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Review Article

Smart Campus Applications: A Literature Review on Transportation Research and Big Data

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Abstract: Industry 4.0-related technologies are being implemented to improve societal well-being, and smart campus is a significant application area. Smart campus integrates various technologies for online class management, energy usage observation, warning systems, smart vehicles, and people flow management. Therefore, this study aimed to list and classify surveys on smart campus applications. Unlike previous reviews, a broad range of topics, and characteristics of smart campus applications were explored. A total of 43 studies were identified and screened using Google Scholar database according to the PRISMA framework. An overview of each application topic was provided, detailing its functions, related data, and technologies used. In addition, transportation problems related to these applications were identified, offering areas for future studies to optimize smart campus systems.

Keywords: Review; Smart campus; Survey; Transportation

1. Introduction

The rapid development of IoT, big data, and optimization techniques offers significant opportunities for new applications in universities. There is a necessity to improve education quality because the sector is an important source of innovation and a key factor in the development of smart cities (Zhuhadar et al., 2017). A smart campus is defined as a facility that combines technologies with physical infrastructure to improve decision-making and learning quality (Min-Allah and Alrashed, 2020). Moreover, the use of these technologies helps identify hidden problems and propose effective solutions to users (Berawi, 2022), which contribute to a more comfortable and convenient education (Muhammad et al., 2017). Effective education requires a conducive environment, such as appropriate lighting and temperature (Hakim et al., 2021). Apart from focusing on users, it is important to ensure the education facility management supports the concept of green campus and environment preservation (Fatriansyah et al., 2021). These issues can be addressed by collecting and integrating real-time data, and enabling fast decision-making (Singgih et al., 2016).

The current study was conducted to facilitate the understanding of recent developments in smart campus topics and propose better or new applications. In this context, understanding the main characteristics of smart campus system can promote its implementation by decision-makers. After

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providing an overview of all relevant topics, potential transportation problems within the smart campus are addressed. Meanwhile, the importance of identifying and solving problems in smart system has motivated studies in various fields, including smart logistics (Feng and Ye, 2021), smart manufacturing (Khakifirooz et al., 2019), smart waste collection (Jorge et al., 2022), and smart grid (Anjos and Gómez, 2017). Addressing operations research problems in the smart campus offers several benefits, namely (1) efficient and effective decision-making that reduces operational costs and time using the collected big data and (2) leveraging operations research computational methods to process big data for valuable decision-making. In addition, operations methods in smart system studies have been used to (1) minimize energy consumption or cost (Nutakki and Mandava, 2023; Mohajer and Mousavi, 2023) and (2) maximize user comfort (Khan et al., 2023). Therefore, effectively identifying and solving the operations research problems (transportation issues, in the context of the current study) can support smart campus to improve education quality, promote innovations, and ensure sustainability.

2. Literature Review

This study was compared with previous reviews on smart universities, as shown in Table 1. The reviews were searched using the Google Scholar database through the Publish or Perish 8 search engine (Harzing, 2023) with the keywords "smart AND (university OR campus)". Based on Table 1, this study was novel for several reasons, namely (1) provides a clear and comprehensive list of characteristics for each smart university application, (2) includes a larger number of studies, and (3) covers a broader range of smart university application topics.

The contributions are as follows:

- Studies on smart campus topics are listed and classified based on their application types and detailed characteristics (available functions, considered information, software, and hardware).
- Possible definitions of transportation problems are proposed, which can serve as a basis for future studies to develop and apply appropriate solution methods.

Table 1 Novelty comparison with related review papers

Reference	Publication Year	Reasons for Our Novelty		
		Number of Considered Studies on Smart University	Number of Considered Topics	Clear and Complete Characteristic List for Each Application
(Zhuhadar et al., 2017)	2017	2	-	No
(Abuarqoub et al., 2017)	2017	-	4	No
(Alghamdi and Shetty, 2016)	2016	-	5	No
(Muhammad et al., 2017)	2017	-	5	No
(Min-Allah and Alrashed, 2020)	2020	-	-	No
Our study		43	10	Yes

3. Method

The target studies were screened and selected using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Page et al., 2021), as shown in Figure 1. PRISMA is a well-established method (Murray, 2022) that (1) facilitates the reproduction of review due to its standardized review method (Liu et al., 2021) and (2) ensures a systematic and thorough review that guarantees quality (Lescinsky et al., 2022). At the time of the manuscript submission, the PRISMA framework had been cited over 43,000 times. Using PRISMA, the process started by identifying the source used to search for the papers, listing the number of papers found, and detailing the criteria for screening, leading to the final list for discussion.

Studies were searched using the Google Scholar database through the Publish or Perish 8 search engine (Harzing, 2023), with a maximum of 200 results due to journal page limitations. The keywords "smart AND university OR campus" were used, and studies between 1973 to 2022 were initially found. During the first screening, studies were filtered based on titles and abstracts, reducing to 92 studies. A total of 73 was obtained after removing inaccessible studies. In the final screening process, full texts were reviewed, and studies not related to smart campuses were excluded, resulting in 43 studies published between 2001 and 2020. Subsequently, review and classification were carried out and the results were verified. This review was not registered, and no protocol was prepared.

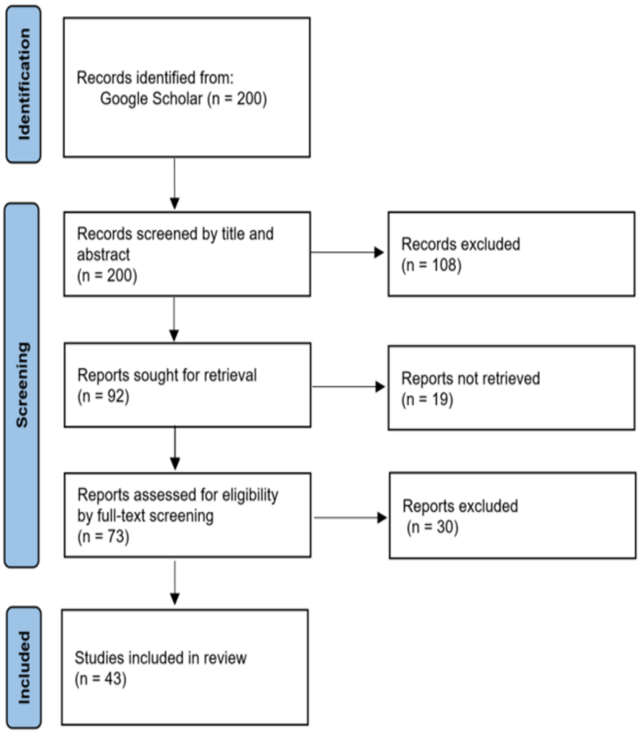

Figure 1 Review methodology in this study

4. General Overview of the Review Results

In this section, the statistics of the 43 reviewed studies were presented, with the majority having a significant number of citations. Table 2 presents the 30 most-cited while Figure 2 shows the number of published papers per year for all 43 selected studies.

The studies were classified based on smart campus application types, as shown in Table 3. These classifications were derived from previous reviews (listed in Table 1) as follows, (1) indoor/outdoor and energy monitoring (Min-Allah and Alrashed, 2020; Abuarqoub et al., 2017; Alghamdi and Shetty, 2016), (2) equipment monitoring and control (Min-Allah and Alrashed, 2020; Abuarqoub et al., 2017; Alghamdi and Shetty, 2016), (3) people flow monitoring (Muhammad et al., 2017), (4) class management (Min-Allah and Alrashed, 2020; Muhammad et al., 2017; Abuarqoub et al., 2017; Alghamdi and Shetty, 2016), (5) room and resource management (Min-Allah and Alrashed, 2020), (6) personnel activity and behavior management, (7) security (Min-Allah and Alrashed, 2020; Muhammad et al., 2017), (8) finance (Muhammad et al., 2017), (9) health and hygiene (Muhammad et al., 2017; Abuarqoub et al., 2017; Alghamdi and Shetty, 2016), (10) communication and data (Muhammad et al., 2017). Further subtopics within these classifications were defined and listed in Figure 3, ensuring that each class differed.

Table 4 presents the classification of the studies. Based on information from the listed papers, each smart campus application in Table 3 is detailed in Table 5

. The list includes functions of each application, distinguishing between manual and automatic features, and provides details on the relevant information considered.

Figure 3 provides the percentage of studies for each smart campus topic. This percentage represents the number of studies in each smart campus topic divided by the total number, namely 43. Insights that could be extracted from the reviewed studies related to smart campus concepts and applications are elaborated into the following points.

Table 2 Top 30 highly cited papers

Study	Number of citations
(Tan and Wang, 2010)	1435
(Sivanathan et al., 2017)	342
(Simmhan et al., 2013)	338
(Coccoli et al., 2014)	275
(Fortino et al., 2018)	242
(Ji et al., 2014b)	202
(Moreno et al., 2017)	162
(Hirsch and Ng, 2011)	146
(Atif et al., 2015)	120
(Bracco et al., 2014)	119
(Xu et al., 2019)	114
(Villegas-Ch et al., 2019)	112
(Yu et al., 2011)	105
(Alvarez-Campana et al., 2017)	97
(Kwok, 2015)	96
(Bates and Friday, 2017)	94
(Veeramanickam and Mohanapriya, 2016; Caţă, 2015; Ji et al., 2014a)	89
(Szabó et al., 2013)	85
(Nie, 2013)	83
(Villegas-Ch et al., 2020)	81
(Majeed and Ali, 2018)	80
(Zhamanov et al., 2017)	77
(Aqeel-ur-Rehman et al., 2008)	74
(Adamkó et al., 2014)	72
(Yagol et al., 2018)	71
(Chieochan et al., 2017)	68
(Dong et al., 2020)	67
(Trilles et al., 2017)	66

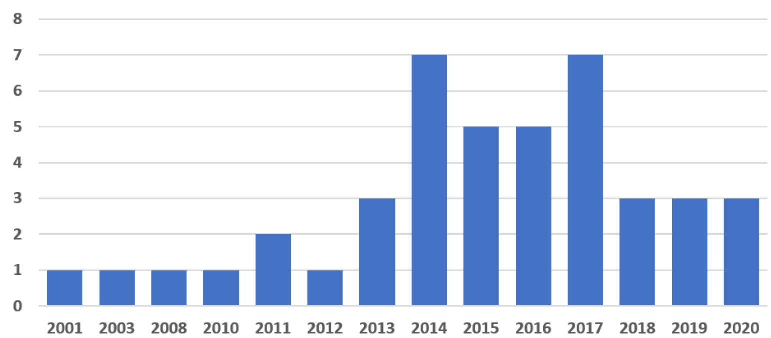

Figure 2 Number of selected studies per year after the screening

4.1. Good Insights from the Studies

The variety of system purposes, along with the hardware and software used in the studies, showed that implementing a smart campus was a practical reality. Several surveys provided detailed explanations of how the hardware and software were selected and how the database used in smart campus systems was designed. The main challenge was designing an effective method to extract and analyze the data appropriately and provide suitable solutions to relevant decision-makers or users (Channamally et al., 2025; Hakim et al., 2023).

4.2. Weakness of the Studies

Future studies were recommended to consider the following points:

- Clearly defining the problem (objectives, input data) and providing a comprehensive software and hardware design to implement the smart campus concept. Some of the reviewed studies lacked comprehensive information, making the concept challenging to understand or implement effectively. Designing procedures that ensure reproducibility is important to produce good solutions for the benefit of many people (Camprodon et al., 2019).
- Appropriate recognition and comparison with similar previous studies are necessary. Several studies proposed new smart campus applications without thorough comparison with existing ones. For example, using certain machine learning techniques without extensive comparison experiments with other methods. Constructing a comprehensive database to record each implementation of a topic could facilitate future updates.
- Engaging users more in the smart campus system design and implementation is crucial (Kaisermayer et al., 2024; Chen et al., 2014). Effective system design should commence with user requirement identification, followed by benefit analysis for various system actors (campus as the regulator and individuals within the campus as users), and continuously improving the system design and operation. Campus should consider applying a more decentralized approach, allowing users to access open data and propose various solutions for smart campus topics. This approach can facilitate the development of smart campus system.
- It is crucial to conduct studies that address more integrated problems. Most of the reviewed studies discussed each smart campus topic separately, potentially leading to decisions that optimize only a part of the whole campus system. The following are examples of integrated studies worth exploring, (1) route recommendation based on the populated area or predicted weather, (2) integrated room scheduling and energy-saving initiatives, and (3) people grouping suggestions to balance density levels (from the formed activities) across the whole campus area.

In the integrated problems, synchronization between decision-making in the related subproblems becomes important to ensure the good performance of the whole system (Zhuang et al., 2025; Saletti et al., 2022).

4.3. Managerial Insights for Smart Campus Technology Applications

It is essential to consider the following before decision-makers apply the smart campus architectures presented in Table 5.

- *Digital vs Smart*

  Being smart differs from being digital. Simply having the hardware installed to collect big data in the smart campus is insufficient to improve quality without the ability to analyze data effectively, specifically providing important information to users (Sumanthi, 2025; Coccoli et al., 2014).

Table 3 Classification of smart campus studies

Classifications	Subtopic
1. Indoor/outdoor and energy monitoring	1a. Indoor situation and environment monitoring
	1b. Outdoor environment monitoring
	1c. Energy saving effort
	1d. Energy usage prediction
	1e. Vibration analysis
2. Equipment monitoring and control	2a. Equipment monitoring
	2b. Equipment control
	2c. Multi-device automatic connection
3. People flow monitoring	3a. Individual identification
	3b. Individual location identification
	3c. Density analysis
	3d. People group identification
	3e. Vehicle parking location recommendation
	3f. Public transportation deployment
	3g. Vehicle/people flow monitoring
	3h. Vehicle/people route recommendation
4. Class management	4a. Online class (no specifics)
	4b. Class attendance management
	4c. Automatic phone control in rooms
	4d. Class activity monitoring
	4e. Online material sharing
	4f. Class material mining
	4g. Course homepage design
	4h. Interactive course material design
	Practical training
	4j. Assignment and evaluation
	4k. Student note sharing
	41. Class recommendation
	4m. Personalized material generator
	4n. Remote library resource retrieval
	4o. Class material security
5. Room and resource management	5a. Room booking
	5b. Room utilization monitoring
	5c. Automatic room setting
6. Personnel activity and behavior management	6a. Activity schedule information
	6b. Activity and time recommendation
	6c. Programming contest planning and execution
	6d. Student problem identification
7. Security	7a. Building access
	7b. General *attendance* checking
	7c. Surveillance
8. Finance	8a. e-wallet
	8b. Expense reduction simulation
9. Health and hygiene	9a. Health monitoring
	9b. Epidemic alert
	9c. Sensor-based waste pickup
10. Communication and data	10a. Multi-platform sharing
	10b. Data backup and recovery

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Table 4 Classification of studies based on subtopics

Study	1a	1b	1c	1d	1e	2a	2b	2c	3a	3b	3c	3d	3e	3f	3g	3h	4a	4b	4c	4d	4e	4f	4g	4h	4i
(Tan and Wang, 2010)	√		√																						
(Sivanathan et al., 2017)						√																			
(Simmhan et al., 2013)				√																					
(Coccoli et al., 2014)																									
(Fortino et al., 2018)	√		√		√																				
(Ji et al., 2014b)													√												
(Moreno et al., 2017)	√		√	√																					
(Hirsch and Ng, 2011)	√		√															√			√				
(Atif et al., 2015)																									
(Bracco et al., 2014)			√	√																					
(Xu et al., 2019)																									
(Villegas-Ch et al., 2019)			√								√			√											
(Yu et al., 2011)										√	√														
(Alvarez-Campana et al., 2017)	√	√	√								√				√										
(Kwok, 2015)																		√							
(Bates and Friday, 2017)	√	√	√																						
(Caţă, 2015)	√	√																	√						
(Veeramanickam and Mohanapriya, 2016)			√					√												√	√				
(Ji et al., 2014a)													√			√									
(Szabó et al., 2013)																									
(Nie, 2013)													√					√							
(Villegas-Ch et al., 2020)																									
(Majeed and Ali, 2018)									√	√	√										√				
(Zhamanov et al., 2017)																		√			√				
(Aqeel-ur-Rehman et al., 2008)						√	√			√															
(Adamkó et al., 2014)																									
(Yagol et al., 2018)																√									
(Chieochan et al., 2017)	√					√	√																		
(Dong et al., 2020)															√							√		√	
(Trilles et al., 2017)	√															√									
(Hentschel et al., 2016)																									
(Sutjarittham et al., 2019)																									

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Table 4 Classification of studies based on topics (cont.)

Study	1a	1b	1c	1d	1e	2a	2b	2c	3a	3b	3c	3d	3e	3f	3g	3h	4a	4b	4c	4d	4e	4f	4g	4h	4i
Bueno-Delgado et al., 2012)																									
(Kopotun et al., 2020)																					√				
(Bellagente et al., 2015)				√			√																		
(Hipwell, 2014)			√														√	√							
(Popescu et al., 2016)																									
(Halawani and Mohandes, 2003)																	√								
(Khabou et al., 2014)	√						√																		
(Al Shimmary et al., 2015)							√																		
(Doulai, 2001)												√									√		√		
(Prasolova-Førland et al., 2017)																									√
Baryshev and Babina, 2016)																									

Study	4j	4k	4l	4m	4n	4o	5a	5b	5c	6a	6b	6c	6d	7a	7b	7c	8a	8b	9a	9b	9c	10a	10b
(Tan and Wang, 2010)																							
(Sivanathan et al., 2017)																							
(Simmhan et al., 2013)																							
(Coccoli et al., 2014)													√					√					
(Fortino et al., 2018)																							
(Ji et al., 2014b)																							
(Moreno et al., 2017)																							
(Hirsch and Ng, 2011)										√	√			√	√	√			√	√			
(Atif et al., 2015)			√	√							√												
(Bracco et al., 2014)																							
(Xu et al., 2019)			√							√	√												
(Villegas-Ch et al., 2019)														√		√							
(Yu et al., 2011)		√									√												
(Alvarez-Campana et al., 2017)								√								√							
(Kwok, 2015)	√										√												
(Bates and Friday, 2017)																							
(Cață, 2015)															√								
(Veeramanickam and Mohanapriya, 2016)		√																					
(Ji et al., 2014a)																							
(Szabó et al., 2013)										√	√												
(Nie, 2013)					√									√	√								
(Villegas-Ch et al., 2020)											√		√										
(Majeed and Ali, 2018)								√						√	√								

Table 4 Classification of studies based on topics (cont.)

Study	4j	4k	4l	4m	4n	4o	5a	5b	5c	6a	6b	6c	6d	7a	7b	7c	8a	8b	9a	9b	9c	10a	10b
(Tan and Wang, 2010)																							
(Sivanathan et al., 2017)																							
(Simmhan et al., 2013)																							
(Coccoli et al., 2014)													√					√					
(Fortino et al., 2018)																							
(Ji et al., 2014b)																							
(Moreno et al., 2017)																							
(Hirsch and Ng, 2011)										√	√			√	√	√			√	√			
(Atif et al., 2015)			√	√							√												
(Bracco et al., 2014)																							
(Xu et al., 2019)			√							√	√												
(Villegas-Ch et al., 2019)														√		√							
(Yu et al., 2011)		√									√												
(Alvarez-Campana et al., 2017)								√								√							
(Kwok, 2015)	√										√												
(Bates and Friday, 2017)																							
(Cață, 2015)															√								
(Veeramanickam and Mohanapriya, 2016)		√																					
(Ji et al., 2014a)																							
(Szabó et al., 2013)										√	√												
(Nie, 2013)					√									√	√								
(Villegas-Ch et al., 2020)											√		√										
(Majeed and Ali, 2018)								√						√	√								

- *Combination of Historical and Real-Time Data*
  Considering that each user might utilize data differently, it is important to provide (1) historical data of specific user and other users with similar characteristics, and (2) real-time data to identify the current situation and make optimal decisions (Alvarez-Campana et al., 2017). A good example was the previously proposed framework (Singgih, 2021), where historical data were used to predict system performance, while real-time statistics were continuously updated and utilized to make the best decisions based on the system's dynamic behavior.
- *Data Security and User Right Issues*
  Discussions around data security and user rights issues are crucial. Most studies did not address how users are notified and asked for consent before sharing data. It is crucial to clearly discuss the types of data disclosed and data access privileges for each user type when data are shared anonymously.

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Table 5 Characteristics of each smart campus application

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
1a	Indoor situation and environment monitoring	• [a] Locating people and objects inside a room (Tan and Wang 2010; Alvarez-Campana et al. 2017; Khabou et al. 2014) • Monitoring a room's condition, e.g., humidity, light, and temperature (Chieochan, Saokaew, and Boonchieng 2017; Trilles et al. 2017) • [a] Automatic alert sending regarding some unusual situations, e.g., high noise, temperature, and humidity (Caţă 2015)	• Humidity, temperature, light, and presence information (Fortino et al. 2018; Moreno et al. 2017; Hirsch and Ng 2011; Bates and Friday 2017; Chieochan, Saokaew, and Boonchieng 2017) • Energy consumption and flows within the university (Alvarez-Campana et al. 2017; Bates and Friday 2017)	• Radial basis functions to predict user positions (Moreno et al. 2017) • Particle filter to estimate future states (Moreno et al. 2017) • Cloud system (Caţă 2015)	• Humidity, temperature, light, and presence sensors (Fortino et al. 2018; Moreno et al. 2017; Chieochan, Saokaew, and Boonchieng 2017; Trilles et al. 2017) • Infrared and RFID to estimate people's location (Moreno et al. 2017) • Data on heat and power generator and boiler room (Bates and Friday 2017) • Arduino (Chieochan, Saokaew, and Boonchieng 2017) • Internet and WiFi (Chieochan, Saokaew, and Boonchieng 2017)
1b	Outdoor environment monitoring	• Measuring outdoor air quality and using them, e.g., to limit car parking and speeds (Alvarez-Campana et al. 2017; Caţă 2015)	• Local meteorological data, e.g., temperature, relative humidity, wind speed, and minutes of sun (Alvarez-Campana et al. 2017; Bates and Friday 2017)		• Environmental sensors, e.g., noise, humidity, temperature, light (Alvarez-Campana et al. 2017; Bates and Friday 2017)
1c	Energy saving effort	• [a,m] Managing campus facilities, e.g., heating and ventilating system, air conditioner (HVAC), elevator (Tan and Wang 2010; Fortino et al. 2018; Bracco et al. 2014; Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Veeramanickam and Mohanapriya 2016; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008; Hipwell 2014) • Optimizing indoor temperature, lighting, and humidity, e.g., minimizing the energy usage level from the defined threshold (Moreno et al. 2017; Bates and Friday 2017; Dong et al. 2020) • Conducting a smart energy harvesting (Hirsch and Ng 2011)	• HVAC and elevators' behavior (Tan and Wang 2010) • Equipment maintenance information (Bracco et al. 2014) • Emission data (Bracco et al. 2014) • Energy produced from wind turbines, including information on wind speed and direction, blade rotation speed (Bates and Friday 2017)		• WiFi (Tan and Wang 2010) • RFID (Tan and Wang 2010; Moreno et al. 2017; Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008) • Device actuators (Fortino et al. 2018; Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Bates and Friday 2017)

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Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
1d	Energy usage prediction	• Predicting energy usage for the next few hours or the day after (Simmhan et al. 2013; Moreno et al. 2017; Bracco et al. 2014; Bellagente et al. 2015) • [a] Notifying energy usage to users with high energy use (Simmhan et al. 2013)	• Historical data on energy usage (Simmhan et al. 2013)	• Regression tree machine learning and ARIMA time-series for accurate predictions (Simmhan et al. 2013; Moreno et al. 2017) • Support vector machine, artificial neural network, random forest, tracking algorithm (Moreno et al. 2017) • Principal component analysis to identify important factors for the prediction (Moreno et al. 2017) • Android mobile app for energy usage visualization (Simmhan et al. 2013) • Cloud system (Simmhan et al. 2013)	• Equipment sensors, e.g., for heating and ventilating system, air conditioner (HVAC) (Simmhan et al. 2013) • Smart meters that record energy usage by each user (Simmhan et al. 2013)
1e	Vibration analysis	• Monitoring bridge's structural health (Fortino et al. 2018)	• Recorded vibration (generated through vehicles and pedestrians on the bridge) (Fortino et al. 2018) • Predetermined vibration threshold (Fortino et al. 2018)		• Accelerometer (vibration) sensors (Fortino et al. 2018) • WiFi (Fortino et al. 2018) • Bluetooth (Fortino et al. 2018)
2a	Equipment monitoring	• Classifying IoT and non-IoT devices (Sivanathan et al. 2017) • Identifying specific IoT devices (Sivanathan et al. 2017) • Observing power status (on/off) of equipment (Chieochan, Saokaew, and Boonchieng 2017)	• Device ID and basic information (address, wired/wireless) (Sivanathan et al. 2017) • Traffic load (Sivanathan et al. 2017) • Signalling patterns (Sivanathan et al. 2017) • Active and sleep times of equipment (Sivanathan et al. 2017) • Power status (on/off) of equipment (Chieochan, Saokaew, and Boonchieng 2017)	• Cloud servers (Sivanathan et al. 2017)	• WiFi router (Sivanathan et al. 2017)

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Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
2b	Equipment control	• [a] Turning on desktop lamp for users based on environmental conditions (Fortino et al. 2018) • Turning on/off devices (e.g., lights, fans, air conditioner), e.g., based on the role of the detected user and environment condition (Fortino et al. 2018; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008; Chieochan, Saokaew, and Boonchieng 2017; Bellagente et al. 2015; Al Shimmary, Al Nayar, and Kubba 2015) • Limiting access to specific devices right before the load exceeds the CPU load, available memory, and bandwidth (Khabou et al. 2014)	• Light intensity (Fortino et al. 2018) • People's presence in the rooms (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)		• Wearable sensors placed on the wrist, waist, and leg (Fortino et al. 2018) • Users' smartphones for receiving real-time information about the environment and users' conditions (Fortino et al. 2018) • Controlling servers (Fortino et al. 2018) • RFID (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008) • Arduino (Chieochan, Saokaew, and Boonchieng 2017) • Actuators (Bellagente et al. 2015)
2c	Multi-device automatic connection	• Connecting smart boards to multiple classrooms to allow note sharing (Veeramanickam and Mohanapriya 2016)			• Smart boards (Veeramanickam and Mohanapriya 2016)
3a	Individual identification	• Identifying each individual accurately to ensure appropriate service provision, e.g., cashless payments (Majeed and Ali 2018)			• ID cards (Majeed and Ali 2018) • Wristbands (Majeed and Ali 2018)
3b	Individual location identification	• Identifying the users' locations to find the closest empty room to study (Yu et al. 2011) • Locating users and their position at any time period (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)	• Number and locations of empty seats in each room (Yu et al. 2011)		• WiFi (Yu et al. 2011) • RFID (Majeed and Ali 2018; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)
3c	Density analysis	• Identifying high-density areas during specific times, e.g., winter and summer, and presenting the results, e.g., using a heat map (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Yu et al. 2011; Alvarez-Campana et al. 2017)	• Accurate locations of people and staying time based on their devices (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Yu et al. 2011)		• Wireless local area network (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Yu et al. 2011) • User devices, e.g., smartphones (Yu et al. 2011) • WiFi (Alvarez-Campana et al. 2017)

Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
3d	People group identification	• Organizing and maintaining group projects (Doulai 2001) • Providing appropriate tasks for each group based on their requirement levels, e.g., undergraduate and postgraduate students (Doulai 2001)		• Website (Doulai 2001)	
3e	Vehicle parking location recommendation	• Recommending a car parking location (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014; Nie 2013) • Providing car parking information (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Tracking a car (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014)	• Car license plate (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Car position when parking (Ji, Ganchev, O'Droma, and Zhang 2014)	• Cloud application (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • University intranet (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Android mobile app for navigation (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Google map (Ji, Ganchev, O'Droma, and Zhang 2014)	• RFID (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Laser (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Infrared (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Radar (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Ultrasonic (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • Acoustic (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • CCTV (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • GIS (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014) • GPS (Ji, Ganchev, O'Droma, Zhao et al. 2014; Ji, Ganchev, O'Droma, and Zhang 2014)

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Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
3f	Public transportation deployment	• Determining bus stop locations and stopping times (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019)	• Locations of users based on the video surveillance and academic management systems (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019) • Distances to be traveled by users based on the decided bus stop locations (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019)	• Hadoop to store data and run applications (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019)	
3g	Vehicle/people flow monitoring	• Observing and analyzing people flow, including people counting, movement pattern analysis (Alvarez-Campana et al. 2017; Dong et al. 2020) • Extracting key information from the moving people (Dong et al. 2020)	• Places with a higher transit of people (Alvarez-Campana et al. 2017) • People staying time at certain locations (Alvarez-Campana et al. 2017)	• Artificial intelligence (Dong et al. 2020)	• WiFi on users' devices (Alvarez-Campana et al. 2017)
3h	Vehicle/people route recommendation	• Providing a route to reach the best parking lot based on the current situation (Ji, Ganchev, O'Droma, and Zhang 2014) • Showing name of buildings located around the user (Yagol et al. 2018) • Suggesting a route between two places (Trilles et al. 2017)	• Car presence at each parking lot (Ji, Ganchev, O'Droma, and Zhang 2014) • Name of building (Yagol et al. 2018) • The distance from the building to the user (Yagol et al. 2018)	• Car parking mobile app (Ji, Ganchev, O'Droma, and Zhang 2014) • Google map (Ji, Ganchev, O'Droma, and Zhang 2014) • Augmented reality (Yagol et al. 2018)	• RFID (Ji, Ganchev, O'Droma, and Zhang 2014) • Laser (Ji, Ganchev, O'Droma, and Zhang 2014) • Infrared (Ji, Ganchev, O'Droma, and Zhang 2014) • Radar (Ji, Ganchev, O'Droma, and Zhang 2014) • Ultrasonic (Ji, Ganchev, O'Droma, and Zhang 2014) • Acoustic (Ji, Ganchev, O'Droma, and Zhang 2014) • CCTV (Ji, Ganchev, O'Droma, and Zhang 2014) • GIS (Ji, Ganchev, O'Droma, and Zhang 2014; Yagol et al. 2018) • GPS (Ji, Ganchev, O'Droma, and Zhang 2014)
4a	Online class (no specifics)	• Conducting online classes (Hipwell 2014; Halawani and Mohandes 2003)			

Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
4b	Class attendance management	• [a] Automatically recording students' attendance when entering a classroom (Hirsch and Ng 2011; Nie 2013; Hipwell 2014) • Allowing students to join classes remotely using any device, e.g., mobile phones or computers (Hirsch and Ng 2011) • Providing student seat plans in classes to help lecturers to check the absence of the students (Kwok 2015)	• Students' enrolments in the class (Kwok 2015) • Students' photos to help teachers check whether the students are present or not at their allocated seats (Kwok 2015)	• Cloud computing (Nie 2013)	• RFID (Nie 2013)
4c	Automatic phone control in rooms	• [a] Automatically set the users' phones into a specific setting for class when reaching the first tag, e.g., disabled Internet access, turned off Bluetooth, modified call volume, then automatically returning the settings back when reaching the second tag (Caţă 2015)			• RFID to detect the entrance of class participants into the classroom (Caţă 2015) • Near Field Communication (NFC) tags to automatically manage the settings of smartphones of the users (Caţă 2015)
4d	Class activity monitoring	• Recording class activities and sharing them with class participants (Veeramanickam and Mohanapriya 2016) • Detecting fatigue of the students (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020) • Collecting and sharing information on learning activities, time, location, participants, and tasks (Dong et al. 2020) • Observing the psychology of the students during their study (Dong et al. 2020)		• Cloud (Veeramanickam and Mohanapriya 2016) • Face and speech recognition (Dong et al. 2020)	• Smart whiteboard (Veeramanickam and Mohanapriya 2016) • Camera (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020)
4e	Online material sharing	• Allowing students to access materials anywhere and at any time (Hirsch and Ng 2011; Veeramanickam and Mohanapriya 2016; Majeed and Ali 2018; Zhamanov et al. 2017; Kopotun et al. 2020; Doulai 2001)		• Cloud (Hirsch and Ng 2011; Veeramanickam and Mohanapriya 2016; Majeed and Ali 2018; Zhamanov et al. 2017)	
4f	Class material mining	• Mining learning materials from other platforms worldwide based on the students' requirements and sending them to students' devices (Dong et al. 2020)	• Students' real-time knowledge (Dong et al. 2020) • Students' learning records (Dong et al. 2020) • Students' learning preferences (Dong et al. 2020)	•	

Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
4g	Course homepage design	• Generating dynamic course and student homepages without programming (Doulai 2001)			
4h	Interactive course material design	• Presenting book materials interactively in 3D (Dong et al. 2020) • Providing course material accessibility for users with special needs, e.g., with visual, hearing, mobility, and cognition aspects (Dong et al. 2020)	• Information on the objects (Dong et al. 2020) • User requirements related to their experience and satisfaction (Dong et al. 2020)	• Augmented reality (Dong et al. 2020) • Voice-text conversion technology (Dong et al. 2020)	• Course textbooks (Dong et al. 2020)
4i	Practical training	• Assisting students to perform their activities in a simulation of a real situation (as an individual member or in a team) (Prasolova-Førland et al. 2017) • Using virtual laboratories to provide intuitive experience for the students (Dong et al. 2020)	• Tutorial video on how to use the simulation (Prasolova-Førland et al. 2017) • Template/layout of an actual situation (Prasolova-Førland et al. 2017) • Scenario considered during the simulation, including the number of players (Prasolova-Førland et al. 2017) • Historical data on the diseases (Prasolova-Førland et al. 2017)	• Virtual reality (Prasolova-Førland et al. 2017) • Augmented reality (Dong et al. 2020) • Audio (Dong et al. 2020) • Video (Dong et al. 2020)	
4j	Assignment and evaluation	• Providing comprehensive student evaluation scores (academic: class scores, achievements, and non-academic: behavior, communication skills, participation in non-academic activities) (Kwok 2015) • [a] Student evaluation before class (Zhamanov et al. 2017) • Providing a visible evaluation results by students (Zhamanov et al. 2017) • Generating students' knowledge map that predicts their learning achievements (Dong et al. 2020) • Assessing the instructors' teaching performance and suggesting the optimal teaching strategy (Dong et al. 2020)	• Students' scores and information (Kwok 2015)	• Kahoot (Zhamanov et al. 2017) • Google sheets (Zhamanov et al. 2017) • Website (Doulai 2001)	

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Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
4k	Student note sharing	• Enabling ease of data sharing between users (Yu et al. 2011; Veeramanickam and Mohanapriya 2016) • Providing a synchronized update of the classroom notes (Veeramanickam and Mohanapriya 2016)		• Cloud (Veeramanickam and Mohanapriya 2016)	• Bluetooth (Yu et al. 2011; Veeramanickam and Mohanapriya 2016)
4l	Class recommendation	• Recommending courses to students based on their objectives and competencies (Atif, Mathew, and Lakas 2015; Xu et al. 2019)	• Learners' profiles (Atif, Mathew, and Lakas 2015; Xu et al. 2019) • History of joined classes (Atif, Mathew, and Lakas 2015)		• 5G (Xu et al. 2019)
4m	Personalized material generator	• Recording the study progress of each student (Atif, Mathew, and Lakas 2015) • Providing personalized services in a digital library (Baryshev and Babina 2016)	• Student's identification (Atif, Mathew, and Lakas 2015) • Qualifications, certifications, interests, and activities (Atif, Mathew, and Lakas 2015) • Student's preferences, language information, disabilities (Atif, Mathew, and Lakas 2015)		
4n	Remote library resource retrieval	• Allowing users to obtain required library physical resources anywhere (Nie 2013) • Helping students to borrow library books easily (Bueno-Delgado et al. 2012; Halawani and Mohandes 2003)			• GPS used to identify required resources (Nie 2013) • NFC reader and tags (Bueno-Delgado et al. 2012)
4o	Class material security	• Securing online class materials from any leakage and disruption (Dong et al. 2020)	• Enabled devices for the class material sharing (Dong et al. 2020)	• Cybersecurity (Dong et al. 2020)	
5a	Room booking	• Booking a room (Hipwell 2014) • Connecting the booked room to an energy usage report for continuous improvement (Majeed and Ali 2018)			

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Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
5b	Room utilization monitoring	• Providing information on empty seats in a room (e.g., the library) with additional related information, e.g., temperature, level of noise, and air particle concentrations, to evaluate their effects on the study concentration (Alvarez-Campana et al. 2017; Majeed and Ali 2018) • Allocating rooms intelligently (Dong et al. 2020) • Presenting the room utilization statistics (Hentschel et al. 2016; Sutjarittham et al. 2019)	• Number of available spaces, e.g., number of seats (Alvarez-Campana et al. 2017; Majeed and Ali 2018) • Noise level (Alvarez-Campana et al. 2017) • Temperature (Alvarez-Campana et al. 2017) • Air particle concentrations (Alvarez-Campana et al. 2017) • Class timetable information (Hentschel et al. 2016)		• WiFi (Alvarez-Campana et al. 2017)
5c	Automatic room setting	• Setting a room based on the person who enters/exits it (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008; Al Shimmary, Al Nayar, and Kubba 2015)	• People' profiles (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008) • List of connected equipment (e.g., lights, fans, air conditioners, data show) (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)		• RFID (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)
6a	Activity schedule information	• Sending personalized schedule reminders to users before the activities (e.g., students' classes) based on their current positions and moving directions (Hirsch and Ng 2011; Xu et al. 2019; Adamkó, Kãdek, and Kósa 2014; Dong et al. 2020) • Sharing a calendar of class timetables, calendar, announcement, deadlines, faculty members' and staff's open hours (Szabó et al. 2013; Doulai 2001)	• Class timetable (Szabó et al. 2013) • Academic deadlines (Szabó et al. 2013) • Open hours of faculty members and staffs (Szabó et al. 2013)	• Web application (Szabó et al. 2013; Adamkó, Kãdek, and Kósa 2014)	

Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions (a: automatic, m: manual)	Information	Software	Hardware
6b	Activity and time recommendation	• Encouraging social interactions between people (Hirsch and Ng 2011; Yu et al. 2011) • Allowing users to know the current locations and activities of their user friends to motivate them to participate in group studies (Yu et al. 2011) • Forming groups of learners for each specific topic (Atif, Mathew, and Lakas 2015; Kwok 2015; Dong et al. 2020) • Providing real-time information on university facilities and their occupancy information (Yu et al. 2011) • Formulating extra-curricular teams based on comprehensive information on students' activities (Kwok 2015) • Allowing users to subscribe to the notification of activities based on their interests (Szabó et al. 2013) • Providing activity recommendation that could improve the students' academic performance (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020) • Informing planned activities located nearby the users' locations (Adamkó, Kãdek, and Kósa 2014) • Finding possible meeting time slots that are suitable for multiple users (Adamkó, Kãdek, and Kósa 2014)	• Users' locations (Yu et al. 2011; Adamkó, Kãdek, and Kósa 2014) • Users' capabilities (Atif, Mathew, and Lakas 2015) • Real-time photos of the facilities (Yu et al. 2011) • Rank of users based on their activeness in providing information for other users (Yu et al. 2011) • Student's activities (pending and completed ones) (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020)	• K-means clustering to group learners based on their profiles and interests (Atif, Mathew, and Lakas 2015) • Chatbot (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020) • Natural language processing and understanding (NLP/NLU) (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020) • Students' social media (Dong et al. 2020)	• WiFi (Adamkó, Kãdek, and Kósa 2014) • Smartphone (Adamkó, Kãdek, and Kósa 2014)
6c	Programming contest planning and execution	• Conducting a programming contest that shows important knowledge for the users (Adamkó, Kãdek, and Kósa 2014) • [a] Suggesting when the current evaluations are sufficient to measure the participants' skills (Adamkó, Kãdek, and Kósa 2014) • Providing a platform for participants to evaluate the problems to be used as input for the next contest design (Adamkó, Kãdek, and Kósa 2014) • Showing statistics of the results related to the correlation of some data (Adamkó, Kãdek, and Kósa 2014)	• Success rate of each applicant (Adamkó, Kãdek, and Kósa 2014) • List of accepted answers with the following measures: length of source code, required memory, computational time, number of iterations (Adamkó, Kãdek, and Kósa 2014)	• Web application for storing the competition data, solutions, and information about the competitors (Adamkó, Kãdek, and Kósa 2014)	•

Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
6d	Student problem identification	• Predicting students' absence and dropout (Coccoli et al. 2014) • Suggesting individual plan design and curriculum modification to increase the graduation rate (Coccoli et al. 2014) • Cause identification for student's low performance using Chatbot (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020)	• Each individual identification (Coccoli et al. 2014) • Student's history (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020)	• Chatbot (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020) • Cloud computing (Villegas-Ch, Arias-Navarrete, and Palacios-Pacheco 2020)	
7a	Building access	• People's access and controls (Hirsch and Ng 2011; Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Nie 2013; Majeed and Ali 2018; Dong et al. 2020; Bueno-Delgado et al. 2012; Hipwell 2014)		• Facial recognition application (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019)	• Camera to identify people (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019) • Access card to enter rooms based on user permissions (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019) • NFC (Majeed and Ali 2018; Bueno-Delgado et al. 2012) • RFID (Majeed and Ali 2018) • Smart card (Dong et al. 2020)
7b	General attendance checking	• Observing who enters a room and notifying important stakeholders during unwanted situations, e.g., high noise (Caţă 2015; Nie 2013; Majeed and Ali 2018; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008; Bueno-Delgado et al. 2012; Al Shimmary, Al Nayar, and Kubba 2015)			• RFID to detect people who enter a room (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Caţă 2015; Nie 2013; Majeed and Ali 2018; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008) • NFC (Bueno-Delgado et al. 2012)
7c	Surveillance	• Collecting people's existence data (time and location) (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Alvarez-Campana et al. 2017; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008) • Generating reports of activity for each person (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019) • Conducting an emergency response, e.g., finding people in the disaster area based on their devices (Hirsch and Ng 2011; Alvarez-Campana et al. 2017) • Locating a missing equipment and the last person using it (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008) • Observing potential security risks based on real-time object movement tracking and sending an early warning to the security staff (Dong et al. 2020)	People building access data (Villegas-Ch, Palacios-Pacheco, and Luján-Mora 2019; Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)	Artificial intelligence for extracting key information on tracked moving objects (Dong et al. 2020)	• WiFi (Alvarez-Campana et al. 2017) • RFID (Aqeel-ur-Rehman, Abbasi, and Shaikh 2008)

Table 5 Characteristics of each smart campus application (cont.)

No.	Application	Functions ([a]: automatic, [m]: manual)	Information	Software	Hardware
8a	e-wallet	• Performing an electronic payment (Bueno-Delgado et al. 2012; Halawani and Mohandes 2003)	• User profile (Bueno-Delgado et al. 2012) • Accessible services (Bueno-Delgado et al. 2012)		• A simple but integrated identity card (Halawani and Mohandes 2003) • NFC tag and reader (Bueno-Delgado et al. 2012)
8b	Expense reduction simulation	• Forecasting, managing, and scheduling risks in university management to reduce expenses and insurance costs (Coccoli et al. 2014)		• Cloud computing (Coccoli et al. 2014) • Simulation (Coccoli et al. 2014)	
9a	Health monitoring	• Conducting a remote health monitoring (Hirsch and Ng 2011)			
9b	Epidemic alert	• Providing an epidemic alert (Hirsch and Ng 2011)			
9c	Sensor-based waste pickup	• Informing the waste picking up company when garbage bins need to be emptied (Popescu et al. 2016)	• Garbage bin fill level (Popescu et al. 2016) • Garbage bin temperature (Popescu et al. 2016)	• Internet (Popescu et al. 2016)	• GPS (Popescu et al. 2016) • WebCam(Popescu et al. 2016) • Temperature sensor (Popescu et al. 2016) • Weight sensor (Popescu et al. 2016)
10a	Multi-platform sharing	• Conducting asynchronous information sharing on various platforms, e.g., email, bulletin board, forums, newsgroup (Doulai 2001) • Conducting synchronous sharing, e.g., chatting platforms, whiteboard, group browsing (Doulai 2001)	•	• Website (Doulai 2001)	•
10b	Data backup and recovery	• Providing a backup and crash recovery function for the administrator (Doulai 2001)	•	•	•

- *Potential for Combining Operations Research and Machine Learning Techniques for Solving Problems in Smart Campus*
  Most of the studies listed primarily discussed the smart campus concept and its applications, with a focus on machine learning methods. These studies used various approaches to combine operations research and machine learning techniques. Examples include:
  - Implementing machine learning to predict certain data, which is subsequently used as input to solve operations research problem. For instance, predicting factors contributing to high throughput and using this information to optimize a production system (Singgih, 2021).
  - Integrating machine learning-trained operators into metaheuristic algorithm for solving operations research problem (autonomous ridesharing operations) (Bongiovanni et al., 2022). These operators were trained using big data from ridesharing cases.
  - Using machine learning techniques to solve operations research problems, such as reinforcement learning (Madabathula et al., 2025; Mazyavkina et al., 2021). This approach is often used when decisions need to be made quickly while maintaining acceptable quality.

Considering these combinations can help reduce costs (often used to evaluate operational decisions) by leveraging big data and machine learning-based data analysis results.

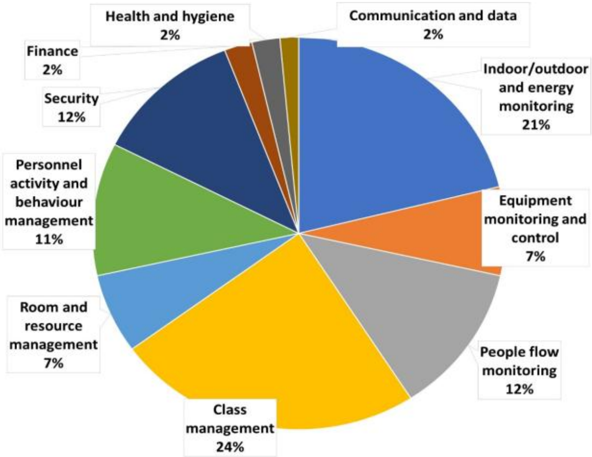

Figure 3 Number of studies for each smart campus topic

5. Transportation Issues in Smart Campus

This section provided a detailed information on transportation problems arising from the listed smart campus topics. Previous studies have shown the importance of addressing operations research issues in smart system, evident in smart manufacturing (Serrano-Ruiz et al., 2022), home appliances (Maurya and Nanda, 2023), and traffic lights (Younes et al., 2023). Moreover, addressing operations research problem is essential to optimize system operations and reduce total costs. Transportation-related studies were selected based on the following reasons, (1) routing problems have been studied with various variants over the years by researchers in the operations research community (Soares et al., 2023), (2) several new solution methods have been proposed in the last decade (Fleckenstein et al., 2023), and (3) transportation is a crucial aspect of sustainability (Mubarak and Rahman, 2020), as emissions from the transportation sector constitute a quarter of total emissions, particularly in Europe (Leviakangas and Ahonen, 2021). Based on these reasons, discussions were limited to the operations research issues related to transportation aspects. Dealing with transportation-related smart campus topics becomes possible due to (1) the advancement of information technology, e.g., online systems with recorded historical data (Handojo et al., 2023; Singgih and Kim, 2020), and (2) the vast development of more efficient optimization techniques (Singgih and Singgih, 2024) and revolutionary machine learning approaches (Singgih and Singgih, 2024). A representative overview of existing studies for each selected smart campus topic was provided, along with the input data, objectives, and decision variables (output) for each topic that follows a basic representation for a mathematical model (Riaventin et al., 2021; Singgih et al., 2021a; 2021b).

5.1. Vehicle Parking Location Recommendation

Parking lots at a smart campus use sensors to collect various data, including air quality and usage (Abdeen et al., 2021). Leveraging the collected data helps to understand parking behavior based on historical data, predict future usage, and optimize selection for vehicle users. An example of decision-making based on the collected data was presented in (Wu et al., 2021).

Operation research problems for parking lot recommendation in smart campus can be described as follows:

- Input data:
    - Utilization of each parking slot (current status, historical data).
    - Historical data on users' recently preferred parking slots.
    - Current users' location and destination (e.g., building, meeting area, classroom).

- Required time to park the car considering the current parking lot congestion level.
- Objectives:
  - Minimizing the total walking distance/time for the users from the parking lot to destination.
  - Maximizing utilization considering potential future parking slot selections and opportunity loss based on users' preferences.
- Decision variables (output):
  - Best candidates for parking lot for the users, with information of their detailed convenience level (travel distance/time, congestion level).

5.2. Public Transportation Deployment

The traditional approach for planning and deploying the movements of public transportation assets relies on static routes and schedules. While these routes may be determined based on historical data of users' movements, the drawback of this system lies in its predetermined routes for the whole day. This rigidity may not allow for optimal utilization of transportation assets based on hourly demand fluctuations. Flexible routes matching the real-time demand of the travelers within the campus are crucial. To achieve this, continuous collection of travelers' data is essential (using WiFi connection established within the campus area or deploying sensors at strategic locations). These route and schedule updates can be easily communicated to users through smartphones.

An illustration of an intelligent transportation system incorporating the considered data was presented in (Cheng et al., 2022; Rojas et al., 2020). The deployment of public transportation could be designed as follows:

- Input data:
  - Current routes and schedules of the same type of transportation assets.
  - Station locations, current routes, and schedules of different types of transportation assets. Examples of different transportation assets within a campus are buses and bicycles. Information on these different transportation assets can complement each other and influence travelers' decision-making.
  - Real-time information on travelers at each station (number of travelers and the estimated waiting time before departure).
  - Congestion levels on roads within the transportation network.
  - Real-time travelers' selection probabilities for different types of transportation assets (Su et al., 2022). This decision is significantly influenced by the current environment (weather, road congestion) and system conditions (movements of transportation assets, transportation assets, breakdowns).
  - Real-time updates on the activities travelers can participate after using the transportation assets.
- Objectives:
  - Minimizing the waiting times of the travelers.
  - Maximizing the deviation between the occupancy level and the transportation assets' capacity. Overcrowded transportation assets reduce the comfort level of travelers.
- Decision variables (output):
  - Updated routes and schedule of the transportation assets.

5.3. Route Recommendation based on Vehicle/People Flow Monitoring

Route recommendations for each person or users' vehicle should be provided based on real-time information on congestion of the area or road network to be traveled. The system can function effectively only when data are collected comprehensively, and algorithms with short computational times are used for route finding. Several routing (rerouting) procedures based on collected data were presented in (Mushtaq et al., 2023; Rahman et al., 2021).

The route recommendation based on vehicle/people flow monitoring results can be described as follows:

- Input data:
  - People and vehicle density in the surrounding area.
  - Scheduled routes of other vehicles passing the area.
  - Historical data of individual travel speeds (estimated values based on period and area information).
  - Users' preferences regarding which facility to pass (or not pass) during the movement.
- Objectives:
  - Minimizing the travel time of the user or vehicle.
- Decision variables (output):
  - Recommended routes for the user or vehicle.
  - Suggested travel speed required to avoid congestion.
  - Users' satisfaction level when traveling through the suggested route, based on the facilities passed.

5.4. Sensor-based Waste Pickup

For waste collection at a smart campus, real-time information regarding waste bin fill levels (weight and volume as shown in (Henaien et al., 2024; Roy et al., 2022; Lozano et al., 2018) is crucial for scheduling effective collecting truck routes. The number of required truck routes can be reduced by ensuring that trucks pick up almost-filled waste bins. This smart system also ensures the comfort level of people on campus, as waste levels impact campus cleanliness and aesthetics (especially when bins are predicted to overflow, leading to waste accumulation outside the bins).

This sensor-based waste pickup process is described as follows:

- Input data:
  - Locations of waste bins.
  - Current levels and predicted fill levels of waste bins.
- Objectives:
  - Minimizing the total travel times of trucks.
- Decision variables (output):
  - Waste collecting schedule (routes and departure times).

5. Conclusions

In conclusion, this study compiled smart campus papers, identifying 43 studies between 2001 and 2020. The surveys were subsequently classified into 10 main classes (each comprising several subtopics), and detailed information on functions, considered information, used software, and hardware was provided. The most frequently discussed topics included class management, indoor/outdoor, and energy monitoring. Moreover, transportation issues relevant to smart campuses were addressed. This study had the following limitations, namely (1) detailed data transfer scheme and their relation to hardware and software for each smart campus application were not included, and (2) recent studies were not incorporated into the review. The following steps were proposed for future studies, (1) formulating each proposed transportation problem, (2) designing the software and hardware required to obtain solutions for each problem, (3) implementing the proposed systems at campus to validate the technologies and ensure stakeholders' benefits, and (4) conducting review without limiting the maximum number of search results to incorporate and analyze more recent studies.

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Author Contributions

Ivan Kristianto Singgih: Data curation, Formal analysis, Investigation, Software, Visualization, Writing – original draft, Writing – review & editing; Aditya Rio Prabowo: Resources, Validation; Stefanus Soegiharto: Project administration, Writing – review & editing; Moses Laksono Singgih: Methodology, Conceptualization, Supervision, Writing – review & editing; Fajar Pitarsi Dharma: Validation.

Conflict of Interest

There is no conflict of interests.

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