Journal of Science and Technology Policy Management

117

Designing the future smart campus: integrating key elements to enhance user experience

Mike Elbertsen, Herman Kok and Negin Salimi
Department of Business Management and Organization, Wageningen University and Research, Wageningen, The Netherlands

Received 19 October 2024
Revised 3 March 2025
16 June 2025
27 July 2025
Accepted 31 July 2025

Abstract

Purpose – The purpose of this study is to define the key design elements necessary for developing a future smart campus that enhances user experience. By integrating advanced technologies such as artificial intelligence (AI), Internet of Things (IoT) and data-driven systems into campus infrastructure, the study aims to explore how these elements can optimize both operational efficiency and user satisfaction. The research focuses on understanding the interrelated factors that contribute to a smart campus environment, with an emphasis on user-centered improvements that address the evolving needs of students, staff and faculty in higher education institutions.

Design/methodology/approach – This study uses a two-phase qualitative research approach to explore the conceptualization of a smart campus and its impact on user experience. In the first phase, semi-structured interviews were conducted with experts in campus architecture, smart technologies and relevant stakeholders. The second phase involved focus groups and ad hoc discussions with campus users to validate and rank key areas identified in the interviews. Data from both phases were analyzed using a coding approach and statistical tests, including the Friedman test and Kendall's W, to examine the significance of user rankings on smart campus design elements.

Findings – The study identifies 12 key areas that enhance user experience on a smart campus, with workplace availability and findability, energy efficiency and indoor climate comfort being the highest-ranked by users. Participants emphasized the importance of real-time data systems for space management and sustainability, as well as the need for user-friendly technologies. While advanced technologies like robotics and virtual reality were less prioritized, the study highlights that integrating intuitive systems and continuous feedback mechanisms can significantly improve campus efficiency and user satisfaction. The findings suggest a balance between immediate practical solutions and long-term technological advancements for future smart campuses.

Practical implications – This study offers valuable insights for university administrators, campus facility managers and policymakers aiming to develop smart campuses. The findings emphasize the importance of a user-centered approach, transparent communication and continuous improvement when integrating smart technologies into campus infrastructure.

Originality/value – This study offers a unique, user-centered approach to smart campus design by focusing not only on technological integration but also on enhancing user experience through practical, data-driven solutions. It bridges the gap between operational efficiency and user satisfaction, emphasizing the importance of real-time data use and intuitive systems. Unlike previous research, which often concentrates on isolated technologies, this study provides a comprehensive framework for how interconnected design elements can work together to create a responsive and efficient campus environment, making it valuable for universities seeking to implement future-focused, sustainable smart campus solutions.

Keywords Smart campus, User experience, Facility management, User-centered design, Campus infrastructure

Paper type Research paper

Journal of Science and Technology Policy Management
Vol. 16 No. 10, 2025
pp. 117-137
Emerald Publishing Limited
2053-4620
DOI 10.1108/JSTPM-10-2024-0414

1. Introduction

Modern universities are complex organizations that provide a diverse range of student-facing services, activities and roles for users to engage with. Most universities are situated on campuses designed as well-organized spaces with high-quality infrastructure conducive to education and research (Dong *et al.*, 2016). Historically, the primary role of university campuses has been to create supportive environments for teaching and learning, as research indicates that when students feel supported, their engagement and academic outcomes tend to improve (Azevedo, 2015; Gilboy *et al.*, 2015).

In this study, the term user refers to individuals who interact with the university campus environment, including students, academic staff, non-academic employees and other stakeholders using campus facilities and services. This definition aligns with the perspective that a smart campus involves various stakeholders such as students, instructors, parents and management teams, each with distinct roles and expectations (Dong *et al.*, 2020).

Recently, there has been a growing focus on enhancing the overall campus experience for users, ultimately aiming to boost user satisfaction (Lowe and Wright, 2024). A well-designed campus positively influences students' satisfaction and academic performance, and it is essential to recognize that this environment comprises interconnected design elements, including physical spaces, facilities, services and ambient conditions tailored to meet users' needs (Bitner, 1992; Kok, 2015). The user experience is significantly shaped by interactions with these design elements in the context of a (smart) university campus, as described by Pullman and Gross (2004) and Hume *et al.* (2006).

As global priorities shift toward improving user experience in higher education, there is a growing emphasis on usability as a crucial component (Kim *et al.*, 2013; Rasila *et al.*, 2010). Enhancing usability involves not only making resources accessible but also ensuring they effectively support users in achieving their goals. The concept of a smart campus presents opportunities to enhance user experience and educational performance through the optimization of existing infrastructure, incorporating technology for a user-friendly and efficient environment (Dong *et al.*, 2020).

Smart technologies, which include advanced information and communication technologies (ICT), artificial intelligence (AI) and the Internet of Things (IoT), are integral to this transformation (Abuarqoub *et al.*, 2017; Baldassarre *et al.*, 2018; Xu *et al.*, 2019; Valipour Parkouhi *et al.*, 2024). These technologies enable the integration of data from various sensors and devices, optimizing resource allocation and improving decision-making (Cheong and Nyaupane, 2022). Yet, equipping a university campus with smart technologies does not inherently make it "smart". A campus becomes smart when these technologies work together in an interconnected way to optimize the use of campus resources (Alrashed, 2020; Das *et al.*, 2022; Marques *et al.*, 2023).

While previous studies on smart campuses have predominantly focused on technological advancements, operational efficiency and sustainability (Alrashed, 2020; Cheong and Nyaupane, 2022; Das *et al.*, 2022; Huang *et al.*, 2019; Sutjarittham *et al.*, 2019), limited attention has been given to understanding how these technologies can be integrated into campus infrastructure to enhance the overall user experience. Also, existing frameworks often emphasize individual technologies without considering their interrelation or alignment with user needs (Dong *et al.*, 2020; Omotayo *et al.*, 2021). This study contributes to filling this gap by adopting a user-centered approach that identifies not only the key design elements of a smart campus but also how these elements interact to create a cohesive, user-friendly environment.

By bridging the gap between technological potential and user-centered implementation, this study provides practical recommendations for university administrators, facility managers and policymakers. It emphasizes the importance of a clear vision, open communication and continuous feedback loops to ensure that smart campus initiatives remain user-driven and adaptable to evolving needs. This focus on enhancing user experience through integrated design elements distinguishes this study from prior research and offers a valuable framework for future smart campus development.

The structure of this paper is as follows: Section 2 presents the relevant literature on smart campuses and user experience. Section 3 outlines the methodology used in the study, including the two-phase qualitative research approach. Section 4 describes the main findings derived from expert interviews and user validation. Section 5 discusses these findings in relation to existing literature. Finally, Section 6 provides the conclusion, integrates the theoretical, practical and societal implications, addresses limitations of the study and offers directions for future research.

2. Literature review

2.1 Smart campus

The built environment alone is no longer sufficient for universities to achieve their goals; a smart campus could offer a viable solution (Dong *et al.*, 2020). A smart campus differs from the traditional campus primarily through the incorporation of advanced technologies. The term "smart" in the context of a smart campus refers to self-monitoring, self-analyzing and self-reporting technologies that integrate data from various sensors, devices and networks to optimize resource allocation, improve decision-making and enhance the overall user experience within the campus environment (Cheong and Nyaupane, 2022). These technologies typically include advanced ICT, AI, smart devices, the IoT (Abuarqoub *et al.*, 2017; Baldassarre *et al.*, 2018), cloud computing, 5G networks (Xu *et al.*, 2019), immersive technologies such as augmented reality (AR) (Chen *et al.*, 2017; Santos *et al.*, 2014) and virtual reality (VR) (Dong *et al.*, 2020). The interconnected application of these technologies aims to improve both operational efficiency and the user experience across various campus services.

Recent literature highlights additional technological innovations that further enrich the campus environment. Ahmed *et al.* (2020) identified key components essential to a smart campus, such as "smart transportation", "security and safety", "analytics data centers", "smart facility services", "smart classrooms" and "energy management". These components are designed not only to optimize space usage and resource allocation but also to enhance campus accessibility and improve the overall educational experience. Furthermore, technologies like drones, robots and smart lamp posts are increasingly integrated into smart campus systems, further enhancing both functional and experiential aspects (Ahmed *et al.*, 2020).

While the application of such technologies in smart campuses is typically driven by technological innovation, the core mission of universities is to deliver educational services. Thus, the integration of these technologies should primarily focus on improving the learning experience and educational outcomes (Dong *et al.*, 2020). This user-centered approach is central to the design of the smart campus, which should focus on enhancing the experience for students, staff and faculty while simultaneously improving the overall educational performance of the institution (Dong *et al.*, 2020). According to Dong *et al.* (2020), a human-centered, learning-oriented approach should be adopted when designing a smart campus to meet both the technological and educational needs of its users.

Moreover, the increasing number of students and the growing demand for flexible, hybrid and blended education models are requiring universities to adapt by integrating smart technologies. Challenges such as overcrowded classrooms, underused spaces and the demand for physical meetings are becoming more pressing (Teufer, 2021). In addition, issues like the reservation of spaces without actual use can be mitigated through smart technologies. For instance, sensors that track space usage and provide feedback to campus systems can help address these inefficiencies (Valks *et al.*, 2016). This points to a gap in current research, where technological innovations often focus on operational efficiency but fail to address the practical, day-to-day challenges students and staff face in using campus spaces.

Recent studies underscore the significance of smart campus initiatives in higher education, each focusing on different aspects of sustainability and user experience. Research from Delft University of Technology, for instance, explored optimizing space use through smart tools, revealing that while universities aim to enhance space effectiveness, their approach often remains limited to immediate management challenges rather than innovative future solutions (Valks *et al.*, 2018). A systematic review of smart energy systems in UK institutions identified pathways toward achieving net-zero carbon emissions by integrating smart building principles. However, this primarily emphasized energy systems and operational efficiency, neglecting user experience and broader campus integration (Kourgiozou *et al.*, 2021).

In a different context, a comparative study of green campus paradigms in Malaysian universities developed a policy framework aimed at improving collaboration among sustainability practitioners. Despite recognizing the importance of green practices for sustainability, the study highlighted that inadequate interdisciplinary collaboration hinders effective implementation (Anthony Jnr, 2021).

Recent studies have emphasized the need for smart campus initiatives to align not only with technological innovation but also with inclusive, user-centered planning approaches that account for both local and global educational contexts. For example, Domínguez-Bolaño *et al.* (2024) explore smart university transformations across Europe, highlighting the role of co-creation and service design in achieving sustainable outcomes. Similarly, comparative empirical studies demonstrate that human-centered digital environments must be adaptable, inclusive and responsive to evolving pedagogical and cultural needs. For instance, Gomes *et al.* (2016) analyzed multiple university pilots in Lisbon, Helsinki, Luleå and Milan, revealing critical interactions between users and energy management systems within European smart campuses. Likewise, research on Hong Kong's smart university ecosystem underscores the importance of bottom-up, humanistic design principles in delivering adaptive and equitable learning infrastructures (Zhang *et al.*, 2020). These studies align with socio-technical systems theory by illustrating how social and cultural dynamics shape the success of smart campus implementation.

Integrating service design methodologies such as journey mapping and persona building has also been shown to enhance stakeholder engagement and improve the relevance of implemented solutions (Palumbo and Manna, 2018; Sanders and Stappers, 2008). In addition, comparative studies across European and Asian smart campuses reveal diverse implementation strategies, suggesting that cultural, infrastructural and regulatory contexts significantly shape smart campus design (Cheong and Nyaupane, 2022). These global findings support the need for contextualized, user-driven frameworks.

Viewing the smart campus as a service ecosystem (Barile and Polese, 2010) also enables researchers and designers to emphasize interdependencies between digital infrastructure, institutional goals and user experience. This perspective, widely adopted in smart city research, is increasingly being applied to campus development (Valks *et al.*, 2021).

While these studies provide valuable insights into smart campuses and sustainability, this research builds on this foundation by adopting a more comprehensive approach. By focusing on the interrelated design elements that enhance user experience, this study addresses operational efficiency while prioritizing advanced technologies like AI and real-time data systems within the smart campus framework. This user-centered approach ensures that the campus environment is not only efficient but also engaging and responsive to user needs, bridging the gap between sustainability goals and user satisfaction.

2.2 User experience

User experience (UX) refers to the interactions users have with a product, service or environment, in this case, the university campus. An experience is defined as "any sensation or knowledge acquired from interacting with the elements created by the service provider" (Pullman and Gross, 2004). The user's interpretation of these interactions shapes their overall experience, which is critical for institutions aiming to improve the satisfaction and success of their users (Hume *et al.*, 2006). The design elements that influence user experience in a campus setting are diverse and include the physical environment, facilities, services and ambient conditions (Bitner, 1992; Pine and Gilmore, 1999; Zomerdijk and Voss, 2010). These elements combine to form the user journey, which encompasses all user interactions and the accompanying feelings and attitudes (Matus *et al.*, 2021; Zomerdijk and Voss, 2010).

Vischer (2008) argued that the built environment should be designed with the user in mind, supporting their functional, psychological and emotional needs. A user-centered approach is thus essential for improving user satisfaction and overall experience. Vischer (2008) presents a framework for assessing user experience, emphasizing that the built environment's effectiveness can be enhanced by offering comfort, both physical and psychological. This framework underscores the importance of usability in creating a user-friendly environment, which Kim *et al.* (2013) define as the extent to which a product or service enables users to achieve their goals effectively, efficiently and with satisfaction.

While research on user experience often focuses on usability in physical spaces, the role of smart technologies in optimizing user experience is increasingly significant. Smart technologies can improve effectiveness and efficiency by collecting real-time data, providing insights into space usage and enabling responsive systems that cater to the users' evolving needs (Dong *et al.*, 2020). However, research addressing the integration of such technologies with user experience on smart campuses is still limited, especially in terms of how these technologies enhance student well-being, mental health and academic success. Recent studies, such as those by Kahu and Nelson (2017) and Tight (2020), highlight the growing importance of the student experience beyond academic achievement, emphasizing the need for universities to support student mental health and overall well-being.

Recent literature also expands the concept of user experience in smart environments to include emotional, cognitive and social dimensions. For instance, Zhang *et al.* (2020) argued that a smart campus should provide inclusive, responsive and personalized experiences that support learning and well-being. Similarly, Gomes *et al.* (2016) demonstrate the importance of designing user interfaces and energy systems that accommodate diverse student populations, including international and accessibility-needing users. These studies align with the increasing call for user experience research in educational spaces to incorporate principles of digital well-being, human-centered AI and participatory co-design (Sanders and Stappers, 2008).

A pleasant and well-designed campus environment can greatly contribute to users' satisfaction, which in turn can enhance their engagement and retention (Baik *et al.*, 2019; Hutchinson, 2003; Sujata, 2014). Thus, universities should prioritize not only academic success but also the holistic well-being of students. This necessitates a deeper integration of smart technologies that can address both educational and social needs, supporting students' mental health and fostering a sense of community (Lowe and Wright, 2024; Strayhorn, 2018).

The design and operation of smart campuses can be examined through *socio-technical systems theory* (STS), which emphasizes the interrelationship between people (the social system) and technology (the technical system). STS theory suggests that the success of technological implementations, such as smart campus initiatives, depends on both the technical infrastructure and how users interact with these technologies (Bostrom and Heinen, 1977). By applying STS, this study highlights the necessity of integrating user-centered design principles with technological innovation, ensuring that smart technologies not only optimize campus functions but also enhance the overall user experience.

3. Methods

The research was conducted on behalf of the facilities department of Wageningen University and Research (WUR), a globally top-ranked institution in The Netherlands. WUR is among those institutions struggling to envision the future of their smart campus. This study used a two-phase qualitative research approach.

The first phase of qualitative research in this study involved conducting semi-structured interviews with experts on the smart campus concept. These interviews aimed to explore key themes identified in the literature and gain deeper insights from experts regarding their views on smart campus development. The semi-structured format allowed for flexible yet focused discussions, enabling participants to elaborate on topics they deemed most relevant. Specific questions were designed to gather perspectives on how smart technologies can enhance user experience in various campus spaces, such as educational areas, laboratories and informal collaboration zones. Participants were also asked to identify essential smart technologies and other decisive elements for campus design. This approach allowed for a comprehensive exploration of smart campus indicators and their potential impact on both functionality and user experience.

Participant selection followed a purposeful sampling approach, ensuring that interviewees possessed expertise in areas relevant to smart campus development. To qualify, participants needed to demonstrate substantial knowledge in fields such as campus architecture, specific smart technologies or stakeholder perspectives within the Wageningen campus ecosystem. While many participants were affiliated with WUR, inclusion was not limited to WUR employees. To enrich the study with external perspectives, a few non-WUR respondents with expertise in smart technologies and campus innovations were also invited.

Given WUR's diverse fields of expertise, priority was given to experts in AI, Data Science and technology-related disciplines. According to Bekele and Yohannes (2022), a qualitative study typically includes 6–12 interviews to achieve sufficient depth. Following this guideline, 11 expert interviews were conducted, after which data saturation was reached, indicating that additional interviews were unlikely to yield new insights.

Expert participants were pre-selected based on their expertise and invited via email to participate in the study. Upon agreeing to participate, interview dates were scheduled. Prior to each interview, participants received a consent form outlining the study's purpose, the intended use of their data and their right to withdraw from the study at any time.

The second phase used a qualitative approach to validate expert-proposed key areas through discussions with WUR campus users. A focus group ranked these areas by importance and discussed their reasoning. Participants were also encouraged to introduce new topics for additional insights. In addition, ad hoc mini focus groups with random individuals on campus were conducted to broaden the range of input and enhance representativeness. These discussions provided valuable insights into the reasoning behind participants' rankings.

To gather diverse perspectives, this phase aimed to include various WUR campus users, though engaging academic staff was challenging. The focus group included 4 students and 1 non-academic employee, while the field study involved 29 students and 1 non-academic employee. Participants were randomly selected after expressing interest, recruited via researcher networks, WUR Facilities and Services and promotional efforts through WUR buildings, apps and newsletters. For the field study, individuals were approached for brief, ad hoc discussions. A structured guide ensured consistency, covering 12 predefined themes and allowing for exploration of additional topics.

Participants in the focus group and field study ranked the key areas that emerged from phase 1 by importance using a card-sorting method, followed by a researcher-facilitated discussion to explain their rankings. Interviews, focus groups and field studies were conducted face-to-face in English or Dutch. Interviews lasted 75 min, focus groups 120 min and field studies 5–10 min. All but the field studies were recorded, transcribed and analyzed using a three-phase coding approach: open coding to identify concepts, axial coding to group them into categories and selective coding to refine these into key constructs.

The focus group and field study rankings were analyzed using the Friedman test and Kendall's W test to investigate whether respondents' opinions differ from each other. The Friedman test indicates whether there is an overall statistically significant difference between the mean ranks of raters. Kendall's Concordance Coefficient W quantifies the level of agreement among multiple raters, ranging from 0, no agreement to 1, perfect agreement.

4. Results

This section presents the results from the expert interviews, followed by the results from the focus groups and field study. The expert interviews, regarded as the primary method for exploring the conceptualization and development of a smart campus, provide the foundational insights upon which the subsequent phases of the research are built.

4.1 Findings phase 1: expert interviews

A total of 11 expert interviews were conducted, achieving data saturation as per the guidelines of Bekele and Yohannes (2022). An overview of the 11 interviewees' backgrounds is provided in Table 1. The discussions explored the concept of a smart campus and its potential

Table 1. Experts' background

Expert	Role	Affiliation	Organization
E1	Senior teacher facility management (FM)	Provides courses "smart FM" and "service design"	HAN*
E2	Solution director	Focus area university campus	Planon**
E3	Global product strategy director	Focus area smart technologies	Planon
E4	Policy officer quality and strategic information	University schedule and needs of students and teaching staff	WUR
E5	Professor AI and data science	AI and data	WUR
E6	Employee knowledge valorization	AI and added campus value	WUR
E7	Product owner network services and datacenter management and storage solutions	Smart technologies, smart buildings	WUR
E8	Policy officer CREFM***	PhD on smart campus	TU delft****
E9	Program director	Often involved in campus development	WUR
E10	Head integral facility management	Main focus on user experience and bringing multiple solutions together	WUR
E11	Head location facilities	Main focus on serving campus user	WUR

Note(s): *HAN University of Applied Sciences; **Worldleader in FM and building software; ***Corporate Real Estate and Facility Management; ****TU = Technical University
Source(s): Authors' own creation

to improve user experience, resulting in 24 codes. These codes were then organized into categories covering both conceptual definitions and practical implications (see Table 2).

Experts view "smart" as a marketing term, but clarified that it means performing tasks more intelligently. It involves creating systems that actively respond to their environment by measuring and interpreting conditions. Smart technologies should also be minimally invasive, operating seamlessly in the background.

A smart system collects data from its environment and uses it to achieve specific goals. For example, a coffee machine with a sensor alerts when beans are low; the "smart" aspect lies in using data to prevent running out. This aligns with Cheong and Nyaupane (2022), who highlighted how self-monitoring, self-analyzing and self-reporting create intelligent systems. In this context, data becomes actionable insights, managed by humans or automated systems. Experts defined a "smart campus" and its key elements, goals and development approach during the interviews. Table 3 summarizes these characteristics, which were identified through axial coding, grouping related codes under each characteristic.

Experts define a "smart campus" as a university with interconnected smart buildings where hardware, software, services and infrastructure work together seamlessly, mostly in the background, to enhance user experience. The focus is on optimizing operations for efficiency, with the effective application of technology being key. This aligns with research by Alrashed (2020), Das *et al.* (2022) and Marques *et al.* (2023), highlighting that a smart campus results from strategic, user-centered use of technology, not merely adding advanced tools. Experts emphasize that developing a smart campus requires considering long-term

Table 2. Coding tree

Category	Code(s)	*n*
Definition smart	Definition smart	20
	Term for smart	1
Definition smart campus	Definition smart campus	45
	Approach	41
	Vision on smart campus	24
	Communication	22
	Goal of smart campus	21
	Perspective on smart campus	20
	Smart technologies	11
	Interrelated and interactive system	11
	Functionality	8
	Change of campus in the future	4
	New contracts	3
	Digital strategy	3
	Safeguards	1
Key areas	Applying smart technologies	175
	User needs	17
	Workplaces	12
	AI	7
	Educational spaces and labs	5
	Front desk	3
	Coffee (corner)	2
	Printing	1
Pitfalls smart campus	Bottlenecks/pitfalls	39

Note(s): *n* indicates the frequency of each code
Source(s): Authors' own creation

Table 3. Smart campus characteristics

Smart campus characteristics	Expert
User oriented	All
Consists of (smart) infrastructure (hardware, software)	All (except E9)
Runs (mostly) on background	E1, E2, E3, E4, E7, E8, E9, E10, E11
Uniform	All
Interrelated	E1, E2, E3, E4, E6, E7, E8, E9, E10, E11
Social interaction / social hub	All
Enhance efficiency	E1, E2, E3, E7, E8, E9, E10, E11
Broad audience	All
Collects data	E1, E2, E3, E7, E8, E9, E10, E11
(Pro-)interrelated and interactive system	All

Source(s): Authors' own creation

goals and diverse user needs. Technologies should be intuitive, allowing users to function without difficulty. If a technology is too complex, experts question, "Is this really smart?"

Moreover, a smart campus should serve as a social hub, fostering spontaneous interactions and aligning with the university's mission. Effective resource use is key, with the focus on how data improves user experience, not just the technology itself. One expert noted, "If we don't use the data correctly, we have a dumb campus" (E10). Effective data use should be predictive, enabling proactive, data-driven campus management. One expert described a smart campus as "a collective environment of interconnected smart buildings" (E1), while another noted that "users shouldn't notice background operations" (E4). Other experts emphasized that "smart is about efficiency and responsiveness" (E2 and E3), "with systems helping users seamlessly, like ensuring the coffee machine works and the printer always has paper" (E7).

4.1.1 Goals of smart campus. Experts indicated that a smart campus should aim to achieve specific goals, primarily focusing on improving operational efficiency, enhancing user experience or both. Table 4 lists the possible goals of a smart campus and, motivation to achieve each goal.

To develop a smart campus, experts recommend a user-oriented, bottom-up approach, listening to users ($n = 5$) and identifying key areas and design elements for improvement ($n = 4$). Establishing a clear vision with goals ($n = 4$) and maintaining open communication with users, including feedback, is essential ($n = 4$).

E4 described a workplace sensor that cancels reservations if unoccupied for 30 min, which can cause user dissatisfaction if not communicated properly. E1 suggested better communication from the facility department about services and new implementations to keep users informed. In addition, real-time data could introduce new contract models like pay-per-use. This aligns with facility marketing literature, which stresses the importance of communicating environmental achievements and operational improvements to enhance user experience (Bhatt *et al.*, 2021; Friday and Cotts, 1994). E7 noted that users can optimize campus use while generating data to inform long-term decisions, like building new facilities or renovating.

4.1.2 Key areas for enhancing user experience. Experts identified key areas to enhance user experience in smart campus development, using both smart technologies and improved traditional elements. These areas include visible features like canteens, front desks and workplaces, as well as indirect factors like indoor climate and energy efficiency, all of which

Table 4. Goals of smart campus

Main goal	Sub-goal	Motivation
Enhance efficiency	Energy efficiency ($n = 5$)	Boosting energy efficiency through sensors, resulting in being more efficient in resources and financial savings
	Efficient in operations/ services ($n = 5$)	Data provides a foundation for managing operations and services in a more efficient way. E.g. data provides a more solid base for decision-making than just “guess work”
	Boost productivity ($n = 4$)	Technological advancements can contribute to creating a better environment, taking over work that can be done through e.g. a digital assistant for boosting productivity
	Compliance in regulations ($n = 2$)	Data can provide accurate information for compliance on regulations
	Financial savings ($n = 4$)	E.g. Data can help in decision making for example better utilization of rooms instead of building a new building, can contribute to efficiency of resources, energy, operations for cost savings
	Data-driven decision making ($n = 5$)	Data provides foundation for decision making
Enhance user experience	User-based ($n = 9$)	(Smart) technologies should have the purpose to serve the user and the user experience (when implementing new technologies)
	Innovative ($n = 4$)	Implementing advanced smart technologies creates an inspiring environment that fosters innovation and can help attract new students and employees, complementing other factors like educational quality
	Increase satisfaction ($n = 5$)	Smart campus should provide a foundation to use campus in a better way to boost satisfaction of campus users
	Increase wellbeing and provide a comfortable surrounding ($n = 8$)	Indoor air quality can be regulated more efficient for a better wellbeing, and services through pro-actively reacting to data
	Collect feedback users ($n = 4$)	For enhancing user experience feedback of users is of importance, a feedback tool can be placed in interactive screens (for example, in a booking system next to the rooms door)
Enhance efficiency and user experience	Collect data ($n = 8$)	Collect data for the goals named in this table to create an efficient and user-oriented environment
	Reduce ecological footprint ($n = 3$)	According to the experts, campus users value this aspect, reducing footprint will therefor also contribute to enhancing experience

Note(s): *n* indicates the number of experts who mentioned each sub-goal
Source(s): Authors’ own creation

significantly affect the user experience. The explanation of the 12 key areas is presented alphabetically:

(1) Canteen. Experts suggested canteens provide detailed information on food, like nutrients and allergens and offer healthier options. E1 proposed a system where users can scan their phone at the register when paying to see nutritional info via an app. Experts also recommended showing waiting times for campus eateries, ideally integrated with an app displaying room availability and campus crowdedness.

(2) Digital front desk. Experts discussed adding digital front desks for remote campus locations, such as a tablet or screen for video calls with staff. More advanced options could include digital kiosks for information access. However, in larger

buildings, digital kiosks would complement existing front desks, as staff provide essential services like social control, emergency response and equipment lending.

(3) Digital twin and VR. Experts highlighted the value of a digital twin, a virtual replica of a physical object, system or process used to simulate and optimize real-world systems, for managing campus crowdedness, environmental conditions and infrastructure like heating, ventilation, and air conditioning (HVAC). They also noted the potential of VR for immersive simulations, allowing students to perform tasks like dissections or handling hazardous materials digitally, reducing costs and increasing accessibility.

(4) Energy efficiency. Experts suggested optimizing energy efficiency with sensors providing real-time data, combined with automated controls for heating, cooling and lighting. This leads to cost savings and sustainability benefits, and communicating these efforts to users enhances their experience.

(5) Indoor (climate) comfort. Experts recommended using sensors and automation to regulate temperature, humidity, CO_2 and noise levels for optimal indoor comfort. Data could guide users to spaces that meet their preferences, like warmer or quieter areas.

(6) Interrelated and interactive system. Experts stressed the importance of an interconnected system using sensors to detect and respond to conditions. For example, sensors could trigger refills for coffee machines or maintenance for printers. Such systems could either signal services to act or make autonomous adjustments based on data.

(7) Nudging. Experts saw potential in nudging – subtle environmental cues influencing behavior without restricting freedom. While not inherently smart, nudging could help manage crowdedness, workplace availability and energy use. For example, nudges in room reservation systems could suggest off-peak times to optimize space utilization.

(8) On-campus mobility: Experts see on-campus mobility as crucial for enhancing the smart campus experience, with significant potential to improve user satisfaction. These items include: wayfinding (n = 10), easy navigation through clear indoor signs and a digital campus map app, ideally integrated with a booking system; people finder ("FindMe") (n = 9), finding and connecting with people on campus. A system integrated with room reservations and wayfinding, while complying with privacy regulations, could allow users to share their location via a university app; parking (n = 8), finding available parking near preferred buildings, for both cars and bikes. Ideally, this information should be visible in the wayfinding app; crowdedness (n = 8), displaying campus crowdedness, can help users choose suitable spots and distribute activity across buildings. This data also enables predictive scheduling in the future; and external mobility (n = 5), lendable bikes unlocked via app or student card and self-driving vehicles for transport on and off campus could optimize movement between buildings.

(9) Robotics. Experts discussed using robots for tasks like cleaning, catering and front desk operations. They see potential in robots for non-critical tasks, such as floor cleaning or collecting dishes. However, current technology is not advanced enough for significant impact. Experts stressed robots should enhance workflows, not serve as novelties, citing a failed pilot with a welcoming robot.

(10) Safety detection. Experts, especially R8, emphasized opportunities for smart safety systems like movement sensors, accident detection and emergency response. E7

gave an example of sensors warning drivers about nearby cyclists or pedestrians, enhancing safety at intersections.

(11) Virtual assistant. Experts highlighted AI advancements, like AI-based chatbots, for virtual campus assistance. Chatbots could answer educational queries, provide lecture notes, assist with room bookings and integrate with systems like Brightspace. They could be accessible via the university website, intranet or kiosks.

(12) Workplace. Workplace availability, including individual, collaborative and meeting spaces, was a key theme in expert interviews. Experts stressed the importance of managing these spaces, especially in an activity-based workplace concept, with E8 highlighting the challenge of finding available workspaces as a major issue in campus facility management. Experts suggest all workplaces on a smart campus should be easily findable with a unified booking system (n = 9). Users should access a single app to view room/workplace availability (n = 11), book spaces and navigate. Displays outside rooms should also show availability and booking info. Experts (n = 5) stress the importance of designing flexible spaces for a smart campus, such as using removable walls to adapt to changing needs. This flexibility is crucial as hybrid working reduces traditional space use. R8 highlights the potential for synergy between businesses and the university, suggesting a shared system for space availability to optimize use across campus buildings. It was also indicated that users prefer some autonomy over their environment, such as adjusting light, temperature or blinds (n = 4). This is feasible in smaller spaces like group rooms or focus pods, but not in larger areas like lecture halls or libraries due to differing preferences.

4.1.3 Challenges in developing a smart campus. Experts identified potential pitfalls in developing a smart campus, as outlined in Table 5. These concerns, raised by multiple experts, highlight issues in design and decision-making. Experts emphasized the importance of addressing these challenges, particularly ensuring digital systems are accessible to users of all ages and tech proficiency. Poorly designed systems could lead to frustration and hinder the user experience, echoing findings by Kim *et al.* (2013) and Rasila *et al.* (2010), who highlight the critical role of usability. As E10 noted, "Do it right, or don't do it at all."

Experts caution that data should be interpreted carefully, considering context. For instance, a 60% full classroom might be fully used if students need more space. Human interaction is valued, so automating service roles should be considered thoughtfully to avoid harming the user experience. Also, transparency in data collection is essential to address privacy concerns, with clear communication helping to ease user resistance.

4.2 Findings phase 2: user validation

In the second phase, a focus group of four students and one non-academic employee ranked the 12 key areas for enhancing user experience through smart campus development identified in the first phase. In the field study, 30 participants (29 students and 1 non-academic employee) also ranked these key areas in ad-hoc mini focus groups. The Friedman test and Kendall's W test were used to analyze the rankings provided by participants. The results are presented in Table 6.

Results from the Friedman test showed there was a statistically significant difference in how participants ($N = 35$) ranked the importance of the 12 key areas, $\chi^2(11) = 115.708$, $p < 0.001$. Key area workplace ($\bar{X}$ = 3.80) was ranked as the most important, and robotics ($\bar{X}$ = 9.57) was considered least important. The Kendall W test indicated Kendall's $W = 0.301$, $\chi^2(11) = 115.708$, $p < 0.001$. This result suggests fair agreement among participants' rankings.

Table 5. Pitfalls of implementing a smart campus

Smart campus pitfalls	Description
User-friendly technology design ($n = 8$)	Experts stress that campus technologies must be intuitive and user-friendly to ensure accessibility for all users. As E1 noted, “Users don’t always know how to use the systems, and that can be frustrating”
Digital security and infrastructure protection ($n = 7$)	Experts agree that a smart campus must prioritize the security of digital networks, technologies and data. E7 highlights secure access controls and backup systems for malfunctions or hacks. As E6 noted, “As long as it is secure”
Data management and insights ($n = 4$)	E1 notes that sensors generate vast data, and experts highlight the challenge of turning it into actionable insights. Careful consideration of data resolution is crucial, whether it shows, e.g. general availability or detailed individual spaces
Limitations of data-driven decision-making ($n = 5$)	Experts stress that decision-making should not rely solely on data, as it may not capture the full picture. For example, cleaning needs vary, as E7 noted, “One person can make a toilet dirtier than 200 others”. Similarly, space needs differ depending on the use purpose
Data integrity ($n = 2$)	E1 notes that users can intentionally deceive sensors, leading to inaccurate data.
Addressing user resistance and concerns ($n = 6$)	Experts warn that smart technologies may face user resistance due to privacy concerns, highlighting the need for transparent communication. Poorly implemented concepts like activity-based working can cause frustration, leading staff to prefer working from home. Over-digitalization of education may also prompt students to question the value of their tuition fees, as noted by E7
Technology implementation strategy ($n = 6$)	Poorly implemented or unsuitable technologies can harm user experience. It’s essential to first ask, “Will this enhance user experience?” before investing in new smart solutions
Inclusive design ($n = 6$)	A smart campus should be broadly accessible to all users, accommodating different generations. While addressing every individual’s needs in detail is not feasible, finding a balance that serves everyone is essential
Technology overload ($n = 5$)	Overloading users with too many systems, apps or technologies, such as multiple screen-sharing setups, can cause frustration and diminish the user experience.
Human interaction vs automation ($n = 7$)	Experts stress that human interaction is vital on a smart campus, and replacing roles like front desk staff or cleaners with digital solutions may not always improve user experience

Note(s): *n* indicates the number of experts who mentioned each pitfall
Source(s): Authors’ own creation

Most participants agreed that workplace findability and availability were crucial. They expressed frustration over the lack of available spaces, suggesting that a system for real-time availability, reservations and canceling unused bookings could improve user experience. Energy efficiency, ranked second in importance ($\bar{X}$ = 3.86), had fewer concrete suggestions. Participants supported automating energy-saving measures like sensor-based temperature control and switching off lighting and climate systems in unused spaces, driven by sustainability values. Indoor climate comfort ($\bar{X}$ = 4.57) ranked third, with participants suggesting an interactive system for temperature control. They valued some autonomy, proposing minor manual adjustments (e.g. 0.5-degree steps up to ±3 degrees from the automated setting) alongside automatic regulation. In group spaces, they favored automation linked to room reservations for efficiency and comfort. On-campus mobility ($\bar{X}$ = 4.77) ranked next, with participants emphasizing better signage, easier navigation, accessible parking and real-time crowdedness data. One participant suggested indicating building crowdedness upon campus entry. They also proposed a bicycle-sharing system for easier travel between remote buildings. For canteen ($\bar{X}$ = 5.63), participants suggested real-time seating and queue information, better nutritional transparency and food waste prevention.

Table 6. Ranks of 12 key area – Friedman test and Kendall's W test

Key area	Mean rank ($\bar{X}$)
Workplace	3.80
Energy efficiency	3.86
Indoor climate	4.57
Mobility	4.77
Canteen	5.63
Nudging	6.17
Interrelated and interactive system	7.00
Virtual assistant	7.57
Safety detection	8.31
Digital twin and VR	8.37
Digital front desk	8.37
Robotics	9.57

Note(s): The mean rank shows the average score of each key area, with lower scores indicating higher importance and higher scores indicating lower priority
Source(s): Authors' own creation

They also proposed robot-assisted dish collection to improve efficiency without replacing necessary human interaction. Participants valued nudging ($\bar{X}$ = 6.17) for managing crowdedness and encouraging use of less busy areas. They suggested subtle nudges like color-coded paths for safety and waste sorting to evenly distribute campus capacity. Participants valued an interrelated and interactive system ($\bar{X}$ = 7.00) for automating infrastructure and detecting malfunctions, like stock issues. They stressed the need for user control in smaller workspaces, while larger spaces might not need such autonomy. For example, they wanted the ability to override automated blinds when necessary. Participants found virtual assistants ($\bar{X}$ = 7.57) useful for tasks like generating lecture notes or answering questions, but were skeptical about their effectiveness compared to traditional note-taking. One noted, "A virtual assistant is less effective than taking our own notes". Safety detection systems ($\bar{X}$ = 8.31) were seen as a lower priority since current systems are adequate, though participants saw potential for smart technology to improve traffic safety. Participants were divided on using digital twins and VR ($\bar{X}$ = 8.37) for education. Some saw potential in replacing physical materials, while others worried it could reduce hands-on learning. One said, "Students need real experience". while another noted, "If I learned from it, it's okay". Digital front desks ($\bar{X}$ = 8.37) and robotics ($\bar{X}$ = 9.57) faced resistance, with participants preferring human interaction for complex tasks like customer service. Digital kiosks were seen as useful for simple tasks in remote areas like wayfinding and room reservations, while robotics were preferred for non-human-dependent tasks like dish collection.

5. Discussion

This study aimed to identify key design elements for a smart campus that enhance user experience. The results, drawn from expert interviews (Phase 1) and user validation through focus groups and field study (Phase 2), offer several important insights.

In Phase 2, users ranked workplace availability and findability, energy efficiency and indoor climate comfort as top priorities. This finding confirms earlier research suggesting that the physical and functional campus environment significantly affects student satisfaction, engagement and retention (Baik *et al.*, 2019; Valks *et al.*, 2016). Similarly, the emphasis on clear wayfinding, parking availability and comfort aligns with Zomerdijk and Voss (2010), who stress the importance of seamless service environments in shaping positive user experiences. These findings suggest that smart campus development should prioritize foundational user needs before investing heavily in emerging technologies.

Conversely, insights from Phase 1 revealed a broader scope of ambition among experts, who emphasized the integration of advanced technologies like robotics, digital twins and VR systems. While these technologies are frequently highlighted in the smart campus literature (Ahmed *et al.*, 2020; Dong *et al.*, 2020), they were deprioritized by users in this study. This contrast suggests a gap between strategic vision and immediate user needs, echoing critiques in Sutjarittham *et al.* (2019) and Cheong and Nyaupane (2022) that smart campus initiatives sometimes outpace users' readiness or expectations.

The finding that data-driven systems are valued by both experts and users supports previous studies on the centrality of real-time data and AI in optimizing campus infrastructure (Marques *et al.*, 2023; Das *et al.*, 2022). However, while experts (Phase 1) emphasized predictive and automated systems, users (Phase 2) preferred real-time tools that enhance usability, such as space finders and climate adjusters. This nuance extends the findings of Dong *et al.* (2020), by reinforcing that data systems must also meet user expectations for immediacy and transparency.

This divergence between expert ambition and user prioritization suggests the need for iterative co-design practices, where both user and expert perspectives are continuously integrated throughout planning and implementation stages (Sanders and Stappers, 2008). In particular, the two-phase approach used in this study can serve as a model for reconciling strategic innovation with everyday user expectations.

In addition to technical features, another key insight is users' desire for autonomy, simplicity and intuitive design, particularly in adjusting their environments. This supports Vischer's (2008) framework on user comfort and Kim *et al.*'s (2013) emphasis on usability in smart buildings. In addition, the positive response to nudging techniques confirms its relevance as a subtle design strategy to influence behavior (e.g. energy use or mobility), aligning with studies on behavioral interventions in public environments (Thaler and Sunstein, 2021; Dolan *et al.*, 2012; Hagman *et al.*, 2015).

Finally, concerns raised by both experts and users regarding technology overload, loss of human interaction, inclusivity and privacy reinforce critical warnings in previous literature (Rasila *et al.*, 2010; Bostrom and Heinen, 1977). This study supports those findings and adds further user-based evidence that successful smart campus adoption must balance automation with maintained human connection, accessible design and meaningful communication.

In sum, this study both confirms and extends prior work. It confirms that user-centered design is vital, as widely suggested in the literature, but also reveals a gap between long-term institutional ambitions and the everyday needs of campus users. A truly smart campus, therefore, must integrate technology in a way that enhances – not overwhelms – the campus experience.

6. Conclusion: implications and future directions

The aim of this study was to define the design elements necessary for a future smart campus to enhance the campus user experience. To address this, the primary research question was: "What interrelated design elements constitute a smart campus to enhance user experience?".

Twelve key areas for enhancing campus user experience emerged from expert interviews, which were subsequently prioritized by campus users. A key area is best understood as an area of focus consisting of a mix of design elements or a digital solution that has a specific use function or serves a specific purpose. To enhance the user experience on a smart campus, workplace availability and findability were seen as crucial, with a need for real-time availability systems. Energy efficiency was also important, supported by automated energy-saving measures. Indoor climate comfort ranked third, favoring interactive control systems with some manual adjustments. Campus mobility improvements included better signage, accessible parking, real-time data on crowdedness and a bicycle-sharing system. For canteens, participants suggested real-time seating and queue data, nutritional transparency and robot-assisted dish collection. Participants valued nudging techniques for managing crowdedness and distributing capacity, as well as an interrelated system for automating infrastructure, with user control in smaller spaces. Virtual assistants were seen as useful but less effective compared to traditional methods. Safety detection systems were a lower priority, though participants saw potential for enhancing traffic safety. Participants were divided on digital twins and VR, with concerns about reduced hands-on learning. Digital front desks and robotics faced resistance for complex tasks, but were seen as useful for simple roles like wayfinding and dish collection.

The goal of a smart campus is to create an efficient, user-friendly environment through a user-centered approach, emphasizing continuous improvement, clear vision, open communication and transparency. It appears that an enhanced campus experience involves ease, usability, simplicity, transparency, efficiency and comfort. A smart campus integrates technology into traditional infrastructure, enhancing efficiency through effective data use and informed decision-making, whether by management or through automated AI/algorithms. Effective use, not just technology addition, defines a smart campus. The 12 key areas are interdependent, relying on integrated interaction between technologies, data and users for a coherent, efficient user experience.

Remarkably, experts seem to have defined a modern university campus that addresses current issues with familiar key areas, rather than envisioning a future campus. Thus, the key areas reflect everyday technologies already in use or well-known. It seems that participants ranked key areas based on familiarity with current technologies, resulting in lower rankings for advanced innovations like robotics, digital twin and VR. This indicates a focus on immediate challenges rather than long-term possibilities, making the findings more applicable to present-day issues rather than future smart campus evolution.

These findings provide a foundation for understanding how theory, practice and policy can collectively shape the future of smart campuses.

6.1 Theoretical implications

Beyond the practical contributions, this study advances the theoretical development of STS by applying it to the smart campus context and highlighting the interdependence between user experience and technological functionality. STS emphasizes the mutual shaping of social systems (users and their behaviors) and technical systems (technological infrastructure), and this research reinforces that smart campus success depends not only on the deployment of advanced technologies (e.g. IoT, AI and VR) but also on their alignment with users' daily needs, autonomy and comfort. By combining qualitative methods with co-design principles, the study adds methodological rigor and offers a replicable framework for future research on user engagement in digital campus environments. Importantly, it demonstrates that "smartness" is not defined by technological complexity alone, but by perceived usability, transparency and support for human interaction – contributing to a more nuanced, integrative understanding of smart campus design within STS literature.

6.2 Societal implications

Smart campuses, when designed through a user-centered and inclusive lens, can serve as models for sustainable and equitable public infrastructure. By supporting energy-efficient operations, minimizing waste and promoting behavioral nudges toward sustainability (e.g. smart wayfinding, climate-responsive spaces), smart campuses can reduce environmental footprints while enhancing users' quality of life. Furthermore, equitable design, accommodating diverse generations, levels of tech literacy and privacy expectations – ensures accessibility and inclusivity, reinforcing the university's broader social mission. Beyond institutional boundaries, smart campuses can influence broader digital transformation policies in the education sector by showcasing how technology can enhance service delivery, sustainability and inclusivity in complex public systems. As living labs, universities have the potential to shape policy agendas on smart infrastructure, urban development and public well-being by providing scalable, evidence-based models.

6.3 Practical implications

The findings have practical implications for campus administrators, facility managers and designers tasked with implementing smart campus strategies. The user-centered approach highlighted in this study shows that smart technologies must prioritize transparency, ease of use and user autonomy. Data systems should not only collect and process information but also do so in ways that are accessible and meaningful to campus users. Integrating real-time feedback mechanisms and providing minor control over personal environments (e.g. lighting or climate in small rooms) can significantly enhance satisfaction. Moreover, a hybrid decision-making strategy that combines top-down infrastructure planning with bottom-up user insights can improve the acceptance and effectiveness of smart systems.

6.4 Recommendations for practice

Based on the implications outlined above, the following practical recommendations are proposed for institutions developing or improving smart campuses:

- *Adopt a user-centered approach*: Incorporate feedback mechanisms and usability testing into the design of all smart systems. Engage users from different roles (students, faculty and staff) early in the planning process.
- *Create an integrated and intuitive digital ecosystem*: Develop a unified platform (e.g. a single app or dashboard) that integrates space booking, real-time occupancy data, energy use feedback and other campus services.
- *Ensure transparency and trust in data use*: Clearly communicate what data is collected, how it is used and how it benefits users. Transparency enhances trust and acceptance of smart technologies.
- *Maintain a balance between automation and human interaction*: Automate simple, repetitive tasks (e.g. space management, queue updates), but retain human interfaces for services that require empathy, problem-solving or oversight (e.g. front desk, safety).
- *Explore emerging technologies gradually and strategically*: While core functionalities are a priority, universities should pilot and evaluate the applicability of future-oriented innovations like digital twins, virtual assistants and robotics with real users before broad implementation.
- *Design for inclusivity and adaptability*: Ensure that smart campus tools are accessible across different user demographics, accounting for varying levels of digital proficiency and physical ability.

6.5 Limitations and future research

While this study provides valuable insights into smart campus design from both expert and user perspectives, several limitations must be acknowledged. First, the research was conducted within the context of a single institution, Wageningen University and Research, which may limit the generalizability of the findings. Institutional culture, technological maturity and infrastructure vary significantly across universities, suggesting that some results may not be directly transferable to other settings.

Second, the study relied predominantly on qualitative data gathered through expert interviews and user engagements. While this approach enabled rich, in-depth insights, it did not assess actual user behavior or technology adoption in real-world environments. Furthermore, the sample was composed primarily of students, with limited representation from faculty, administrative staff or individuals with accessibility needs. This limited diversity may have constrained the scope of perspectives captured, potentially narrowing the applicability of user-centered recommendations.

These sampling and methodological constraints raise important questions about inclusivity and contextual generalizability. Broader representation, particularly of underrepresented or marginalized groups, would enhance the framework's relevance to a wider range of institutional and cultural contexts.

Future research could address these limitations in several ways. A cross-institutional comparative study involving multiple universities could test the generalizability of the identified key areas and validate the framework in diverse settings. In addition, adopting mixed-methods or longitudinal approaches would offer more robust evidence of how smart campus design influences user satisfaction, operational efficiency and sustainability over time. Finally, future work should explore the practical integration and user acceptance of emerging technologies such as digital twins, robotics and AI-based virtual assistants to better understand their long-term impact on the campus experience.

References

Abuarqoub, A., Abusaimeh, H., Hammoudeh, M., Uliyan, M., Abu-Hashem, M., Murad, S., Al-Jarrah, M. and Alfayez, F. (2017), A survey on Internet of Things enabled smart campus applications, *Proceedings of the International Conference on Future Networks and Distributed Systems*, pp. 1-7, doi: 10.1145/3102304.3109810.

Ahmed, V., Abu Alnaaj, K. and Saboor, S. (2020), "An investigation into stakeholders' perception of smart campus criteria: the American University of Sharjah as a case study", *Sustainability*, Vol. 12 No. 12, p. 5187, doi: 10.3390/su12125187.

Alrashed, S. (2020), "Key performance indicators for smart campus and microgrid", *Sustainable Cities and Society*, Vol. 60, p. 102264, doi: 10.1016/j.scs.2020.102264.

Anthony Jnr, B. (2021), "Green campus paradigms for sustainability attainment in higher education institutions–a comparative study", *Journal of Science and Technology Policy Management*, Vol. 12 No. 1, pp. 117-148, doi: 10.1108/JSTPM-02-2019-0008.

Azevedo, R. (2015), "Defining and measuring engagement and learning in science: conceptual, theoretical, methodological, and analytical issues", *Educational Psychologist*, Vol. 50 No. 1, doi: 10.1080/00461520.2015.1004069.

Baik, C., Larcombe, W. and Brooker, A. (2019), "How universities can enhance student mental wellbeing: the student perspective", *Higher Education Research and Development*, Vol. 38 No. 4, pp. 1-14, doi: 10.1080/07294360.2019.1576596.

Baldassarre, M., Caivano, D., Dimauro, G., Gentile, E. and Visaggio, G. (2018), "Cloud computing for education: a systematic mapping study", *IEEE Transactions on Education*, Vol. 61 No. 3, pp. 1-11, doi: 10.1109/TE.2018.2796558.

Barile, S. and Polese, F. (2010), "Smart service systems and viable service systems: applying systems theory to service science", *Service Science*, Vol. 2 Nos 1-2, pp. 21-40.

Bekele, W. and Yohannes, F. (2022), "Sample size for interview in qualitative research in social sciences: a guide to novice researchers", *Research in Educational Policy and Management*, Vol. 4 No. 1, pp. 42-50, doi: 10.46303/repam.2022.3.

Bhatt, U., Antorán, J., Zhang, Y., Liao, Q.V., Sattigeri, P., Fogliato, R., Melançon, G., Krishnan, R., Stanley, J., Tickoo, O., Nachman, L., Chunara, R., Srikumar, M., Weller, A. and Xiang, A. (2021), "*Uncertainty as a form of transparency: measuring*", *communicating, and using uncertainty Proceedings of the 2021 AAAI/ACM Conference on AI, Ethics, and Society, Virtual Event, USA*, 10.1145/3461702.3462571

Bitner, M.J. (1992), "Servicescapes: the impact of physical surroundings on customers and employees", *Journal of Marketing*, Vol. 56 No. 2, pp. 57-71, doi: 10.2307/1252042.

Bostrom, R.P. and Heinen, J.S. (1977), "MIS problems and failures: a socio-technical perspective", *Part I: The Causes. MIS Quarterly*, pp. 17-32, doi: 10.5465/255372.

Chen, P., Liu, X., Cheng, W. and Huang, R. (2017), "A review of using augmented reality in education from 2011 to 2016", *Innovations in smart learning*, Springer, pp. 13-18, doi: 10.1007/978-981-10-2419-1_2.

Cheong, P.H. and Nyaupane, P. (2022), "Smart campus communication, internet of things, and data governance: understanding student tensions and imaginaries", *Big Data and Society*, Vol. 9 No. 1, p. 20539517221092656, doi: 10.1177/20539517221092656.

Das, D., Lim, N.D. and Aravind, P. (2022), "Developing a smart and sustainable campus in Singapore", *Sustainability*, Vol. 14 No. 21, p. 14472, available at: www.mdpi.com/2071-1050/14/21/14472

Dolan, P., Hallsworth, M., Halpern, D., King, D., Metcalfe, R. and Vlaev, I. (2012), "Influencing behaviour: the Mindspace way", *Journal of Economic Psychology*, Vol. 33 No. 1, pp. 264-277.

Domínguez-Bolaño, T., Barral, V., Escudero, C.J. and García-Naya, J.A. (2024), "An IoT system for a smart campus: challenges and solutions illustrated over several real-world use cases", *Internet of Things*, Vol. 25, p. 101099.

Dong, X., Kong, X., Zhang, F., Chen, Z. and Kang, J. (2016), "OnCampus: a mobile platform towards a smart campus", *SpringerPlus*, Vol. 5 No. 1, p. 974, doi: 10.1186/s40064-016-2608-4.

Dong, Z.Y., Zhang, Y.C., Yip, C., Swift, S. and Beswick, K. (2020), "Smart campus: definition, framework, technologies, and services", *IET Smart Cities*, Vol. 2 No. 1, pp. 43-54, doi: 10.1049/iet-smc.2019.0072.

Friday, S. and Cotts, D.G. (1994), "Quality facility management: a marketing and customer service approach", Wiley, available at: https://books.google.nl/books?idusZjnsmSbQC

Gilboy, M.B., Heinerichs, S. and Pazzaglia, G. (2015), "Enhancing student engagement using the flipped classroom", *Journal of Nutrition Education and Behavior*, Vol. 47 No. 1, pp. 109-114, doi: 10.1016/j.jneb.2014.08.008.

Gomes, R., Pombeiro, H., Silva, C., Carreira, P., Carvalho, M., Almeida, G., … Ferrão, P. (2016), "Towards a smart campus: building-user learning interaction for energy efficiency, the Lisbon case study", *Handbook of Theory and Practice of Sustainable Development in Higher Education*, Vol. 1, pp. 381-398. Springer International Publishing, Cham.

Hagman, W., Andersson, D., Västfjäll, D. and Tinghög, G. (2015), "Public views on policies involving nudges", *Review of Philosophy and Psychology*, Vol. 6 No. 3, pp. 439-453.

Huang, L.-S., Su, J.-Y. and Pao, T.-L. (2019), "A context aware smart classroom architecture for smart campuses", *Applied Sciences*, Vol. 9 No. 9, p. 1837, available at: www.mdpi.com/2076-3417/9/9/1837

Hume, M., Sullivan Mort, G., Liesch, P.W. and Winzar, H. (2006), "Understanding service experience in non-profit performing arts: implications for operations and service management", *Journal of Operations Management*, Vol. 24 No. 4, pp. 304-324, doi: 10.1016/j.jom.2005.06.002.

Hutchinson, L. (2003), "Educational environment", *BMJ*, Vol. 326 No. 7393, pp. 810-812, doi: 10.1136/bmj.326.7393.810.

Kahu, E. and Nelson, K. (2017), "Student engagement in the educational interface: understanding the mechanisms of student success", *Higher Education Research and Development*, Vol. 37 No. 1, pp. 1-14, doi: 10.1080/07294360.2017.1344197.

Kim, M.J., Oh, M.W. and Kim, J.T. (2013), "A method for evaluating the performance of green buildings with a focus on user experience", *Energy and Buildings*, Vol. 66, pp. 203-210, doi: 10.1016/j.enbuild.2013.07.049.

Kok, H.B. (2015), *Facility Management in Dutch Higher Education*, [internal PhD, WU, Wageningen University]. Wageningen University, doi: 10.18174/346604.

Kourgiozou, V., Commin, A., Dowson, M., Rovas, D. and Mumovic, D. (2021), "Scalable pathways to net zero carbon in the UK higher education sector: a systematic review of smart energy systems in university campuses", *Renewable and Sustainable Energy Reviews*, Vol. 147, p. 111234, doi: 10.1016/j.rser.2021.111234.

Lowe, T. and Wright, S. (2024), "Mapping the student experience: a framework for assessing student support, success, community and voice", *Student Success*, Vol. 15 No. 1, pp. 92-98, doi: 10.5204/ssj.2866.

Marques, G. A., Saini, J. and Dutta, M. (2023), *IoT Enabled Computer-Aided Systems for Smart Buildings*, Springer, doi: 10.1007/978-3-031-26685-0.

Matus, N., Rusu, C. and Cano, S. (2021), "Student eXperience: a systematic literature review", *Applied Sciences*, Vol. 11 No. 20, p. 9543, available at: www.mdpi.com/2076-3417/11/20/9543

Omotayo, T., Moghayedi, A., Awuzie, B. and Ajayi, S. (2021), "Infrastructure elements for smart campuses: a bibliometric analysis", *Sustainability*, Vol. 13 No. 14, p. 7960, available at: www.mdpi.com/2071-1050/13/14/79609543

Palumbo, R. and Manna, R. (2018), "What if things go wrong in co-producing health services? Exploring the implementation problems of health care co-production", *Policy and Society*, Vol. 37 No. 3, pp. 368-385.

Pine, B.J. and Gilmore, J.H. (1999), "The experience economy: Work is theatre and every business a stage", Harvard Business School Press, available at: https://books.google.nl/books?ids-tyRrSXMC.

Pullman, M.E. and Gross, M.A. (2004), "Ability of experience design elements to elicit emotions and loyalty behaviors", *Decision Sciences*, Vol. 35 No. 3, pp. 551-578, doi: 10.1111/j.0011-7315.2004.02611.x.

Rasila, H., Rothe, P. and Kerosuo, H. (2010), "Dimensions of usability assessment in built environments", *Journal of Facilities Management*, Vol. 8 No. 2, pp. 143-153, doi: 10.1108/14725961011041189.

Sanders, E.B.N. and Stappers, P.J. (2008), "Co-creation and the new landscapes of design", *CoDesign*, Vol. 4 No. 1, pp. 5-18.

Santos, M.E., Chen, A., Taketomi, T., Yamamoto, G., Miyazaki, J. and Kato, H. (2014), "Augmented reality learning experiences: survey of prototype design and evaluation", *IEEE Transactions on Learning Technologies*, Vol. 7 No. 1, pp. 38-56, doi: 10.1109/TLT.2013.37.

Strayhorn, T. (2018), *College Students' Sense of Belonging*, doi: 10.4324/9781315297293.

Sujata, J. (2014), "Customer experience management: an exploratory study on the parameters affecting customer experience for cellular mobile services of a telecom company", *Procedia – Social and Behavioral Sciences*, Vol. 133, pp. 392-399, doi: 10.1016/j.sbspro.2014.04.206.

Sutjarittham, T., Gharakheili, H.H., Kanhere, S.S. and Sivaraman, V. (2019), "Experiences with IoT and AI in a smart campus for optimizing classroom usage", *IEEE Internet of Things Journal*, Vol. 6 No. 5, pp. 7595-7607, doi: 10.1109/JIOT.2019.2902410.

Teufer, M. (2021), *Campus Van De Toekomst*, Internal Document University of Leiden.

Thaler, R.H. and Sunstein, C.R. (2021), *Nudge*, Penguin.

Tight, M. (2020), "Student retention and engagement in higher education", *Journal of Further and Higher Education*, Vol. 44 No. 5, pp. 689-704, doi: 10.1080/0309877X.2019.1576860.

Valipour Parkouhi, S., Safaei Ghadikolaei, A., Fallah Lajimi, H. and Salimi, N. (2024), "Smart manufacturing implementation: identifying barriers and their related stakeholders and components of technology", *Journal of Science and Technology Policy Management*, doi: 10.1108/JSTPM-09-2023-0148.

Valks, B., Akkersteijn, M., Heijer, A. and Putte, H. (2016), "Smart campus tools: een verkenning bij nederlandse universiteiten en lessen uit andere sectoren".

Valks, B., Arkesteijn, M.H., Koutamanis, A. and den Heijer, A.C. (2021), "Towards a smart campus: supporting campus decisions with Internet of Things applications", *Building Research and Information*, Vol. 49 No. 1, pp. 1-20.

Valks, B., Arkesteijn, M.H., Den Heijer, A.C. and Vande Putte, H.J. (2018), "Smart campus tools– adding value to the university campus by measuring space use real-time", *Journal of Corporate Real Estate*, Vol. 20 No. 2, pp. 103-116.

Vischer, J.C. (2008), "Towards a user-centred theory of the built environment", *Building Research and Information*, Vol. 36 No. 3, pp. 231-240, doi: 10.1080/09613210801936472.

Xu, X., Li, D., Sun, M., Yang, S., Yu, S.-J., Manogaran, G., Mastorakis, G. and Mavromoustakis, C. (2019), "Research on key technologies of smart campus teaching platform based on 5G network", *IEEE Access*, Vol. 7, p. 1, doi: 10.1109/ACCESS.2019.2894129.

Zhang, Y., Dong, Z.Y., Yip, C. and Swift, S. (2020), "Smart campus: a user case study in Hong Kong", *IET Smart Cities*, Vol. 2 No. 3, pp. 146-154, doi: 10.1049/iet-smc.2020.0047.

Zomerdijk, L.G. and Voss, C.A. (2010), "Service design for Experience-Centric services", *Journal of Service Research*, Vol. 13 No. 1, pp. 67-82, doi: 10.1177/1094670509351960.

Further reading

Arnold, K.D. (2016), "Designing for learning: creating campus environments for student success", *Journal of College Student Development*, Vol. 57 No. 2, pp. 224-226.

Hajrasouliha, A.H. and Ewing, R. (2016), "Campus does matter: the relationship of student retention and degree attainment to campus design", *Planning for Higher Education*, Vol. 44 No. 3, pp. 30-45.

Jansz, S.N., Terry van, D. and Mobach, M.P. (2020), "Critical success factors for campus interaction spaces and services – a systematic literature review", *Journal of Facilities Management*, Vol. 18 No. 2, pp. 89-108, doi: 10.1108/JFM-08-2019-0041.

Jansz, S.N., Mobach, M., van Dijk, T., de Vries, E. and van Hout, R. (2022), "On serendipitous campus meetings: a user survey", *International Journal of Environmental Research and Public Health*, Vol. 19 No. 21, p. 14504, available at: www.mdpi.com/1660-4601/19/21/14504.

Min-Allah, N. and Alrashed, S. (2020), "Smart campus – a sketch", *Sustainable Cities and Society*, Vol. 59, p. 102231, doi: 10.1016/j.scs.2020.102231.

Nenonen, S. (2005), "*The Nature of The Workplace for Knowledge Creation*", Turku Polytechnic, available at: https://books.google.nl/books?id=bjZsNAAACAAJ

Polin, K., Yigitcanlar, T., Limb, M. and Washington, T. (2023), "The making of smart campus: a review and conceptual framework", *Buildings*, Vol. 13 No. 4, p. 891.

WUR (2019), "Strategisch plan 2019-2022".

WUR-FB (2024), "FB: Motor van digitale vooruitgang".

Yang, A.M., Li, S.S., Ren, C.H., Liu, H.X., Han, Y. and Liu, L. (2018), "Situational awareness system in the smart campus", *IEEE Access*, Vol. 6, pp. 63976-63986, doi: 10.1109/ACCESS.2018.2877428.

Corresponding author
Negin Salimi can be contacted at: negin.salimi@wur.nl