial intelligence and digital technology research, such as the Institute of Data Science, the

Institute of Intelligent Systems, the Grab-NUS AI Lab, and the AI Singapore program, among many others. In total, the university hosts over 20 centers, institutes, and labs focused on smart technologies (NUS, 2023).

Figure 7. Building Housing Centers and Institutes for Smart Technology Research

The most recently established centers and labs at NUS include:

1. Center for Trusted Internet and Community: Integrates social and behavioral science research, digital technology, data-driven approaches, and policy research to comprehensively understand the internet and its social impacts.
2. Center on AI Technology for Humankind: Promotes human-centered thinking in the use of AI technology by advancing research in areas such as leadership and power, workforce improvement, trust, and ethics.
3. Center for Technology, Robotics, Artificial Intelligence, and the Law: Studies legal, ethical, policy, philosophical implications, and regulations related to the use and development of IT, AI, data analytics, and robotics in legal practice.
4. NUS-Singtel Cyber Security Research and Development Laboratory: Focuses on researching and developing digital solutions to protect individuals, businesses, and public agencies in Singapore from cyber threats (NUS, 2023).

These centers and institutes are located in a specially designed building to meet the needs of smart technology research. Over the years, NUS has delved into specific aspects of smart technologies and has developed new smart technologies to benefit the community and society. In other words, smart technologies are not only applied to the university's activities but also contribute to the community, society, and the nation.

Smart Campus

Figure 8. National University of Singapore campus

A smart campus is an essential part of NUS's transition to a smart university model. NUS is currently constructing several new buildings on its campus, with plans to establish smart infrastructure for these structures.

For the buildings, the construction team uses Building Information Modelling (BIM), creating and managing digital representations during the design, construction, and operation phases. This technology enhances construction productivity and better captures building information.

The construction process also employs GIS technology to collect real-time data on the geographical terrain and campus features, facilitating land planning and management. The buildings are operated by a real-time management center capable of processing, receiving, and making immediate decisions.

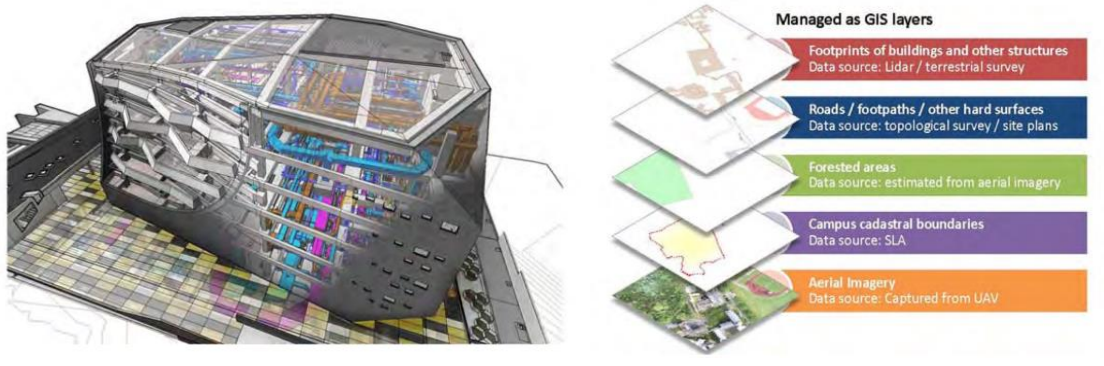

Figure 9. Illustration of BIM and GIS systems in land management and construction

The learning and classroom spaces in the new buildings are designed as Active Learning Classrooms. With intelligently arranged interiors, teachers and students can easily collaborate and exchange ideas while working in these classrooms. Additionally, the classrooms are equipped with advanced audio-visual technologies. Other spaces are meticulously planned to save energy and connect easily with smart devices (NUS, 2023).

Figure 10. An active learning classroom at the University

Beyond infrastructure, the campus is also equipped with sensors, cameras, smart transportation vehicles, etc. In the context of the Covid-19 pandemic, some new smart technologies have been applied to suit social distancing requirements, such as AI automated messaging systems, electronic menus, electronic payments, smart cameras, thermal sensors, mobile keys, virtual event organization, project management via web platforms, tools to measure the impact of trees on campus temperature, and more. The application of these technologies adheres to the criteria of being smart, safe, and sustainable (NUS, 2022).

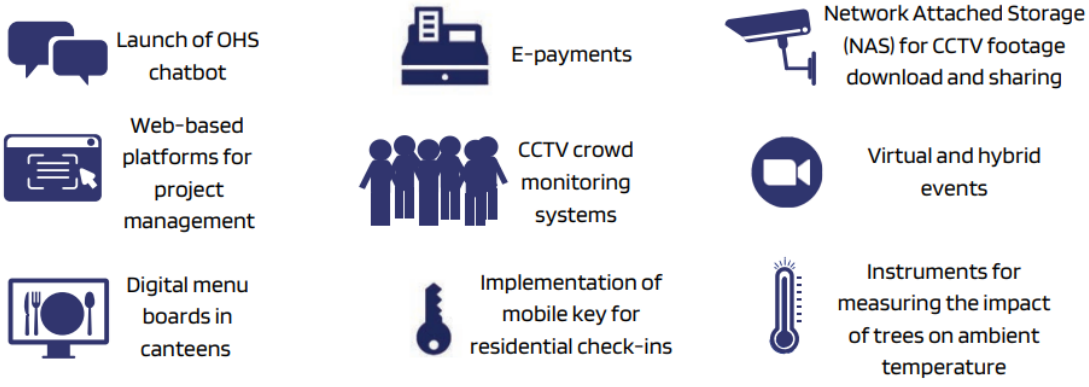

Figure 11. **T**echnologies applied to prevent Covid-19

2.4. Stanford University (SU, USA)

SU was founded in 1885 and consistently ranks among the top universities worldwide according to ARWU, QS, and THE rankings. The campus covers over 3,000 hectares, located near Silicon Valley. SU offers nearly every field of study for both undergraduate and postgraduate students; in 2021, it had over 15,000 students, 2,219 faculty members, and more than 10,000 staff (SU, 2022).

Stanford's vision is "driven by optimism, ingenuity, and a sense of responsibility, the university strives to accelerate purposeful impact for the world" (SU, 2022). Reflecting this spirit, the university's teaching and innovation are geared towards addressing specific global issues (sustainable development). The university ensures that learners are equipped with the appropriate knowledge to face a rapidly changing world.

The Stanford campus has over 100 buildings serving various functions, such as lecture halls, research centers/institutes, hospitals, dormitories, churches, museums, recreational areas, gardens, and farms. This makes the SU campus a complete ecosystem capable of meeting the needs of its inhabitants. Developing a sustainable ecosystem within the campus is one of SU's long-term goals. The 2020-2021 academic year was designated as the Year of Sustainability at SU, implementing many smart technology solutions to develop a sustainable ecosystem amid the Covid-19 pandemic (SU, 2022).

Figure 12. Stanford University campus

Online Teaching

In 2020-2021, due to the Covid-19 pandemic, teaching and learning at the university focused on virtualizing the curriculum to allow both instructors and learners to access it from anywhere. Online education will become an indispensable part of learning even after the Covid-19 pandemic ends. Virtual classrooms have been developed as an inevitable trend of the present and future (SU, 2022).

Smart and Sustainable Campus

SU is developing and testing new solutions to capture, transmit, store, analyze, visualize, and automate responses to the vast amount of data the university manages daily. The SU campus has an advanced control system to maximize efficiency in operating the campus's energy supply system.

Figure 13. Inside the campus management room

SU has an Energy Management Team that oversees building operations. This team uses many smart technologies in managing the buildings. Over 40 buildings (out of more than 135 buildings) on the main campus rely on automation systems equipped with advanced diagnostic and fault detection tools. These tools enable intelligent analysis across various aspects, including building operation, temperature management of chilled and hot water, and monitoring ventilation modes for the building's air handling units. Some buildings are also equipped with solar panels that convert thermal energy into electricity, providing clean energy for the buildings.

To combat the Covid-19 pandemic, the buildings' ventilation was increased to dilute the Covid-19 virus particles. The Facilities Energy Management Team developed guidelines to increase building ventilation levels without significantly impacting energy costs and adjusted settings in the building automation system to meet these guidelines.

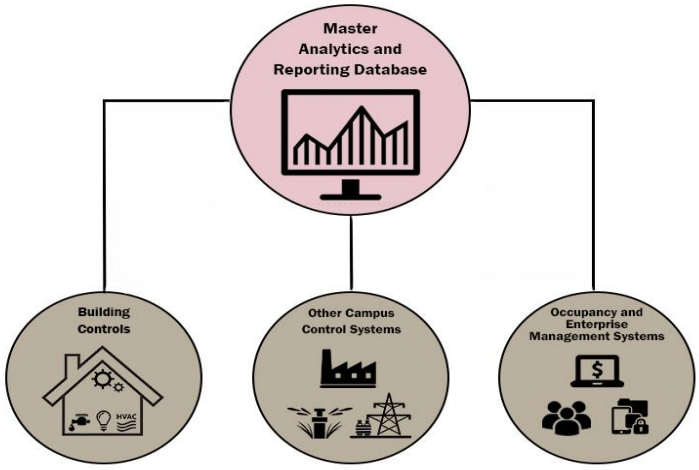

Figure 14. Management system controlling buildings and surrounding environment

The transition to a smart campus has achieved positive results aligned with sustainability goals, with criteria including:

1) Energy cost savings;
2) Maintenance cost savings;
3) High operational efficiency;
4) Building occupant satisfaction;
5) Transferability of IT infrastructure and improvements in reliability and cybersecurity (SU, 2022).

2.5. The University of Tokyo (U-Tokyo, Japan)

U-Tokyo, also known as Todai, is one of Japan's oldest universities. Established in 1877, it has educated many generations of leaders for the government and top businesses in Japan. The university's mission and goals are stated as follows: “The University of Tokyo aims to nurture global leaders with a high sense of responsibility to the community and a pioneering spirit, possessing both deep expertise and broad knowledge. The University of Tokyo aims to expand the horizons of human knowledge in relation to society” (U-Tokyo, 2023).

In 2011, the university ranked second only to Harvard in the number of alumni serving as CEOs of Fortune 500 companies. Fifteen Prime Ministers of Japan were also educated at this university. Like other famous universities worldwide, U-Tokyo ranks high in global university rankings. It is ranked 23rd in the QS World University Rankings, holds high positions in the QS WUR by Subject, and is 11th in the Asian University Rankings, among many other rankings (TopUniversities, 2023b).

Currently, U-Tokyo has 10 undergraduate faculties and 15 graduate schools with over 30,000 students. Many of the university's courses are taught entirely in English, and the university hosts 2,100 international students. A key feature of undergraduate education at U-Tokyo is that the first two years (known as the Junior Division) are dedicated to acquiring the basic skills necessary for further study. In the last two years of undergraduate education (known as the Senior Division), students pursue their specialized fields (U-Tokyo, 2023).

Smart University Education Program

A notable initiative of the university is the training program called the Smart City University. As planning and building future cities require expertise and practical knowledge in many fields, this program is designed to nurture talented future leaders in urban and regional development (U-Tokyo, 2023).

The smart university education program is a new concept introduced by the University of Tokyo, Japan, aimed at training students to be creative, critical thinkers, and adaptable to the times. Launched in 2022, the smart university education program at U-Tokyo involves various faculties, institutes, and schools within the university. The program includes lectures and modules on the latest smart technologies, taught by leading faculty members

in the field of science and technology. Students also gain hands-on experience with smart technologies and visit leading research centers in the field. The smart university education program at U-Tokyo has yielded positive results, enhancing the university's reputation and quality both regionally and globally.

Figure 16. Smart University sessions held at U-Tokyo's Hongo campus in April 2022

Campus with Unique Smart Buildings

The University of Tokyo has five campuses: Hongo, Komaba, Kashiwa, Shirokane, and Nakano. These campuses are managed by the Campus Management Research Center. The center has three main responsibilities: facility management, asset management, and information management. For facility management, the center is responsible for renovating old facilities and optimizing energy use while integrating smart technologies into the university's facilities. For asset management, the center has a strategy to develop modern campuses while preserving historical values; significant historical sites are maintained to retain the distinctive character of the campus. For information management, the center builds a digital spatial platform, establishing an ICT framework for real-time data collection technologies across the campus (University of Tokyo, 2023).

Some of the university’s buildings have also been smart-enabled. For instance, the Daiwa Comprehensive Computing Research Building on the Hongo campus is equipped with a range of sensors to monitor wind speed, radiation, dust particles, temperature, humidity, and other factors. The collected data is uploaded to the network and can be used for various purposes related to building management and computational research activities (University of Tokyo, 2023).

Figure 17. Daiwa Comprehensive Computing Research building

3. Discussion

Regarding commonalities in implementing the smart university model, the universities mentioned above are all developing smart campuses. This indicates that establishing a smart campus is a more feasible aspect of implementing a smart university model. Utilizing technology in the design and construction of buildings, corridors, and school facilities, and in public spaces within the university, raises fewer privacy concerns compared to installing sensor technologies and cameras in classrooms.

On the differences, universities prioritize different elements of the smart university model. For Metropolia University of Applied Sciences, as an applied university, it prioritizes developing smart, practice-oriented educational methods. The university invests heavily in phenomenon-based innovation centers, where learners interact with smart technology to address social challenges/issues, as a key part of its 2020-2030 strategy.

For the University of Sydney, with multiple campuses and learners worldwide, the university has developed a diverse and rich array of online learning methods with many online courses through various software platforms. Learners also engage with virtual reality classes, customizing classroom environments to match course content.

For the National University of Singapore (NUS), as the national hub for science and technology, NUS not only applies technology to the learning environment but also establishes numerous centers, institutes, and laboratories to develop and master these technologies for the community, society, and the nation.

For Stanford University, the goal is sustainable development. Smart technologies are used to address sustainability issues. The university also offers online classes to reduce on-campus travel (saving energy), and it has a control center that uses real-time data to assess consumption, emissions, and renewable energy.

The University of Tokyo also develops courses and programs on smart technology, smart cities, and smart universities. Many of its students participate in practical training at smart technology centers and research institutes. The university creatively develops its smart campus by designing and constructing smart buildings according to their intended use.

Thus, in terms of the elements of a smart university, creative application and prioritizing which elements to develop first according to each university's goals are more practical than attempting to implement all elements without clear objectives. Additionally, the smart campus should be considered the first element to deploy when building a smart university. This is likely because applying technology to infrastructure is easier than in human interactions.

Installing smart technologies and collecting real-time data in classrooms to enhance education quality shows promise but is less commonly applied in practice. This may be due to concerns about the privacy and freedom of learners and instructors. Data collected by smart technologies can include various types of information about students in the classroom, such as grades, personal information, study habits, gestures, and behavior. However, these technologies can make learners and instructors feel constrained and stressed, as they are not always able to focus entirely on the lesson or lecture. Installing sensor cameras to observe classroom dynamics can also be met with resistance due to potential privacy invasions for both learners and instructors.

4. Conclusion

The universities mentioned above have been transitioning to the smart university model. A common feature in their transformation is the implementation of smart campus elements within the smart university model. Accordingly, the campuses of these universities are integrated with smart technologies such as sensors, smart cameras, motion detectors, and more, providing real-time data. New or under-construction facilities are integrated with smart technologies to monitor and analyze energy consumption, emissions, and other metrics. Real-time data about the campus informs management about ongoing activities, thereby facilitating easier management, security, order, and environmental protection.

Implementing smart campus elements over other elements may be due to the greater acceptance among university members. For instance, the installation of sensor cameras or devices measuring concentration in smart classrooms may not be well-received by both instructors and students due to privacy concerns. Designing smart education programs also requires significant changes in teaching and learning processes, which may be challenging for both instructors and students to adapt to. Therefore, choosing which elements of the smart university model to implement should consider the suitability and capacity of the university.

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