Metropolia University of Applied Sciences

Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

Smart Campus Environments: A Multicriteria Approach to Evaluating the Impacts of Smart Campus Features

Master Thesis

Name of the Study Programme

Construction and Real Estate Management

Faculty of Engineering

from

Mehran Attar

Date:

Berlin, 05.07.2024

1st Supervisor: Mr. Jorma Säteri

2nd Supervisor: Prof. Dr.-Ing. Nicole Riediger

Acknowledgement

The following document presents the thesis I conducted as part of my master's degree in Construction and Real Estate Management at HTW Berlin and Metropolia University of Applied Sciences. Conducting my thesis on the topic of smart campus allowed me to integrate my interest in smart technologies and real estate management.

I would like to thank my two supervisors, Jorma Säteri and Nicole Riediger, for their guidance and support throughout the thesis process. I also would like to thank all the interviewees for their time and valuable insights.

Thank you, and I hope you enjoy reading this.

Mehran Attar

Berlin, July 2024

Metropolia

htw. Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia Helsinki and HTW Berlin

date 30.06.2023

Conceptual Formulation
Master Thesis for Mr./Ms. Mehran Attar
Student number S0585971

Topic:

Assessment of Smart Campus Environments: A Multicriteria Approach to Evaluating the Impacts of Smart Campus Features

Background

The advancement of technologies such as the Internet of Things (IoT), artificial intelligence (AI), cloud computing, and big data has had a significant impact on the real estate industry. Universities, like many other organizations, have started implementing these technologies to provide a better environment for users, optimize space utilization, and subsequently reduce costs and energy consumption (Polin et al., 2023).

The concept of 'smart campus', which refers to the digital transformation of campuses, has become even more appealing to universities due to the growing number of challenges affecting campus operations and development. According to Valks et al. (2021), the demand for facilities and services is becoming less certain as the influx of students has become unpredictable. This uncertainty was further exacerbated by the events of the COVID-19 pandemic. Additionally, securing research funding has become significantly more competitive, leading to increased resource competition (Valks, 2021). As a result, there has been an increase in temporary contracts and uncertain demand for office and research spaces.

Despite being a relatively new phenomenon, the 'smart campus' is an emerging topic that has been well-researched over the past few years. However, most of these studies tend to focus only on one aspect of it. For example, the impact of smart features on space utilization has been extensively covered by Valks (2021). On the other hand, the impact on the end-user, the financial implications, and the impact on CO2 reduction are rarely addressed. Therefore, this study aims to investigate the impacts of smart campus features on four domains mostly associated with sustainable development: economy, society, environment, and governance.

Research Questions

The main research question that this study aims to address is:

How and to what extent does the implementation of smart campus features meet the needs and requirements of universities?

Metropolia

htw. Hochschule für Technik und Wirtschaft Berlin
University of Applied Sciences

To answer this main research question, several sub-questions need to be addressed:

Sq1: What defines a smart campus, and which smart features can be identified?

Sq2: What is campus management, and what is the added value of smart campus features?

Sq3: What are the effects of implementing smart features on universities?

Methodology

Literature Review: The literature review will involve studying smart campus environments, their features, and assessing their potential financial, environmental, social, and strategic impacts.

Empirical Research; Case Studies and Interviews: Case studies will be conducted to identify smart campus features already in practice and measure their impact depending on the availability of data (accessing data regarding all aspects might be challenging). Interviews will be conducted to gather the experiences and ideas of students, staff, and facility managers for the research.

Expert Panel: An expert panel will be formed to explore the perceived usefulness of smart features and the importance of the added values resulting from the implementation of smart technology in universities. This would be particularly useful for impacts where no (reliable) quantitative data is available.

References

Polin, K., Yigitcanlar, T., Limb, M., & Washington, T. (2023). The Making of Smart Campus: A Review and Conceptual Framework. *Buildings*, *13*(4), 891.

Valks, B., Arkesteijn, M. H., Koutamanis, A., & den Heijer, A. C. (2021). Towards a smart campus: supporting campus decisions with Internet of Things applications. *Building Research & Information*, *49*(1), 1-20.

Valks, B. (2021). Smart campus tools: Technologies to support campus users and campus managers.

Signature of the Supervisor

Jorma Säteri
Head of school

Prof. Dr. Rüdiger
2nd supervisor

15. APR. 2024

Abstract

The main objective of this research was to identify the impacts of smart technology implementation on the overall performance of university campuses. Universities are currently facing several challenges, from uncertainty in space demand to financial constraints and having to adapt their environment to meet the changing demands and behaviours of their users (Beckers et al., 2014; Valks et al., 2021). Many universities have started deploying technologies such as the Internet of Things (IoT) and Artificial intelligence (AI) in their campuses to address the challenges mentioned above and meet their objectives. However, despite this rapid transformation, very few studies have been conducted on smart campuses and the role they play in adding value to their stakeholders. Therefore, in addition to the main research goal, this study aimed to fill the gap in the literature by investigating the characteristics and features of smart campus and aligning them with the campus management strategies in terms of value addition.

For the research methodology a qualitative research approach consisting of literature review and case study was adopted. The literature review provided the required knowledge on a topic that is not widely studied and provided support for the empirical findings of the research. The case studies were primarily conducted by doing in-depth interviews with smart campus stakeholders in three Finnish universities. Finally, the findings from both approaches were compared and analysed together to provide answers to the research questions.

The findings from the study showed that smart campus features can impact the campus stakeholders in two ways: 1. by providing smart functionalities to the end-user via smart applications and user interfaces. 2. by providing data to the management for decision-making. This study also identified that the implemented smart features (especially wayfinding and space booking) significantly increase user satisfaction and user productivity. Furthermore, monitoring space use through occupancy and booking data increases space efficiency directly, leading to cost reduction and emission reduction.

Table of Contents

Table of Figures

List of Tables

List of Abbreviations

AIR	Active Infrared
AR	Augmented Reality
AI	Artificial Intelligence
BAS	Building Automation System
BEMS	Building Energy Management System
BMS	Building Management System
CREM	Corporate Real Estate Management
HVAC	Heating, Ventilation and Air Conditioning
FM	Facility Management
IoT	Internet of Things
PIR	Passive Infrared
PREM	Public Real Estate Management
RFID	Corporate Real Estate Management
SRE	Smart Real Estate
UWB	Ultra-Wideband
VR	Virtual Reality

1. Introduction

1.1 Problem statement

The continuous expansion of advanced technologies such as Internet of Things (IoT), artificial intelligence (AI), cloud computing, and big data has provided new opportunities for developing environments that can positively impact their users and therefore has had a significant impact on the real estate industry. In the past few decades, real estate has been gradually transforming from traditional into what is known as smart real estate or SRE (Apostolopoulos et al., 2020). One that is equipped with sensors, technologies and applications that interacts with its inhabitants (Streitz et al., 2019) and can provide information to real estate managers to manage assets and resources more efficiently (Ullah et al., 2018).

The same trend is seen happening on university campuses. The rapid increase in the appeal of smart technologies among universities can be traced back to the significant number of challenges they are facing at the moment (Valks et al., 2021). Some of the most notable challenges are unclear demand for space and facilities, financial difficulties, increasing demand for new ways of learning and the growing pressure for environmental sustainability (Dong et al., 2020; Valks et al., 2021).

The inflow of new students at universities has become more uncertain over the past ten years as the overall number of new students fluctuates while, at the same time, the number of international students continues to grow (OECD, 2024). This has created an unprecedented level of uncertainty regarding space needs and increased the demand for more diverse and flexible facilities (Polin et al., 2023). Moreover, due to the financial difficulties that the universities are facing, the number of temporary contracts has risen, which has made the demand for office and research spaces more uncertain (Finley, 2021; Valks et al., 2021).

The financial challenges and the reduction in government funding have also pushed many universities to pursue alternative funding models, such as leasing and private development (McCann et al., 2019), which has made strategic decision-making more difficult for campus management. Furthermore, the emergence of new learning approaches, the development of online learning platforms and changes in student behaviours and expectations in recent years have increased the pressure on

universities to provide innovative solutions that can support new ways of learning. (Beckers et al., 2014; Dong et al., 2021). Finally, the ambitious goals set by many universities in Finland to become carbon neutral over the next five to ten years have encouraged investing in technologies that can enhance the energy efficiency of their campuses (UNIFI, 2020).

In order to be able to respond to these challenges, universities have begun equipping their campuses with smart technologies which can help enhance the efficient management of their resources and meet the changing needs and demands of their stakeholders (Chagnon-Lessard et al., 2021; Polin et al., 2023). This digital transformation is generally referred to as “smart campus”. Today, more and more universities are going through this transformation. According to one estimate, from 2022 to 2027, the global smart education market will grow at 17.98% annually, which is a two per cent increase compared to the previous period (Global Smart Education Market, 2023).

Despite the growing interest and investment in smart campus initiatives, there is a lack of comprehensive understanding in the literature regarding the concept of smart campus and its components, as there is no consensus on what defines a smart campus. Some studies (Cheng et al., 2022; Fragma-Lamas et al., 2019) look at the smart campus as an extension of the smart building concept, focusing mainly on the technological aspect of it. Other studies (Imbar et al., 2020; Zaballos et al., 2021) see it as a miniature model of the smart city model. Valks et al. (2021) define smart campus predominantly as a campus that uses advanced technologies such as IoT for utilising their spaces, while Dong et al. (2020) and Chen and Liu (2021) look at the role of “smart campus” in the enhancement of the learning environment.

The ambiguity regarding the smart campus concept and the limited research on the topic, combined with the increasing use of smart tools and technologies at university campuses, emphasises the need for further research. There is a noticeable need for research on what constitutes a smart campus, its features, and how it can help campus management meet the university objectives and provide added value to the campus stakeholders.

1.2 Research objectives

This research aims to investigate the impacts of smart technology implementation at university campuses on meeting university objectives and addressing the challenges they are facing at the moment. As mentioned earlier, these challenges are mainly about the mismatch between space supply and space demand, which is exacerbated by the universities' financial constraints, the changing behaviour and expectations of the university community and environmental concerns.

Several studies have looked at these impacts in an office context and identified varying levels of success (Riratanaphong & Van der Voordt, 2015; Ahmed et al., 2020; Remes et al., 2020). However, apart from some similarities, there are noticeable differences between office space and university campus. In addition, because of the novelty of smart campus, there is a gap in the literature about its definition, its components, the technologies and features that are deployed in them, and the way they can provide value to the campus management and the campus stakeholders.

To achieve the overarching goal of the research and fill the existing gap in the literature, this study aims to first identify what actually constitutes a smart campus and look at the smart features that are provided in one. This step is necessary as there is no current consensus and agreement regarding its definition and furthermore there are no standards for categorising smart campus features.

To better understand the impacts of transitioning to a smart campus, it is important to investigate university objectives and the role the campus management plays in achieving them. By studying the strategies, the campus management uses to provide added value to the campus stakeholders, this study will be able to identify the ways in which the implementation of smart tools impact them.

1.3 Research questions

The following research questions are defined to help the researcher in achieving the research objectives:

Research Question:

How and to what extent does the implementation of smart campus features meet the needs and requirements of universities?

Sub-questions:

1. What are the defining characteristics of a smart campus, and which smart campus features can be identified?
2. What is campus management, and how does it add value for campus stakeholders?
3. What are the effects of implementing smart features on university campuses?

1.4 Research design

To gain a better understanding of the impacts of smart campus development and answer the questions of the research, a qualitative research approach will be adopted. This approach will consist primarily of literature review and case study analysis. The literature review will formulate the knowledge basis that features the central themes of this study. This step provides the required knowledge on a topic that is not widely researched and provides support for the empirical findings of the research. For the empirical part of the thesis, the case study approach is selected as it fits this study better (due to the novelty of the research topic). The case studies will be performed using in-depth interviews and desk research. Figure 1 provides an overview of the research design and the steps that will be taken to address the central question of this thesis paper.

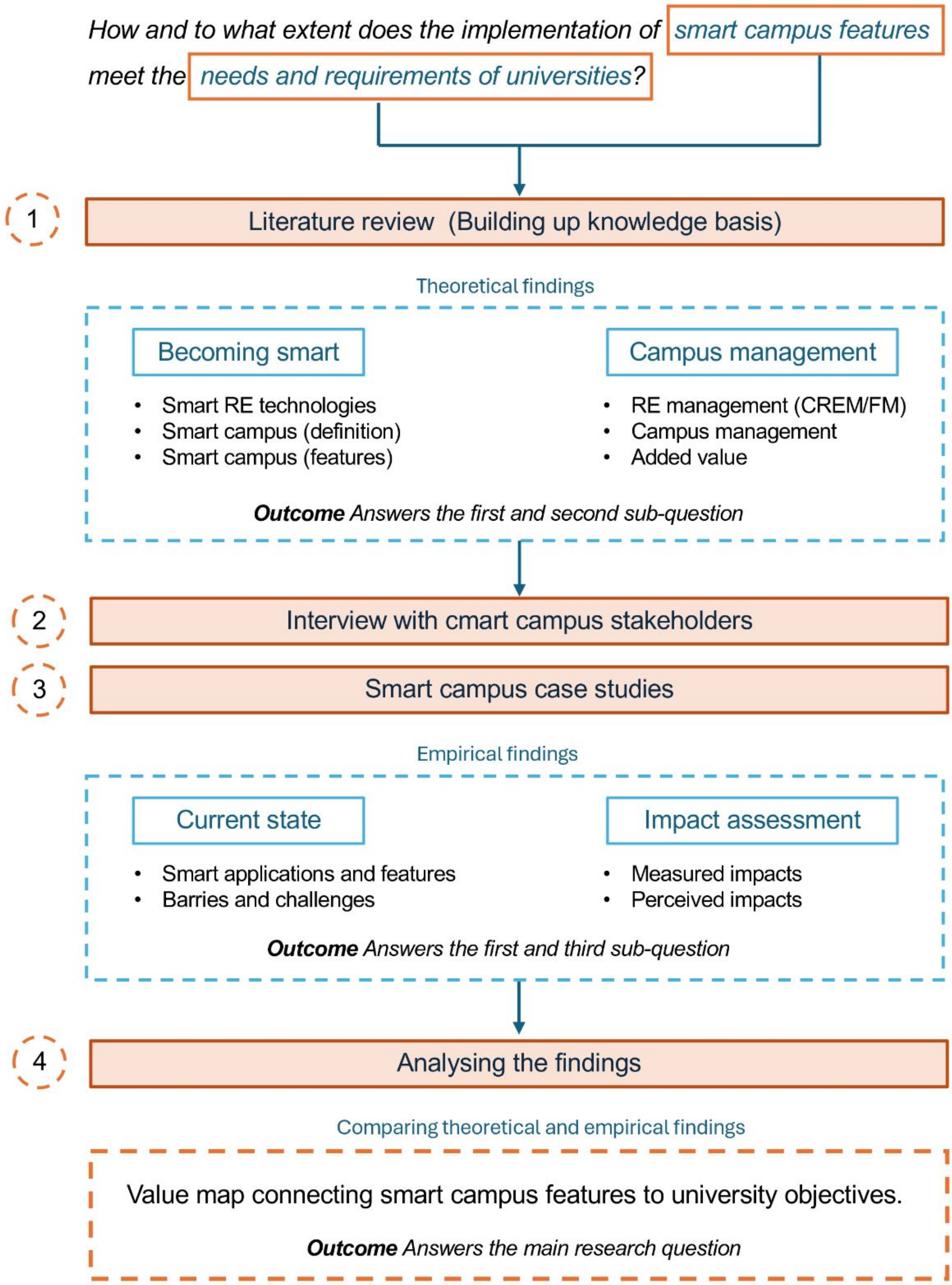

Figure 1. Research design[1]

1 Own Illustration

As seen in Figure 1, the research begins with an overview of the literature to help the researcher better understand the key knowledge areas of the research. This phase explores the existing definitions, frameworks, technologies and features associated with the concept of “smart campus” by analysing academic articles and industry reports. This will then be followed by an overview of campus management strategies and the process of value addition by investigating the objectives and needs of campus stakeholders. This step will be based on two commonly known frameworks: Value added framework and corporate real estate management (CREM).

Following the literature review, a theoretical framework will be developed to illustrate the interrelationship between smart campus features and the value they add to university operations. This framework will link specific stakeholder objectives and campus management strategies to the identified smart campus features. The developed framework will serve as the basis for guiding the empirical phase of the research.

A case study approach will be taken to validate and refine the theoretical framework. To do so, first the cases based on the defined selection criteria will be identified. The cases will be selected based on certain criteria defined in the Methodology chapter In general, the cases will be university campuses with similar characteristics and similar geographical locations that have adopted various smart tools and features. The criteria for selection of the case studies are further explained in the method overview section of the next chapter.

The data collection process will consist of semi-structured interviews with campus managers to gather qualitative data on the implementation and impact of smart campus features. Additionally, desk research will be performed to review relevant documents, reports, and records from the selected campuses.

Lastly, the collected data will be analysed to identify the available smart campus features and evaluate their impact on meeting the needs and requirements of the universities. This step involves comparing the findings from the case study with the theoretical findings to see how well they align with each other. Combining the theoretical and empirical findings provides a robust evaluation of smart campus initiatives, contributes to the broader understanding of their effectiveness and highlights the extent to which smart campus implementations meet university needs

and providing insights into best practices and potential areas for improvement. The findings from the analysis chapter will be used to provide a comprehensive understanding of the smart campus features and their added value and provide answers to the main research question.

1.5 Thesis outline

This thesis consists of six chapters. The research methods utilised to conduct this research and the ethical considerations are explained in chapter two. Chapter three presents the findings from the literature and provides the research basis required to conduct the case studies and looks at two overarching areas: Smart campus (concept, technologies and features) and Campus management (campus real estate management, facilities management, frameworks and added values).

The fourth chapter describes the findings from each case study and the interviews conducted as part of them. The three cases are the Myllypuro campus (Metropolia University of Applied Sciences), Otaniemi Campus (Aalto University) and Linnanmaa campus (University of Oulu). The fifth chapter starts with a cross-case analysis to provide a holistic view of the current state of smart campus development and its effects on campus stakeholders. Furthermore, it continues by comparing the findings from the case study chapter with those from the literature review to provide a smart campus value map that shows the link between the smart campus features and the value framework developed in the literature review chapter. The outcome of this chapter is the answers to the three research subquestions. The sixth and final chapter presents the conclusion and recommendations and answers the main research question. Furthermore, recommendations for practice and research and the limitations during the conduction of the thesis are presented.

2. Methodology

The second part of this thesis presents the research methodology in detail. The chapter explains how the study was conducted in order to provide an answer to the research questions. Later, a detailed overview of the methods and techniques that were applied for data collection and the justification for the choices are given. The research methods consist of literature review, case studies and semi-structured interviews. Finally, the ethical considerations relevant to the selected approach are addressed.

2.1 Methods overview

As explained earlier in the research design (see Figure 1), three primary research methodologies were utilised to conduct this study: literature review, case study and in-depth interviews. This section provides a detailed overview of each of these methods.

2.1.1. Literature review

The first step in conducting the thesis was the literature study. At first, more than 40 scientific papers that were published over the past five years (Since 2019) on smart real estate, smart office and smart campus were reviewed. This provided the state-of-the-art on the topic and helped the researcher form the research problem and identify the research gaps. Later, as the research objectives and questions were finalised, more papers were analysed.

The main goal of this step was to gain a better understanding of the research themes and create a theoretical framework as the basis and a guideline for the case study research. Furthermore, the literature review provided preliminary answers to the research sub questions: *1. What are the defining characteristics of a smart campus, and which smart campus features can be identified? 2. What is campus management, and how does it provide added value for the campus stakeholders? 3. What is the effect of implementing smart features on university campuses?* Finally, this step provided the basis for the researcher to identify the missing elements that had to be covered via case studies.

Online databases and websites such as Scopus, Google Scholar and ScienceDirect were used to search and gather relevant scientific studies. Additionally, university

company websites that offer smart building solutions were searched to find relevant documents on the topics that have received less scientific attention. Due to the innovative nature of the topic, several studies had to be revised before the decision was made on whether to include them in the literature review or not.

The first step in conducting the search was to develop a research criterion based on the relevance and accuracy of the information that was being collected. The keywords used to answer the first sub question were “smart campus”, “smart workplace”, “smart office”, and “smart building technologies”. For the second sub-question, the keywords were “campus management strategies”, “corporate real estate management”, “campus stakeholders”, and “adding value to real estate users”. Furthermore, all these searches were filtered to only papers that were published over the past five years (2019-2024). The abstracts for the first five to ten papers on each topic were revised to further develop the research criteria for the selection of further study papers. Finally, a list of all the relevant papers and their main findings for each topic were developed. This was then used to write the literature review chapter as well as form the theoretical framework of the thesis.

2.1.2. Case studies

Since the literature on the research topic is not sufficient enough, the case study approach was used to supplement the research methodology. The main goals of utilising this approach were to address the limitations of the scientific literature on the topic, confirm its findings and provide empirical evidence needed to address the central question of the research: *How and to what extent does the implementation of smart campus features meet the needs and requirements of universities?*

Hartley (2004) defines case study as a research strategy that involves an empirical investigation of a phenomenon using data collected over a time period. The phenomenon that was investigated in this research, was the integration of smart building technologies on university campuses. Furthermore, Hollweck and Yin (2014) argues that the case study approach is best used to answer the “how” and “why” questions that are relevant to the research. Case studies can help the researcher understand why certain decisions were made, how they were implemented, and what their results were (Hollweck & Yin, 2014). Based on these definitions, this research

utilised case studies to observe smart campuses in practice and determine how they had impacted campus stakeholders.

In total, three case studies were identified and analysed separately, and then through a cross-case analysis, they were compared to provide an overview of smart campuses, particularly in Finland. This approach is based on the case study model developed by Hollweck and Yin (2014). This model divides the case study process into three phases: 1. case study design, 2. case preparation and data collection and 3. analysis and conclusion. During the first phase, theoretical background, case study protocol, and case selection criteria are defined, and case studies are selected. In the second phase, the case studies are performed, and the corresponding report for each case study is conducted. Finally, the produced reports are cross-analysed, conclusions are made, and necessary changes to the theoretical framework are applied.

To narrow down the selection of cases, three criteria were defined:

- The case must be a university campus.
- The case must feature smart technologies and/or be branded as a smart building.
- The case must be located in Finland.

Five university campuses were identified based on these criteria, and relevant stakeholders from each campus were contacted. Out of those, three cases were selected in which at least one interview with a relevant stakeholder could be conducted. For each of these cases, four topics were investigated in order to contribute to addressing the research questions:

- The current state of implemented smart tools and features
- The way they work and are utilised
- The reasons for implementing them
- The results and outcome of implementing them, focusing on value addition to campus stakeholders.

The methods used to gather information about these topics were desk research (document reviews) and semi-structured interviews. However, interviews were the main source of information, as there was a noticeable lack of available information, and most universities tend to keep such information internally. Chapter four presents the description of each case and the results of the case studies.

2.1.3. In-depth interviews

As mentioned earlier in this chapter, the main methodology used for gathering empirical data was in-depth interviews with relevant stakeholders of the case studies (IT and Technology managers, facility managers, development managers and faculty members) as well as other experts in the field. Holding interviews with such stakeholders helped the researcher gather in-depth information about cases not found through desk research. This section provides further information on how and why these interviews were conducted and how they contributed to the findings of the research.

The semi-structured interview method was selected to conduct the interviews. Semi-structured interviews provide a level of flexibility for the interviewer while maintaining a structure to stay on topic. This approach allows the interviewer to ask additional questions during the conversation, which can help deepen the understanding of the answers given to the structured questions (Bryman, 2016).

In order to ensure that the required information is collected from the interviewees, four guiding questions on the four thematic areas of the research were formulated. The four thematic areas are: (1) available smart tools and features, (2) The way they work and are utilised, (3) the reasons for their implementation and (4) the results of implementing them and their added value for campus stakeholders.

Depending on the role of the interviewee, more emphasis was given to one or more of the guiding questions than the others. Technology and IT managers were asked more about the first two areas of the research (the existing technologies and how they work). The development and facility managers were asked more about the third and fourth themes (reasons for implementing them, their alignment with campus management strategies and value addition). Finally, employees and faculty members were mainly interviewed concerning the second and fourth areas (impact and value addition, familiarity with the tools and how they utilise them. The complete list of the questions asked of the interviewees can be found in Appendix 1.

<u>Choice of interviewees</u>

After the case studies were finalised, several tools and approaches were used by the researcher to identify and contact the potential interviewees. These included searching via LinkedIn, university websites and online articles as well as networking through

already established contacts. Table 1 presents the list of interviewees for each of the case studies as well as their roles and responsibilities at the university campus.

Because of the focus of this thesis on campus management and the alignment of smart campus tools and features with their strategies regarding value addition, the primary target group for interviews was the facility and development managers. In addition, technology managers were interviewed to provide a better picture of the implemented technologies and how they work. Finally, the end-users, such as faculty members, were interviewed to understand the impacts of the implemented smart technologies from their point of view.

Metropolia University of Applied Sciences	Aalto University	University of Oulu
Facility manager	Development manager at ACRE	Facility manager
Technology manager	Faculty member	Head of smart campus program
Faculty member		
Faculty member		

Table 1 list of the people interviewed for the research

A separate interview protocol was developed for each of the interviewees presented in Table 1, which can be found in Appendix 1. The questions were developed according to the interviewee's roles and responsibilities and provided a structure to ensure that all thematic areas of the research were covered.

Interview process

In this section, the interview procedure, as well as how they were transcribed and coded, will be explained. The interviews were held between April and June of 2024. For each interview, the oral consent of the interviewee was taken before each interview was recorded. A voice recorder was used to record the interviews. Furthermore, Microsoft Teams' transcription feature was used for some of the interviews. However, all the interviews were transcribed manually by the researcher. Only the parts of the audio recordings that were relevant to the research and answering the research questions were transcribed.

After summarising the transcribed interviews, the summaries and the full transcriptions were sent back to the interviewees for their feedback, allowing them to correct or

further elaborate on their statements if they wanted to. Finally, the transcriptions were colour-coded for further analysis. The coding system was based on the four research topics explained in the case study section and extra insights that did not fit under those themes but were deemed necessary for answering the research questions.

2.2. Ethical considerations

During the research conduction, several ethical principles have to be considered to protect the human beings involved in the process. This is even more important in qualitative research as this kind of research aims to find in-depth information about the interviewees. Polonsky and Waller (2018) present five principles that should be considered while performing qualitative research: 1) participation is voluntary, 2) informed consent is given, 3) confidentiality and anonymity are maintained, 4) potential for harm is analysed and taken into consideration, and 5) the results are presented without plagiarism or misinformation.

This research ensured that every step was communicated with the participants. Before conducting the interviews, the role of the researcher, the subject of the research and the reasons behind conducting the research were explained to them so they could make informed decisions on whether they would like to participate in the research. Furthermore, permission to record the interview was requested from all the participants. Furthermore, desk research was conducted and compared with the interviews to ensure the validity of the results.

According to Opdenakker (2006), researchers should make sure that their personal perception does not affect the outcome of the interview. To achieve this, the research protocol was developed in a way, so that the questions do not guide the interviewees to specific answers but rather allow them to formulate their answers themselves. Furthermore, the interview transcripts were sent to the participants so they could check and decide whether they would like to add/remove or provide further explanation on their answers.

3. Literature Review

This chapter develops the knowledge base required to conduct the case studies and ultimately achieve the main objective of this research. The literature review chapter is divided into two sections, each aiming to provide preliminary answers to one of the research sub-questions.

The chapter begins with an overview of campus management by first looking at real estate management, CREM (corporate real estate management) and facility management and how they apply in the context of university campuses. Then, it will continue by studying university objectives and the role campus management plays in achieving them, and we close this section by looking at value addition definitions and frameworks via FM and CREM, particularly within a campus context. This section answers the second sub question: *What is campus management, and how does it provide added value for campus stakeholders?*

The second part of this chapter provides preliminary answers to another sub question: *What are the defining characteristics of a smart campus, and which smart campus features can be identified?* To achieve this, we look at the definitions for smart real estate and PropTech (property technology) and identify smart building technologies. After that, the various existing definitions and frameworks for the concept of "smart campus" are reviewed and then followed by an overview of the current state of smart campus development and the existing smart applications. Finally, this section closes by exploring the features in smart campuses and how they benefit the users and the management of campuses.

3.1. Management of university campuses

This section of the literature review begins by studying the concept of campus management, focusing on how it adds value and addresses the needs and requirements of campus stakeholders. First, it examines real estate management and its subcategories, providing the basis for defining campus management in the following section. The chapter then explores the challenges faced by campuses and identifies the specific needs and requirements of their stakeholders. Finally, it outlines the objectives of campus management in generating added value for the campus stakeholders. The outcome of this section helps in the development of the added value

framework to be used to assess the impact of smart campus features and provides an answer to the second sub question of the research: *What is campus management, and how does it provide added value for the campus stakeholders?*

3.1.1. Real estate management

The premise of real estate management is to manage and maximise the value of real estate for its stakeholders. The increase in the number of corporate organisations over the past few decades has expanded corporate portfolios, thereby elevating the importance of real estate management as a practice. This shift transformed the perception of real estate from a liability to an asset that can provide added value to an organisation (Jensen et al., 2013), leading to the creation of specialised real estate management departments. Initially, these departments were responsible for monitoring the technical and financial aspects of buildings. Today, the focus of real estate management has broadened to emphasise how buildings can add value to their owners as well as the users (Den Heijer, 2011).

Valks et al. (2020) categorise real estate management into three general specialisations: portfolio management, corporate real estate management (CREM), and public real estate management (PREM). Each of these specialisations considers the added value of real estate from different perspectives. Portfolio management focuses on maximising the financial value of properties, whereas CREM and PREM aim to achieve a broader set of targets. Krumm et al. (1999) define CREM as the management of a corporation's real estate by aligning services with the core business to maximise business value and optimise corporate performance. PREM, as defined by Van der Voordt and Jensen (2017), is the management of a public real estate portfolio to meet user needs while aligning with political goals and the financial policy of the government. Over the years, both PREM and CREM have shifted their focus towards enhancing the performance of core processes rather than merely monitoring the technical and financial aspects of buildings (Krumm et al., 1999).

Another aspect that requires further study is facility management, which is often used interchangeably with CREM. FM is a rapidly developing profession that has gained significant attention and popularity over the past few decades, particularly since the outsourcing of services became common practice (Nazali Mohd Noor & Pitt, 2009).

Earlier definitions of FM, such as that by RICS (2010), describe it as the management of the day-to-day activities of a building. However, Potkany et al. (2015) argue that the FM definition should also encompass a long-term vision that includes the entire building lifecycle. Furthermore, FM acts as the communication link between the strategic and operational parts of an organisation. Incorporating cost-effective and service-oriented initiatives ensures the achievement of strategic goals while improving daily operations to enhance user satisfaction.

While there are some overlaps and similarities between Corporate Real Estate Management (CREM) and Facility Management (FM), such as their focus on relationship and stakeholder management, their scopes are quite different (Jensen et al., 2013). FM focuses on services and processes related to the needs of the end user. In contrast, CREM has a more physical and financial focus and is more project-oriented (Jensen et al., 2013).

3.1.2. Campus management

In order to better understand campus management, first, we need to identify what a campus is. Hobbs et al. (2017) define the campus as a physical location where people from related fields of work use and share the combined benefits. A university campus, therefore, can be defined as the location of buildings that support the strategic and institutional goals of the university, where the buildings can be either owned or rented (Den Heijer, 2011). The functions of a campus go far beyond academic activities and include other related non-academic activities, such as residential activities, retail, and leisure (Den Heijer, 2011). Many view campuses as miniature cities with their own infrastructure, buildings, and services that are dynamic and, like cities, should adapt to the changing needs and requirements of their diverse users (Magnini et al., 2018). Therefore, the management of campus real estate is of great importance for meeting the needs and requirements of its users and can have both negative and positive impacts.

Both theories of CREM and PREM can be utilised for the management of university campuses (Valks et al., 2021). However, it can be argued that CREM is even more applicable, as universities are facing significant financial constraints and are becoming increasingly dependent on private funding. A recent study identified that over 75 per

cent of both public and private universities in the US consider a lack of funding and financial resources to be their biggest challenge (Finley, 2021). As such, this study attempts to define campus management primarily through CREM.

CRE within the context of the university campus is defined by Den Hejer (2021) as the alignment of the campus real estate with the changing context of a university in order to 1. Meet the evolving needs of different campus stakeholders, and 2. Enhance the university's performance. Azizi et al. (2020) provide a similar definition for campus management. They define it as CREM within a university setting where the strategies are to improve productivity, profitability, competitiveness and environmental sustainability. This definition can be seen in the campus management framework developed by Den Heijer (2011). The framework categorises the different stakeholder perspectives involved in decision-making processes as policymakers, users, financial controllers, and technical managers. Figure 2 depicts the framework.

Each of these domains is further distinguished by their specific stakeholders. General management is responsible for developing the overall goals and visions of the organisation and setting policies. Asset management is concerned with the financial aspects of real estate management at the strategic level. Technical management addresses the physical aspects of the university, such as construction and maintenance. Finally, facility management has a functional perspective and manages the end users' needs and requirements.

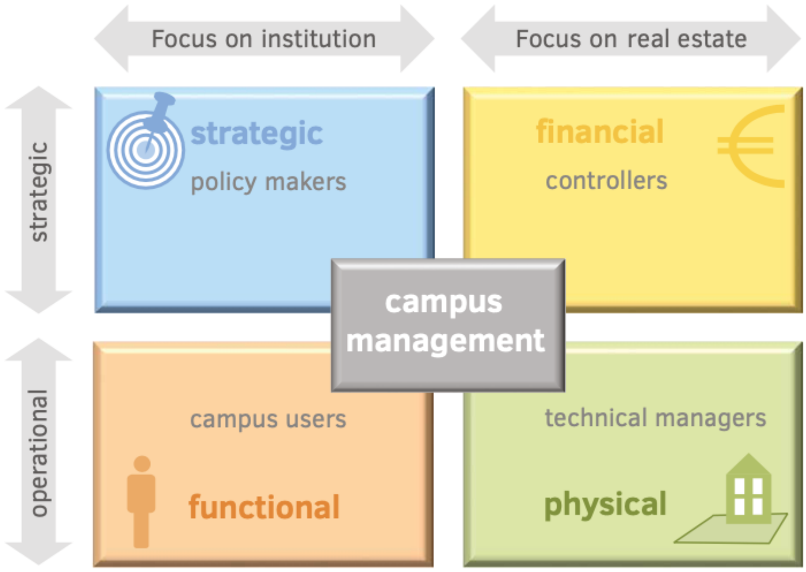

Figure 2 Campus Management framework[2]

The role of campus management is to add value to the performance of campus real estate by maintaining a balance between the four perspectives (Den Heijer, 2021). This is a very challenging task for campus management as the needs and objectives of a diverse group of campus stakeholders need to be considered. In many cases, these needs contradict each other. In other words, the focus of the campus manager should not be one-dimensional, only focusing on one aspect, such as cost reduction. Instead, it should consider all the aspects that can add value to the campus's overall performance, including user satisfaction, educational enhancement and meeting organisational goals (Den Heijer, 2011).

3.1.3. Campus objectives and added value

There are various ways in which real estate management can benefit an organisation by adding value to the performance of its properties. Value is defined as something that contributes to the core business of an organisation or can address the stakeholder's needs (Oudot, 2019). Research on the added value of real estate management has identified different benefits for organisations. These benefits include cost reduction, increased flexibility, and higher asset value (Den Heijer, 2011; Magnini et al., 2018; Valks et al., 2021). In addition, users can benefit from effective building

[2] Den Heijer (2011)

management, leading to increased productivity and satisfaction levels (Appel-MeulenBroek, 2014). In other words, real estate management indirectly influences productivity and profitability by impacting organisational goals.

Universities are currently facing many challenges from an imbalance between the supply and demand of resources, particularly the type and size of building spaces, which has led to inefficient use of them (Valks, 2020). Furthermore, Universities are facing financial difficulties. A recent survey among higher education institutes in the US found that over 75% of the universities identify a lack of financial resources as the most significant challenge they are currently facing (Finley, 2021). The same pattern can be seen in other parts of the world (McCann et al., 2019). This has led universities to seek alternative funding models, making strategic decision-making more difficult (Valks et al., 2021). Moreover, students' expectations and needs are changing, and new ways of learning have emerged, requiring further adjustments in university strategies. For campus management to be able to address these issues and add value to their users, their strategies needs to be evolved to align with their real estate strategies regarding the operation and management of their campuses (Beckers et al., 2014).

To better understand campus objectives and the added value of campus management, several studies on value addition through FM and CREM were analysed and compared. While some studies specifically examined campus real estate, others focused on the overall added value of CREM. An overview of these value frameworks and how they compare with each other can be found in Table 2. This comparison aims to compare the strategies from both FM and CREM points of view in a university context to achieve a value framework that is aligned with university needs and objectives.

Values	Den Heijer (2011)	Beckers et al. (2014)	Lindholm and Aaltonen (2011)	Jensen and Van der Voort (2017)	Oudot (2019)
	CREM (Campus)	CREM (Campus)	FM (Office)	FM and CREM (Office)	CREM (Office)
Innovation	Stimulating innovation	Support innovation	Increase Innovation	Innovation and creativity	innovation
Collaboration	Stimulating collaboration	Stimulate collaboration			
Culture	Supporting culture	Support culture		Culture	Culture
Image	Supporting image	Support corporate image		Image	Branding
Satisfaction	increasing user satisfaction	Increase user satisfaction	increase satisfaction	Satisfaction	satisfaction
Health and safety				Health and safety	Health
Productivity	Supporting user activities	Support user activities	Increase productivity	Productivity	productivity
Flexibility	increasing flexibility	Support change	Increase flexibility	Adaptability	flexibility
Cost reduction	Decreasing cost	Control real estate costs	Decrease costs	Cost	cost reduction
Added revenue	Increasing revenue				
Asset value	Increasing RE value		Increase value of assets	Value of assets	Asset value
Risk control	Controlling risks	Control physical risk		Risk	Risk
Environmental sustainability	reducing Co2 footprint	Support environmental responsibility	Support environmental sustainability	Sustainability Corporate responsibility	Sustainability

Table 2 Comparison of added value parameters in reviewed studies

One of the first and most well-known campus management frameworks is the one developed by Den Heijer (2011). The framework identifies thirteen ways campus management can provide added value. These are further categorised into four groups, each impacting different campus stakeholders. The strategic goals include collaboration and innovation stimulation, image support, culture support, and improvement of the quality of the campus space. Furthermore, the financial goals comprise risk control, cost reduction, and increasing real estate value. The functional goals are listed as supporting user activities, increasing user satisfaction, and enhancing flexibility. Finally, the physical goals include energy reduction and space use reduction. The added values are depicted in Figure 3.

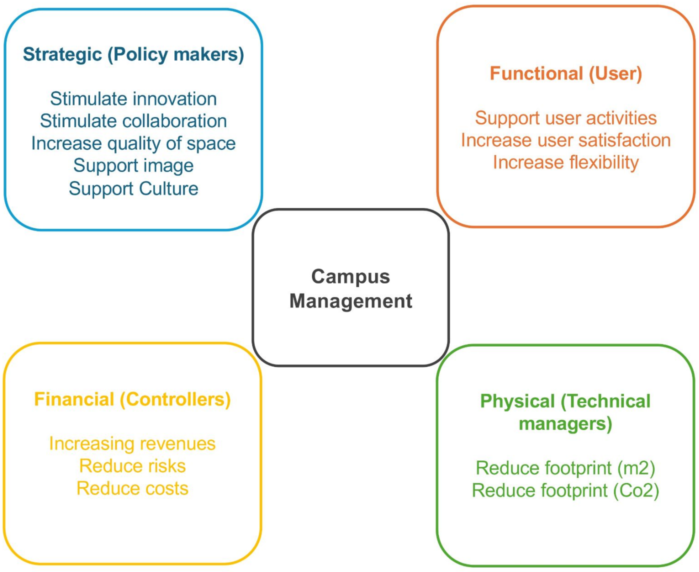

Figure 3 Campus stakeholders and their goals[3]

Beckers et al. (2014) conducted a study of real estate strategies and their applicability at several universities of applied sciences in the Netherlands. They found similar goals and objectives for value creation at university campuses. The study further analysed the significance of these objectives and found cost control to be the most important objective, followed by support of user activities, culture support, and stimulating collaboration. On the other hand, innovation and environmental sustainability were identified as the objectives with the lowest significance.

[3] based on Den Heijer (2011)

Van der Voort and Jensen (2017) analysed several pieces of literature on the topic to identify and benchmark the key value drivers of FM and CREM for organisations. The presented values are further categorised into four key groups: people, processes, economy, and societal. However, the values are quite similar to the studies by Beckers et al. (2014) and Den Heijer (2011), except for the addition of corporate social responsibility for the users, the planet and profit as an additional key value driver. Table 3 provides a quick overview of the identified strategies and value parameters, accompanied by the strategies for achieving them. The study further provides interventions to achieve the identified objectives.

Value Framework	Description
Innovation	Stimulating innovation and creativity by providing virtual and physical spaces where people can meet, communicate, and share their knowledge.
Collaboration	Stimulating communication and teamwork through space interventions and facilities provision, such as creating meeting spaces for students and staff, and establishing a hub for linking internal and external stakeholders.
Culture	Supporting the organizational culture, creating a sense of community and supporting collaboration by providing appropriate RE portfolio to the end-users.
Image	Enhancing corporate image and brand by providing an environment that contributes to a positive perception of the organisation.
Health and Safety	Improving user health, safety and wellbeing by providing users with a higher level of personal control over the environment, better indoor comfort and air quality.
Satisfaction	Increase user satisfaction by improving quality of space, providing suitable and collaborative environments and creating a better indoor climate.
Productivity	Supporting user activties and enhancing productivity by providing high-quality and flexible educational spaces that meet diverse needs and offer good indoor working environment conditions.
Flexibility	Having a flexible portfolio that can be easily modified in response to changing demand, while adopting a future-oriented approach towards education and learning activities.
Emission Reduction	Minimising carbon footprint of the campus by reducing energy use, water consumption and waste generation and promotion of sustainable transportation.
Cost reduction	Minimising operational costs by focusing on efficiency through the effective allocation of financial resources and the efficient use of energy and space.
Asset value	Increasing the real estate market value by upgrading properties, reducing risks, and lowering vacancy rates.
Risk control	Monitoring and managing financial, functional and technical risks through emergency and recovery plans, backup supply systems and insurances.

Table 3 Value framework[4]

3.2. Becoming smart

The second body of knowledge reviewed for this research focuses on the digitalisation of the built environment and the use of advanced technologies in real estate, which is also referred to as smart real estate. To achieve this, this chapter first looks at the concepts and definitions of PropTech and smart buildings. Then, a list of smart technologies and their applications in smart buildings is presented. Finally, the

[4] based on (Den Heijer. 2011; Beckers et al., 2014; Lindholm and Aaltonen, 2011; Jensen & Van der Voort 2017)

literature on the existing smart features, their impacts, and the challenges in their implementation is overviewed.

3.2.1. PropTech and smart real estate

PropTech is a broad term that refers to the use of advanced technologies in the real estate and property industry (Baum et al., 2020). These technologies include, but are not limited to, the use of virtual and augmented reality for marketing, integration of artificial intelligence into property and facilities management, the development of online platforms for renting and selling properties, and predictive analytics (Baum, 2017).

Furthermore, PropTech utilises Internet of Things, databases, and applications, providing benefits to multiple areas, from construction and real estate management to maintenance and facility management. The PropTech sector has impacted all areas of real estate, including property, facility, and asset management. The sector is further divided into smart real estate or smart buildings, shared economy, and FinTech (Baum e*t al.*, 2020). However, only the first category, smart real estate, is of interest to the research topic.

Smart real estate, also known as smart building, incorporates various advanced technologies to manage a real estate asset (Baum *et al.*, 2020). Smart real estate is a broad term that is used to refer to all smart built environments, such as smart homes, smart campuses and smart cities (Polin et al., 2023). Not only SRE provides information about the performance of the asset but can actively monitor and manage building services (Baum, 2017). In fact, according to Apanaviciene et al. (2020) the main objective of Smart Real Estate is to support the management of real estate assets, facilities and processes.

Despite its prevalence in the academic and practical world, there is no explicit and widely accepted definition of smart buildings. De Groote *et al.* (2017) describe a smart building as a structure that utilises smart technologies such as smart lighting, cooling, heating and security to manage its operations. Al Dakheel *et al.* (2020) argue that a building should have four essential functions to be considered smart: 1) climate response, 2) user response, 3) grid response and 4) supervision, emphasising their adaptiveness as the key feature. According to Lindström (2023), the purpose of smart buildings is to save energy and reduce costs while improving the comfort and safety of

the users. To achieve these goals, buildings typically implement automation systems, Internet of Things, and real-time data analysis).

3.2.2. Smart building technologies

Building Automation

Building automation is mainly responsible for controlling the building services and, therefore, is directly linked to control systems (Valks *et al.*, 2021). The way control systems are used in buildings has changed over time. Before, each control system had its own name, which is still being used by many, such as building management system (BMS) and energy management system (BEMS).

These days, the building automation system (BAS) is used as an umbrella term, which refers to all the systems that monitor and control building services. The main objective of BAS is to enhance the performance of the building. In its earlier definitions, BAS only focused on ventilation, heating and HVAC systems and ignored the user interaction with the building (Wong *et al.*, 2005). Similar to the concept of smart building, BAS now includes the enhancement of user safety and comfort as part of its performance goals (Valks *et al.*, 2021).

Internet of Things

The general idea for Internet of Things (IoT) is that any physical object, such as buildings and vehicles, can be connected to the Internet (Baum *et al.*, 2020). By doing so, these devices can collect data and communicate with other systems and each other, consequently allowing them to be monitored and controlled remotely (Lindström, 2023). IoT has many applications in different areas, from smartwatches to self-driving cars and smart homes.

Li *et al.* (2015) categorised the IoT ecosystem into four general layers: the sensing layer, the networking layer, the service layer and the interface layer. The first layer, which is the sensor layer, is where the data is collected through the integration of sensors. Examples of sensors include temperature, noise, NFC, RFID, and light. The second layer is the communication layer, which is responsible for transmitting the data via networks. Then comes the information layer, which is the layer that stores the collected data in data warehouses. The next layer is the analytics layer, where the stored data is processed and analysed. The fifth and final layer is the vertical layer,

also known as the business or interface layer. This is the layer where the analysed data can finally be used for decision-making via applications and system management platforms.

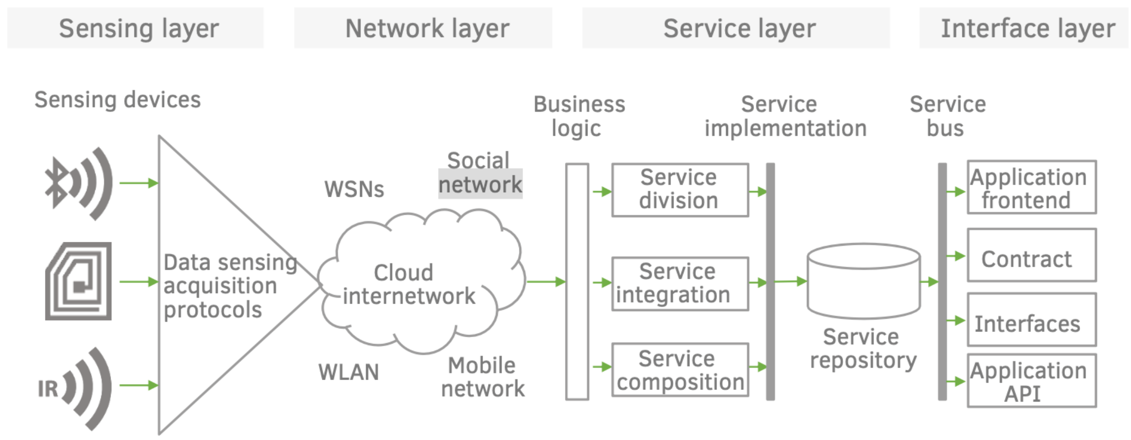

Figure 4 Internet of things ecosystem[5]

IoT has had a significant impact on the way buildings are being managed. Implementing IoT sensors into building systems has created the possibility to remotely monitor and control buildings, resulting in enhanced comfort and security and higher energy efficiency (Valks et al., 2021). Furthermore, IoT devices can be used to monitor and analyse data such as occupancy rates, energy usage rates and the maintenance needs of a building (Lindström, 2023), which can further improve the user experience and reduce operational costs.

Sensing technologies

Nowadays, several smart sensors and tools are implemented in buildings to collect the data required to monitor and analyse building operations. Sensors and tools such as RFID, Wearables, WIFI, and cameras can be used to collect all sorts of data, including occupancy, climate variables, and user health (Valks et al., 2021). Different sensors that are currently used in smart buildings have been identified in the literature and presented in this section.

[5] (Li et al., 2014)

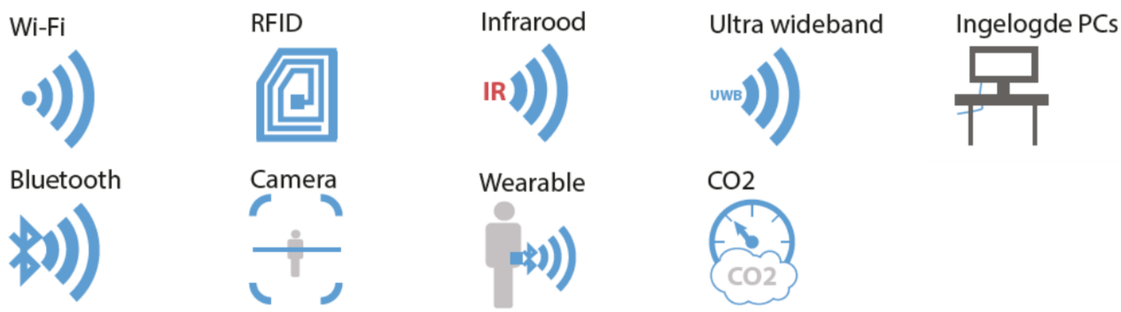

Figure 5 Overview of different types of sensors[6]

WI-FI: Wi-Fi networks are used to find out the location of a device within their network. Due to the increase in the number of access points and mobile devices such as phones and laptops, their accuracy has increased significantly. Serraview (2015) has identified the advantages and disadvantages of using Wi-Fi networks. Their biggest advantage is that they are relatively cheap. Furthermore, they can be easily scaled to fit the needs of a building. Their main disadvantage is that occupancy at room level cannot be achieved, and its level of accuracy is dependent on many factors, as mentioned earlier. In addition, privacy can be an issue as they are connected to personal devices.

Bluetooth: Similar to Wi-Fi, Bluetooth is a wireless technology that is used to transfer data between devices within a short distance. Furthermore, as the number of devices that have Bluetooth is increasing, the accuracy of this technology continues to grow as well. However, for Bluetooth devices to be used, they need to be activated by the user. To measure occupancy, Bluetooth beacons are installed in rooms and specific parts of the buildings that the occupancy wants to be measured. Therefore, they can be more accurate than Wi-Fi networks because they cover a smaller area.

Ultra-Wideband (UWB): UWB functions similarly to Wi-Fi and Bluetooth. However, it is much more accurate and does not get blocked or weakened by physical objects such as doors and walls.

RFID: RFID stands for Radio Frequency Identification and allows a device to read information from a chip. They are mainly used for theft prevention or access via entry gates. Their accuracy for measuring occupancy depends on whether or not an access card is used to enter the space. This approach is quite inexpensive and requires very little maintenance; however, their detection range is relatively small (Serraview, 2015).

[6] (Valks et al., 2020)

Another way of using RFID is to install reading devices on desks or through different floors, which is very accurate, but at the same time, it is quite expensive to implement (Valks, 2020).

Infrared: Infrared devices are divided into active infrared (AIR) and passive infrared (PIR) and consist of infrared beams that are emitted to detect infrared lights (Serraview, 2015). AIR is mainly used to measure passage of people in and out of a space and is an inexpensive method for measuring room level occupancy quite accurately. PIR on the other hand can measure the variance in energy in a certain space. Therefore, they are used to trigger lighting or are implemented in desks and in rooms such as meeting rooms to identify whether they are occupied or not. The main advantage of infrared systems is that they are both economical and anonymous.

Camera: Camera devices are used in multiple ways to measure space use and occupancy. They can be used for tracking, counting, and identifying locations and types of activity (Trivedi & Badarla, 2019). Even though cameras can provide accurate occupancy information, their implementation is relatively expensive and gives users a feeling that they are being monitored (Valks, 2020).

Indoor climate sensors: Some examples of sensors that are implemented to monitor indoor climate are temperature sensors, noise sensors, luminance sensors and Co2 sensors (Valks, 2020). The data gathered from these sensors are then used to enhance user comfort and allow users to choose where they would like to work based on their personal preferences.

Use of other devices: Other devices can also be used to measure the occupancy of a space. For example, the number of logged-in computers in one room combined with the number of docking stations that are being used can provide an estimate of the number of people currently occupying the space. However, their accuracy is dependent on whether these devices are used. Even though this method can raise privacy concerns and their accuracy can be questionable, it can still provide room-level occupancy information at a low cost.

Other notable technologies

In addition to building automation systems and IoT, which are at the forefront of smart building practices, other smart technologies such as Artificial Intelligence (AI), virtual reality (VR), augmented reality (AR), and big data are some of the other notable

categories found in smart buildings. In this section, these technologies are briefly discussed, and some examples of their application in the real world are provided.

At the moment, most of the monitoring and analysis processes in smart buildings are being performed by people. A person is required to transfer the collected data into usable information. Integration of Artificial Intelligence (AI) into existing smart systems allows for machines to perform the analysis and draw conclusions. While IoT focuses on identifying and monitoring information, AI can learn from the collected data and use it to predict and further improve the efficiency and effectiveness of smart environments (Baum, 2017).

According to Peterson and Desrocher (2018), AI platforms significantly improve building interaction with users while making them more efficient and sustainable. Furthermore, AI can identify user preferences and provide services that are tailored to those preferences, which can increase user satisfaction. Peterson and Desrocher (2018) identify the main benefits of incorporating AI into building systems as follows: higher efficiency due to predictive analytics, reduction in operational costs, reduction in energy consumption, lower maintenance costs, and environments that can predict user needs.

Virtual reality (VR) refers to the technology of creating virtual environments without interacting with the real world. VR is commonly used to allow users to move within a 3d model of a property without physically being there. Augmented reality (AR) is an emerging technology that combines the real world with the virtual environment in order to provide a seamless overlap of the two worlds to the user (Dong *et al.*, 2020). AR can be utilised in various areas, such as maintenance, navigation, wayfinding, and space planning.

3.2.3. Smart campus: definition and frameworks

The higher education sector is currently going through a digital transformation that aims to enhance the performance of university campuses and improve the teaching and learning experiences of its students and faculty members (Polin *et al.*, 2023). This transformation has led to the emergence of the “smart campus“ concept. However, beyond its reliance on advanced technologies such as sensors, big data, Internet of

Things (IoT) and artificial intelligence (AI), there is no consensus regarding its definition (Polin *et al.*, 2023).

In literature, the idea of smartness has been deployed at different scales (see Figure 1), ranging from smart homes to smart regions. In each of these contexts, a similar definition can be identified. That is why some of the existing definitions (Imbar *et al.*, 2020; Zaballos *et al.*, 2021) perceive smart campus as a smaller iteration of its more established counterpart, smart city. For instance, Imber *et al.* (2020) define smart campus as a small-scaled smart city that operates in a smart city context and offers intelligent solutions to its citizens in order to improve their quality of life.

Other studies focus more on the role of the smart campus in the enhancement of the learning environment. Chen and Liu (2020) depict the smart campus as an intelligent teaching environment achieved through integrating IT into educational practices. Additionally, Dong *et al.* (2020) view it as an educational environment leveraging technology to improve academic performance while at the same time addressing stakeholders' needs and demands.

The final group of definitions identified in the literature underscore the technological aspect of the smart campus. Fragma-Lamas *et al.* (2019) describe it as an intelligent infrastructure that uses sensors and actuators to collect information and collaborate with the other parts of a university campus. Cheng *et al.* (2022) defines smart campus as a data-oriented and collaborative research and teaching system that is intelligent and is based on advanced technological infrastructure.

In recent years, several conceptual frameworks for smart campus development have emerged (Chagnon-Lessard *et al.,* 2021; Polin *et al.*, 2023; Valks *et al.*, 2021) that aim to bring all the definitions that are mentioned above together and provide a more comprehensive understanding of how "smart campus" is conceptualised and practised. In one of the earliest attempts, Pagliaro *et al.* (2016) planned and implemented a framework for transforming La Sapienza University into a smart campus and highlighted its key action points as governance, control, information and management.

In a similar attempt, Ahmed *et al.* (2020) proposed a framework comprising smart buildings, smart mobility, smart education, smart health and access control management. Furthermore, the framework developed by Chagnon-Lessard *et al.* (2021), which is based on an extensive review of the literature on the topic, identified

the main domains of smart campus as follows: smart government, smart people, smart living, smart mobility, smart environment, smart building and smart data.

In order to develop a more inclusive framework, Polin *et al.* (2023) adopted the four widely used and familiar domains within the field of sustainable development: economy, governance, environment and society, where each is aligned with the fifth domain of the framework being the smart technology and data. Furthermore, each domain was broken down into four subcategories to provide the key aspects to be investigated when attempting to develop a smart campus. Furthermore, Valks *et al.* (2021) proposed a conceptual design for a smart campus dashboard that follows the same four domains while using different terminologies. His framework is based on the campus management framework developed by Den Heijer (2011), which categorises each domain according to different operational, strategic, financial, and physical management CREM areas.

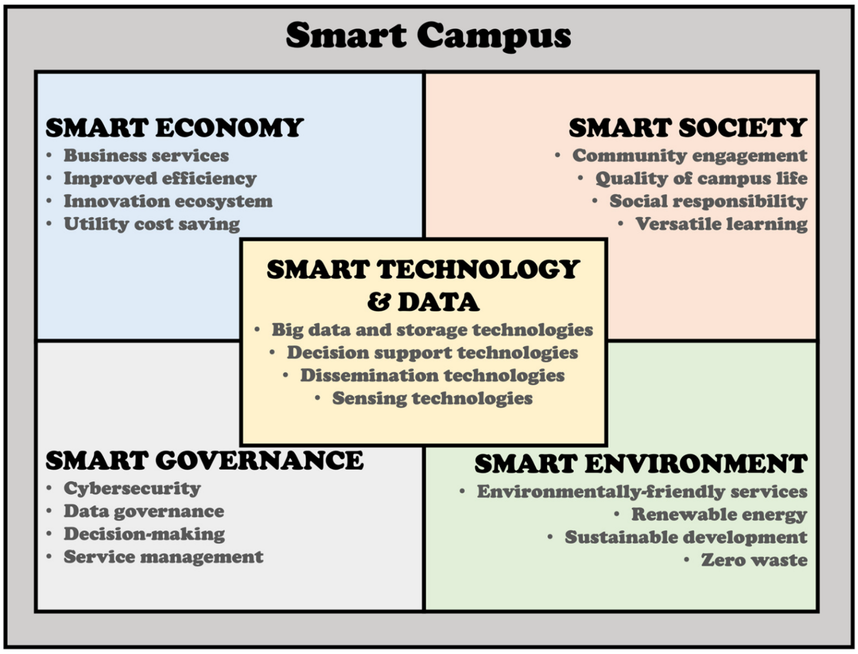

Figure 6 Smart campus framework[7]

As mentioned earlier, many see smart campuses as a miniature model of the smart city model, which is why some authors developed their smart campus frameworks based on the smart city principles. For example, Dong et al. (2020) proposed a user-centred smart campus framework based on the smart city model where the stakeholders are at the centre of the framework, surrounded by the infrastructure,

[7] developed by Polin et al. (2023)

service and technology layer. Furthermore, Min-Allah and Alrashed (2020) developed a framework based on the smart city model that consists of resources, people, education, improved services, and smart microgrids. Finally, Omotayo et al. (2021) designed a model for smart campus development consisting of the four domains of smart building, smart learning, smart technology and continuous improvement.

3.2.4. Smart campus: current state

Chagnon-Lessard et al. (2021) by analysing the studies over the last decade found that Internet of things and sensors are by far the most utilised technologies in smart campuses followed by AI and cloud computing. Valks (2020) reviewed the technologies in Dutch universities and identified that nine universities have deployed some kind of smart tools and technologies in their campus. Out of which only five universities have fully implemented them, and the rest were at the piloting phase. Furthermore, he found out that the main functionalities of these tools are for the management to monitor frequency and occupancy of the spaces and allow students to find and book study spaces. WIFI and Infrared sensors were the main tools for data collection. Only two of the universities were measuring actual occupancy of the space using infrared sensors while the other universities were relying on schedule data to observe them.

In a follow up study by Cazemier (2021), the same universities were studied again to see what has changed and how they have utilised them for managing Covid 19 situation. He found that 3 other universities have added infrared sensors to measure actual occupancy. Measuring actual occupancy and being able to identify no-shows was found to be one of the main drivers for implementing technologies post Covid-19. In general in the Dutch universities, the smart tools are mostly implemented for the management to monitor space use or help students book rooms, find vacant space and navigate through the campus (Valks, 2020; Cazemier, 2021)

Furthermore, these studies the smart solutions that are implemented at each university. Cazemier (2021) found that the majority of user interfaces that are in use are web-based and only two universities have provided mobile apps for such purposes. On the other hand, report features and dashboards are equally implemented for the use by the campus management. In addition, when comparing the results they found

that the use of smart interfaces has doubled compared to the study by Valks (2020) which further emphasises the findings from previous studies that smart campuses are rapidly becoming the standard and norm in campuses.

Smart Applications	Universities	User Info	Management Info
Mapiq	- TU Delft - University of Amsterdam	- Space finding - Real time occupancy - Space Booking - Wayfinding	- Dashboards using real time and historical data - Data analysis (Space use, scheduling, cleaning and maintenance, reducing energy consumption)
PIE, Clocks	Wageningen University		- using location management to see how many people are in the building - Real time occupancy - no shows
Planon	TU Eindhoven Radboud University	- Booking rooms - Real Time Occupancy - Wayfinding	-Frequency rate and occupancy rate of buildings

Table 4 Smart applications at Dutch universities[8]

3.2.4. Smart campus features

So far, the tools, technologies, and components deployed in smart campuses have been presented. This section describes the smart features that these technologies have provided to the campus stakeholders. Studies focusing on smart features are primarily user-oriented, as *features* are generally defined as part of a property provided directly to its users (Van Susante, 2014). However, smart features can also add value to the management team, particularly by providing information required for decision-making (Valks et al., 2021).

Due to the novelty of the topic and the fact that the studies on smart campuses are still quite limited, this section additionally reviews the research on smart workplaces, as there is much overlap between the two. Most of the features identified and studied in the literature refer to those found in smart workplaces and smart offices. This section first identifies the smart office and smart workplace features that apply to the campus setting. This will be followed with the overview of the literature on smart campuses to identify the features that are tailored to address the specific needs of the university campus.

[8] (Valks, 2020; Cazemier, 2021)

Majchrzak (2019) reviewed the literature on the smart office features that are most relevant to the users and identified ambient control, occupancy data, booking and colleague finding as the most significant services provided. In a similar study, Remes et al. (2021) investigated the literature on smart workspace solutions. They categorised them into three main layers based on their prevalence. They found booking, occupancy and wayfinding to be the most recurrent features, followed by people flow, calendar sync and indoor environment quality (IEQ).

Valks et al. (2021) analysed the smart applications utilised at several Dutch universities and identified space finding, space booking and navigation as the most common features provided to campus users. Table 6 depicts the investigated studies and the smart features identified in each of them. Furthermore, since there are no standards or benchmarks for smart campus features, the reviewed studies used different terminology and categorisation of smart features. Therefore, the descriptions of the features were compared with each other beforehand to ensure compatibility of the results.

Since the literature on smart campus and smart office features is quite limited, it was decided to identify current solutions and review them to gain a more comprehensive understanding of the currently available features. To identify the state of the art of smart workspace and campus features that are currently available in the market. Several companies and startups provide smart solutions and services that aim to meet the needs of management and the users of offices and campuses. These tools and services utilise the technologies described in the previous section to achieve this goal.

Smart features	Mustafa et al. (2021)	Ahmed et al. (2020)	Zeeshan (2021)	Remes et al. (2020)	Schinde et al. (2020)	Valks (2020)	Dong et al (2020)	Cazemier (2021)	Total
Occupancy status	x	x		x		x		x	5
Space finding and booking		x		x	x	x		x	5
Air quality regulation				x	x	x	x	x	5
Temperature and lighting control				x	x	x		x	4
Smart check-in and attendance	x	x					x		3
Wayfinding				x			x	x	3
Asset tracking	x			x			x		3
Augmented learning	x		x				x		3
User feedback and incident reporting			x	x					2
People finding				x	x				2
Access Control	x						x		2
Remote learning		x							1

Table 5 Smart campus features identified in the literature

While there are a lot of smart solutions, only the ones that have been used at university campuses are reviewed. These workspace and campus solutions are Mapiq, developed at Delft University, Empathic Buildings, Planon, Comfy, Hubstar, Mazemap, and SWYCS. These solutions provide property users with various smart features to meet the needs and requirements of people (management, users, investors) and the environment and to increase profitability (Haltian, 2024; Siemens, 2024; Mapiq, 2024; Planon, 2024). Table 6 depicts the features that the reviewed applications provide to the users. Similarly, Table 7 shows the data provision and the reporting system provided to the campus management for decision-making purposes.

Smart features (User)	Empathic Building	Mapiq	Planon	Comfy	Hubstar (PIE, Clocks)	Mazemap	SWYCS	Total
Occupancy status (free, occupied)	x	x	x	x	x	x		6
Booking status (reserved, available)	x	x	x	x	x	x	x	7
space finding	x	x	x	x	x	x	x	7
Room booking	x	x	x	x	x	x	x	7
Desk booking	x	x	x	x	x	x		6
No show communication		x				x		2
Wayfinding	x	x		x		x	x	5
People finding	x	x		x	x	x		5
Incident reporting	x		x	x				3
Parking overview		x		x				2
Other		x	x	x				3

Table 6 User features provided by smart workspace solutions

Smart features (Management)	Empathic Building	Mapiq	Planon	Comfy	Hubstar (PIE, Clocks)	Mazemap	SWYCS	Total
Occupancy data	X	X	X	X	X	X	X	7
Reservation data			X	X	X	X		4
No shows				X	X	X		3
People flow and heatmaps	X			X	X	X		4
Energy performance			X				X	2
IEQ	X					X		2
Asset Tracking			X			X		2

Table 7 Management features provided by smart workspace solutions

Based on the findings from the previous studies as well as the overview of the current market of smart campus solutions the following features were identified. Furthermore, the added benefits and the impacts of each feature is reviewed as well. These features will provide the basis for the analysis of the case studies on the next chapter. It is important to mention that through this analysis it was found that in addition to the features that are directly available to the campus management such as access control and asset tracking, the collected data from user-oriented features can offer additional features such as people flow and heatmaps.

Occupancy status

Provides users with real-time information on whether a space is free or occupied based on the data collected from the occupancy sensors. Occupancy rates were originally only used for the way a room is used and utilised (Space management, 2006). Therefore, the primary use of this feature is to identify occupancy of the rooms, however depending on the type and availability of the sensors, some interfaces provide the information for desks, lockers and parking spaces as well. Providing real time occupancy information to the user significantly increases their productivity and improves their level of satisfaction (Valks et al., 2020). When synced by the booking data, this feature can provide secondary features such as the possibility to cancel the unused bookings and to communicate the no-shows with the user so that others can use them (Saralegui et al., 2019).

The data from occupancy sensors can strongly support campus management in their decision making. Having access to actual use of spaces addresses one of the biggest shortcomings of CREM in monitoring space use which was being reliant on booking data alone. By knowing the actual frequency and occupancy rate of spaces, the campus management can identify no-shows and reduce the gap between predicted use and actual use of the spaces leading to improved utilisation rate of spaces (Valks et al., 2020). In addition, the insights from the data can help indicate the actual demand for different spaces and different parts of the campus which directly impact the real estate portfolio and reduce the risk of vacancy. Furthermore, the increase in space use efficiency can lead to noticeable cost reductions and increase energy efficiency (Elsaadany, 2017). In a study by (Sutjarittham et al., 2019) it was found through mathematical modelling that the combination of actual use and predicted use can lead to a 10% reduction in room costs. Finally, linking the occupancy sensors to the building

automation system can help reduce energy use of the building (Masoso & Grobler, 2010).

Space finding and booking

Booking services allow users of the campus to reserve a suitable space to work or study based on their specific needs and preferences (Budie *et al.*, 2019). For example users can specify whether they are looking for a space for individual work, team work, if there are standing desks, double screens etc. and select their preferred space based on the set criteria. The provision of this service ensures that the user has access to a space that can meet their needs which directly impacts user satisfaction and enhances collaboration opportunities. Furthermore, it allows the management to identify the demand level for different rooms by their type and the features they offer to improve quality of spaces and provide rooms that are in more demand (Valks *et al.*, 2021).

Wayfinding

Wayfinding provides the campus users to seamlessly navigate the campus and quickly locate a workspace, a classroom or where an event occurs (Chen *et al.*, 2019). This can significantly reduce the time and the hassle of finding a space and can be specifically useful for campus visitors and those who are not familiar with the campus area. By providing users of the campus with an ease of mind, wayfinding helps users to put their focus on learning and teaching activities (Dong et al., 2020).

Indoor climate control and optimisation

Allowing users to control the temperature and lighting intensity helps users to create their preferred environmental conditions (Papagiannidis & Marikian, 2020). Furthermore, Borghero (2018) argues that allowing users to control the condition of their indoor environment, empowers the user, leading to higher productivity and higher level of user health and satisfaction. In addition, the utilisation of environmental sensors such as temperature, noise, co2 and humidity sensors can allow the management to monitor and control the indoor climate in real time which will enhance the productivity and wellbeing of the users (Papagiannidis & Marikian, 2020). Thermal comfort is one of the most common needs of building occupants and one of the main causes of complaints and has the highest impact on the comfort level and productivity of the building users (Seppanen & Fisk, 2004). Utilisation of automation detection

systems can ensure the optimal indoor environmental conditions through collecting and analysing the data from the deployed sensors (Papagiannidis & Marikian, 2020).

3 Case Studies

This chapter describes the cases and presents the findings from each case. The three cases studied for this research are Metropolia's Myllypuro campus, Aalto University's Otoniemi campus and the University of Oulu's Linnanmaa Campus. The criteria for selecting the case studies are explained in the Methodology chapter. The case studies are performed primarily via semi-structured interviews with campus facility managers, development managers, and other relevant stakeholders. The complete list of interviewees is depicted in Table 2. Desk research is also used to supplement the findings from the interviews.

Chapter three provided the knowledge basis for the research. The goal of the literature review chapter was to develop an understanding of the key themes of the research (smart campus and features, campus management, campus objectives and added value) and investigate the relationship between them. This chapter uses the literature findings to validate and supplement the findings of this chapter.

First, an overview of the campuses, their stakeholders, and their objectives is presented. This is then followed by an examination of the current state of the implemented smart technologies. Afterwards, the case findings are presented and summarised to provide case-specific answers to the research sub-questions regarding the existing smart features, their impacts, and their added value in achieving the campus objectives. The findings from this chapter will then be evaluated with the findings from the literature to provide a holistic view of the smart campus features and the added value they provide to campus stakeholders.

4.1 Metropolia University of Applied Sciences - Myllypuro campus

4.1.1 Case introduction

The first case in this research is the Myllypuro campus, which is Metropolia's newest and largest campus. The campus is owned by the City of Helsinki and used by the Metropolia University of Applied Sciences. The first phase of campus construction was completed and opened in January 2019, with the second phase opening a year later. Myllypuro hosts the faculties of Construction and Real Estate Management and the

Faculty of Health and Wellbeing. The campus covers 56,000 square metres and accommodates 552 staff members (FTE) and 7,500 students (Ojala et al., 2023). In 2023, Myllypuro became the first university campus in Finland to receive the gold level Smart Building Certification from Smart Building Collective (Smart Building Collective, 2023).

Size (Gross area): 56000 m^2
Students: 7500
Staff (FTE): 552
Faculties: 2

Figure 7 General information about the Myllypuro campus

Myllypuro campus has been designed and built to align with the City of Helsinki's strategic objectives regarding sustainability, indoor environment, and energy use. To achieve this, the campus was equipped from the beginning with numerous environmental sensors and an advanced building automation system that controls the main functions of the building services and optimises the campus's energy use. Additionally, as a university of applied sciences, Metropolia's primary interest has been to enhance data utilisation for educational purposes and provide hands-on learning experiences for its students. Metropolia's School of Real Estate and Construction has continuously integrated additional smart building features to utilise the collected data better and enhance teaching and learning experiences to achieve these objectives.

Technology landscape

In addition to the building automation system, Myllypuro is equipped with over 4,000 temperature sensors, 150 CO_2 sensors, as well as humidity and occupancy sensors. Every room has CO_2, temperature, and occupancy sensors, while every floor is equipped with humidity sensors. Furthermore, the campus features surveillance and access control systems, people counters at entrances, and a parking system that

indicates the availability of parking spots, including those with charging stations. A weather station, currently in its piloting phase, is installed on the roof of one of the campus buildings to provide more accurate weather forecasts. This weather station is intended to be integrated with the building automation system for predictive energy management. Additionally, virtual reality is utilised at the HVAC lab to provide virtual training for students and enhance the maintenance of the systems.

The harmonisation and standardisation of data flow are managed through the Platform of Trust. All data gathered from the sensors is processed through this platform, enabling data exchange with other systems and interfaces. Haltian's Empathic Building serves as the primary data analytics and information management interface used by campus management and the users. This web-based interface provides features such as desk and room occupancy status, indoor environmental conditions (CO_2 levels, temperature, and humidity), space finding, parking overview, and incident reporting. In addition to real-time data, Empathic Building can visualise historical data on space utilisation and indoor environmental quality and generate reports. The interface also provides access to information such as the campus restaurant menu, public transport schedules, and educational information. Empathic Building was first piloted in Building A of the campus, where the School of Real Estate and Construction is located, and later expanded to the entire campus.

Upcoming plans

The main priority of campus management is to improve space monitoring and utilisation further. This includes integrating reservation and occupancy data to compare actual space usage with booked spaces and identify no-shows. Another planned initiative is the implementation of the building information system (Empathic Building) across the other three campuses. Additionally, there are plans to encourage more users, especially students, to use the Empathic Building, as the current usage rate is very low.

4.1.2 Case findings

Smart features

Deploying several smart tools and technologies at the Myllypuro campus has provided campus management and its users with various smart features. These features and the data and information they provide are primarily accessible via the Empathic Building interface. This interface gathers and visualises data, providing reporting and analytics features. The identified smart features are as follows:

Room and desk occupancy status: The data is visualised through the Empathic Building interface, which everyone with Metropolia email (students and employees) can access. Users can check the real-time occupancy status of different spaces. It allows management to monitor space use over time and create reports.

Space finding and booking: Users can search for different spaces on the campus. The spaces can be filtered by type as well as by its features. Some of the spaces can only be booked by the employees. The booking of the spaces is done through a different platform (the Tuudo app for students). However, the data is visualised on the empathic building platform, allowing the users to see whether a space or a desk is booked but not occupied.

Indoor environmental conditions: The current temperature, CO2, and humidity levels of the rooms throughout the campus are visualised so users can check and see the current indoor conditions. The campus management can also use this information to identify flaws in the HVAC system.

People flow: While there is no indoor positioning system to identify the flow of the people inside the building, people counters at the entrance and exit points allow the management to check the overall number of people currently present at the campus.

Incident reporting: Users can report property flaws, logistic issues, or technical issues by specifying their exact location through the Empathic Building's service ticket feature. They can also check if the problem has been reported before.

Parking overview: Parking spaces can be checked in real time. Furthermore, users can check their availability in the next hours based on historical data.

Data and Information availability

Users can check the real-time occupancy status of rooms and desks, as well as the current temperature, humidity, and CO2 levels for each room, allowing them to reserve

a room based on their preferences. Additionally, they can see the availability of parking spaces, check the restaurant menu, and view the public transportation schedule. Educational materials, such as a 3D model of the ventilation system and other space-specific educational information, are available through the interface to enhance students' learning experience.

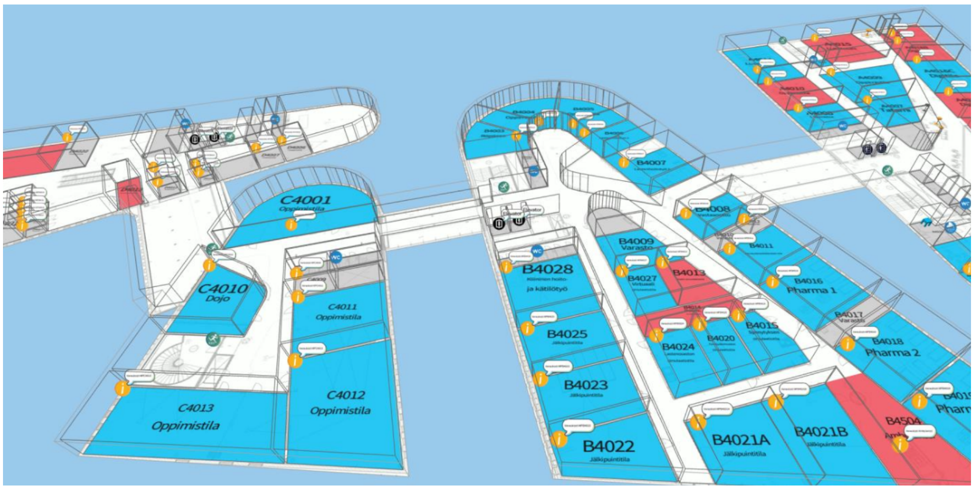

Figure 8 Empathic Building interface showing real-time occupancy status on Myllypuro campus.

<u>Management</u> can have an overview of desk and room occupancy and indoor environmental data (real-time and historical) to monitor space use and indoor environmental conditions. Additionally, they can use the analysis and reporting features of the Empathic Building to create reports through the app or export the data for further analysis using other tools such as Power BI. Reservation data can be accessed through the ERP system (Peppi), allowing comparisons with actual occupancy data. Furthermore, management can see the number of people currently on campus, as recorded by people counters at the entrance gates.

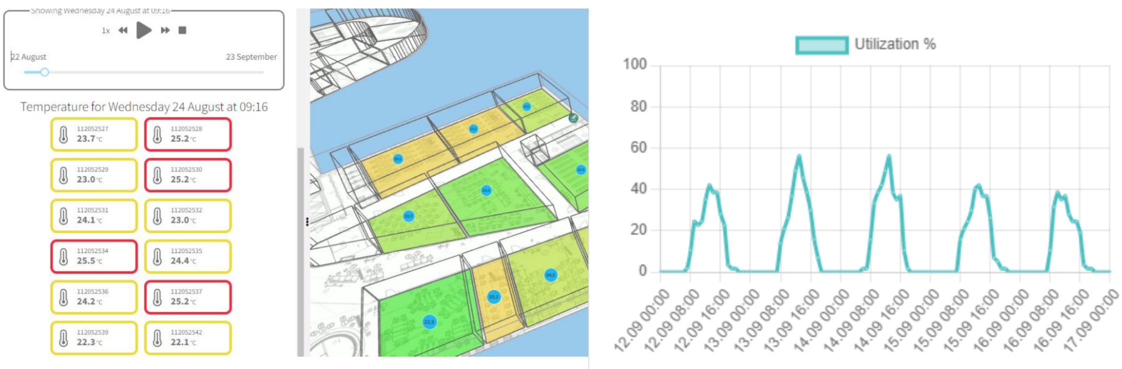

Figure 9 Overview of indoor environment conditions (left) and the utilisation rate report of part of the campus (right) via the Empathic building interface

Challenges

Before examining the impacts that the identified smart features have had on the campus stakeholders, it is essential to discuss some of the challenges identified in the interviews, as they can hinder the full potential of the available smart features. These challenges are mainly the low usage rate of the user interface, especially among the students, and the scatteredness of the features across multiple platforms.

Low usage rate of the user interface: Only around 500 out of 8,000 users actively use the Empathic Building, and most of them use it mainly for educational purposes. This is partly since it has only been fully implemented on the campus for one year. However, no attempt has been made to introduce the interface and its features to the users during that time period either. All the interviewees mentioned this as a challenge that should be addressed.

Availability of the smart features across various services: The booking feature is done via one platform, while the occupancy status is available through another interface. One of the interviewees mentioned this as being inconvenient and the reason for not using Empathic Building as much. Furthermore, the lack of one unified application for smart features means that the data required for analysis and decision-making should also be collected from multiple platforms. At the moment, the facility management team does not have any dashboard that can aggregate and show all the information they require, which has made the process more challenging.

Impacts

Due to the recent implementation of smart tools and technologies at the campus, it is quite early to reach concrete results regarding their effectiveness and their impacts on the campus stakeholders. However, the perceived impacts of the smart features on the stakeholders identified through the interviews are gathered and presented here. Table 8 shows an overview of the effects of each available smart feature on the campus. Furthermore, it links the identified impacts with the added value framework (See Table 4 in section 3.1.3) to identify the added value of each implemented feature.

Smart Features	Impacts	Added Value
Occupancy status	- Increased utilisation rate through scheduling adjustments and identification of lecture rooms that are booked and not used (combined with reservation data). - Identification of users' space demands by looking at those that are most frequented.	- Flexibility - User satisfaction - Productivity
Space finding and booking	- Identification of users' space demands by looking at those that are booked the most. - Users can find the spaces that meet their specific needs conveniently. - Increased space utilisation rate by identifying lecture rooms that are booked but not used (combined with occupancy data).	- Flexibility - User satisfaction - Productivity - Collaboration
Indoor environmental conditions	- Allowed the users to select their work or study space based on their ideal indoor conditions. - Reduction in energy use by adjusting the overall temperature while maintaining thermal comfort - Identification of HVAC system flaws and maintenance needs in real-time.	- User satisfaction - Productivity - Health and Wellbeing - Emission reduction - Risk
People flow	- Monitoring flow of the people into and out of the campus has helped reduce food waste by adjusting the amount of food based on the number of people inside of the campus.	- Emission reduction
Parking overview	- Employees can check if parking spots such as the ones with charging cable are available or not beforehand which can save time and increase user convenience in the morning	- Productivity - User Satisfaction
Smart learning features	- Utilisation of smart technologies for educational purposes has increased the hands on learning experience opportunities supporting the users' needs as well as enhancing their image as auniversity of applied sciences.	- Productivity - Image - Innovation
Overall concept of the "Smart Campus"	- Increased collaboration with new partners and increased funding, impacting the image of the university as a smart campus and enhancing the innovation and knowledge sharing. - The campus have acheived the Smart Building Certificate which enhances the image and value of the asset.	- Asset value - Collaboration - Innovation - Income - Image

Table 8 The impacts and added value of available smart features at the Myllypuro Campus[9]

Having access to occupancy data has helped the campus management better understand and utilise the spaces on the campus. The provision of this information allowed the management team to notice that while they were receiving complaints from users about lack of space, the campus occupancy rate was below fifty per cent, meaning that less than half of the available spaces were actually being used. Through this knowledge, a new approach was taken in developing the class schedules for the next academic year (2024-25) to ensure that all the spaces are used regardless of the class’s field of study. Additionally, by combining the occupancy data with the reservation data for the lecture rooms, the management has been able to identify those that are booked but not used, allowing the room to be used for other purposes.

[9] Based on the interviews with the campus stakeholders

The availability of real-time information on indoor environmental conditions such as temperature and air quality has had a noticeable impact on energy saving and cost reduction at the campus. According to the manager of the facility services at Metropolia, knowing the overall temperature of the campus allowed them to reduce the heating during the colder days or reduce the running time of the air conditioning system during the summertime while maintaining optimal thermal comfort. Through this, the energy use of the campus has been reduced by around 25% in a two-year period. Additionally, this feature has allowed the management team to quickly identify whether systems such as the HVAC system are not working properly and whether they require maintenance.

Showing the temperature at the room level also gives users insight into the space conditions before booking them. One of the interviewees stated this to be very valuable for them as they prefer their working environment to be on the colder side. So, they look for rooms that are around 21-22 degrees when searching for a place to book. However, this is not very convenient at the moment as the booking is done via a different application.

Another noticeable impact has been the reduction of food waste, which was enabled by knowing the number of people present at the campus in real-time based on the people counting system at the entrance and exit points. By looking at the number of people on the campus an hour or two before lunchtime, the food provider has been able to adjust the amount of food required for the day, leading to food waste reduction, which consequently leads to cost and emission reduction.

Incident reporting and the communication feature that is provided through Empathic Building’s ticket service were mentioned by the facility manager to be an extremely useful tool because they allow the users to specify the exact location of the problem on the map, which is more convenient and enhances the productivity of the maintenance team. However, due to the unfamiliarity of the users with the tool and its low usage rate, most people still use the old reporting system, which is text-based and in many incidents, people fail to give accurate and exact locations.

The deployment of smart technologies at Myllypuro and its capability to collect and utilise campus data has increased their collaboration with new partners and increased the R&D funding, impacting the university's image as a smart campus and enhancing

innovation and knowledge sharing. Being a smart campus further contributes to the positive perception of the organisation and its image, given that the School of Construction and Real Estate Management is located there. According to the technology manager of the faculty, Branding was one of the main drivers in becoming a smart campus because “we teach building technologies in this campus, so it is very important to have the most advanced building technologies, which has allowed us to make the education process more innovative”.

4.1.3 Summary and Conclusion

Contrary to many university buildings that are old, Myllypuro is a recently built campus that has integrated smart technologies such as an advanced building automation system and a large number of environmental and occupancy sensors even before its operational phase began. This has made the integration and deployment of additional smart tools much easier.

The main objectives of the building owner in deploying these tools have been improving sustainability, the indoor environment, and energy efficiency. In addition, Metropolia has been focusing on other objectives, such as supporting education and research activities and enhancing its image as a smart campus. So far, several smart tools and technologies have been deployed on campus to achieve these goals.

This study identified the following smart features at the Myllypuro campus:

- Occupancy status
    - Real-time room occupancy (lecture rooms, office spaces, meeting rooms, study spaces)
    - Real-time desk occupancy
    - Space utilisation reports (real-time as well as for the whole measurement period)
- Space finding and booking
    - Finding spaces based on type and available features
    - Room and desk availability (free/booked)
    - Room and desk booking (workspaces, meeting rooms, study spaces)
- Indoor environmental conditions

    - Real-time temperature, CO_2 and humidity level (room level)
    - Environmental reports (real-time and for the whole measurement period)
- Other
    - Smart learning features (smart hospital, virtual HVAC maintenance training)
    - People flow (Into the building via counters at entrance gates)
    - Parking overview (current and near-future availability)
    - Incident reporting

Most of these features are provided to the users via the Empathic Building platform, the main user interface on campus. Due to its recent implementation, it was not possible to identify concrete and measurable impacts. In addition, because of the application's low usage rate, not all the smart features have been used as often. However, some perceived impacts were gathered from the interviews and analysed.

The impacts and the added value of the smart feature at the Myllypuro campus have been mainly achieved through the data the features provide rather than the features themselves. For instance, the occupancy data has enhanced curriculum planning, improved space allocation, and helped identify popular and less favoured space types. The availability of indoor environmental conditions at room level has given users more control over their indoor environments, leading to energy savings and cost reduction. Additionally, it has assisted the management in identifying flaws in the HVAC system. Finally, the availability of all these features and technologies and the data they provide have enhanced the image of Metropolia as a smart campus and attracted new research partners and funding opportunities.

4.2 Aalto University - Otaniemi Campus

4.2.1 Case Introduction

Otaniemi campus is Aalto University's main campus located in the Otaniemi region of Espoo near Helsinki. Aalto comprises thirty buildings, most of which are located at the Otaniemi campus, including the engineering schools, the School of Science and the School of Arts, Design and Architecture. All these premises are owned by the Aalto

University Foundation and managed by the Aalto University Campus and Real Estate (ACRE). ACRE is responsible for developing, maintaining and leasing them. Aalto University has reduced its facility usage from 302,000 m^2 in 2014 to 210000 m^2 in 2023, allowing it to rent out or use the space for other purposes (Aalto Annual Report, 2023).

Because of the size of the campus, navigating and finding spaces takes a lot of work for the users. So, the main objective for deploying smart technologies on the campus has been providing a user-oriented service that addresses their needs. Another goal for utilising such solutions has been the efficient use of the spaces. 54000 m^2 of the campus facilities are rented out to the university partners, bringing financial benefits and collaboration opportunities with external partners.

Aalto University

Size (Gross area): 264000 m^2
Students: 13941
Staff: 4884
Faculties: 5

Figure 10 General information about the Otaniemi campus

Technology landscape

Aalto Space is the primary user interface of Aalto University used by the students, employees, and the companies that have leased spaces on campus. It was implemented in 2016, and since then, it has doubled its coverage area for almost the whole campus. Aalto Space is a space information system allowing users to find vacant spaces and book them via phone. Furthermore, users can use it to navigate the campus. Bluetooth beacons are installed on the hallways and on the ceilings of the campus buildings to make indoor navigation as accurate as possible. Additionally, all rooms are equipped with displays that show their reservation status as well as the duration of the booking, helping the users use a space that is booked but not occupied.

Another functionality that has recently been added to Aalto space is a feature that allows the companies that have leased spaces on the campus to book spaces, such as meeting rooms for an additional fee if it exceeds the amount of time stated in the lease agreement. Furthermore, in a few buildings, Aalto space is connected to the remote thermostats for radiators and ventilation systems, allowing the option to adjust the temperature through the app.

In addition to the Aalto space, several other smart tools have been implemented on the campus. However, they are mostly in the piloting phase or have been discontinued. For these projects, ACRE collaborates with researchers at Aalto and other service providers to identify solutions that can provide value and implement them.

One example is a project in which they have equipped several spaces with occupancy sensors, including lecture halls, office spaces, and meeting rooms. This project aims to compare the actual occupancy of the rooms with their use based on booking data to identify no-shows. Another project in the piloting phase is linking the automation system in one of the buildings with the space use data to enhance energy efficiency. Additionally, they have started monitoring people flow and generating heat maps based on indoor positioning sensors to find the spaces that are more popular than the others. According to the Development manager at ACRE, the information from heat maps is used for better development of the campus and adjusting the location of the services based on their use.

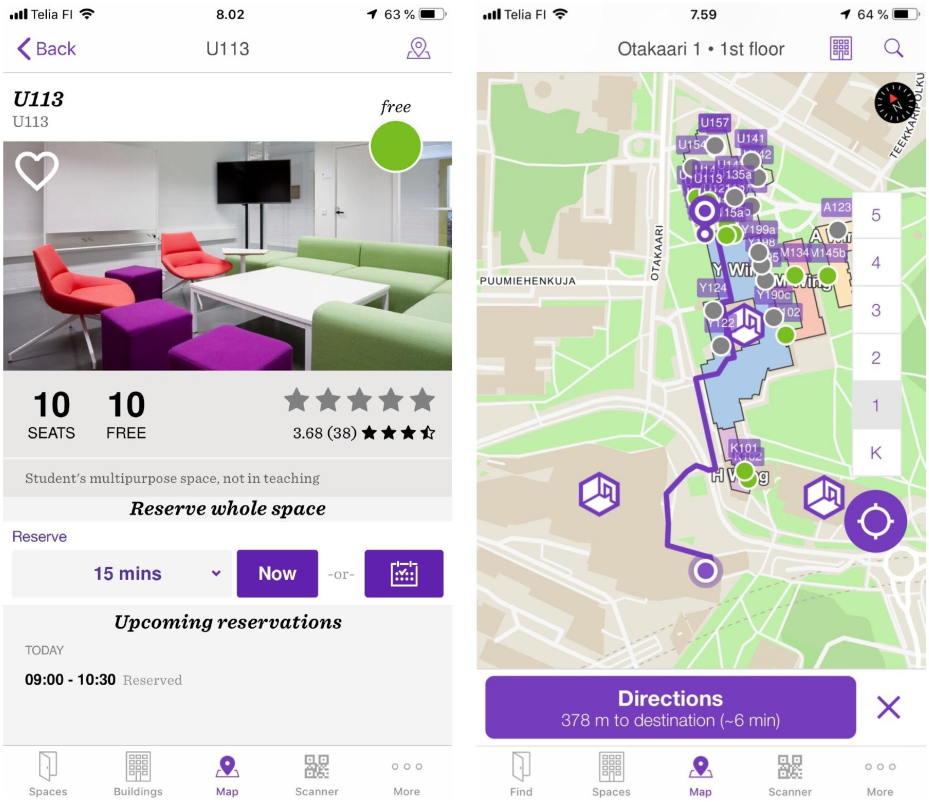

Figure 11 Aalto Space Interface

Upcoming plans

Both of the pilot projects mentioned above are planned to be implemented. In addition, the space-finding feature of Aalto space will be enhanced to include more search criteria. Finally, a digital leasing platform will be deployed by the autumn of 2024, allowing external companies and individuals to lease spaces for a short time.

4.2.2 Findings

Smart features

The deployment of Aalto space has provided both management and campus users with several smart features. Users can access these features mainly via the mobile app. Furthermore, the app provides anonymous raw data to the management, which has been collected by management since its implementation in 2016 and used for decision-making and research purposes. The identified smart features are as follows:

Space finding and space booking: Users can search for different spaces on the campus and see their availability. The spaces can be filtered by type as well as by the features they offer. Some of the spaces can only be booked by the employees, and some are only available to the students. Students can book study places as well as rooms for group work. Reservations can be made via the app, Outlook, or the university website. During Covid, it was also possible to book desks in order to track people who had been in contact with those infected. However, this feature is no longer available as there are so many rooms available and no need for it was identified.

Wayfinding: Users can navigate the campus via the app and find the best route to their destination. Bluetooth beacons installed in the buildings provide the user with accurate indoor location.

Temperature adjustment: In rooms where the thermostats can be remotely controlled, users can adjust the temperature via the app. However, the ventilation systems in most buildings are too old and not advanced enough to support this feature.

Communication feature: The management can announce emergency messages via the app. Furthermore, users are able to give feedback about different spaces on the campus as well as the app itself.

People flow and heatmap: The management can view the generated heat maps based on the indoor positioning data to identify places on the campus that are more frequently used and adjust the provision of services accordingly. This feature is still at the pilot stage.

Information availability

Users can check and see vacant spaces in real-time via their phones. They can also check their live location and navigate to their destination on the campus. Furthermore, students can check the physical displays next to each room that show the reservation information, allowing them to use the spaces that are booked but not used.

Management uses the data collected through the app and combines it with other data sources in PowerBI for analysis and decision-making. They can check the booking rate and the utilisation rate of the spaces. Furthermore, by looking at the reservation data,

the total number of people who are on campus can be estimated. The user feedback regarding the app and the bookable spaces can also be viewed.

Impacts

Unlike the situation at Metropolia, Aalto Space has been in use for more than eight years now, which is enough time to evaluate its impact and draw conclusions regarding the benefits and the added value it has provided the users and the management of the Otaniemi campus. Many impacts and benefits have been realised, such as increasing the utilisation and reservation rates of the rooms available via the app, allowing the university to reduce its facility usage noticeably. Table 10 provides an overview of the impacts that each of the available smart features has had on the operation of the campus and its users. Table 10 depicts the impacts as well as the added value provided by each of the features provided.

Smart Features	Impacts	Added Value
Space finding and booking	- Improved user convenience, productivity and collaboration possibility by allowing them to find and book spaces for study, work and meeting. - Understanding users' space demands by looking at those that are booked the most. - Significant increase in the number of bookings via the Aalto Space app. - Less demand for new facilities and reduction in facility usage allowed vacant spaces to be leased bringing financial value to the owner and lower rent for the university. - Monitored space use during Covid-19 to ensure safe use of campus.	- Flexibility - User satisfaction - Productivity - Collaboration - Emission reduction - Risk - Cost reduction - Health and safety
Wayfinding	- Has met the biggest need of the users which is finding the correct route to their destination directly impacting user satisfaction and prodictivity. - Especially useful feature for new students. This is evaluated by the raise in the app's number of active users during the first months of the semester.	- User satisfaction - Productivity
People flow	- Monitoring flow of the people allowing management to allocate services based on the areas that are more frequently used.	- Flexibility - User satisfaction
Temperature adjustment	- Users are allowed to control the temperature of the room based on their preferences	- Health and well-being - User satisfaction

Table 9 The impacts and added value of available smart features at the Otaniemi campus[10]

For a large campus that comprises a lot of facilities, navigation and wayfinding were found to be highly beneficial to its users. One of the interviewees who used to work in

[10] Based on the interviews with the campus stakeholders

an office building before mentioned that the wayfinding feature is something that he never felt he needed before, but here, because of the large number of buildings, it is a necessary feature. Another interviewee mentioned that after several years of working on the campus, they still feel the need to use the app to navigate to their destination. In addition, wayfinding has been found to be very beneficial for new students. This is evident by the massive rise in Aalto Space's number of active users during the first month of each semester.

Being able to search for places and book them via their mobile phone has noticeably reduced the time users spend to find an available space. According to the development manager at Aalto Campus and Real Estate (ACRE), it takes less than five minutes now to find an available space that suits the users' needs while before they had to go and check the rooms one by one before finding one that was vacant. Furthermore, there has been a significant increase in the booking rates via the app, meaning that the spaces are used more frequently.

The increased booking rate and the decisions made based on the reservation data have allowed the management to increase the utilisation rate of the campus facilities significantly. This has allowed the university to reduce the usage rate of the campuses and allowed more space to be rented out to companies and startups, which has brought financial value to the landowner while enhancing collaboration and supporting innovation as well as the image of the university as a hub for technology and innovation. Furthermore, the high utilisation rate has reduced the need for new construction, leading to cost savings and a noticeable emissions reduction as construction is a very carbon-intensive activity.

The reservation data has also allowed the management to better understand the preferences of the students and the employees by identifying the spaces that are booked more frequently. Through this, they were able to provide spaces that were most suitable for each user group and their needs. Additionally, providing spaces where people can meet supports one of the university's main goals, which is to create a sense of community and collaboration among the students, researchers and faculty members. According to one of the employees, meeting in person is much more important in a university setting than in an office, where it might be okay to do your work remotely all the time. Furthermore, by being able to track space use and space

reservation during COVID-19, the management was able to ensure the health and safety of the user while on campus.

4.2.3 Summary and Conclusion

Otaniemi campus is a significantly larger campus than Metropolia, with older buildings, making the implementation of new smart features more challenging than in Myllypuro campus. This change can also be seen in their objectives for the deployment of the smart campus tools. The main goals for the owners of the campus have been to enhance the utilisation rate of the campus and reduce the university's space footprint, allowing them to use the other facilities for leasing and other purposes. In addition, the university's primary focus has been the enhancement of users' experience and satisfaction. The most significant need of the users in the campus with a large area and multiple buildings was the difficulty in finding a space and navigating their way to their destination. To achieve these objectives, they deployed a space information system in 2016 called Aalto Space.

Over the past few years, ACRE, who is responsible for the Real estate management of the campus has continued to pilot several other tools such as AI driven automation systems and occupancy sensors. These pilot projects are often in collaboration with researchers, so they are primarily done to reach their objectives while allowing ACRE to analyse their potential benefits and the feasibility of implementing them. However, the majority of these piloting projects are either still ongoing or have been discontinued. Therefore, in this study, the focus was entirely on Aalto space and the features that it provides. These identified smart features were as follows:

- Space finding and space booking
    - Space finding based on space type and available features
    - Room availability (free/booked)
    - Room booking (workspaces, study rooms, meeting rooms)
- Wayfinding
- Temperature adjustment (in some rooms)
- Other
    - People flow and heatmaps (based on indoor positioning data)
    - Emergency messaging

- User feedback (about the spaces and Aalto space)

Aalto space has been in use since 2016 and has over 8000 active monthly users. As such, several impacts and benefits have been identified over the years. The space finding and wayfinding features have reduced the time it takes for the users to find a vacant space and find their way to it, which has increased user satisfaction and user productivity, evident by a significant increase in application usage rate and space booking rates. By tracking user preferences, the management has identified and provided suitable spaces for different user groups. During COVID-19, the management used the space tracking and reservation data to ensure safe use of the campus.

In addition to the features mentioned above, Aalto Space provides raw anonymous data to the management. ACRE has continuously collected this data over the years for analysis and decision-making. The data has helped the campus management increase space efficiency and utilisation, which has reduced the need for new buildings and reduced the university’s carbon footprint.

4.3 Oulu University - Linnanmaa Campus

4.3.1 Introduction

The final case of this study is the University of Oulu's Linnanmaa campus. Linnanmaa is the university's largest campus, covering an area of 113,600 sqm, of which the university buildings cover 96,000 sqm. Six of the eight faculties of Oulu are located in Linnanmaa, including the faculty of IT and Electrical Engineering, which has been involved in deploying sensors and other smart tools on campus over the past two years. The campus is owned by the University Properties of Finland and rented by the university who are responsible for the development of university properties and campuses outside the Helsinki metropolitan area.

The university's main objectives for deploying smart tools have been research purposes and support for campus users. In addition, the campus management is very interested in enhancing the campus's utilisation rate, which is currently around 20-25 per cent.

Size (Gross area): 113,600 m^2

Students: 14200

Staff: 3800

Faculties: 6

Figure 12 General information about Linnanmaa campus

Technology landscape

Compared to the other two cases, the Linnanmaa campus is in quite a different situation as there is not one specific smart application or data management system available. According to the head of facility services at the university, there are currently several user interfaces and different projects, each with its own sensors, tools, and objectives, and they do not communicate with each other.

One of these applications is the Oulu Campus Navigator application, which is the main navigation and wayfinding service. Students, faculty, and visitors can use the application without login information. The other user interface is the Cella application, which allows users to check room availability and book rooms. Both tools will be replaced by Mazemap starting in the Autumn semester of 2024-25.

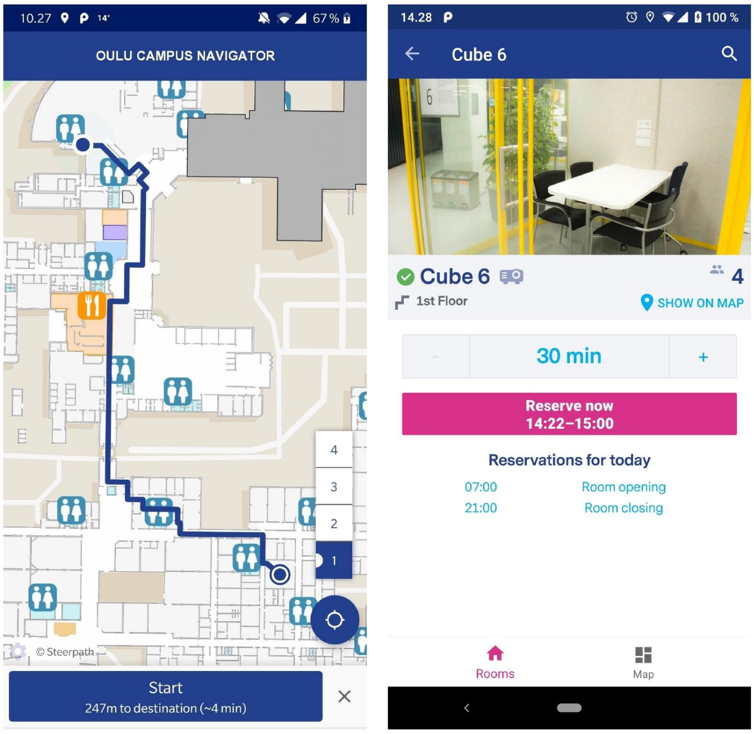

Figure 13 Oulu Campus Navigator (left) and Cella booking app (right)

As part of the Smart Campus program, the IT and Electrical Engineering faculty has equipped the university with 331 sensors that measure CO2 levels, temperatures, humidity, and light levels. Furthermore, they have developed a web interface where everyone can access the data and a dashboard system where the environmental conditions of the campus can be checked in real-time and for the whole measurement period. However, the primary purpose of this project is research, and due to some challenges mentioned later in the challenges section, the campus management does not use the information from the Smart Campus website in their decision-making. Furthermore, they have utilised AR to maintain the sensors, where the maintenance team can use their phone to check and see sensor measurements and find whether a sensor is faulty.

Around 100 occupancy sensors are implemented on desks in the office spaces to observe and collect data regarding their actual use. Furthermore, several lecture halls have been equipped with cameras to measure the occupancy and the number of people in each classroom. This project is still in the pilot stage. Similar cameras are deployed in the university's restaurants to measure the length of the queues in real time and provide information regarding the estimated waiting times. They have also

piloted the use of cameras in parking spaces to show users the availability of the parking lots. However, this project has been discontinued. Finally, the toilets are equipped with sensors that send signals when they run out of toilet paper.

Upcoming plans

The most significant plan at the moment is the deployment of a new information management system called the Mazemap, which will be available as a mobile app and a web app starting from the 2024-25 academic year. The new tool will combine all the features from the old applications, such as wayfinding and space booking, into one and allow users to see other campus-related information, such as the length of the restaurant queues, in real time.

The management is developing a dashboard system to enhance their reporting process and have all the data available in one place. The main goal would be to monitor the space use better and increase the utilisation rate of the campus. In addition, there are plans to equip all lecture rooms with occupancy sensors, allowing the campus management to identify no-shows and to see the number of people present to match the lecture rooms with the size of each class. An AI system is also being developed that will use the collected data from the occupancy sensors at lecture halls to make reservations automatically based on the collected data. This feature will be used for around 60% of the lecture rooms.

4.3.2 Findings

Smart features

Lecture room occupancy: Infrared cameras are installed in some lecture rooms, providing campus management with the occupancy rate and the number of people in the room. The management compares this feature to the reservation data to identify no-shows and match the supply and demand of the lecture rooms.

Desk Occupancy: The desks in the office spaces are equipped with occupancy sensors. The management collects the data to monitor how much office space is being used. To ensure the privacy of the employees, the data is only collected from the sensors and not the login information, and only the desks in open spaces are equipped with them. The desks in employees' rooms are not tracked.

Space finding and booking: Users can search for different spaces on the campus and see their availability in real-time. The spaces can be filtered by type and by the features they offer. Some spaces can only be booked by employees, and some are only available to students. Reservations can be made via the Cella app or Outlook.

Wayfinding: Users can navigate the campus via the app and find the correct route. The indoor positioning of the users is determined by the use of Bluetooth transmitters on campus. The Oulu Campus Navigator app provides this feature and is open to anyone, including those visiting the campus. The data from the app is not available to management, so they cannot use it to identify heat maps and users' moving patterns. When I asked the facility manager about it, he specified that there are no report features on the app and the project was developed for research purposes.

Indoor environmental conditions: The Oulu Smart Campus website provides users with data regarding noise, temperature, and air quality, which is collected from the sensors that are installed all over the campus. A dashboard shows the temperature, noise, and CO2 levels in real-time and for the whole measurement period. This data, however, is only available at the campus level and does not show which sensors the data is coming from. Furthermore, the sensors are not maintained, and 30-40% are offline. Due to these reasons, the facility management does not use this feature in its decision-making.

Other features: Students can check in real-time the length of the queues in the campus restaurants as well as their estimated waiting time. The data is provided via infrared cameras that are installed near the users' queue. In addition, toilets are equipped with sensors that send notifications to the cleaning services when toilets run out of toilet paper. However, the cleaning service provider does not use them as they have their own system. Additionally, sensors can be checked with the use of AR by the maintenance to see whether they are faulty or not.

Information availability

Users can check the vacant spaces on the campus and book some of them, such as meeting rooms available for group work and study rooms, via the Cella app or through Outlook. Furthermore, they can use the Oulu campus navigator application to see their current location on their mobile phone and find the best route from their location to any room on the campus. In addition, students can use the data for research purposes.

According to the head of the Smart Campus program, five different courses have used the data collected from the sensors for study purposes.

Management can request booking reports from Cella app but cannot export raw data from it. The navigation system does not have a report feature and does not allow for data to be exported either. They can check the reservation data for the lecture halls from the university's ERP system.

Challenges

Availability of the smart features across apps: Users such as faculty members and students perform the bookings via one app and have to use another app for wayfinding. Furthermore, neither of the platforms provides data for data analysis. Only the Cella app provides the campus management with a report of the space booking rates and not for the whole measurement period. At the moment, the facility management team does not have any dashboard that can aggregate and show all the information they require, which has made the process more challenging.

Lack of funding: Another challenge faced by management in not being able to deploy new smart tools on campus is the lack of funding, as mentioned by the head of facility services. Even though they have piloted several smart features, mainly due to lack of sufficient financial resources, the vast majority of them end up being discontinued and not expanded. One of the most recent examples was a pilot project for parking spaces to equip them with occupancy cameras, and even though it was found to add value to the campus users, they decided not to implement it because the initial cost, as well as the maintenance cost, was too much to justify its implementation.

Many smart tools are primarily for research: Most of the smart technologies implemented on the campus are primarily for research purposes and do not consider the needs of the facility management team. The most significant example is the smart campus program, which is the Faculty of Electrical Engineering research project, which has equipped the campus with around 300 temperature, noise and CO2 sensors. Although they provide the data for free on their website and have a dashboard where you can see the current conditions because of different goals with the facility management team, the sensors are not maintained long-term, and the information does not specify from where and which sensor the data is coming from. Even though

they have continuous meetings with each other, the facility management team has not been able to use the data for decision-making.

Smart features not being adopted by service providers: Another challenge specified by the campus management is that some of the projects that were piloted for maintenance and other facility services, such as cleaning, are not used by the service providers because they have their own system and are not interested in using them. For example, the toilet paper rolls in the toilets are equipped with sensors that alert when a toilet runs out of it, which can show where new toilet papers are needed and, at the same time, show which toilets are used more and in need of cleaning. However, the cleaning service provider does not use this system as it would disrupt their business model.

Impacts

As mentioned earlier, compared to the other two cases, the campus management at the University of Oulu has not been using the data for decision-making so far. One reason is that the apps that provide smart features to the user do not provide data to the management. Furthermore, the environmental sensors around the campus are not maintained, and the management cannot tell which sensors are collecting the data as the data collected from those sensors are not processed and readable for campus management purposes. Therefore, most of the impacts identified are the direct impacts of the application functionalities on the campus users. Table 11 provides a quick overview of the features and their impacts.

Smart Features	Impacts	Added Value
Occupancy status	- Allocated unused spaces observed via occupancy sensors in office spaces to other uses that are in high demand (meeting rooms).	- Flexibility - User satisfaction - Productivity
Space finding and booking	- Improved user convenience, productivity and collaboration possibility by allowing them to find and book spaces for study, work and meeting.	- User satisfaction - Collaboration
Wayfinding	- High impact on user convenience and time-saving as evaluated through user feedback and high number of active users.	- User satisfaction - Productivity
Smart learning features	- Provided researchers to prototype new features on the campus bringing funding and collaboration with external companies. - Several study courses have used the data provided through the sensors to enhance learning of the students	- Productivity - Image - Innovation - Culture - Collaboration
Restaurant queue overview (real-time)	- Improved user convenience, reduce wasted time and hassel during lunchtime.	- User satisfaction - Productivity

Table 10 The impacts and added value of available smart features at the Linnanmaa campus[11]

The ability to view the restaurant queue length in real-time has addressed one of the main complaints of the users and led to time-saving and enhanced convenience for the users. According to the head of facility services at Oulu, users usually have around 30 minutes to one hour of lunchtime, including the time it takes to get to a restaurant, the waiting time in the queue and the time spent for lunch. Before, a lot of this time was spent queuing as some restaurants were more crowded than others, but now users have the ability to check the queue beforehand and go to the restaurant with the shortest wait time.

Another challenge that many students, especially those new to the campus, had was their ability to find their destination as the campus is quite big, and the old buildings have a layout that is hard to navigate. The same thing can be said about the space reservation system, which allows users to select their suitable room based on the features that it provides to them. While no feedback has been received from the users, an increase in the number of application's active users has been observed.

[11] Based on the interviews with the campus stakeholders

By monitoring the actual occupancy of office desks using desk occupancy sensors, the campus management discovered that the office spaces are not used very often. This number has been decreasing since COVID-19. Through this knowledge, they were able to allocate some of that space to meeting rooms as there was more demand for them. Furthermore, equipping lecture halls with occupancy sensing cameras has shown to have significant cost and energy reduction benefits. Even though the project is still in the piloting phase, the management calculated that the cost that will be saved through the utilisation of the lecture halls is more than the cost of their implementation.

4.3.3 Summary and Conclusion

Linnanmaa campus is very similar to the Otaniemi campus and different from Metropolia's Myllypuro campus as it has a large campus with buildings that were mostly built between the 1960s and 1990s, therefore creating similar challenges to the Otaniemi campus. Similar to Otaniemi, at Linnanmaa, the objectives for the deployment of smart tools have been the same, namely, to support users in finding spaces and navigating the campus. However, the main difference between the two universities is that, unlike Aalto, the smart features at Linnanmaa are accessed via multiple platforms, and no data is available from the implemented smart apps for decision-making. Therefore, the available features are mainly for the users, except for a few projects directly implemented by the campus management. All the features identified at the University of Oulu are presented below:

- Occupancy
  - Lecture room occupancy data (pilot)
  - Office desk occupancy
- Space finding and space booking
  - Space finding based on space type and available features
  - Room availability (free/booked)
  - Room booking (workspaces, study rooms, meeting rooms)
- Wayfinding
- Indoor environmental conditions
  - (near) Real-time temperature, CO_2 and noise level (campus level)
- Other

- Restaurant queue overview (real-time)

5. Analysis

This chapter combines the findings from the case study chapter with the ones from the literature review to meet the three research objectives identified in the introduction and provide final answers to the research sub-questions. To do so, a cross-case analysis of the three cases is performed and evaluated with the results from the literature in order to validate the findings and/or supplement them. This chapter provides the answers to the three research sub-questions, which consequently help answer the main research question of this study.

5.1. Smart campus and its features

Chapter four provided an overview of the cases and technologies deployed on the studied campuses. The case study chapter aimed to provide case-specific answers to the research sub-questions. Here, we look at these three cases side by side to gain a holistic view of the current state of smart campus development in the Finnish higher education sector. The results from the cross-analysis of the cases are then supplemented with the findings from the literature so that the case findings can be generalised and the sub-questions can be better answered. This research aimed to answer the first sub-question: *What are the defining characteristics of a smart campus, and what features does it provide for the campus stakeholders?* For the first part of the question, we look at smart technologies and the objectives for implementing them.

5.1.2. University objectives

By looking at the university objectives, it was found that the main Objectives for implementing various smart technologies were for research and educational purposes, either by providing new ways of learning or providing data to be used for research or to support the day-to-day activities of the users. From a CREM perspective, both of these fall under productivity and user satisfaction. The other goals of the studied cases were to help management monitor space use, enhance space efficiency, and monitor indoor climate and energy use. The findings from the three cases are generally aligned with the findings from the literature. Cazemier (2021) performed a similar study on Dutch universities and identified user support to be by far the main driver of implementing smart technologies, followed by monitoring space use.

Many of these technologies were implemented to address other university needs and objectives as well. However, since they fall under the outcome and not the main drivers for implementation, they will be addressed in more detail when discussing the impacts and the added value of these technologies.

Smart features	Myllypuro Campus	Otaniemi Campus	Linnanmaa Campus
Support user activities		X	X
Enhance education and research	X		X
Monitor space use and enhance space efficiency		X	X
Indoor climate control	X		
Energy efficiency	X		

Table 11 Comparison of objectives stated for the deployment of smart technologies

5.1.3. Smart technologies

Similar to the findings from the literature, the primary technology identified in the three cases was the use of IoT. Occupancy and environmental sensors and Bluetooth beacons for indoor positioning followed this. The upcoming projects can be categorised into two areas: (1) enhancing space monitoring and identifying no-shows and (2) utilising AI for predictive and more informed decision-making. All three universities mentioned that enhancing the utilisation rate of the campus is their main priority going forward. To achieve this, the focus is to combine reservation data with occupancy data to find no-shows, especially when it comes to the lecture halls.

University	Smart technologies	Future plans
Metropolia	- Environmental sensors (temperature, CO2, humidity) - Occupancy sensors (rooms, hallway, desks, parking) - Information management system (Empathic Building) - People counters at entrance gates - AR/VR for education and maintenance - AI-driven Building Automation System (pilot)	- Enhance space monitoring and identify no-shows - Expand Empathic Buildings to other campuses - Encourage students and faculty to use Empathic Buildigs. - Utilise data for predictive maintenance and energy management.
Aalto University	- Bluetooth beacons for indoor positioning - Space management system (Aalto Space app) - AI-driven Building Automation System (pilot) - People flow and heatmaps (pilot) - Management dashboard (Power-BI)	- Develop a platform to allow short-term lease of spaces to external companies and individuals. - Enhance space finding feature to include more search criteria.
University of Oulu	- Environmental sensors (temperature, CO2, noise) - Occupancy sensors (office desks) - Cameras with AI detection for occupancy counting (lecture rooms, restaurant queues) - Bluetooth beacons for indoor positioning - Space management system	- Implementation of Mazemap as the sole smart campus application from Automn of 2024. - Developing a dashboard for monitoring space use KPIs and identify no shows. - AI-reservation system for lecture halls.

Table 12 Comparison of smart technology landscape in the three case studies

Smart campus features

For the second part of the first sub-question, we aimed to identify the smart campus features of the implemented technologies provided to the stakeholders. Multiple smart features were identified through the literature review and the three case studies conducted. In general, the smart campus features can be divided into two categories: (1) smart features/functionalities that are available via the user interfaces and (2) the data and the information that is provided to campus management for monitoring and decision-making. These features can be further categorised into five groups: Occupancy-related features, space-finding and booking features, wayfinding, indoor

climate control and other features that did not fit any of the groups mentioned above. Table 14 provides a comparison of these features.

Feautre group	Smart features	Myllypuro Campus	Otaniemi Campus	Linnanmaa Campus
Occupancy status	Room occupancy status (real-time)	X		
	Desk occupancy status (real-time)	X		
	Occupancy reports	X		
	Occupancy data	X		X
Space finding and booking	Space finding	X	X	X
	Room booking	X	X	X
	Desk booking	X		
	booking status	X	X	X
	booking data	X	X	
Wayfinding	Indoor navigation		X	X
	people flow and heatmaps		X	
Indoor climate control	Indoor climate conditions (real-time)	X		X
	Temperature adjustment		X	
	Indoor environment report	X		
	Indoor environment data	X		
Other	incident report	X	X	
	parking overview (real time)	X		
	restaurant queue overview (real time)			X

Table 13 Comparison of existing smart features available in the three case studies

<u>Occupancy status:</u> Two out of the three cases have utilised occupancy sensors on their campuses but to varying extents. Only Metropolia has equipped all of their rooms on the campus with occupancy sensors, allowing users to see real-time occupancy of all the rooms on the campus. The work desks and parking spaces are also equipped with such sensors. Both users and management in Myllypuro can check the occupancy status of desks and rooms. Additionally, the management can produce occupancy reports via the app or export the raw data for further analysis. The University of Oulu has only utilised occupancy detection sensors in some lecture halls. Because of their high accuracy, the use of cameras can detect the occupancy of the rooms in addition

to frequency. However, this project is still piloting, and users cannot see the actual occupancy. In addition, Oulu has equipped around 100 office desks with occupancy sensors. Aalto does not use any occupancy sensors at the moment, although there are plans to equip several space types with them. Users from all three universities are able to check the booking status of the rooms.

Space finding and booking: This feature is provided to the university users, faculty members, and staff. In addition, Aalto provides this feature to the companies who have leased spaces on their campus as well. However, the space types that can be booked, the means provided to the users and the data they provide to the management are quite different. However, there are differences in the tools that provide this feature; the space types that can be booked and the information provided to the user and the management are quite different. All three campuses allow users to find their suitable space based on the space type as well as the features of the room. Desk booking is only available at Metropolia. Furthermore, different user groups have access to certain rooms and spaces. In both Metropolia and Aalto booking data is available to the management. However, only Aalto University has been actively monitoring this data.

Wayfinding: Both Otaniemi and Linnanmaa campuses are large campuses with several detached buildings. Therefore, wayfinding has been an essential need on both campuses by allowing the users to navigate the campus via their phone and find the best route to their destination. Furthermore, both utilise Bluetooth beacons to provide the user with accurate indoor location. However, only Aalto monitors this data by generating heatmaps to identify which parts of the campus are more frequently used and provide services accordingly. Metropolia does not have indoor positioning sensors installed on the campus.

Indoor climate control: Metropolia has equipped all of the rooms on the campus with temperature, CO2 and humidity sensors, allowing users to view real-time temperature and air quality of different rooms. In addition to the sensors at Myllypuro, Oulu University has also installed noise sensors. However, the data can only be seen for the whole campus. Only Metropolia management uses the data from this feature for decision-making as they can produce reports and export the data for any time period.

Other features: Besides the features mentioned above, several other smart features were identified in the cases but would not fall under any specific category. Metropolia

uses VR technology at their HVAC lab for both maintenance and educational purposes. In addition, people counters allow the management to identify the total number of people on the campus. Myllypuro also utilises a smart parking system where users (employees) can check parking lot availability in real-time and in the near future (based on historical data). The incident report allows users at Myllypuro and the Otaniemi campus to report any flaws in the rooms via the user interface. Finally, Oulu University provides users with real-time restaurant queue length and waiting time to decide which restaurant to go to during lunchtime.

4.4.2. The impacts of smart features

This section aims to answer the third research sub-question: *What are the effects of implementing smart features on university campuses?* To answer this question, we examined the measurable and perceived impacts of the smart campus features identified above. These impacts are analysed in terms of the added value they provide to the overall performance of the campus. This is achieved by comparing the findings from the cases with the description of values identified in the literature review.

The findings from the cases show that in addition to the impacts these features have on the campus users, the insights that the collected data offers the campus management are significant for their decision-making. For example, the real-time overview of the temperature on the campus allowed the facility manager at Metropolia to reduce energy consumption by decreasing temperature while maintaining optimal thermal comfort. In addition, it assists them in identifying flaws in the HVAC system. By tracking the movement of people on the campus during COVID-19, the campus management at Aalto was able to ensure safe use of the campus.

However, the most noticeable impact on campus management decision-making comes from the insights gained from Occupancy data and reservation data. By monitoring the space use, campus management can better understand the space needs of the users, reduce facility usage and the need for new buildings and better allocate the vacant spaces. For example, at the Linnanmaa campus, the unused workspaces were transformed into meeting rooms in much higher demand. Aalto University has been able to reduce its space needs, leading to fewer new constructions on the campus. They have even been able to lease the vacant spaces to external companies. By

knowing the actual frequency rate of lecture halls at Myllypuro, the management could increase their utilisation rate by adjusting the scheduling of classes.

Users have benefited the most from space reservation and wayfinding features. Both features have increased user satisfaction, user productivity and user efficiency. By providing an option to search for different space types and the features they provide, users are able to find a place to meet or study without wasting time looking for an unoccupied space. These features have encouraged more students at Aalto University to come to the campus even when they do not have classes, which, in addition to better use of the spaces, has increased collaboration possibilities. The wayfinding feature was found by the Aalto and Oulu University users to be the most necessary and helpful feature. Because of the large scale of the campuses, this feature has allowed users to navigate the campus accurately and efficiently and find their destinations more quickly.

Furthermore, deploying smart technologies on campuses has allowed new ways of learning, research, and teaching that were not possible before and has enhanced the image of universities. According to a faculty member at Metropolia, the utilisation of smart technologies for educational purposes has increased the students' hands-on learning experience opportunities and improved their overall understanding of the learning. Furthermore, it has enhanced their image as a university of applied sciences. The availability of all these features and technologies and the data they provide have enhanced the image of Metropolia as a smart campus and attracted new research partners and funding opportunities. At Aalto University, the data collected from the equipped sensors have been used in five different courses, which helped students better understand the process from data collection to analysis.

4.4.3. Smart campus value addition

After examining the impacts of the smart campus features on campus stakeholders, the value these features provide can be identified by linking the case findings with the value framework identified and developed in the literature review chapter. Table 15 shows how each of these features has contributed to the campus's overall performance. Similar to our findings from the literature review as well as the value drivers identified in this chapter, we can see here that the implemented smart features

have contributed the most to the user satisfaction and user productivity. Furthermore, each feature and the way it can provide added value are explained.

Added Values	Occupancy status	Space finding and booking	Wayfinding	Indoor climate control	"Smart Campus" concept	Other
User satisfaction	X	X	X	X		X
Productivity	X	X	X	X		X
Flexibility	X	X	X			
Space optimisation	X	X	X			
Innovation					X	X
Collaboration		X			X	
Culture		X				X
Image					X	X
Health and Safety		X		X		
Emission reduction		X		X		
Cost reduction	X	X				
Risk control		X		X		
Asset value					X	

Table 14 Added value of smart campus features of the conducted cases

Occupancy status: Allowing users to see the real-time availability of study and workspaces can enhance user productivity by helping them avoid hassles and be more efficient, especially when combined with reservation status (Valks et al., 2020). By having access to the data, the management can observe the spaces that are more frequently identified to identify space types that are in more demand (Myllypuro, Linnanmaa), further enhancing user satisfaction and productivity (Papagiannidis & Marikian, 2020). By looking at occupancy status, the unused spaces can be allocated to other in-demand space types, directly providing added portfolio flexibility (Oulu). Monitoring actual occupancy can allow the management to increase space utilisation, leading to reduced costs and energy use (Myllypuro, Linnanmaa) (Elsaadany, 2017).

Added values: improve user satisfaction, improve productivity, enhance portfolio flexibility, reduce costs, and optimise space.

Space finding and space booking: This feature ensures that the user has access to a space that can meet their needs, directly impacting user satisfaction and productivity and indirectly enhancing collaboration opportunities (Myllypuro, Otaniemi,

Linnanmaa). Furthermore, it allows the management to identify the demand level for different rooms by their type and the features they offer to improve the quality of spaces and provide rooms that are in more demand (Myllypuro, Otaniemi) (Valks *et al.*, 2021). Monitoring and tracking users can ensure the safe use of the campus, which improves the health and safety of the users (Otaniemi). Reduced demand for new spaces can lead to significant cost and emission reduction as the need for new buildings is reduced (Otaniemi), indirectly reducing risks.

Added values: improve user satisfaction, improve productivity, enhance portfolio flexibility, cost reduction and space optimisation, emission reduction, health and safety improvement, support culture and collaboration and risk control.

<u>Wayfinding and monitoring people flow:</u> This can significantly reduce the time and the hassle of finding a space and can be specifically useful for campus visitors and those unfamiliar with the campus area (Otaniemi, Linnanmaa. By providing campus users with ease of mind, wayfinding helps users focus on learning and teaching activities (Otaniemi) (Dong et al., 2020), which directly increases productivity and user satisfaction. Monitoring people's flow based on the user movement lets the management better allocate resources (Otaniemi), further improving space efficiency and portfolio flexibility.

Added values: improve user satisfaction, improve productivity, enhance portfolio flexibility, space optimisation.

<u>Indoor climate control:</u> Allowing users to control the condition of their indoor environment empowers them, increases productivity, improves health, and enhances user satisfaction (Myllypuro) (Borghero, 2018). Using environmental sensors such as temperature, noise, CO2 and humidity sensors can allow the management to monitor and control the indoor climate in real-time, directly impacting user health and productivity (Papagiannidis & Marikian, 2020). Having an overview of the campus temperature can allow the manager to adjust them while maintaining thermal comfort, directly impacting energy consumption and cost reduction (Myllypuro). Flaws in the HVAC system can be identified immediately, which helps control the risks of further damage to the property (Myllypuro).

Added values: improved user satisfaction, productivity, portfolio flexibility, space optimization, emission reduction, health and safety improvement, and risk control.

Overall concept of "smart campus": The availability of smart technologies and the data they provide significantly improves the image of the university and attracts new research partners and funding opportunities enhancing collaboration and innovation (Myllypuro, Linnanmaa) (Majchrzak, 2019). Furthermore, it can lead to achieving smart certification further impacting the branding and increasing the value of the assets (Myllypuro).

Added values: stimulate innovation, support collaboration, enhance image and increase asset value

Other: Utilisation of smart technologies and the data they provide for educational purposes has increased the hands-on learning experience opportunities of the students and improved their overall understanding of the learning and, at the same time, enhanced their image as a university of applied sciences, supporting users, organisational culture and stimulating innovation (Myllypuro, Linnanmaa) (Dong et al., 2020). Providing users with real-time information useful to them such as the current occupancy of parking spaces or the restaurant queue length and waiting time enhances user satisfaction and productivity (Myllypuro, Linnanmaa).

Added values: improve user satisfaction, improve productivity, stimulate innovation, support culture, enhance image and increase asset value.

6. Conclusion

The main objective of this research was to identify the impacts of smart technology implementation on the overall performance of university campuses, especially in meeting campus objectives. This objective was further divided into several smaller goals that had to be met before achieving the main goal. These objectives provided the basis for the research question and sub-questions of the thesis.

To answer these questions, several steps had to be taken. A literature review was first performed to help the researcher build a knowledge basis for the main themes of the research and prepare the background information required for performing the case studies. The case studies were conducted to collect empirical data to compare and evaluate the findings from the literature with the reality of smart campus development in Finnish higher education institutes. This step was crucial for research on a topic that has only recently gained attention, and the literature on it is still limited. After conducting the three case studies, the findings were compared and then weighted against the findings of the literature to provide a holistic view of the smart campus and the impacts it can have on university stakeholders. With the completion of the last step, the research questions can be answered, and conclusions can be made.

6.1. Answering the research sub-questions

To answer the main research question of the thesis, the research sub-questions should first be answered. This section provides answers to the three research sub-questions.

6.1.1. Smart campus definition and feature identification

Sub question 1: What are the defining characteristics of a smart campus, and which smart campus features can be identified?

<u>Defining characteristics</u>

This study found no concrete definition of a smart campus besides its reliance on smart technologies exists in the literature. By analysing various “smart campus” definitions and frameworks in the literature, we identified two defining characteristics for “smart campus”: the technologies that are implemented and the objectives for implementing

them. The outcome of the literature and case studies regarding these two characteristics are presented:

Technologies: The most utilised smart technologies identified in the literature are IoT (sensors, integrated platforms, user interfaces), AI, and Cloud computing (Cazemier, 2021; Chagnon-Lessard et al., 2021; Valks et al., 2020). Similar results were found in the three case studies: occupancy sensors (rooms and desks), environmental sensors (temperature, CO2, humidity) used to collect data for research and decision-making, smart applications for navigation and space booking and AR/VR for virtual learning and maintenance. Artificial intelligence for occupancy counting and predictive energy management is another technology that is gaining attraction.

Objectives: The main drivers for smart campus development were identified as enhancing the learning environment and supporting users, followed by space efficiency, indoor climate optimisation, and energy efficiency.

Therefore, a “smart campus” can be defined as:

A university campus that uses several smart technologies, such as IoT, AI, and AR, to provide students, faculty members, visitors, and campus management with information and smart applications in order to enhance the learning environment, support users in their activities, optimise space utilisation, improve indoor climate and energy efficiency on the campus.

Smart campus features

Smart campus features can be categorised into two groups: one, the features that are directly provided to the campus users via smart applications and user interfaces, and two, the data that is collected and the information that is provided to the campus management for decision-making purposes. Both groups are further categorised into five general categories: occupancy-related features, space finding and space booking, navigation and wayfinding and indoor climate optimisation.

Smart features	
Occupancy status	Room occupancy status (real-time)
	Desk occupancy status (real-time)
	No-show communication
	Occupancy reports
	Occupancy data
Space finding and booking	Space finding
	Room booking
	Desk booking
	booking status
	booking data
Wayfinding	Indoor navigation
	people flow and heatmaps
Indoor climate control	Indoor climate conditions (real-time)
	Temperature adjustment
	Indoor environment report
	Indoor environment data
Other	incident report
	People finding
	parking overview (real time)
	AI-driven energy management
	AR/VR learning
	restaurant queue overview (real time)

Table 15 list of identified smart campus features

6.1.2. Campus management and value addition

Sub question 2: What is campus management, and how does it add value for campus stakeholders?

Campus management is defined as the alignment of the campus real estate with the changing context of a university to 1. Meet the evolving needs of different campus stakeholders, and 2. Enhance the university's performance (Den Heijer, 2011; Azizi et al., 2020). Therefore, by aligning CRE strategies with university objectives, value can be added to the campus stakeholders. An Investigative analysis of the literature on the added value of CREM and FM on workspaces and university campuses was performed, and the following value framework was developed (see Appendix 2 for a detailed explanation). There are three ways in which campus management can add value to the campus users (students, faculty members, other employees and visitors):

supporting user activities, improving user health and safety and improving user satisfaction (Den Heijer, 2011; Valks et al., 2020; Dong et al., 2020).

Furthermore, campus management can provide added value to other campus stakeholders as well through enhancing the university image, supporting university culture, stimulating collaboration and innovation, reducing university costs, minimising carbon emissions, controlling risks and increasing value of the university assets (Den Heijer, 2011; Beckers et al., 2014; Jensen & Van der Voort, 2017; Valks et al., 2020) While conducting case studies two more added values were identified: space optimisation and increased investment and funding opportunities.

6.1.3. Impacts on the campus performance

Sub question 3: What are the effects of implementing smart features on university campuses?

Due to the novelty of the topic, the majority of literature focuses on the development aspect of smart campuses rather than evaluating their actual impacts. Furthermore, in the three studied cases, because of the recent implementation of smart technologies, not many concrete and quantitative impacts could be identified, and the ones that could, were for pilot projects and, therefore cannot be generalised. Therefore, the impacts identified in this research are generally the perceived ones identified through the case interviews.

The most noticeable impact identified through the interviews was improved user experience and user satisfaction. This has been achieved mainly through wayfinding and space reservation features of the smart applications. In addition, allowing users to control their indoor climate conditions noticeably improves user empowerment, leading to increased productivity, improved health and higher user satisfaction. The biggest impact on campus management has been the insight they gain on how the spaces are used, which has led to various adjustments that have led to improved space utilisation and better allocation of resources. Space optimisation has directly impacted costs and emission reductions as the need for new buildings is reduced. Real-time space tracking allowed the management at Aalto to ensure the safe use of the campus during the COVID-19 pandemic. Having an overview of real-time indoor conditions allowed the campus management at Metropolia to reduce energy usage by 25 per cent within a

two-year period without impacting user comfort. Becoming a smart campus can enhance the image of the university and attract new research opportunities. Furthermore, it can increase the value of the campus for the owner. Furthermore, the university's image can be enhanced by providing new learning technologies to the students.

The areas where no measurable and perceived impacts were identified were its impact on maintenance and service providers. Even though there are a lot of technologies that can be used to benefit the maintenance team, they are rarely used either because they are very technical or are considered disruptive to the current system. Finally, the negative impact that was identified in the cases and in the literature (Jensen & Van der Voort, 2017; Oudot, 2019) is the high costs associated with the deployment and operation costs. This was identified in two of the cases as the main reason for many pilot projects being discontinued and not expanded to the whole campus.

6.2. Answering the main research question

In this section the main research question is answered: *How and to what extent does the implementation of smart campus features meet the needs and requirements of universities?*

To answer this question, the following themes had to be investigated first: university objectives and value addition, smart technologies and smart campus features. The campus objectives were identified through the literature as well as the case studies. The link between the objectives and value addition was primarily investigated through several campus management, CREM and FM frameworks in order to align the two, which resulted in the development of the value framework for university campuses (see Table 3). The overview of smart technologies was primarily done via the literature (see section 3.2.2) and later identified through the case studies. Smart campus features were identified through a similar process (see section 3.2.4). Furthermore, the link between these research areas was analysed by looking at the impacts of these features to understand the extent of their impacts and by looking at the added value they have provided to find out how they impact the users.

By performing these steps, the following answer to the research question can be presented:

Smart campus features can impact the campus stakeholders in two ways: 1. By providing smart functionalities to the end-user via smart applications and user interfaces. 2. By providing data to the management for decision-making. For the first category, the user's needs are addressed through real-time information such as real-time room and desk occupancy status, real-time overview of indoor climate and any other useful information such as restaurant queues and real-time parking occupancy. These features were found to directly improve user satisfaction and user productivity. Another way that the first category can add value to campus users is through the interactive functionalities of smart applications such as wayfinding, space reservations and temperature adjustment. These features can directly enhance user productivity, increase their satisfaction and improve their health and well-being. Furthermore, providing users with spaces to work and study at the university improves collaboration opportunities, supports the organisational culture, and stimulates innovation.

The second category provides campus management with data and information to be used in decision-making that not only impacts campus users but also provides added value to other campus stakeholders. By having access to real-time and historical occupancy data as well as reservation data, the universities can enhance the space utilisation rate, which will directly reduce costs, minimise carbon emissions, and allow the extra spaces to be better utilised. Furthermore, it allows the management to gain insight into how the spaces are used, which space types are more in demand and allocate services and spaces accordingly, which can significantly increase productivity, user satisfaction, portfolio flexibility and reduce vacancy risks. By comparing the occupancy data with the reservation data, the management can identify the spaces that are booked and not used. This is particularly beneficial in lecture halls where many of the classes that are scheduled either do not take place or have a low-frequency rate, helping with higher portfolio flexibility, cost reduction and significant space utilisation. In addition, having an overview of indoor climate in real-time management can improve indoor comfort, which directly impacts user health, and the dysfunctions in the HVAC system can be identified, which can noticeably reduce risks of further damage and health hazards.

Deploying smart technologies on campuses can impact the core business of universities (learning, research, and teaching) in ways that were not possible before. Such features can enhance the image of the universities and bring in new partnership

and funding opportunities, which can directly impact collaboration, support culture, and stimulate innovation. Finally, by transitioning into a smart campus, the possibility of achieving smart certificates increases, as evidenced by one of the cases, which can noticeably increase the property's value and enhance the university's image.

6.3. Recommendations for further research

Smart campus is an evolving topic, and universities are continuously piloting new projects and/or discontinuing the existing ones. This was very evident while conducting the case studies. Each of the three cases had plans to implement new smart features within the next six months to one year. The same phenomenon was observed in the literature, where two studies that analysed the same universities in the Netherlands within a two-year period saw a 60% increase in the number of implemented smart tools. Furthermore, the same research can be expanded to other universities in Finland that have implemented the same tools.

Conversely, the same study can be conducted for universities in other countries. Besides this study that was conducted in Finland, only two other studies have analysed smart campuses from a real estate and facility management point of view, and both were conducted in the Netherlands (Valks et al., 2020; Cazemier et al., 2021). Furthermore, a comparison between smart campuses and other organisations can yield interesting results as noticeable differences were identified between a campus and an office building. However, most of the available technologies and features at universities are designed and developed for office spaces.

To better understand the impacts of smart campus features, it is important to conduct a quantitative study on the impacts of the smart campus. This study identified that even though the campus management and the users have both benefited from the implementation of smart tools, no measurable outcomes were identified. This is partially due to the fact that most of the smart features were implemented over the last two to three years, which might not be enough time to have quantitative results. Having said that, there is a lot of data available that can be used for such purposes; however, when asked why no impact assessment studies were performed, the lack of time and resources were mentioned.

Finally, a similar study can be conducted that studies the impacts of campus features from the user's point of view. While conducting this research, it was found that none of the studied cases have collected feedback or asked them to evaluate the impacts of the implemented tools. In most studies, the impact on users is either perceived or evaluated based on the number of active application users. While such numbers can indicate a level of satisfaction and usefulness from the users, performing qualitative research can provide an in-depth understanding of the impact of the smart tools on the users, which can be beneficial for the further development and implementation of smart campus features.

6.4. Research limitations

Although this research has provided a better understanding of smart campus features and their impacts on campus stakeholders, especially in Finland, it also has some limitations.

The first limitation is that this study was mainly conducted with the development and facility managers, with a few other interviews with faculty members and technology managers. However, no student was interviewed during the research. The students' experience within the same context might differ from that of an employee or the management as they have access to different features, and their objectives might differ. The second limitation is the difference in size and other physical conditions of the conducted cases, which might make it harder to generalise the findings.

Furthermore, qualitative research has its own limitations, especially when processing and analysing the data. Even though various research methods and data sources were used to ensure the reliability of the data. However, while interpreting the data, there is a risk of misinterpretation. In addition, the language barrier might have impacted the overall outcome of the interviews as some interviewees were not as fluent in English. However, to minimise the risks of misinterpretation and misrepresenting the results, the interview transcripts and the analysis were validated again by the interviewees.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

Berlin, 05.07.2024

Location, Date

Signature of the student

Appendix

Appendix 1

The Interview Protocol

- **Introduction**
  - Introduction and thank you
  - Thesis Topic and Purpose of the Interview
  - Permission
- **Background Information**
  - Can you briefly describe your role and responsibilities as the Development Manager at the university?
  - Could you provide an overview of the smart campus initiatives that have been implemented and the background
- **Implementation Process**
  - Can you walk me through the process of planning and implementing these smart campus technologies?
  - What were the major challenges faced during the implementation phase, and how were they overcome?
  - How did you ensure stakeholder engagement and buy-in throughout the process?
- **Questions about the implemented smart tools**
  - Can you describe the main features and functionalities?
  - How was it received by students and staff upon its introduction?
  - How is the data collected used for the management. Has it lead to any strategic changes or to buildings or spaces
  - Are there any metrics or data points that highlight the success or areas for improvement?
- **Added Value of Smart Tools and Technologies**
  - Have the smart technologies led to any cost savings for the university? Can you provide specific examples or data to illustrate these savings?
  - How have these technologies contributed to energy savings and emission reductions on campus? Are there any measurable outcomes?
- **Challenges:**
  - Challenges and risks
  - What is currently missing
- **Future Prospects and Innovations**
  - What are the next steps for further developing smart campus technologies at the university?
  - Are there any upcoming projects or innovations that you are particularly excited about?
- **Closing**
  - Is there anything else you would like to add that we haven't covered in this interview?
  - Are there any other key stakeholders or individuals you would recommend I speak with to gain further insights?
  - Any reports or documents with more in detailed info on smart tools of the uni
  - Follow up questions

Appendix 2

The literature on the added value through CREM/FM

Value Framework	Description
Innovation	- Stimulating idea creation by providing a **place where people can meet and share their knowledge** (Den Heijer, 2011) - Stimulating innovation by **supporting knowledge development** (Beckers et al. 2014) - Encouraging innovation and creativity through **knowledge sharing and enhancement of spatial and social networks** (Jensen and Van der Voort 2017)
Collaboration	Stimulate the **communication and team work** due to **space interventions and facilities provision** (Den Heijer 2011) Create **meeting spaces** supported by restorative facilities for students/staff and providing buildings that perform as a hub where people from inside and outside the organization can meet (Beckers et al 2014)
Culture	Enhancing the organizational culture by providing **appropriate RE portfolio to its end users** (Den Heijer 2011) Create a recognizable home base for students/staff, physical environment that contributes to a **sense of community** (Beckers et al 2014) Environment that supports collaboration through behavior change and provision of shared spaces (Jensen and Van der Voort, 2017)
Image	Providing an Environments that contribute to a **positive perception of the organization** (Beckers et al 2014) Showing the organizational characteristics through the RE portfolio (Den Heijer 2011) Enhancing corporate identity and brand by providing **high quality surroundings and reorganisation of spatial layout** (Jensen and Van der Voort, 2017)
Health and Safety	Enhance user health and comfort by providing better indoor environment and having control over work environment (Oudot , 2019) Improve user safety and wellbeing by providing higher level of personal control and better indoor air quality (Jensen and Van der Voort, 2017)
User satisfaction	Upgrading the **quality of space** in order to respond to the trend '**focus on end users**' (Den Heijer 2011) Offer **inspiring education and teaching** (Beckers et al 2014) Increase user satisfaction through provision of **suitable and collaborative spaces** and **better indoor climate** (Jensen and Van der Voort 2017)
Productivity	Provision of **necessary facilities and good indoor working environment conditions** (Den Heijer 2011) Support user activities with buildings to increase production and productivity, provide **high quality and flexible education as well as spaces that meets diverse needs**. enhance competence based learning and link theory and practice (Beckers et al. 2014) Supporting both team and individual productivity through higher transparency to support collaboration and providing spaces for concentrated and individual work (Jensen and Van der Voort 2017)
Flexibility	Having a flexible portfolio which can be **easily modified when there is change in a demand** (Den Heijer 2011) Act **future-oriented** by focusing on demographic developments, educational developments and providing virtual campus environment (Beckers et al 2014) Enhance building performance by providing flexible spaces (Jensen and Van der Voort 2017)
Emission reduction	contribute to **reducing the carbon footprint of the campus** (Beckers et al 2014) Reducing carbon emissions through **reduction of energy use, water consumption, waste generation and transportation** (Jensen and Van der Voort 2017; Oudot 2019)
Cost reduction	**Minimizing operational costs** by minimizing personnel and/or space (Den Heijer 2011) Focus on efficiency with **efficient allocation of financial resources** and **efficient use of space** (Beckers et al 2014) Reducing space costs through **effective space use, maintenance and energy savings** (Oudot 2019) Reducing costs through **establishing FM department**, **space and process optimisation** (Jensen and Van der Voort, 2017)
Asset value	Raise up the RE market value (incl. land value) due to **upgrading the RE** (Den Heijer 2011) Increasing asset value by lowering risks and lowering vacancy rate (Jensen et al. 2012)
Risk control	Monitoring and managing **financial, functional and technical risks** (Den Heijer 2011) managing risks through emergency and recovery plans, backup supply systems and insurances (Jensen and Van der Voort 2017)

Appendix 3

Detailed list of smart campus features in the three studied cases

Smart features	Myllypuro Campus	Otaniemi Campus	Linnanmaa Campus
Occupancy status	- Real-time room occupancy (lecture rooms, office spaces, meeting rooms, study spaces) - Real-time desk occupancy - Reservation status (desks and rooms) - Space utilisation reports (real-time as well as for the whole measurement period)	Reservation status (workspaces, study rooms, meeting rooms)	- Reservation status (workspaces, study rooms, meeting rooms) - Lecture room occupancy data (pilot) - Office desk occupancy data
Space finding and booking	- Space finding based on space type and available features - Room booking - Desk booking - Booking data available	- Space finding based on space type and available features - Room booking - Booking data available	- Space finding based on space type and available features - Room booking - Booking data not available
Wayfinding		- Indoor navigation and real time location via Bluetooth - Data is used by management to generate heatmaps (pilot)	- Indoor navigation and real time location via Bluetooth
Indoor climate control	- Overview of temperature, CO2 and humidity level (available at room level) - Environmental reports (real-time and for the whole measurement period)	Temperature adjustment (in some rooms)	- Overview of temperature, CO2 and noise level (available at campus level) - Dashboard (real-time and the whole measurement period)
Other	- Augmented learning - Overview of total number of people in the campus - Parking overview (current and near-future availability) - incident reporting	- Emergency messaging - User feedback (about the spaces and Aalto space) - AI-driven Automation system (pilot)	- Restaurant queues overview (real-time)

List of Literature

Ahmed, V., Abu Alnaaj, K., & Saboor, S. (2020). An investigation into stakeholders' perception of smart campus criteria: The American university of Sharjah as a case study. *Sustainability*, *12*(12), 5187.

Al Dakheel, J., Del Pero, C., Aste, N., & Leonforte, F. (2020). Smart buildings features and key performance indicators: A review. *Sustainable Cities and Society*, *61*, 102328.

Apanaviciene, R., Urbonas, R., & Fokaides, P. A. (2020). Smart building integration into a smart city: Comparative study of real estate development. *Sustainability*, *12*(22), 9376.

Apostolopoulos, V., Giourka, P., Martinopoulos, G., Angelakoglou, K., Kourtzanidis, K., & Nikolopoulos, N. (2022). Smart readiness indicator evaluation and cost estimation of smart retrofitting scenarios-A comparative case-study in European residential buildings. *Sustainable Cities and Society*, *82*, 103921.

Appel-Meulenbroek, R. (2014). How to measure added value of CRE and building design. *Knowledge sharing in research buildings. Technische Universiteit Eindhoven*.

Azizi, S., Nair, G., Rabiee, R., & Olofsson, T. (2020). Application of Internet of Things in academic buildings for space use efficiency using occupancy and booking data. *Building and environment*, *186*, 107355.

Baum, A. (2017). *PropTech 3.0: the future of real estate.* Oxford: University of Oxford

Baum, A., Saull, A., & Braesemann, F. (2020). *PropTech 2020: the future of real estate.* Oxford: University of Oxford

Beckers, R., van der Voordt, T., & Dewulf, G. (2015). Aligning corporate real estate with the corporate strategies of higher education institutions. *Facilities*, *33*(13/14), 775-793.

Borghero, S. (2018). *The role of workplace design in employee engagement.* Retrieved from https://workplaceinsight.net/employee-engagement-role-workplace-design/

Bryman, A. (2016). *Social research methods*. Oxford university press.

Budie, B., Appel-Meulenbroek, R., Kemperman, A., & Weijs-Perree, M. (2019). Employee satisfaction with the physical work environment: the importance of a need based approach. *International Journal of Strategic Property Management*, *23*(1), 36-49.

Cazemier, L. (2021). *Smart Campus Tools 2021* (Dissertation). Retrieved from http://resolver.tudelft.nl/uuid:f35d49ce-ca75-47c6-a35c-dfc7efc33131

Chagnon-Lessard, N., Gosselin, L., Barnabé, S., Bello-Ochende, T., Fendt, S., Goers, S., ... & Zhang, P. (2021). Smart campuses: extensive review of the last decade of research and current challenges. *IEEE Access*, *9*, 124200-124234.

Chen, J., Chen, H., & Luo, X. (2019). Collecting building occupancy data of high resolution based on WiFi and BLE network. *Automation in Construction*, *102*, 183-194.

Chen, Z., & Liu, Y. (2021, October). Research and Construction of University Data Governance Platform Based on Smart Campus Environment. In *2020 3rd International Conference on Artificial Intelligence and Advanced Manufacture* (pp. 450-455).

Cheng, Y., Wei, J., Tan, X., Tan, Y., & Lei, Y. (2022, January). Research on key technologies of data-oriented intelligent campus in 5G environment. In *2022 2nd International Conference on Consumer Electronics and Computer Engineering (ICCECE)* (pp. 203-208). IEEE.

De Groote, M., Volt, J., & Bean, F. (2017). Is Europe ready for the smart buildings revolution?. Available at: www.bpie.eu

Den Heijer, A. C. (2011). *Managing the university campus: Information to support real estate decisions*. Eburon Uitgeverij BV.

Den Heijer, A. C. (2021). Campus of the future: Managing a matter of solid, liquid and gas.

Dong, Z. Y., Zhang, Y., Yip, C., Swift, S., & Beswick, K. (2020). Smart campus: definition, framework, technologies, and services. *IET Smart Cities*, *2*(1), 43-54.

Elsaadany, A., & Soliman, M. (2017). *Experimental evaluation of Internet of Things in the educational environment.*

Finley, A. (2021). *Campus challenges and strategic priorities in a time of change.* Association of American Colleges and Universities. https://dgmg81phhvh63.cloudfront.net/content/user-photos/Research/PDFs/Challenges-and-Priorities-Report_080721_0.pdf

Fraga-Lamas, P., Celaya-Echarri, M., Lopez-Iturri, P., Castedo, L., Azpilicueta, L., Aguirre, E., ... & Fernández-Caramés, T. M. (2019). Design and experimental validation of a LoRaWAN fog computing based architecture for IoT enabled smart campus applications. *Sensors*, *19*(15), 3287.

Global Smart Education Market. (2023). *Smart Education and Learning Market Size, Share, Competitive Landscape and Trend Analysis Report by Component, by Learning Mode, by End User : Global Opportunity Analysis and Industry Forecast, 2023-2032.* https://www.alliedmarketresearch.com/smart-education-learning-market

Hartley, J. (2004). What is a case study. *Essential guide to qualitative methods in organizational research*, *323*.

Hobbs, K. G., Link, A. N., & Scott, J. T. (2017). Science and technology parks: an annotated and analytical literature review. *The Journal of Technology Transfer*, *42*, 957-976.

Hollweck, T. (2015). Robert K. Yin.(2014). Case Study Research Design and Methods . *Canadian Journal of Program Evaluation*, *30*(1), 108-110.

Imbar, R. V., Supangkat, S. H., & Langi, A. Z. (2020, November). Smart campus model: a literature review. In *2020 International Conference on ICT for Smart Society (ICISS)* (pp. 1-7). IEEE.

Jensen, P. A., Sarasoja, A. L., Van der Voordt, T., & Coenen, C. (2013, May). How can facilities management add value to organisations as well as to society?. In *Proceedings of the 19th CIB World Building Congress*.

Krumm, P. J. M. M. (1999). *Corporate real estate management in multinational corporations: a comparative analysis of Dutch corporations*. Nieuwegein: Arko publishers.

Li, S., Xu, L. D., & Zhao, S. (2015). The internet of things: a survey. *Information systems frontiers*, *17*, 243-259.

Lindström, D. (2023). *SMARTQUAL LITE : Assessing the Property Management's Technological Service Quality of Office Buildings in Stockholm* (Dissertation). Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-330796

Magnini, E., Butler, T., & Morrell, M. (2018). Campus of the future. Arup.

Majchrzak, H. (2019). *Internet of Things (IoT) in Real Estate: Designing guideline for employee-oriented Internet of Things (IoT) implementation in office real estate* (Dissertation). Retrieved from http://resolver.tudelft.nl/uuid:29027d47-3529-4185-ba3f-f37990c0553a

Masoso, O. T., & Grobler, L. J. (2010). The dark side of occupants' behaviour on building energy use. *Energy and buildings*, *42*(2), 173-177.

McCann, L., Hutchison, N., & Adair, A. (2019). External funding of major capital projects in the UK Higher Education sector: issues of demand, supply and market timing?. *Journal of Property Research*, *36*(1), 97-130.

Min-Allah, N., & Alrashed, S. (2020). Smart campus—A sketch. *Sustainable cities and society*, *59*, 102231. https://doi.org/10.1016/j.scs.2020.102231

Nazali Mohd Noor, M., & Pitt, M. (2009). A critical review on innovation in facilities management service delivery. *Facilities*, *27*(5/6), 211-228.

OECD. (2024). *Population with tertiary education* (indicator). https://data.oecd.org/eduatt/population-with-tertiary-education.htm

Omotayo, T., Awuzie, B., Ajayi, S., Moghayedi, A., & Oyeyipo, O. (2021). A systems thinking model for transitioning smart campuses to cities. *Frontiers in Built Environment*, *7*, 755424.

Opdenakker, R. J. G. (2006). Advantages and disadvantages of four interview techniques in qualitative research. In *Forum Qualitative Sozialforschung= Forum: Qualitative Social Research* (Vol. 7, No. 4, pp. art-11). Institut fur Klinische Sychologie and Gemeindesychologie.

Oudot, J. (2019). *Exploring the value of smart offices* (Dissertation). Retrieved from http://resolver.tudelft.nl/uuid:8ea8287c-4dbf-4169-9d53-5791eeb6bbb9

Pagliaro, F., Mattoni, B., Gugliermenti, F., Bisegna, F., Azzaro, B., Tomei, F., & Catucci, S. (2016, June). A roadmap toward the development of Sapienza Smart Campus. In *2016 IEEE 16th international conference on environment and electrical engineering (EEEIC)* (pp. 1-6). IEEE.

Papagiannidis, S., & Marikyan, D. (2020). Smart offices: A productivity and well-being perspective. *International Journal of Information Management*, *51*, 102027.

Peterson, M. & Desrocher, N. (2018). *Building intelligence into buildings. Integrating artificial intelligence into building ecosystems.* Armonk, NY: IBM Corporation

Polin, K., Yigitcanlar, T., Limb, M., & Washington, T. (2023). The making of smart campus: A review and conceptual framework. *Buildings*, *13*(4), 891.

Polonsky, M. J., & Waller, D. S. (2018). *Designing and managing a research project: A business student's guide*. Sage publications.

Potkany, M., Vetrakova, M., & Babiakova, M. (2015). Facility management and its importance in the analysis of building life cycle. *Procedia Economics and Finance*, *26*, 202-208.

Remes, L., Dooley, K., Ketomäki, J., & Ihasalo, H. (2021). Smart workplace solutions–can they deliver the offices that employees have been waiting for?. *Facilities*, *40*(15/16), 40-53.

RICS. (2010). Royal Institute Chartered Surveyor (RICS). http://www.rics.org/my/knowledge/

Riratanaphong, C., & Van der Voordt, T. (2015). Measuring the added value of workplace change: performance measurement in theory and practice. Facilities, 33(11/12), 773-792.

Saralegui, U., Antón, M. Á., Arbelaitz, O., & Muguerza, J. (2019). Smart meeting room usage information and prediction by modelling occupancy profiles. *Sensors*, *19*(2), 353.

Serraview. (2015). *Managing Workplace Utilization. IoT & Other Technologies for Tracking Workplace Utilization*. Retrieved from: http://info.serraview.com/workplace-utilization-free-guide

Space Management Group. (2006). *Space utilisation: practice, performance and guidelines.* Retrieved from: http://www.smg.ac.uk/index.html

Streitz, N., Charitos, D., Kaptein, M., & Böhlen, M. (2019). Grand challenges for ambient intelligence and implications for design contexts and smart societies. *Journal of Ambient Intelligence and Smart Environments*, *11*(1), 87-107.

Sutjarittham, T., Gharakheili, H. H., Kanhere, S. S., & Sivaraman, V. (2019). Experiences with IoT and AI in a smart campus for optimizing classroom usage. *IEEE Internet of Things Journal*, *6*(5), 7595-7607.

Trivedi, D., & Badarla, V. (2020). Occupancy detection systems for indoor environments: A survey of approaches and methods. *Indoor and Built Environment*, *29*(8), 1053-1069.

Ullah, F., Sepasgozar, S. M., & Wang, C. (2018). A systematic review of smart real estate technology: Drivers of, and barriers to, the use of digital disruptive technologies and online platforms. *Sustainability*, *10*(9), 3142.

UNIFI. 2020. Theses on sustainable development and responsibility. https://unifi.fi/viestit/theses-on-sustainable-development-and-responsibility/

Valks, B., Blokland, E., Elissen, C., van Loon, I., Roozemond, D., Uiterdijk, P., ... & Den Heijer, A. (2021). Supporting strategic decision-making on the future campus with space utilisation studies: a case study. *Property Management*, *39*(4), 441-465.

Valks, B., Arkesteijn, M. H., Koutamanis, A., & den Heijer, A. C. (2021). Towards a smart campus: supporting campus decisions with Internet of Things applications. *Building Research & Information*, *49*(1), 1-20.

van der Voordt, T. J., & Jensen, P. A. (2017). Benchmarking of workplace performance. In the 24th *Annual Conference of the European Real Estate Society* (pp. 124-140).

van der Voordt, T. J., & Jensen, P. A. (2021). Value Adding Management of buildings, workplaces, facilities and services. In *A Handbook of Management Theories and Models for Office Environments and Services* (pp. 140-151). Routledge.

Van Susante, P. (2014) *Differences in employee satisfaction in new versus traditional work environments* [Master's Thesis, Eindhoven University of Technology] Eindhoven, The Netherlands: Eindhoven University of Technology

Wong, J. K., Li, H., & Wang, S. W. (2005). Intelligent building research: a review. *Automation in construction*, *14*(1), 143-159.

Zaballos, A., Briones, A., Massa, A., Centelles, P., & Caballero, V. (2020). A smart campus' digital twin for sustainable comfort monitoring. *Sustainability*, *12*(21), 9196.