Smart Campus Tools

Technologies to support campus users and campus managers

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Smart Campus Tools

Technologies to support campus users and campus managers

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by

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Preface

Smart campus tools. To most, the title of my PhD dissertation raises plenty of questions. What kinds of tools? What, in particular, makes them smart? What makes them specific to the campus? The subtitle “technologies to support campus users and campus managers” provides some more context. This is also where I would start when someone would ask me what my research is about. My research is about how technology can help universities and its users to make better use of their buildings.

The subject of smart campus tools has greatly intrigued me from the start, as for a long time, I have been interested in approaches to help organisations align their real estate to their needs. The potential to also support users and contribute to a sustainable campus makes the topic even more fascinating. However, to those who have known me a bit longer, it may seem strange that I chose to study a technology-oriented subject. When it comes to new technology, I would not exactly be an ‘early adopter’. I got my first mobile phone when I was 16, and my first smartphone around 23. When I go running, I still record my runs via an analogue stopwatch. I only adopt new technology when it has a clear benefit over old technology and, more importantly, little to no drawbacks. This is also the approach I have taken towards smart campus tools – universities should not implement them just for the sake of it, but because they deliver clear benefits to their students, employees, and/or campus managers, and little to no drawbacks.

This book is the end of a journey that started at the end of 2015, when campus managers of the 14 Dutch universities commissioned a research project to explore smart campus tools. Although it is a dissertation, its contents are useful for academics and practitioners alike. I feel very privileged that I had the opportunity to do my PhD research for and about universities and that I could combine academia with practice, working for both TU Delft’s Campus Research Team and TU Delft’s Campus and Real Estate department. University campuses are great places, full of students that are young, ambitious and eager to learn, many PhDs and professors that are knowledgeable, inspiring, and passionate about their work, and a support staff that is friendly, professional, and dedicated. It has been an honour and great motivation to contribute a piece of knowledge to the management of their learning and working environment.

Bart Valks

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To the interviewees of the other cases: Arnaud, Rens, Jeroen, Paul, Michel, Han, Marleen, Sander, Giulia, Arjan, Huib, Richa, Tommy, Frans, Brian, Frank, John, Erik: thank you for taking the time to contribute to my research, inspiring me and showing me how diverse the subject area is.

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List of definitions and abbreviations

Smart campus tools (SCTs)
Smart campus tools measure space use real-time through the use of sensors. These data are translated to real-time information on the availability of spaces on the current campus in order to help students and employees use those spaces more effectively and efficiently, or to steer building services and reduce energy consumption. By collecting data over longer periods of time and analysing those data, campus managers are supported with more detailed and accurate management information to make decisions about the future campus.

Context – campus management (see also section 1.1)	
Campus	The land and buildings in use by the university, not necessarily in a single location. (Den Heijer, 2011)
Campus manager	The person responsible for campus management at a university, in this research mostly the campus director. Alternatively called estate manager, campus planner or facilities manager. (Den Heijer, 2011)
Education space	A space used for educatory purposes, where students receive their education. There are multiple types of education spaces, such as lecture halls, instruction rooms, practical spaces, exam halls, and project rooms. Alternatively: teaching spaces.
Laboratory	A space that is specifically designed for research. Typically, these spaces provide controlled conditions.
Meeting room	A space used for meetings between employees.
Office	A space which contains workplaces for employees.
Portfolio	The collection of all the buildings and land owned or rented by an organisation.
Study places	A workplace which can be used by students to study – either alone or in groups.
University campus	The land and buildings, used for university or university-related functions, either rented or owned by the university, not necessarily on one location. (Den Heijer, 2011)
User	Regular user of the university campus. In this dissertation, ‘user’ refers to student or employee. If ‘visitor’ is meant, this is made explicit.

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Real Estate Management (see also section 2.1)	
Actual use	The frequency or occupancy rate of a space based on measurements or observations (Space Management Group, 2006b). Alternatively: observed use.
Added value	The contribution of real estate to the performance of an organisation as a whole.
CREM	Corporate Real Estate Management; The management of a corporation's real estate portfolio by aligning the portfolio and services to the needs of the core business (processes), in order to obtain maximum added value for the business and to contribute optimally to the overall performance of the corporation" (Krumm et al. 2000).
(CRE) alignment	Corporate real estate alignment. The alignment of an organisation's real estate ('supply') to the needs of the organisation ('demand'). (Arkesteijn, 2019)
FM	Facility management, or FM. FM focuses on the effective and efficient delivery of support services to the organisation it serves. There is an overlap in CREM and FM definitions. In this dissertation, the definition of CREM implies the inclusion of FM services. See: CREM.
Frequency rate	The number of hours a room is in use as a proportion of its total availability (NAO, 1996). The total availability can be defined differently: e.g. the opening hours of a building, or the length of a work week.
Occupancy rate	The average group size as a proportion of the total capacity for the hours the room is in use (NAO, 1996).
Scheduled use	The frequency or occupancy rate of a space based on data stored in reservation systems (Space Management Group, 2006b). Alternatively: predicted use.
Space norms	Ratios relating m^2 to users and/or workplaces (Space Management Group, 2006a). Space norms are used to inform space planning.
Space planning	The (re)design of buildings and environments with a long-term scope (> 10 years); Alternatives: campus development, real estate development.
Space management	The management of existing buildings and environments with a mid-term scope (1 – 5 years).
Space use	The use of spaces by users to work, study, eat, rest, etc.
Space utilisation	The product of the frequency rate and occupancy rate (Space Management Group, 2006b). It describes the number of hours a seat in a room is in use as a proportion of its total availability.
Space utilisation study	A survey that is administered to determine the space use of certain spaces within a building. Space utilisation studies report the space use based on schedules and/or manual counts, in frequency and/or occupancy rates.

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Built environments and Technology (see also section 2.2)	
Accuracy	Accuracy, or occupancy error, indicates how far from the ground truth any occupancy measurement is. (Christensen et al. 2014)
Actuator	A component of a system that is responsible for controlling a mechanism or system.
BACS	Building Automation and Control Systems; BACS is used as umbrella term for building services (see building services)
Building automation	The control of buildings through building services. (Kastner, Neugschwandtner, Soucek, & Michael Newman, 2005)
Building services	Automated control systems within buildings that control heating, ventilation, air conditioning, lighting, security, fire safety, etc.
FMIS	Facility management information systems, or FMIS. These systems are commonly used to register space allocation, service requests, facilities billing. Therefore, they require information on spaces such as their area (m^2), the department or organisation using each space, and the price of each space.
HVAC systems	Heating, Ventilation and Air Conditioning systems. HVAC systems are a subset of BACS and building services.
Implicit occupancy sensing	The use of existing building infrastructure that is not originally intended for occupancy detection to measure occupancy. (Christensen et al. 2014)
Internet of Things (IoT)	Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework. (Gubbi et al. 2013). Abbreviated as “IoT”.
IoT applications	The interaction layer of Internet of Things: interfaces through which a system interacts with users.
Occupancy sensing	Determining the use of a space by occupants. The resolution of occupancy sensing can be specified in time, space and occupant knowledge, which affect the accuracy of the measurement (see accuracy). (Christensen et al. 2014)
Positioning	The general term for determination of a position of an object or a person. It is particularly used to emphasize that the target object has been moved to a new location. (Mautz, 2012)
Sensor	A device or subsystem whose function is to detect changes to the environment and send the data to other electronics in the system.
Smart buildings	Intelligent buildings but with additional, integrated aspects of adaptable control, enterprise and materials and construction, thus offering additional control strategies based on improved occupant interaction. (Buckman et al., 2014)
Smart campus	An umbrella term referring to the increasing presence of Smart buildings and Internet of Things on the university campus to optimise the use of resources. The Smart campus is a continuum in which managers think and make decisions to improve the performance of the campus (Gil-Garcia, Pardo, & Nam, 2015).

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Information Management (see also section 2.3)	
Dashboard	A visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance. (Few, 2006)
FTE	Full-time equivalent - unit used to describe the number of fully employed employees or fully enrolled students.
Information Technology	Information Technology. Information Technology describes the components that make up an information system, e.g. hardware, software, and communications. (Bytheway, 2014)
Information Management	The management of an organisation's information technology in order to deliver value to the organisation (through six management segments and four management processes). (Bytheway, 2014)
Information systems	The totality of technological and human components that work together to produce the information services that are needed, for organisational purposes. (Bytheway, 2014)
Organisational activity	A low-level component of an organisation that makes up a part of a business process; it consumes resources and drives costs. (Bytheway, 2014)
Organisational process	A high-level component of an organisation that is comprised of a number of lower-level business activities; it delivers value to organisational stakeholders. (Bytheway, 2014)
Organisational information	Information that is useful to organisations in decision-making processes. (Bytheway, 2014)
Organisational benefits	The benefits that are achieved through any organisational action. (Bytheway, 2014) See also: *added values*.
Organisational strategy	A long-term plan that directs the activities of an organisation. (Bytheway, 2014)

Abbreviations	
EUR	Erasmus University Rotterdam
LEI	Leiden University
MU	Maastricht University
OU	Open University
RU	Radboud University Nijmegen
RUG	Rijksuniversiteit Groningen (University of Groningen)
TiU	Tilburg University
TUD	TU Delft
TUE	TU Eindhoven
UU	University of Utrecht
UT	Twente University
UVA	University of Amsterdam
VU	Vrije Universiteit Amsterdam
WU or WUR	Wageningen University (and Research Centre)

Summary

Reasons to study Smart campus tools

In recent years, it has become much more challenging for campus managers to accommodate an increasingly dynamic university community of students and employees on the university campus. In order to accommodate substantially larger student populations and given the rising pressure on university resources, Dutch universities have increased the density on campus – by sharing education spaces on campus, by using circulation areas for studying or informal meetings, and by rethinking spatial concepts for working and learning. Consistently, campus managers ask themselves and campus users: is it really necessary to add more space, or can the existing resources be used more effectively and efficiently?

To support decisions on improving space utilization, occasional space use studies often show that there is still enough space available on campus. However, these studies are subject to several limitations. At the same time, campus users increasingly complained about difficulties in finding places to work, meet or study. This paradox in which there is both an abundance and a lack of space, seems to be caused by the unavailability of reliable information on space use in time. This was already identified as a blind spot in campus managers' management information, and it persists at many present-day universities.

On the present-day university campus, existing resources can be used more effectively and efficiently by addressing the territorial use of space. Many spaces are assigned to individuals, groups or organisational units, but used for only a specific type of activity at a specific time during the week, month or even year. Both campus users and managers experience frustration about spaces that were reserved - through reservation systems or by leaving behind belongings - but not actually used, resulting in financial and energy waste (see Figure SUM. 1). When viewed over a period of weeks, months or years, this problem becomes even worse.

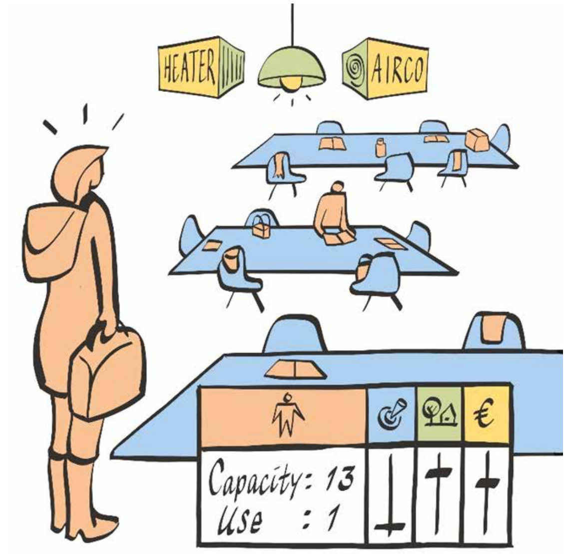

FIG. SUM. 1 An increasing frustration of spaces that are reserved, but not in use (illustration: Mark van Huystee). This results in poor performance on all stakeholder perspectives: an abundancy of available space (strategic, blue) compared to the actual demand for space (functional, orange), resulting in high costs per user (financial, yellow) and high energy use per user (physical, green).

To address this problem, this PhD dissertation proposes the use of Smart campus tools (SCTs): a service or product with which information on space use is collected real-time to improve utilization of the current campus on the one hand, and to improve decision-making about the future campus on the other hand. Smart campus tools address both the users' and campus managers' needs for more information. They measure the real-time use of workplaces, spaces and buildings through sensors. These data can be used to inform students and employees about available places to work or study, the crowdedness in specific spaces, etc. In addition, the data collected by sensors can, over time, provide campus managers with a comprehensive picture of space use across their campuses, which would support their strategic decision-making processes. The main research question is:

How can smart campus tools optimally contribute to the match between demand for and supply of space, both on the current campus and on the future campus?

To answer the main research question, this PhD dissertation uses the structure shown in Figure SUM. 2. First, the theoretical framework (part 1) discusses the input for the research. Then, the main body (part 2) discusses the components of the research and their results. Finally, the synthesis (part 3) concludes the dissertation.

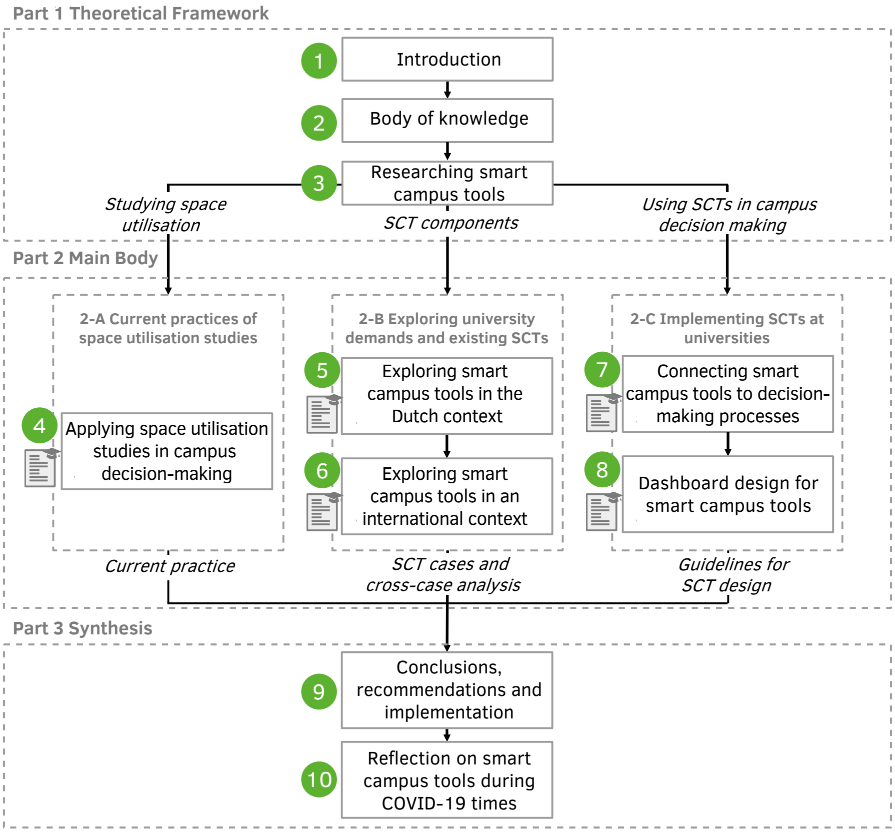

FIG. SUM. 2 Research structure of this PhD dissertation: from theoretical framework (input), through the main body (throughput) to the synthesis (output). Chapters published as papers are indicated by icons.

Various research methods have been applied over the course of this research: these include empirical methods such as literature review, surveys, questionnaires, and interviews, as well as design research. The first phase of the research (2015-17) focused on exploring smart campus tools, identifying different types of smart campus tools and their properties, as well as future demands universities have regarding these tools. The first phase is reported in chapters 5-6. The second phase of the research (2018-20) focused on how smart campus tools can support campus managers in their decision-making processes, first structuring the connection of smart campus tools to decision-making processes through process and information analysis and then designing this connection through dashboard design. The second phase is reported in chapters 7-8. During both phases, the theoretical framework (chapters 2-3) was continuously refined, and a study was conducted on the current use of space utilisation studies in decision making (chapter 4).

Part 1 – Theoretical Framework

Foundations for smart campus tools research

RQ1: Which theories are relevant to implementing smart campus tools at university campuses?

Numerous theories, concepts and instruments are necessary to study smart campus tools. In chapter 2 of this PhD dissertation, they are divided into three sections, connected to the main research question via a conceptual model (Figure SUM. 3):

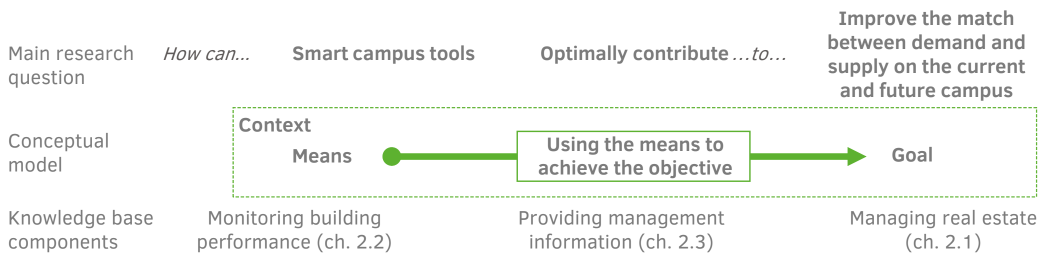

FIG. SUM. 3 Conceptual model used in this research.

- Managing real estate: this PhD research is part of the research programme of Management in the Built Environment (MBE), specifically thethe chair of Public Real Estate. This first section underpins the intended contribution of smart campus tools to campus management.

- Monitoring building performance: the smart campus tools proposed in this PhD require the use and interconnection of multiple IT components. Therefore, this second section provides a foundation for the technological components of smart campus tools.

- Providing management information: in order for the use of smart campus tools to result in the intended organisational benefits, it is necessary to properly connect them (i.e. the means and the ends) to each other. Therefore, this third section discusses the use of Information Management to design a connection of smart campus tools to campus management.

The discussion of these fields is summarised in six foundations. In the synthesis, these are reflected upon using the results of the research.

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Managing real estate:

- SCTs add value to the performance of the university through strategic, financial, functional and physical campus perspectives, as an instrument in campus management.
- SCTs support campus management organisations in their CRE alignment in specific building blocks / process steps, resulting in added value.

Monitoring building performance:

- SCTs are components of smart buildings, which increase performance primarily through increased interaction with building occupants.
- SCTs (or the broader IoT applications) enable smart buildings, campuses and cities, where the meaning of ‘smart’ is not narrowly defined and continuously developing.

Providing management information:

- SCTs require Information management in order to ensure a valuable contribution of its output to campus management.
- The implementation of SCTs may lead to changes in both higher and lower-level organisational processes within the university.

Applying theories in smart campus tools research

RQ2: How are these theories applied to research smart campus tools?

The previously introduced theories, concepts and instruments (chapter 3) are combined to study smart campus tools.

In order to study space utilisation, space use (in frequency and occupancy rates) is connected to space norms (users / m^2). Also, the distinction between scheduled and actual space use is made explicit, and targets for frequency and occupancy rates are discussed.

In order to study smart campus tools, the most prominent frameworks that are combined are: (1) the added values of real estate, (2) the resolutions in which space use is measured, and (3) the various sensing technologies.

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In order to design the connection of smart campus tools to campus management, process and information analysis and dashboards are used. These are informed by existing theories from real estate management.

Part 2 – Main Body

Studying space utilisation at TU Delft – and using it in decision-making processes

RQ3: What is the space use of education spaces and study places at TU Delft, and how does it inform campus decision-making?

The use of TU Delft's education spaces and study places and their development is reported in chapter 4, during a time in which the university's student population continued to grow. Education spaces are used efficiently in terms of frequency rates (availability), close to the target of 75% frequency. In terms of capacity (occupancy), improvement is possible as average occupancy rates are well below the target of 60% occupancy. Study places for self-study are used well with 60-70% occupancy rates, whilst other types of study places can be used more efficiently.

The results have provided campus managers with evidence on which to base decisions about the campus of the future. For education spaces, the results have helped to understand which ratio of seats/student is achievable and desirable. Over time, the results helped to monitor the effect of a decline of the seats/student ratio from around 0,92 in 2014 to 0,8 in 2020 on the space use at the university. Thus, it supported decisions to increase the education capacity both on the short-term and long-term to accommodate the increasing student population. For study places, the results have supported continuous discussion to determine which interventions are needed and if the current capacity meets student's needs.

Exploring smart campus tools in Dutch and international contexts

RQ4: What is the demand for smart campus tools of Dutch universities and what smart campus tools are available?

RQ5: What smart campus tools are being used by international universities and organisations and how do they compare to the use of smart campus tools in the Netherlands?

In the first study, 26 smart campus tools at Dutch universities and 4 from other organisations are studied (chapter 5). The primary function of the existing smart campus tools is to support users – mostly students – to find available spaces on campus. A few smart campus tools also aim at improving the use of teaching spaces. In other industries, the results of the interviews suggest a stronger emphasis on supporting campus managers to achieve a more efficient use of space. The results further show that interviewees have differing perceptions of what is 'smart'. This does not only depend on the use of real-time data collection, as interviewees defined other innovative data collection or analysis methods as 'smart campus tools'.
In general, interviewees foresaw a further increase in the use of real-time data collection in the future, which was confirmed in the second study.

In the second study, 27 cases of smart campus tools are studied (chapter 6): 9 of Dutch universities, 9 of international universities, and 9 of other organisations. Figure SUM. 4 shows several examples. The smart campus tools collected in this exploration adhered strictly to the research definition of smart campus tools (as opposed to those in the previous chapter).

At international universities two implemented smart campus tools are found to help students find study places and one pilot project to optimise teaching space. The other six cases are in a pilot stage or design brief, revealing that many universities are busy with the subject. New smart campus tools are being considered, researched, developed and tested to support students and employees, optimise space use and save energy.

At other organisations most cases reveal that they are working on smart campus tools that both monitor their space use and help their employees find available workplaces and/or meeting rooms; and in two cases also to align energy use with building use. Most smart campus tools are in the implementation phase. Organisations are generally further along than universities with their implementations. Several cases are found that use multiple types of sensors in their smart campus tools.

At Dutch universities smart campus tools are aimed at either real-time monitoring of teaching space or on smart campus tools that support students, in which multiple functions are brought together. Previous research concluded that by looking at all available smart campus tools –which includes more room booking apps and available PC apps- the focus of smart campus tools was for the largest part to add value by supporting students. The cases at Dutch universities are generally further along than those at international universities in terms of their implementation.

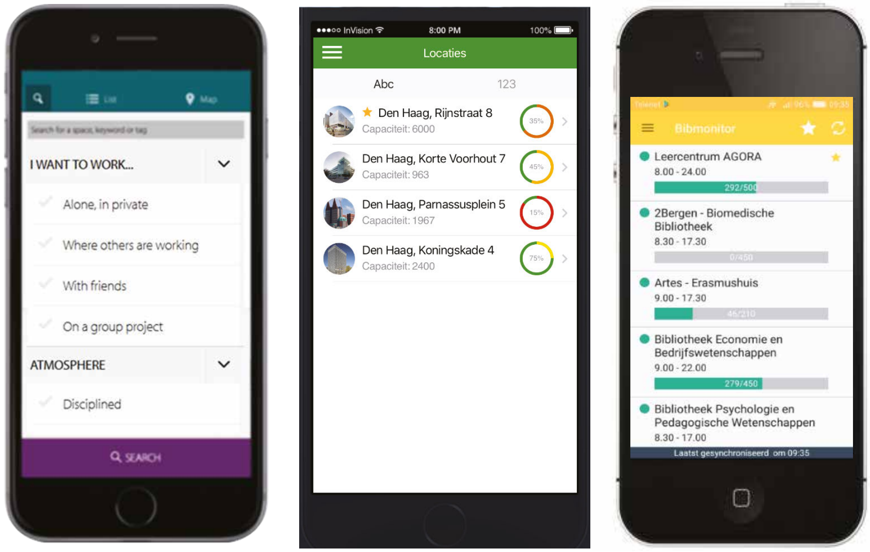

FIG. SUM. 4 Examples of the user interfaces of several smart campus tools.

Through comparison of the smart campus tools at international universities, other organisations and Dutch universities, it suggests that the cases at Dutch universities were generally further along than those at international universities in terms of their implementation, though not as far as other organisations.

Connecting smart campus tools to campus decision making

RQ6: How can IoT technologies be used to effectively support (strategic) decision making in university campus management?

RQ7: How can the information demands of campus management be matched to the capabilities of IoT applications?

Following the explorations of smart campus tools, the focus of the research moves to the connection of smart campus tools to decision making in campus management in two research steps. The first step, is the connection between the Internet of Things (IoT)[1] and campus decision-making processes. In the second step, dashboards support the activities (i.e. parts of the decision-making process) that will make use

1 In chapter 7 and 8, smart campus tools are termed ‘Internet of Things (IoT) applications’, thereby adopting a wider perspective that agrees with the attention for strategic issues in these chapters. Smart campus tools are thought to be a subset of IoT applications.

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of the information from the IoT. Because many types of information come together in these activities, the process to design dashboards is used to determine what the information requirements of campus managers are.

To connect IoT applications to campus decision-making processes, a literature study of 60 papers is combined with four case studies (chapter 7). First, the research gap stated by both researchers and practitioners is confirmed in the literature review: it is mostly unclear how the information from IoT applications are, could or should be used in decision making. Next, the literature study identifies types of IoT applications, returning new capabilities: room-level accuracy or higher is possible with most applications, using various sensing technologies. Furthermore, environmental aspects and user feedback can be incorporated.

Next, the findings from the literature study are connected to four separate process analyses of (re)developing a campus strategy. The studied processes reveal a distinction between 'matching' the demand for space and supply of spaces prior to developing strategies (on a portfolio level), and doing this after determining their strategy (on a building level). For a portfolio-level approach, the capabilities of IoT applications are matched to the information needs of the process.

Following the findings of chapter 7, chapter 8 presents dashboard design as a method to determine which information from IoT applications to match to campus decision-making processes. For two cases, dashboard prototypes were designed and tested. The chapter has two objectives: (1) to develop a connection between IoT applications and real-life decision-making processes and (2) to design usable dashboards for campus managers.

With regards to the second objective, chapter 8 describes the translation of various principles and the outcomes of process and information analysis into a conceptual design for dashboards. The dashboards for both cases are compliant with these principles. The use of these dashboards by the participants in workshops show that it is possible to design usable dashboards for a portfolio of study places and for an entire real estate portfolio at a university, combining data from existing systems and data to be delivered by the IoT,

With regards to the first objective, the workshops resulted in the selection of variables and in improved usability of the dashboards in the second workshop. The use of multiple workshops to test the dashboards, to assess which indicators are useful and if the total dashboard is still a good overview, helps with the selection of information. The use of dashboard design was thus found to be a suitable method for the purpose of this research.

Methods have been developed to structure the use of information from both smart campus tools and legacy systems in decision-making processes at the university (chapter 7 and 8). . Previously, this information was either unavailable or had to be retrieved from many separate sources. Process and information analysis help structure the flow of information, ensuring it is used at the right time and in the right form, while dashboards provide a place where relevant information comes together. By presenting the information in a compact, meaningful way, the dashboards are usable in making decisions regarding the future campus. This intended improvement is visualised in Figure SUM. 5.

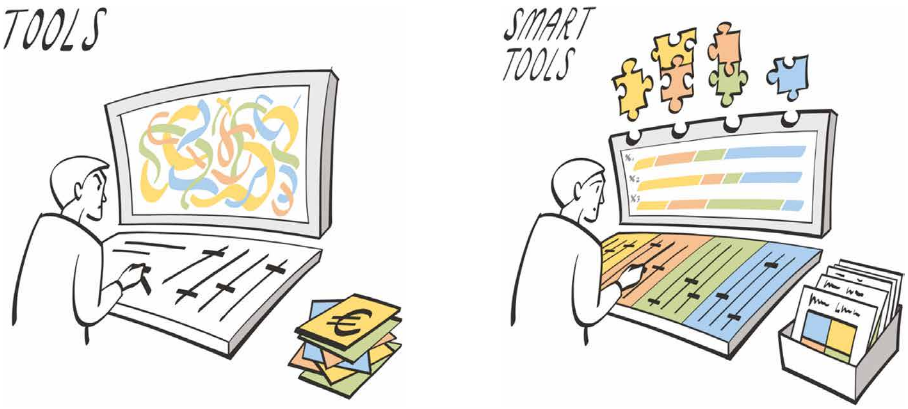

FIG. SUM. 5 Connecting the information from smart campus tools to organisational processes; from previously many unorganised sources in different formats (left) to a single overview (right) (illustration: Mark van Huystee).

Part 3 – Synthesis

Theoretical contributions – updating the body of knowledge

The theoretical contribution of this research (chapter 9) revisits and updates the six foundations formulated in chapter 2: see Figure SUM. 6.

1 Smart campus tools directly add value to the campus through functional goals e.g. supporting users and increasing user satisfaction, and physical goals e.g. reducing CO_2 footprint or enhancing safety. Furthermore, the use of smart campus tools over a longer period of time supports goals such as reducing the m^2 footprint or reducing costs. Indirectly, various strategic goals can be achieved. Several adjustments are

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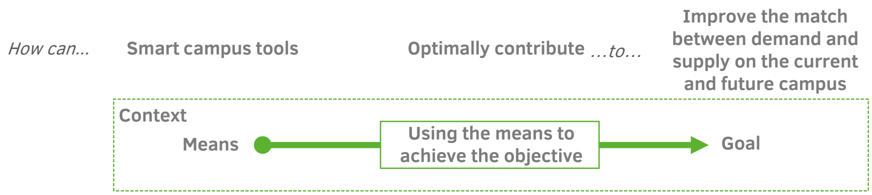
made to the added value model to make it more usable for smart campus tools: reducing the footprint is split into m^2 footprint and CO_2 footprint; and enhancing safety and optimising the mix of spaces are added as added values.

2 Smart campus tools support CRE alignment primarily through matching the existing demand to the existing supply. In doing so, they also support the actions and decisions in further steps of CRE alignment. In addition, smart campus tools promise to increase the precision and frequency of alignment of demand to supply. The precision increases due to the availability of significantly more accurate data. The frequency increases due to different types of decisions that can be supported through this data.

3–4 Smart campus tools should be considered as a part of the ongoing integration of systems and/or the interaction between them, as a result of technological development. This offers opportunities for smart campus tools to add even more value to campus management. The ongoing integration and interaction also affect the use of the word ‘smart’ and what is considered smart: as evidenced in this research, practitioners had different perceptions of what is considered smart, and this is expected to progress further as building automation continues to progress.

5 The implementation of smart campus tools requires campus managers to match their information demands to the available information, now and in the future. The steps taken in chapter 7-8 are reworked in an existing framework in campus management to match the demand for and supply of real estate, now and in the future. Four tasks are completed iteratively to ensure the information delivery from smart campus tools to campus management processes.

6 The implementation of smart campus tools may lead to changes in organisational processes, and even organisational structures. Smart campus tools offer opportunities to match the demand for real estate and supply of real estate on a portfolio level (rather than a building level), along many different variables. Additionally, Smart campus tools can support the integrated delivery of buildings and building services, which could lead to higher-level organisational changes.



	Monitoring building performance (ch. 2.2)	Providing management information (ch. 2.3)	Managing real estate (ch. 2.1)
Theoretical foundations (based on chapter 2) **INPUT** for this research	SCTs are components of smart buildings, which increase performance primarily through increased interaction with building occupants.	SCTs require information management in order to ensure a valuable contribution of its output to campus management.	SCTs add value to the performance of the university through strategic, functional, financial and physical campus perspectives, as an instrument in campus management.
	SCTs (or the broader IoT applications) enable smart buildings, campuses and cities, where the meaning of 'smart' is not narrowly defined and continuously developing.	The implementation of SCTs may lead to changes in both higher and lower-level organisational processes within the university	SCTs support campus management organisations in their CRE alignment in specific building blocks / process steps, resulting in added value.
Theoretical outcomes (based on chapter 4-8) **OUTPUT** of this research	Confirming the position of SCTs within a landscape of systems that is developing towards further integration and interaction.	Confirming the value of information management in designing SCTs for use in campus management.	Confirming the added value of SCTs, and specifying the value added through them.
	Confirming the different perceptions of 'smart' in SCTs and their continuous development.	Confirming the potential of SCTs to support organisational changes.	Confirming the building blocks / process steps in which SCTs support CRE alignment; Identifying the potential of SCTs to increase the frequency and precision of CRE alignment.

FIG. SUM. 6 Summarising the conclusions of this PhD research in relation to the body of knowledge.

Practical contributions – translating the findings into a roadmap

The practical contribution of this research (chapter 9) presents a roadmap to support campus managers in the design and implementation of smart campus tools for their organisation.

In the first part, the roadmap helps campus managers identify the extent to which spaces will be shared on the future campus per space type, along three campus models: the traditional, network and virtual campus. Then, for each campus model and space type, it details how smart campus tools support users, optimise space use and save energy. It also provides argumentation on why to choose for the use of smart campus tools (using real-time data) rather than reservation systems and/or manual audits.

In the second part, the roadmap outlines the process required to design and implement the smart campus tool that has been specified in the first part. This outline makes use of the framework introduced in the theoretical contribution, completing four tasks to match information demands to the available information, now and in the future. These steps are:

- assessing relevant organisational processes and currently used systems;
- exploring changing information demand;
- refining and determining information flows and selecting the required information;
- and implementing the selected smart campus tools and dashboards.

For each step, the process outline contains a set of variables which serves as a checklist: the campus manager can use this checklist to identify ex ante which variables are relevant for each process step, thus designing the implementation process.

Reflecting on smart campus tools during the COVID-19 pandemic

During the last year of this PhD research, an extra chapter was added to explore how the COVID-19 pandemic affected the demand for and supply of smart campus tools. Because of the pandemic, the access to universities, supermarkets, restaurants, shops, museums, stadiums, nightclubs etc. was limited by a revised maximum capacity to ensure social distancing, or access was simply altogether prohibited. This is a reversal of our reality: instead of facilities or resources being available at people's disposal whenever they were needed, suddenly, the limited availability of resources dictated the ability to use them. To facilitate this new situation, reservation systems were introduced on a large scale. However, they are subject to several limitations, which results in suboptimal use of space and energy.

The exploration in this chapter has reaffirmed the idea that smart campus tools require sensors in order to effectively support users, optimise space use, and save energy. The use of reservation systems can be a first step towards an improved use of (campus) resources, but results in suboptimal use of spaces, and thus financial and energy resources. When used improperly, they can even be a step backwards. Although the future campus may still require the use of reservations, this should be integrated within smart campus tools making use of sensors. Additionally, smart campus tools can support internal discussion about the required resources to serve the community and empower users: by not just showing users available spaces, but also by confronting them with the financial and energetic effects of e.g. unused reservations (see Figure SUM. 7).

FIG. SUM. 7 Making inefficient use of spaces and places visible not just by displaying reservations vs. actual use, but also by showing the effects on financial and energy performance.

Answering the main research question

Main RQ: How can smart campus tools optimally contribute to the match between demand and supply of space, both on the current campus and on the future campus?

This PhD research shows that smart campus tools can improve the match between demand and supply in space in multiple ways. On many present-day campuses, much time is wasted in finding available spaces, and many resources – i.e. costs and energy – are wasted as spaces are left unused for long stretches of time. Smart campus tools enable users to share spaces across the university, resulting in satisfied users, a lower m^2 per user, a higher space use, and a reduction of costs and energy consumption.

Furthermore, smart campus tools deliver information that supports decision making, thus improving resource use on the future campus. Space utilisation studies are often used for this purpose. However, because they are time-consuming to collect and analyse, and deliver only a snapshot of the actual space utilisation during the time of the study, decision-making processes are poorly informed. Smart campus tools remove these limitations, as they provide real-time data collected through sensors. The application of process and information analysis and dashboard design in this dissertation show how to ensure a proper connection of the information from smart campus tools to decision-making processes. This connection will enable campus managers to optimize today's use of (energy, financial and spatial) resources and to make decisions about the campus of the future.

Samenvatting

Aanleiding om Smart campus tools te onderzoeken

In de afgelopen jaren is het steeds moeilijker geworden voor campus managers om een steeds dynamischere universitaire gemeenschap van studenten en medewerkers te accommoderen op de universiteitscampus. Om substantieel grotere studentenpopulaties te kunnen huisvesten en gegeven de toenemende druk op universitaire middelen, hebben Nederlandse universiteiten de dichtheid op de campus vergroot: bijv. door het delen van onderwijsruimten op campusniveau, het gebruik van circulatieruimten als studieruimte of voor informele ontmoeting, en door veranderende concepten voor werk- en leerruimten. Continu stellen campus managers zichzelf en de campusgebruikers de volgende vraag: is het echt nodig om meer ruimte toe te voegen, of kunnen we de bestaande middelen effectiever en efficiënter inzetten?

Om besluiten over het verhogen van de bezetting en benutting te ondersteunen, laten periodieke bezettingsmetingen zien dat er nog steeds genoeg ruimte op de campus is. Deze studies hebben echter een aantal beperkingen. Tegelijkertijd gaven campusgebruikers in toenemende mate aan moeite te hebben met het vinden van plekken om te werken, te ontmoeten en te studeren. Deze paradox, waarin er zowel een overschot als een tekort in ruimte is, lijkt te worden veroorzaakt door het ontbreken van betrouwbare informatie over het ruimtegebruik in de tijd. Dit was in het verleden al door de campus managers geïdentificeerd als een blinde vlek in hun managementinformatie, en dat is bij veel universiteiten vandaag nog steeds het geval.

Op de huidige universiteitscampus kunnen middelen effectiever en efficiënter worden ingezet door het territoriale gebruik van ruimten te adresseren. Veel ruimten worden door individuen, groepen or organisatie-eenheden geclaimd, en alleen gebruikt voor een specifieke activiteit gedurende een specifieke tijd van de week, maand of zelfs jaar. Zowel campusgebruikers als –managers ervaren frustraties over ruimten die gereserveerd zijn – via reserveringssystemen of door spullen achter te laten – maar niet daadwerkelijk in gebruik, hetgeen resulteert in verspilling van financiële middelen en energie (Figuur SAM. 1). Wanneer dit wordt gezien over een periode van weken, maanden of jaren, wordt het probleem nog erger.

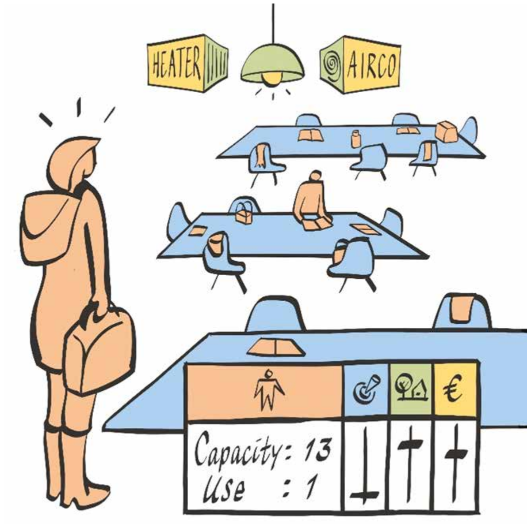


FIG. SAM. 1 Een toenemende frustratie over ruimten die gereserveerd zijn, maar niet in gebruik (Illustratie: Mark van Huystee). Dit resulteert in lage prestaties op alle stakeholder perspectieven: een teveel aan ruimte (strategisch, blauw) vergeleken met de vraag naar ruimte (functioneel, oranje), hetgeen leidt tot hoge kosten per gebruiker (financieel, geel) en een hoog energieverbruik per gebruiker (fysiek, groen).

Om dit probleem te adresseren, stelt deze PhD dissertatie voor om Smart campus tools (SCTs) te gebruiken: een dienst of product waarmee informatie over het ruimtegebruik real-time wordt verzameld om enerzijds het ruimtegebruik van de huidige campus te verbeteren, en anderzijds besluitvorming over de toekomstige campus te verbeteren. Smart campus tools adresseren zowel de behoefte van gebruikers als campus managers voor meer informatie. Ze meten het real-time gebruik van werkplekken, ruimten en gebouwen door middel van sensoren. Deze data kan gebruikt worden om studenten en medewerkers te informeren over beschikbare werk- of studieplekken, de drukte op specifieke plekken, etc. Daarnaast kan de door sensoren verzamelde data over een langere tijdsperiode campus managers voorzien van een gedetailleerd beeld van het ruimtegebruik op de campus, hetgeen hun strategische besluitvormingsprocessen zou ondersteunen. De onderzoeksvraag is:

Hoe kunnen Smart campus tools optimaal bijdragen aan de match tussen de vraag naar en het aanbod aan ruimte, zowel op de huidige als de toekomstige campus?

Figuur SAM. 2 laat de structuur zien die wordt gehanteerd om de onderzoeksvraag te beantwoorden. Eerst behandelt het theoretisch kader (deel 1) de input voor dit onderzoek. Dan bespreekt het hoofddeel (deel 2) de componenten van dit onderzoek en hun resultaten. De synthese (deel 3) concludeert de dissertatie.

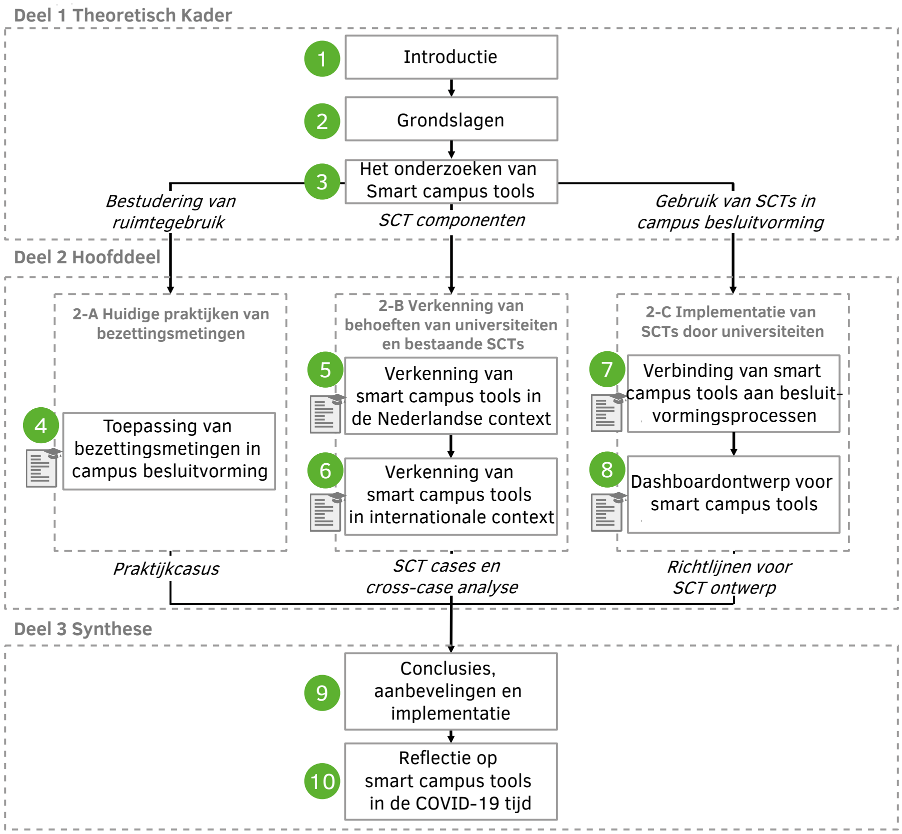


FIG. SAM. 2 Onderzoeksstructuur van deze PhD dissertatie: van theoretisch kader (input) door het hoofddeel (throughput) naar de synthese (output). Hoofdstukken die als papers zijn gepubliceerd, zijn met iconen gemarkeerd.

Meerdere onderzoeksmethoden zijn gebruikt: empirische methoden zoals literatuurstudies, vragenlijsten, interviews, en ontwerpend onderzoek. De eerste fase van het onderzoek (hoofdstuk 5-6; 2015-17) richtte zich op het verkennen van smart campus tools, het onderscheiden van verschillende typen smart campus tools en hun eigenschappen, en de toekomstige vragen van universiteiten met betrekking tot deze tools. De tweede fase van het onderzoek (hoofdstuk 7-8; 2018-20) richtte zich op hoe smart campus tools besluitvormingsprocessen van campus managers kunnen ondersteunen: eerst door de verbinding van smart campus tools naar besluitvormingsprocessen te structureren met proces- en informatieanalyse en daarna door deze verbinding te ontwerpen met dashboardontwerp. Tijdens deze fases is het theoretisch kader (hoofdstuk 2-3) continu bijgewerkt, en is een studie uitgevoerd naar het gebruik van bezettingsmetingen in besluitvorming (hoofdstuk 4).

Deel 1 – Theoretisch kader

Grondslagen voor smart campus tools onderzoek

RQ1: Welke theorieën zijn relevant om smart campus tools te implementeren op universiteitscampussen?

Verschillende theorieën, concepten en instrumenten zijn nodig om smart campus tools te onderzoeken. In hoofdstuk 2 worden deze in drie overlappende terreinen ingedeeld, en verbonden aan de onderzoeksvraag via een conceptueel model (Figuur SAM. 3):

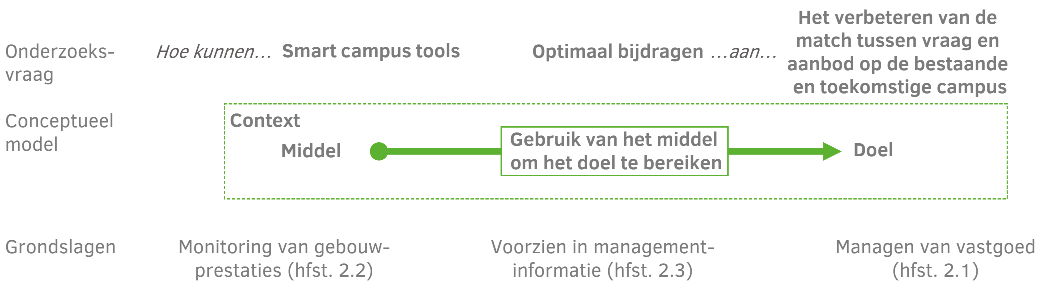


FIG. SAM. 3 Conceptueel model.

- Het managen van vastgoed: dit PhD onderzoek maakt deel uit van het onderzoeksprogramma van Management in the Built Environment (MBE) en wordt uitgevoerd in de leerstoel Publiek Vastgoedmanagement. Deze sectie onderbouwt de voorgenomen bijdrage van smart campus tools aan campus management.

- Het monitoren van vastgoedprestaties: de smart campus tools die in deze PhD worden voorgesteld, vereisen het gebruik van meerdere IT componenten. Daarom biedt deze sectie een onderbouwing voor de technologische componenten van smart campus tools.

- Het voorzien in managementinformatie: om te zorgen dat smart campus tools leiden tot de gewenste voordelen voor de organisatie, is het nodig om ze (de middelen en de doelen) goed met elkaar te verbinden. Daarom bespreekt deze sectie het gebruik van Informatiemanagement om een verbinding te ontwerpen tussen smart campus tools en campus management.

De discussie van deze drie terreinen is samengevat in zes grondslagen. In de synthese wordt er gereflecteerd op deze grondslagen, met gebruik van de resultaten uit het onderzoek.

Het managen van vastgoed:

- SCTs voegen waarde toe aan de prestaties van de universiteit via strategische, financiële, functionele en fysieke campus perspectieven, als een instrument in campus management;

- SCTs leveren toegevoegde waarde aan campus management organisaties door de ondersteuning van CRE alignment in specifieke processtappen, hetgeen resulteert in toegevoegde waarde.

Het monitoren van vastgoedprestaties:

- SCTs zijn componenten van smart buildings, die prestaties verbeteren primair door verhoogde interactie met gebruikers van het gebouw;

- SCTs (of breder gezien IoT applicaties) maken smart buildings, campussen en steden mogelijk, waarbij ‘smart’ niet strict is gedefinieerd, maar continu in ontwikkeling.

Het voorzien in managementinformatie:

- SCTs vereisen informatiemanagement om een waardevolle bijdrage van hun output aan campus management te kunnen leveren;

- De implementatie van SCTs kunnen leiden tot veranderingen in universitaire organisatieprocessen op zowel hogere als lagere niveaus.

Toepassing van theorieën in smart campus tools onderzoek

RQ2: Hoe zijn deze theorieën toegepast om smart campus tools te onderzoeken?

In hoofdstuk 3 worden de hiervoor geïntroduceerde theorieën, concepten en instrumenten gecombineerd om smart campus tools te bestuderen.

Om ruimtegebruik te onderzoeken, wordt het gebruik van ruimte (in bezettings- en benuttingsgraad) verbonden aan ruimtenormen (gebruikers per m^2). Daarnaast wordt het onderscheid tussen geroosterd en daadwerkelijk gebruik expliciet gemaakt, en worden doelstellingen voor bezetttings- en benuttingsgraden besproken.

Om smart campus tools te onderzoeken, worden een aantal instrumenten gecombineerd: (1) het 'added value' model in vastgoedmanagement, (2) de ruimtelijke resoluties waarin het ruimtegebruik kan worden gemeten, en (3) de verschillende sensortechnologieën die voorheen besproken zijn. Daarnaast worden nog een aantal andere eigenschappen minder prominent bestudeerd.

Om een verbinding te maken tussen smart campus tools en campus management, worden proces- en informatieanalyse en dashboardontwerp gebruikt. Deze worden geïnformeerd door bestaande theorieën in vastgoedmanagement.

Deel 2 – Hoofddeel

Bestudering van ruimtegebruik bij de TU Delft – en het gebruik ervan in besluitvormingsprocessen

RQ3: Wat is het ruimtegebruik van onderwijsruimten en studieplekken bij de TU Delft, en hoe informeert het besluitvorming over de campus?

Het ruimtegebruik van de onderwijsruimten en studieplekken van de TU Delft en hun ontwikkeling wordt in hoofdstuk 4 besproken, in een tijd waarin de studentenpopulatie van de universiteit voortdurend is gegroeid. De onderwijsruimten worden efficiënt gebruikt qua bezettingsgraad (beschikbaarheid), nabij het doel van een bezettingsgraad van 75%. Qua benutting (capaciteit) is er verbetering mogelijk, aangezien de gemiddelde benuttingsgraad onder het doel van 60% ligt. Studieplekken voor zelfstudie worden goed gebruikt met benuttingsgraden tussen de 60% en 70%, terwijl andere typen studieplekken efficiënter gebruikt kunnen worden.

De resultaten hebben campus managers ondersteund met bewijs waarop zij hun beslissingen over de campus van de toekomst konden baseren. Voor de onderwijsruimten hebben de resultaten geholpen om te begrijpen welke norm van stoelen / student haalbaar en wenselijk is. Door de jaren heen hebben de resultaten geholpen om te monitoren wat het effect was van een afnemend aantal stoelen / student (van ca. 0,92 in 2014 tot 0,8 in 2020) op het ruimtegebruik van de universiteit. Daarmee zijn beslissingen ondersteund om de onderwijscapaciteit op zowel de korte als de lange termijn te verhogen zodat de toenemende studentenpopulatie gehuisvest kon worden. Voor studieplekken hebben de resultaten voortdurende discussies ondersteund over welke interventies nodig zijn en of de huidige capaciteit voldoet aan de wensen van de studenten.

Verkenning van smart campus tools in de Nederlandse en internationale context

RQ4: Wat is de vraag naar smart campus tools door Nederlandse universiteiten en welke smart campus tools zijn er beschikbaar?

RQ5: Welke smart campus tools worden er gebruikt door internationale universiteiten en organisaties, en hoe verhouden deze zich tot het gebruik van smart campus tools bij Nederlandse universiteiten?

Een overzicht van 26 smart campus tools bij de Nederlandse universiteiten en 4 van andere (Nederlandse) organisaties wordt in hoofdstuk 5 besproken. De primaire functie van de bestaande smart campus tools is om gebruikers te ondersteunen in het vinden van beschikbare (werk)plekken en ruimten op de campus. Een paar smart campus tools zijn ook gericht op het verbeteren van het gebruik van de onderwijsruimten. In andere organisaties duiden de resultaten op een sterkere nadruk op efficiënt ruimtegebruik. Daarnaast laten de resultaten zien dat de geïnterviewden verschillende percepties hebben van wat ‘smart' is. Dat ligt er niet alleen aan of de dataverzameling real-time is, aangezien de geïnterviewden ook tools met andere innovaties in de dataverzameling of –analyse als ‘smart campus tools' definieerden. Wel voorzagen de geïnterviewden een verdere toename in het gebruik van real-time dataverzameling in de toekomst.

Een overzicht van 27 cases van smart campus tools (door het benaderen van 54 organisaties) wordt in hoofdstuk 6 besproken: 9 van Nederlandse universiteiten, 9 van internationale universiteiten, en 9 van andere organisaties. Figuur SAM. 4 laat een aantal voorbeelden zien. In tegenstelling tot bij de vorige verkenning, voldeden deze smart campus tools aan de in deze PhD gehanteerde definitie van smart campus tools.

Bij internationale universiteiten werden twee geïmplementeerde smart campus tools gevonden om studenten te helpen met het vinden van studieplekken en een pilotproject om onderwijsruimten te optimaliseren. De andere zes cases waren in een pilotfase of ontwerpfase, wat weergeeft dat veel universiteiten bezig zijn met het onderwerp. Nieuwe smart campus tools worden overwogen, onderzocht, ontwikkeld en getest om studenten en medewerkers te ondersteunen, ruimtegebruik te optimaliseren, en energie te besparen.

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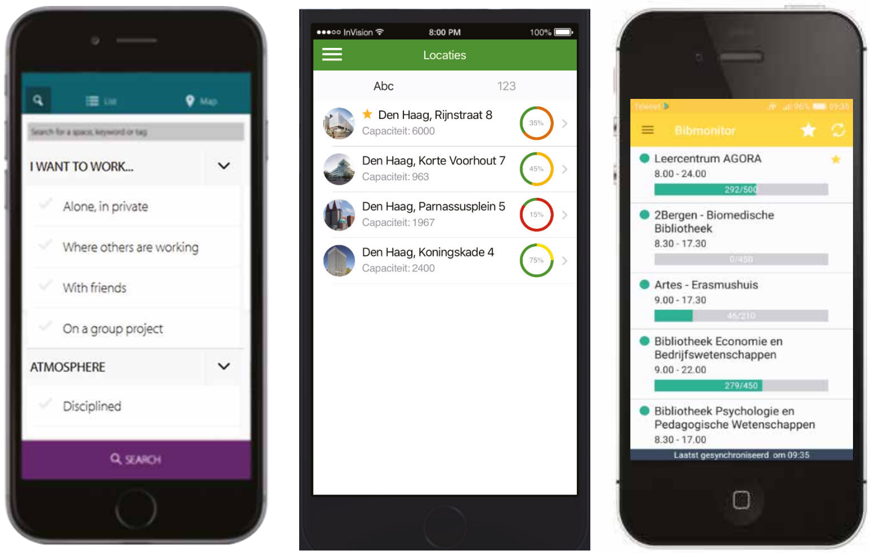

FIG. SAM. 4 Voorbeelden van de gebruikersinterfaces van verschillende smart campus tools.

Bij andere organisaties laten de meeste cases zien dat zij werken aan smart campus tools die zowel het ruimtegebruik monitoren en medewerkers helpen met het vinden van beschikbare werkplekken en/of vergaderruimten. In twee cases wordt dit zelfs gecombineerd met het afstemmen van het energiegebruik op het gebouwgebruik. De meeste smart campus tools zijn hier in de implementatiefase. Organisaties zijn over het algemeen verder dan universiteiten met hun implementaties. Een aantal van de cases gebruiken meerdere typen sensoren in hun smart campus tools.

Bij Nederlandse universiteiten zijn smart campus tools gericht op ofwel het real-time monitoren van het ruimtegebruik van onderwijszalen, ofwel op het ondersteunen van studenten, waarin meerdere functies bij elkaar worden gebracht. Eerder onderzoek (hoofdstuk 5) concludeerde dat door naar alle beschikbare smart campus tools te kijken – inclusief room booking applicaties en applicaties die PC plekken lieten zien – dat de smart campus tools voornamelijk toegevoegde waarde leverden door studenten te ondersteunen. De cases bij Nederlandse universiteiten zijn over het algemeen verder qua implementatie dan bij internationale universiteiten.

Door vergelijking van de smart campus tools bij internationale universiteiten, andere organisaties en Nederlandse universiteiten, wijzen de resultaten erop dat de cases bij de Nederlandse universiteiten over het algemeen geavanceerder zijn dan de cases bij internationale universiteiten, maar niet zo ver als de cases bij andere organisaties.

Het verbinden van smart campus tools aan besluitvorming over de campus

RQ6: Hoe kunnen IoT technologieën worden gebruikt om effectief strategische besluitvorming te ondersteunen in campus management?

RQ7: Hoe kan de informatievraag van campus management worden afgestemd op de mogelijkheden van IoT toepassingen?

Na de verkenningen van smart campus tools verlegt de focus van het onderzoek zich naar de verbinding van smart campus tools aan besluitvorming in campus management in twee onderzoeksstappen. De eerste stap is het ontwerpen van een verbinding de Internet of Things (IoT)[2] en besluitvormingsprocessen op de campus. In de tweede stap worden dashboards ontworpen om de activiteiten (d.w.z. onderdelen van het besluitvormingsproces) te ondersteunen die gebruik maken van de informatie van de IoT. Omdat veel soorten informatie bij elkaar komen in deze activiteiten, wordt het ontwerpen van dashboards gebruikt als middel om te bepalen wat de informatiebehoeften zijn.

Om IoT toepassingen te verbinden aan besluitvormingsprocessen op de campus, combineert hoofdstuk 7 een literatuurstudie van 60 papers met vier case studies. De literatuurstudie ondersteunt eerst de onderzoeks'gap' die zowel door onderzoekers als professionals is aangegeven: het is niet duidelijk hoe de informatie uit IoT toepassingen wordt, kan worden, of zou moeten worden toegepast in besluitvorming. Daarna identificeert de literatuurstudie typen IoT toepassingen, waaruit nieuwe mogelijkheden worden opgemaakt: nauwkeurigheid op kamerniveau of hoger is mogelijk met de meeste toepassingen, door het gebruik van verschillende sensortechnologieën. Daarnaast kunnen omgevingskenmerken en gebruikersfeedback ook worden verzameld.

Daarna worden de bevindingen van de literatuurstudie verbonden aan vier procesanalyses van processen voor het (her)ontwikkelen van een campus strategie. De bestudeerde processen laten een onderscheid zien tussen het matchen van de vraag naar ruimten en het aanbod aan ruimten (matchen op portefeuilleniveau) voorafgaand aan het ontwikkelen van de strategie, en het matchen na het vaststellen van de strategie (matchen op gebouwniveau). Voor de benadering op portefeuilleniveau worden de mogelijkheden van IoT toepassingen afgestemd op de informatiebehoeften van het proces.

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2 In hoofdstuk 7 en 8 worden smart campus tools 'Internet of Things toepassingen' genoemd. Smart campus tools zijn een deelverzameling van Internet of Things toepassingen.

Op basis van de resultaten van hoofdstuk 7 presenteert hoofdstuk 8 het gebruik van dashboardontwerp als methode om te bepalen welke informatie van IoT toepassingen te matchen aan besluitvormingsprocessen. Dashboard prototypen worden in twee cases ontworpen en getest. Het hoofdstuk heeft twee doelstellingen: (1) om een verbinding tussen IoT toepassingen en besluitvormingsprocessen te ontwikkelen en (2) om bruikbare dashboards te ontwerpen voor campus managers.

Met betrekking tot de tweede doelstelling beschrijft hoofdstuk 8 de vertaling van verschillende principes en de uitkomsten van proces- en informatieanalyses tot een conceptueel ontwerp van dashboards. De dashboards die voor beide cases zijn ontworpen, voldoen aan deze principes. Het gebruik van deze dashboards door de deelnemers in workshops laat zien dat het mogelijk is om bruikbare dashboards te ontwerpen voor een portefeuille van studieplekken en voor een gehele vastgoedportefeuille van een universiteit, waarbij data wordt gecombineerd van bestaande systemen en data die door IoT toepassingen zal worden geleverd.

Met betrekking tot de eerste doelstelling beschrijven de resultaten hoe de workshops geleid hebben tot een selectie van variabelen en hoe de verbeteringen in het ontwerp geleid hebben tot meer bruikbare dashboards in de tweede workshop. Het gebruik van meerdere workshops om de dashboards te testen, te beoordelen welke indicatoren bruikbaar zijn, en of het gehele dashboard een goed overzicht biedt, helpt bij het selecteren van de informatie. Het gebruik van dashboard design is daarom geschikt bevonden als methode voor de doelstelling van dit onderzoek.

Hoofdstuk 7 en 8 bieden dus methoden aan om het gebruik van informatie van zowel smart campus tools als legacy systemen te structureren voor het gebruik in besluitvormingsprocessen op de universiteit. Hiervoor was deze informatie niet beschikbaar, of moest zij worden opgehaald uit vele verschillende bronnen. Proces- en informatieanalyse helpen om de flow van informatie te structuren, en zorgen ervoor dat deze op het juiste moment wordt gebruikt en in de juiste vorm, terwijl dashboards de relevante informatie op één plaats bij elkaar brengen. Door de informatie op een beknopte, betekenisvolle wijze te presenteren, zijn dashboards bruikbaar in het maken van beslissingen over de toekomstige campus. Deze voorgenomen verbetering is gevisualiseerd in Figuur SAM. 5.

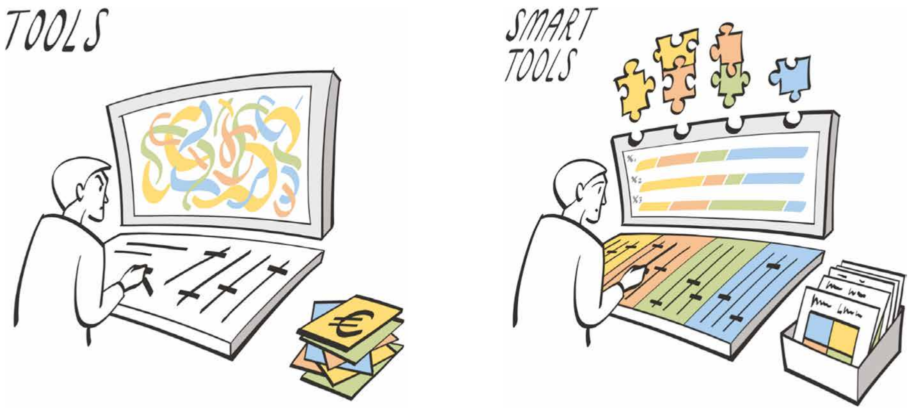

FIG. SAM. 5 Het verbinden van de informatie van smart campus tools aan processen in de organisatie; van voorheen veel ongeorganiseerde bronnen in verschillende formats (links) naar één overzicht (rechts) (Illustratie: Mark van Huystee).

Deel 3 – Synthese

Theoretische bijdrage – updaten van het theoretisch kader

In hoofdstuk 9 worden de bevindingen van het onderzoek geïntegreerd in zowel een theoretische als een praktische bijdrage. De theoretische contributie komt terug naar de zes grondslagen uit hoofdstuk 2 en werkt deze bij: zie Figuur SAM. 6.

1 Smart campus tools voegen direct waarde toe aan de campus via functionele doelstellingen, bijv. het ondersteunen van gebruikers en het verhogen van gebruikerstevredenheid, en fysieke doelstellingen, bijv. het reduceren van de CO_2 footprint en het verhogen van de veiligheid. Daarnaast ondersteunen smart campus tools over langere periode het behalen van doelen die op de lange termijn behaald worden, bijv. het reduceren van de m^2 footprint of kostenreductie. Indirect kunnen ook meerdere strategische doelstellingen behaald worden. Er worden een aantal aanpassingen gemaakt aan het 'added value' model om het bruikbaarder te maken voor smart campus tools: het reduceren van de footprint wordt gesplitst in een m^2 en CO_2 footprint; en het verhogen van de veiligheid en het optimaliseren van de mix van ruimten worden toegevoegd als 'added values.'

2 Smart campus tools ondersteunen CRE alignment vooral in de processtap waarin de bestaande vraag met het beschikbare aanbod wordt gematched. Daarmee ondersteunen zij ook de acties en besluiten in daaropvolgende stappen van CRE

alignment. Daarnaast beloven smart campus tools om de precisie en de frequentie te verhogen van het alignment van vraag en aanbod. De precisie wordt hoger vanwege de beschikbaarheid van nauwkeurigere data. De frequentie wordt hoger vanwege de verschillende typen beslissingen die met deze data kunnen worden ondersteund.

	Monitoring van gebouw-prestaties (hfst. 2.2)	Voorzien in management-informatie (hfst. 2.3)	Managen van vastgoed (hfst. 2.1)
Theoretische beginselen (o.b.v. hfst. 2) **INPUT** voor dit onderzoek	SCTs zijn componenten van smart buildings, die gebouw-prestaties primair verhogen door een toename in de inter-actie met gebruikers van het gebouw. SCTs (of IoT toepassingen) maken een smart building, city en campus mogelijk, waarbij de betekenis van 'smart' niet nauw gedefinieerd is en zich continu ontwikkelt.	SCTs vereisen informatie-management om een waardevolle bijdrage van hun output te verzekeren voor campus management. De implementatie van SCTs kan leiden tot veranderingen in organisatieprocessen op de universiteit, zowel op hoger als lager abstractieniveau.	SCTs voegen waarde toe aan de prestaties van de universiteit in de strategische, financiële, functionele en fysieke campus perspectieven, als instrument in campus management. SCTs ondersteunen campus management organisaties in hun CRE alignment, in specifieke bouwstenen / processtappen, resulterend in toegevoegde waarde.
Theoretische uitkomsten (o.b.v. hfst. 4-8) **OUTPUT** van dit onderzoek	Bevestiging van de positie van SCTs in een landschap van systemen dat zich ontwikkelt in de richting van verdere integratie en interactie. Bevestiging van de verschillende percepties van 'smart' in SCTs en hun voort-durende ontwikkeling.	Bevestiging van de waarde van informatiemanagement in het ontwerp van SCTs voor het gebruik in campus management. Bevestiging van het potentieel van SCTs om veranderingen in de organisatie te onder-steunen.	Bevestiging van de toegevoegde waarde van SCTs en specificering van de waarde die via hen wordt toegevoegd. Bevestiging van de bouw stenen / processtappen waarin SCTs CRE alignment ondersteunen; Identificering van het potentieel van SCTs om de frequentie en precisie van CRE alignment te verhogen.

FIG. SAM. 6 Samenvatting van de conclusies van dit PhD onderzoek in relatie tot de grondslagen (hfd. 2).

3–4 Smart campus tools moeten gezien worden als deel van de voortdurende integratie van systemen en de toenemende interactie tussen de systemen, als resultaat van de technologische ontwikkeling. Dit biedt kansen voor smart campus tools om nog meer waarde toe te voegen aan campus management. De voortdurende integratie en interactie beïnvloeden ook het gebruik van het woord ‘smart’: zoals blijkt uit dit onderzoek, hadden professionals verschillende percepties van wat ‘smart’ was. Dit zal zich ook verder blijven ontwikkelen met de ontwikkeling van de gebouwautomatisering.

5 De implementatie van smart campus tools vereist van campus managers dat zij hun informatievraag matchen met de beschikbare informatie, nu en in de toekomst. De stappen die in hoofdstuk 7-8 worden genomen, zijn herwerkt in een bestaand model voor campus management om de vraag en het aanbod van vastgoed te matchen, nu en in de toekomst. Vier taken worden iteratief volbracht om de informatielevering van smart campus tools naar campus management processen te verzekeren.

6 De implementatie van smart campus tools kan leiden tot veranderingen in organisatieprocessen, en zelfs organisatiestructuren. Smart campus tools bieden kansen om de vraag naar vastgoed en het aanbod aan vastgoed te matchen op portefeuilleniveau (in plaats van op gebouwniveau), langs veel verschillende variabelen. Daarnaast kunnen smart campus tools het integraal voorzien van gebouwen en installaties ondersteunen, hetgeen kan leiden tot veranderingen in de structuur van de organisatie.

Praktische bijdrage – vertaling van de bevindingen in een roadmap

De praktische bijdrage presenteert een roadmap om campus managers te ondersteunen in het ontwerp en de implementatie van smart campus tools voor hun organisatie.

In het eerste deel helpt de roadmap campus managers om te identificeren op welk niveau ruimten op de toekomstige campus zullen worden gedeeld per ruimtetype, langs drie campus modellen: de traditionele, netwerk en virtuele campus. Dan, voor ieder campus model en ieder ruimtetype detailleert het hoe smart campus tools gebruikers ondersteunen, ruimtegebruik optimaliseren en energie besparen. Het geeft ook argumentatie over waarom te kiezen voor het gebruik van smart campus tools (met real-time data) in plaats van reserveringssystemen en/of handmatige tellingen.

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In het tweede deel weergeeft de roadmap het proces dat vereist is om de in deel 1 gespecificeerde smart campus tool te ontwerpen en implementeren. Het schetsontwerp van het proces, dat hier is weergegeven, gebruikt het herwerkte model uit de theoretische bijdrage, waarin vier taken worden voltooid om de informatievraag en het informatieaanbod te matchen, nu en in de toekomst. Deze stappen zijn:

- Het inventariseren van organisatieprocessen en huidige systemen;
- Het verkennen van de veranderende informatievraag;
- Het detailleren en vaststellen van informatie flows en het selecteren van de vereiste informatie; en
- Het implementeren van de geselecteerde smart campus tools en dashboards.

Voor elke stap bevat het schetsontwerp van het proces een set van variabelen, welke als een checklist dient: de campus manager kan deze checklist gebruiken om voorafgaand aan het proces te identificeren welke variabelen relevant zijn voor elke processtap, en daarmee het implementatieproces ontwerpen.

Smart campus tools onderzoek gedurende de COVID-19 pandemie

Gedurende het laatste jaar van dit PhD onderzoek is een extra hoofdstuk toegevoegd om te verkennen hoe de COVID-19 pandemie de vraag naar en het aanbod aan smart campus tools heeft beïnvloed. Vanwege de pandemie was de toegang tot supermarkten, restaurants, winkels, musea, stadions, nachtclubs etc. gelimiteerd door een aangepaste maximale capaciteit om social distancing te waarborgen, of toegang was simpelweg niet mogelijk. Dit is een omkering van onze realiteit: opeens was het de beperkte beschikbaarheid van het aanbod dat de vraag bepaalde, in plaats van dat het onze vraag was die de beschikbaarheid van het aanbod dicteerde. Om deze nieuwe situatie te faciliteren, werden reserveringssystemen op grote schaal geïmplementeerd. Deze kennen echter enkele beperkingen, die leiden tot suboptimaal gebruik van middelen.

De verkenning in dit hoofdstuk heeft het idee bevestigd dat smart campus tools gebruik moeten maken van sensoren om effectief gebruikers te kunnen ondersteunen, ruimtegebruik te kunnen optimaliseren, en energie te besparen. Het gebruik van reserveringssystemen kan een eerste stap zijn richting een verbeterd gebruik van middelen, maar resulteert in suboptimaal gebruik van ruimten, en dus ook van financiële middelen en energie. Als ze niet goed worden ingezet, kan het zelfs een stap terug zijn. Hoewel de toekomstige campus misschien reserveringssystemen nodig blijft hebben, zou deze functionaliteit geïntegreerd moeten worden in smart campus tools die sensoren gebruiken. Daarnaast kunnen smart campus tools interne discussie ondersteunen over de benodigde middelen om de campusgemeenschap te dienen en gebruikers te ondersteunen: door niet alleen het gebruik van ruimten te laten zien, maar ook om ze te confronteren met de financiële en energetische effecten van bijv. ongebruikte reserveringen (zie Figuur SAM. 7).

FIG. SAM. 7 Het visualiseren van inefficiënt ruimtegebruik, niet alleen maar door te laten zien wat het ingeroosterde en het daadwerkelijke gebruik is, maar ook het effect op de kosten en het energieverbruik.

Het beantwoorden van de hoofdvraag van dit onderzoek

Hoofdvraag: Hoe kunnen Smart campus tools optimaal bijdragen aan de match tussen de vraag naar en het aanbod aan ruimte, zowel op de huidige als de toekomstige campus?

Dit PhD onderzoek laat zien dat smart campus tools de match tussen de vraag naar en het aanbod aan ruimte op meerdere manieren kunnen verbeteren. Op veel campussen wordt er veel tijd verspild aan het vinden van beschikbare ruimten, en veel middelen - zowel qua financiën als duurzaamheid – worden verspild doordat ruimten voor lange tijd niet gebruikt worden. Smart campus tools helpen gebruikers om ruimte op de universiteit te delen, hetgeen resulteert in een lager m^2 gebruik per gebruiker, een hogere bezetting en benutting, en een reductie van kosten en energieverbruik.

Daarnaast leveren smart campus tools informatie die besluitvorming ondersteunt, waarmee het gebruik van middelen op de toekomstige campus wordt verbeterd. Bezettingsmetingen worden vaak voor dit doel ingezet. Echter, deze zijn tijdsintensief qua dataverzameling en –analyse, en leveren maar een momentopname van het daadwerkelijke ruimtegebruik, waardoor besluitvormingsprocessen niet optimaal worden geïnformeerd. De resultaten van hoofdstuk 7 en 8 laten zien hoe smart campus tools verbonden worden aan besluitvormingsprocessen, eerst door deze verbindingen te structureren via proces- en informatieanalyse, en daarna door de informatie van smart campus tools en andere systemen in dashboards te consolideren. Deze connectie stelt campus managers in staat om het gebruik van financiële, energetische en ruimtelijke middelen te optimaliseren en om besluiten te nemen over de campus van de toekomst.

Atlas building TU Eindhoven. Photo: Bart van Overbeeke.

TOC

PART 1

Theoretical Framework

TOC

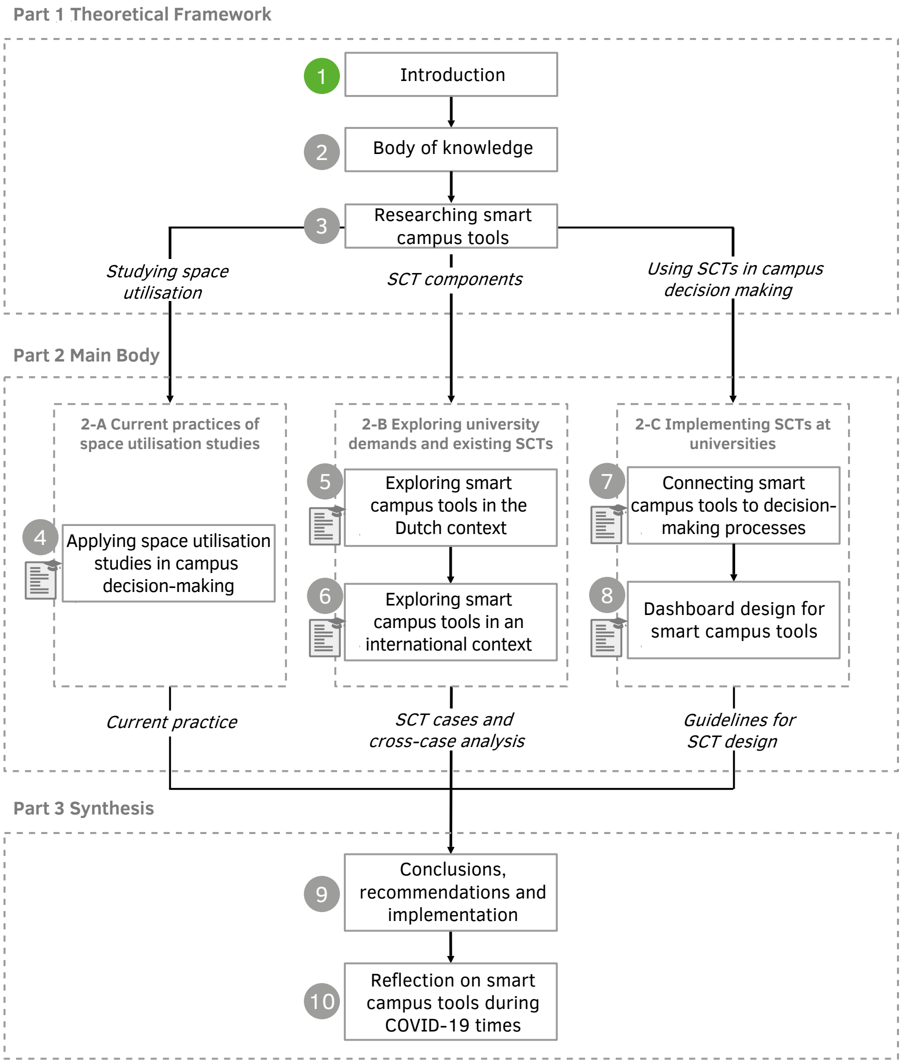

FIG. 1.1 Position of chapter 1 in this research.

1 Introduction

1.1 Research background

Increased density on campus and the need for management information

In recent years, it has become much more challenging for campus managers to accommodate all the university's students and employees on the university campus[3]. In order to accommodate a substantial increase of student populations and given an increasing pressure on university resources, Dutch universities have increased the density on campus. A survey of Dutch universities shows that between 2006 and 2015, Dutch universities have grown significantly in student population (+22%) whilst retaining more or less the same number of m^2 in ownership (-1%) (TU Delft, 2016).

During this period, Dutch universities became more efficient in accommodating their functions, e.g. by sharing education spaces on a campus-level, using circulation areas for studying or as informal meeting space, and by rethinking concepts for working and learning spaces (TU Delft, 2016). This can be described as a shift on campus in how functions are accommodated. Over time, the Dutch university campus is moving from a largely 'traditional' campus towards a more 'networked' campus (Den Heijer, 2011): see Figure 1.2.

3 In this dissertation, the term (university) campus refers to the land and buildings that are used by the university (Den Heijer, 2011). These can be owned by the university or rented from a third party. Also, the university campus can be a single location isolated from the urban setting, or a collection of inner-city locations. Thus, according to this definition, every university has its own campus.

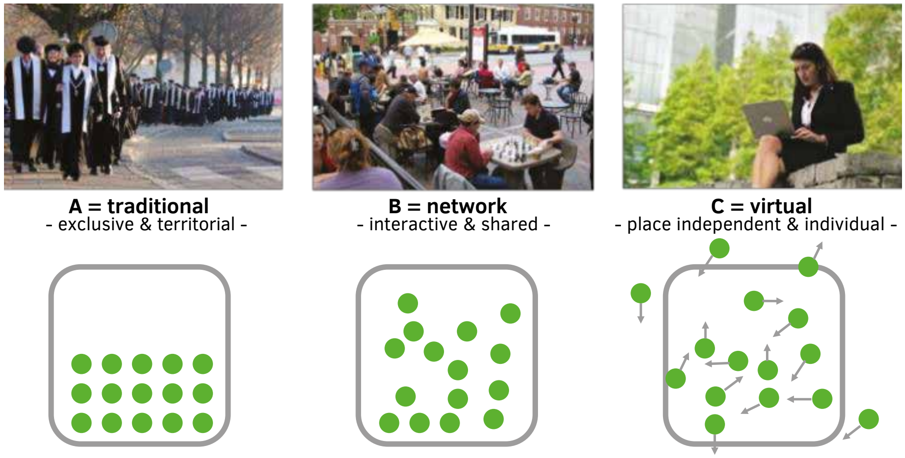

FIG. 1.2 Models for the university campus of the future (Den Heijer, 2011, 2021).

Given the increasing population and pressure on resources, campus managers are continuously asking themselves and campus users: is it really necessary to build more buildings, or can the existing resources be used more effectively and efficiently? To support such decisions on increasing the density, occasional space use studies showed that there was still enough space available on campus (see Appendix 1). However, these studies have several limitations: they may fail to account for changes just before or after a manual count (e.g. the delayed start of an event), they may fail to show parts of the portfolio where utilisation is high and where it is low, and the space use outside of the observed period may be very different from the space use during other times of the year.

At the same time, campus managers indicated that they received increasing numbers of user complaints about difficulties in finding places to work, meet or study. Occasionally, these were also picked up by local and national media (NOS, 2015; Nu.nl, 2018). This paradox in which there is both an abundance and a lack of space, seems to be caused by the unavailability of good information on space use. In Den Heijer (2011), frequency and occupancy rates were identified as a blind spot in the management information available to campus managers: there was information available on the theoretical use – in users per m^2 or use according to schedules – but hardly any information on the actual, observed use. At the start of this research this was still the case at many Dutch universities[4], and it still persists at many universities today.

4 Presentation of the research agenda for universities by Alexandra den Heijer to the facility management department directors of 14 Dutch universities, in which almost all participants indicated a demand for research on the topic of ineffective and inefficient space use.

On the present-day university campus, existing resources can be used more effectively and efficiently by addressing the territorial use of space. Both users and campus managers experience frustration about spaces that were being reserved - through reservation systems or by leaving belongings on workplaces - but not actually used. This problem is analogous to the ‘pool chair problem’ encountered during holidays. This is visualised in Figure 1.3 using four stakeholder perspectives: the pool beds are strategic resources (indicated in blue), which are used by users (orange), and which each have a financial value (yellow) and a CO_2 footprint (green). The user is frustrated by the unavailability of pool beds at a certain moment - which are all claimed by other users – and concludes that there are not enough pool beds to satisfy all users’ needs. The manager is frustrated with the inefficient use of the pool beds, given their cost. The manager’s problem becomes even more apparent on campus (Figure 1.4), where the cost and energy use linked to workplaces is much higher. When visualised in indicators, the campus manager offers a lot of available space, which is left unused for a large amount of time, resulting in wasted financial resources and energy.

When viewing this problem over a longer period of time, it becomes even larger. On campus, study places are used mainly just before and during exam periods, which is for about 12 weeks of the year. In the other 40 weeks, their use is likely well below capacity. Education spaces are typically well used in the first weeks of each academic period, but their use becomes lower as the period progresses. Offices and meeting rooms have a more consistent but lower average use, as many academic staff has their own workplace, which is left unused when during meetings, teaching, or visiting conferences. Additionally, the average use on Wednesdays and Fridays is likely much lower. This is again analogous to the pool chair problem, which only occurs during the summer holidays and during the most sunny hours.

FIG. 1.3 The poor use of pool chair beds due to claim behaviour: reserved, but not in use (illustration: Mark van Huystee).

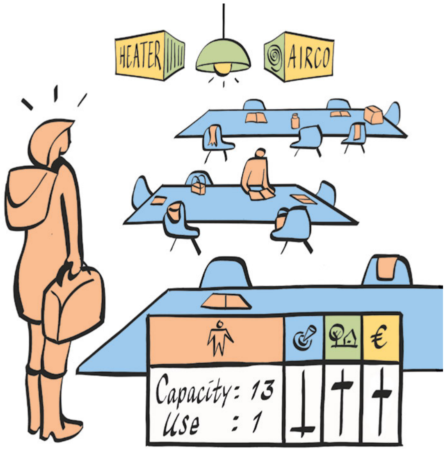

FIG. 1.4 The poor use of study places due to claim behaviour, similar to Figure 1.2 (illustration: Mark van Huystee).

In order to address this problem, the research on smart campus tools (SCTs) was initiated with support of the 14 Dutch universities. SCTs are services or products with which information on space use is collected real-time to improve utilization of the current campus on the one hand, and to improve decision-making about the future campus on the other hand. SCTs measure the real-time use of workplaces, spaces and buildings through sensors. These data can be used to inform students and employees about available places to work or study, the business in specific spaces, etc. In addition, the data collected by sensors would over time provide campus managers with a comprehensive picture of the space use across their campuses, which would support their decision-making processes. However, little is known about (1) the properties of these tools, (2) their use in decision making, and (3) their resulting impact on the future campus.

Pressure on university resources

The density increase at university campuses is caused by a growing pressure on university resources. The causes can be split into organisational developments and campus developments. On the organisational level there is the increasing liberalisation and globalisation of academia. Over the past two decades, universities have become increasingly self-reliant, competitive, and have more autonomy (Schulze-Cleven & Olson, 2017). In particular, there has been a reduction of unconditional public funding per student (Schulze-Cleven & Olson, 2017).

Furthermore, student bodies continue to grow and they are becoming more diverse. The Organisation for Economic Cooperation and Development shows a steady increase of tertiary education graduates over the past 20 years (OECD, 2020b). Regarding diversity, OECD reports around a twofold increase in international student enrolment between 2005 and 2017 (OECD, 2020a). With regards to academic staff, Walker (2015) similarly observes an increasingly international academic staff in the UK, from 22.5% of the total staff in 2007-08 to 28% in 2011-12. According to the UK's Higher Education Statistics Agency, this number has since increased to over 30% in 2018-19 (HESA, 2020). As these numbers are averages for the whole sector, in some universities the figure can be even higher.

The development of public funding and the growing student body were summarised by the Dutch university association VSNU (VSNU, 2016, 2018), revealing the increased pressure on university resources. Between 2000 and 2016, the total student population in the Netherlands increased by 56%, whereas the total amount of public funding increased by only 17%, resulting in a 25% decline in public funding per student. Naturally, this puts pressure on the stated ambitions with regards to education and research. However, as campuses in the Netherlands (and many other countries) are managed by the universities, it similarly pressures the budgets for campus investment and maintenance.

In addition to the organisational pressure on campus investment and maintenance, campus management has its own challenges. Many campuses consist largely of ageing buildings that are often in need of renovation and therefore (re)investment (Den Heijer & Tzovlas, 2014; Kadamus, 2013). In addition, campus investment is subject to more and more requirements due to continuous digitisation, increasing sustainability ambitions and safety requirements. These requirements result in an increase of the investment costs per m^2. As a result, universities are under pressure to pursue alternative financing models for campus investment (e.g. lending, debt funding) (McCann, Hutchison, & Adair, 2019; Newell & Manaf, 2017), with the associated risks and disadvantages.

In summary, campus managers face an enormous challenge. This is visualised in Figure 1.5, where the aforementioned challenges are grouped by four stakeholder perspectives on campus management[5]. Campus managers need to accommodate more students and employees whilst simultaneously realising a high-quality environment to match the university's ambitions. Due to increasing internationalisation, they also need to account for a more diverse demand for facilities and services on campus (Sankari, Peltokorpi, & Nenonen, 2018; TU Delft, 2016). They have to do this with less funding per student, despite higher building requirements and regulations and a significant amount of backlog maintenance.

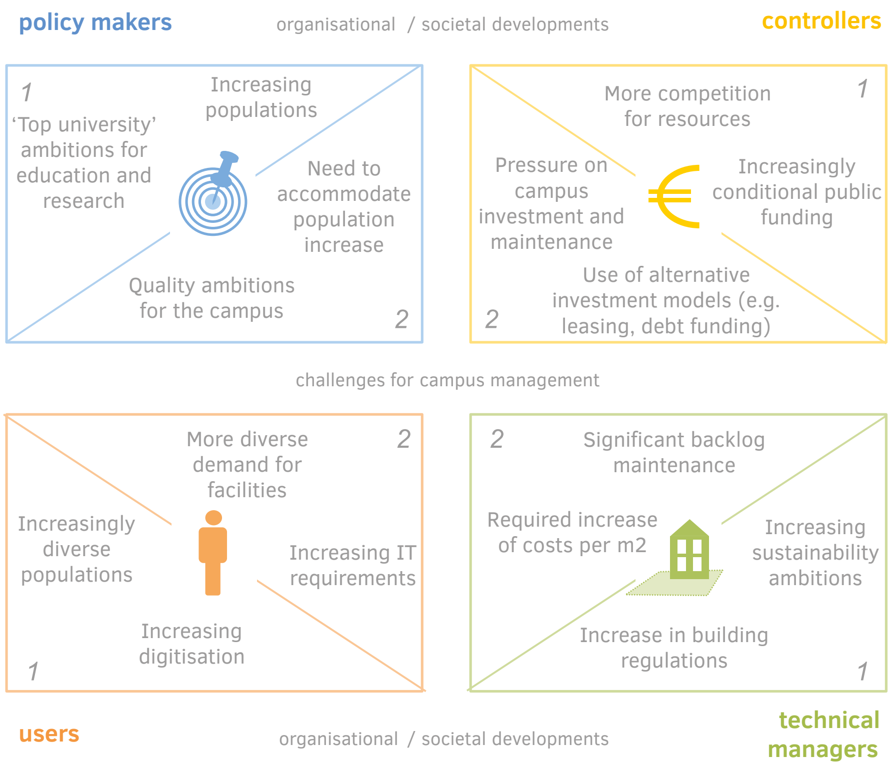

FIG. 1.5 (1) organisational / societal developments and (2) their effect on campus management (based on Den Heijer (2011)).

5 Note that the colours in Figure 1.2 and 1.3 correspond to those used in this figure. The underlying framework for these figures is explained in chapter 2.

1.2 Problem statement and proposed solution

Problem statement

The continuously increasing student population and increasing pressure on campus have caused Dutch universities to increase the density on campus. A paradox occurs in this situation: although users increasingly indicate a lack of space, the evidence collected by campus managers suggests that there is enough space available on campus. This is caused by a lack of good information on the space use at the university. In order to remove this paradox, and use the existing spaces as effectively and efficiently as possible, both end-users and campus managers require better information on the availability and use of space.

Proposed solution

In this dissertation, smart campus tools are seen as a solution to the aforementioned problem. SCTs can measure space use real-time through the use of sensors. These data can be translated to real-time information on the availability of spaces on the current campus in order to help students and employees use those spaces more effectively and efficiently. By collecting data over longer periods of time and analysing those data, campus managers can be supported with more detailed and accurate management information to make decisions about the future campus.

1.3 Aims and objectives, research questions, hypotheses

Based on the problem statement and proposed solution the following aims and objectives, research questions and hypotheses have been formulated.

Aims and objectives

The aim of this research is to support campus managers of (Dutch) universities in the decision-making on SCTs.

The objectives of the research are as follows:

- To provide universities with knowledge and references on SCTs in use at universities and other organisations and guidance on how to use them.
- To provide methods and instruments to help campus management organisations implement SCTs effectively.

Research questions

The main research question is:

How can smart campus tools optimally contribute to the match between demand for and supply of space, both on the current campus and on the future campus?

In order to answer the main research question, the following questions need to be answered:

- **RQ1** Which theories are relevant to implementing smart campus tools at university campuses? (Chapter 2)
- **RQ2** How are these theories applied to research smart campus tools? (Chapter 3)
- **RQ3** What is the space use of education spaces and study places at TU Delft, and how does it inform campus decision-making? (Chapter 4)

- **RQ4** What is the demand for smart campus tools of Dutch universities and what smart campus tools are available? (Chapter 5)

- **RQ5** What smart campus tools are being used by international universities and organisations and how do they compare to the use of smart campus tools in the Netherlands? (Chapter 6)

- **RQ6** How can IoT technologies be used to effectively support (strategic) decision making in university campus management? (Chapter 7)

- **RQ7** How can the information demands of campus management be matched to the capabilities of IoT applications? (Chapter 8)

Assumptions

The main research question contains two assumptions:

- SCTs add value to the university campus and enable universities to simultaneously support increasing user demands (including health and safety) and increase their resource efficiency.

- A review of the required management information and its use in decision making processes enables SCTs to optimally contribute to the match between demand and supply in real estate.

1.4 Relevance

Practical / societal relevance

The knowledge generated in this PhD dissertation is expected to support the implementation of SCTs (see Aims and Objectives) at universities. Also, a large number of findings is expected to be applicable to other real estate portfolios, as the towel problem is not limited to university campuses. However, some solutions may work better at the university than in other contexts, because the university has various user groups, different space types, and a very dynamic use of those space types by the various user groups.

Once implemented, SCTs will benefit the university's users, its financial position, and its energy performance. First, the research problem shows that campus users experience increasing problems with finding available spaces to learn, work, study and meet. The primary objective of a campus is that it provides its users with the space to do these activities. This is not just a question of providing enough spaces, as users have different needs. By offering information on space characteristics to match user needs to suitable spaces, SCTs will increase the effective use of spaces.

Next, SCTs will support more efficient use of the campus. As a result, campus management will require less capital investment and lower operating costs per user for the university with increased satisfaction. This is relevant for universities, as they require public funding to invest and operate their campus, and resources not spent on the campus can be directed towards investment in education and research. In addition, this research provides input for a discussion on what improvements are possible in terms of space use and to what extent it can be improved.

Finally, the implementation of SCTs will result in improved energy performance, and is thus relevant from an energy efficiency perspective. In the U.S., Buildings consume around 40 percent of the country's energy (U.S. Green Building Council, 2016). Using existing buildings more efficiently is a first step towards reducing the carbon footprint of the built environment. Next, the energy consumption can be further reduced by using the sensors from SCTs to control building services only when spaces are occupied.

Scientific relevance

The use of SCTs, or even manual frequency and occupancy measurements, is hardly studied from a CREM perspective. Although space utilisation studies have a strategic role in campus planning (Space Management Group, 2006b), there are only very few studies which document space utilisation studies, let alone detail there use in decision-making processes (see chapter 4). Even though Den Heijer (2011) already identified frequency and occupancy rates as a blind spot in campus managers' management information, not much attention has been given to the matter in the past ten years – despite the seemingly increasing importance of effective and efficient space use on campus.

With regards to SCTs, there is a substantial body of research that describes the development of technologies to position users, determine space use, etc. However, this is not well connected to CREM (see chapter 7): existing research focuses mostly on determining the performance of the system that is developed, rather than using the system to determine the performance of the environment. In addition, it is not apparent from research how this information is, could or should be used in decision-making processes. Therefore, research documenting existing SCTs and researching the connection of SCTs to decision-making processes is a substantial addition to the field of CREM.

Additionally, the societal relevance of this topic influences its scientific relevance. Historically, the field of Corporate Real Estate Management (CREM) is strongly rooted in practice – this is fairly self-evident as it studies how professionals manage corporate real estate portfolios. Therefore, if a topic is relevant to a large group of practitioners, it automatically becomes relevant to study for academics in CRE. This is also the case with SCTs: the topic of SCTs has been defined together with CRE professionals, which has resulted in the initial research project on SCTs.

1.5 Research outline

This final section presents the overall outline of the research. A high-level overview is given of how the research is designed, structured and what strategies are used to answer the research questions.

Scientific position

Prior to making a research design it is important to determine the perspective or ‘scientific position’ in scientific research. Any researcher’s choice for a research design is necessarily framed from the researcher’s own assumptions about the nature of reality (Groat & Wang, 2002, p. 21); this set of assumptions is referred to as system of inquiry or paradigm. The system of inquiry used in this research is termed ‘naturalistic’ by Groat and Wang (2002), alternatively described as qualitative, interpretive and/or constructivist. The ontological premise of naturalists is that there are multiple socially constructed realities; the corresponding epistemological position is that it is neither possible nor necessarily desirable to establish a value-free objectivity through research. This opposes the postpositivist paradigm, which is based on the premise of one reality that needs to be observed in an objective way. By contrast, naturalistic researchers recognize the value and reality of interactive dynamics between the inquirer and the people or setting being researched (Groat & Wang, 2002, p. 33).

In this research the choice for a naturalistic paradigm is not so much based on my own assumptions about the nature of reality – as Groat and Wang suggest – but rather a result of the subject area and its maturity. Edmondson and McManus (2007, p. 1155) introduce this as the methodological fit: “the internal consistency among elements of a research project” – i.e. research question, prior work, research design, and contribution to literature. They suggest that the research design follows the maturity of the theory and research in a field, as displayed in Figure 1.6. When a field is nascent, mostly qualitative research strategies are adopted to explore phenomena. As research develops further, a mix of methods i.e. a hybrid strategy is appropriate as its outcomes can be both preliminary testing of hypotheses as well as proposing new theoretical constructs. Finally, mature theory requires precise quantitative research designs to test previously matured theories. (Edmondson & McManus, 2007)

The research topic of this PhD dissertation is positioned within the methodological fit framework (Figure 1.6). As further chapters will show, this research combines different bodies of literature in order to propose new constructs – this is a typical characteristic of intermediate theory research (Edmondson & McManus, 2007). However, those bodies of literature are relatively new research fields. In addition, this research relies mostly on qualitative data collection and qualitative research strategies – therefore it is positioned in between nascent and intermediate theory on the x-axis of the framework.

The position on the y-axis of the framework – in between hybrid and qualitative data collection – requires some further explanation. The data collection in this research collects mostly qualitative data, and to a lesser extent quantitative data. Examples of qualitative data are explanations of the objectives of SCTs or how they were initiated, or descriptions of steps of decision-making processes at the university. Examples of quantitative data are the frequency and occupancy rates of the university's education spaces, or the scale on which SCTs are implemented (in m^2). Though (simple) quantitative analysis is used e.g. to determine the average frequency rate or to determine the prevalent objectives of SCTs, such methods are applied within qualitative research strategies. Within these strategies, the objectives are exploring and understanding e.g. how space utilisation data is used in decision making, what the demand for SCTs are, and which SCTs are in use. Later, the research moves towards design research. Here, the data collection serves as input for the design of new constructs or models, or to test and refine them.

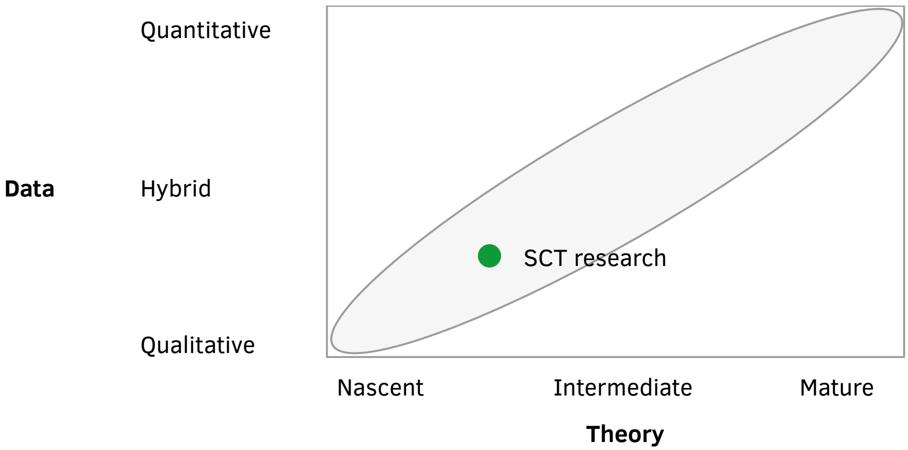

FIG. 1.6 Position of the smart campus tools (SCT) research in the methodological fit framework of Edmondson and McManus (2007).

The naturalistic paradigm fits this stage of methodological fit as it acknowledges a dynamic relationship between the researcher, the practice of campus management and the understanding of SCTs, and allows for the research process to be subject to new insights. However, the choice for a naturalistic paradigm does not mean I oppose the use of a (post)positivist paradigm. In fact, a premise of this research is that SCTs will support campus managers through quantitative data collection and analysis. As technological development and its implementation in the real world continues, so increases the possibility to further mature the existing theories in the field of Corporate Real Estate Management through precise quantitative testing. Hopefully, this research will provide constructs that may underpin such future research.

Research design

This PhD research started out as a one-year research project in assignment of 14 campus managers of Dutch universities, with the objective of exploring the (possible) use of SCTs at universities. Over time, the research gradually expanded to take on its final form as reported in this dissertation. The dissertation consists out of three parts: the theoretical framework, the main body, and the synthesis. Each part consists out of chapters (e.g. chapter 2), sections (2.1), and subsections (2.1.1). The research design, which also serves as a reader's guide throughout the dissertation, is displayed in Figure 1.7.

First, the theoretical framework discusses all the required input for doing this research. It contains the background of the research and the research outline as presented in this chapter. Chapter 2 continues with an overview of the relevant theories and instruments for studying SCTs. Finally, chapter 3 discusses how the different parts of chapter 2 are combined to study SCTs in this research.

Second, the main body discusses the research itself: the data collection, analysis and results. The main body consists out of five chapters:

- Chapter 4 reports on the results of space utilisation studies conducted at TU Delft and their use in decision making processes at the university. The data in this chapter are collected through a survey of space use and document analysis underpinning the use of the data in decision making. Its output provides evidence to illustrate the problem statement, and underpins the potential use of SCTs in campus decision-making.

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- Chapter 5 and 6 report an exploration of the SCTs that are used by universities and other organisations, what demands they have and how these may change in the future. The objective of this part of the research is to identify different types of SCTs and their properties, as well as future demands universities have regarding these tools. Chapter 6 builds on the results of chapter 5, by applying an improved, more systematic data collection, and including more cases with a different context than the Dutch university campus.

  The data in these chapters is collected primarily through interviews with campus managers, collecting data on their demands and understanding SCTs from their perspectives. The output of these chapters consists of multiple case studies (see also Appendix 2 and 3) and a cross-case analysis.

- Chapter 7 and 8 research how SCTs support campus managers in making decisions about the future campus. First, chapter 7 reports how universities can use the information from SCTs in decision making processes. Chapter 8 builds further on chapter 7 by zooming in on the point where SCTs deliver information, i.e. dashboards. The design of these dashboards is used to help universities define their information demands. Dashboard design becomes more necessary if an organisation decides to implement SCTs: because SCTs will lead to an increase in available information, dashboard design can help to determine which information is necessary, and the resulting dashboards can provide effective overviews of the most important information.

  A mixed-methods approach is used in these chapters, using interviews to collect data on the universities' decision-making processes and then using design research for the matching of information needs and for dashboards. The output of these chapters consists of guidelines for the design of SCTs relating to the decision making processes, the use of information in these processes, and the delivery of the information in dashboards.

  Finally, the Synthesis discusses the outcomes of this PhD dissertation. Chapter 9 relates the contents of the main body to chapter 2 and 3 in order to answer the research questions and provide recommendations for future research. Additionally, chapter 10 discusses the impact of the Corona crisis on the contents of this PhD dissertation.

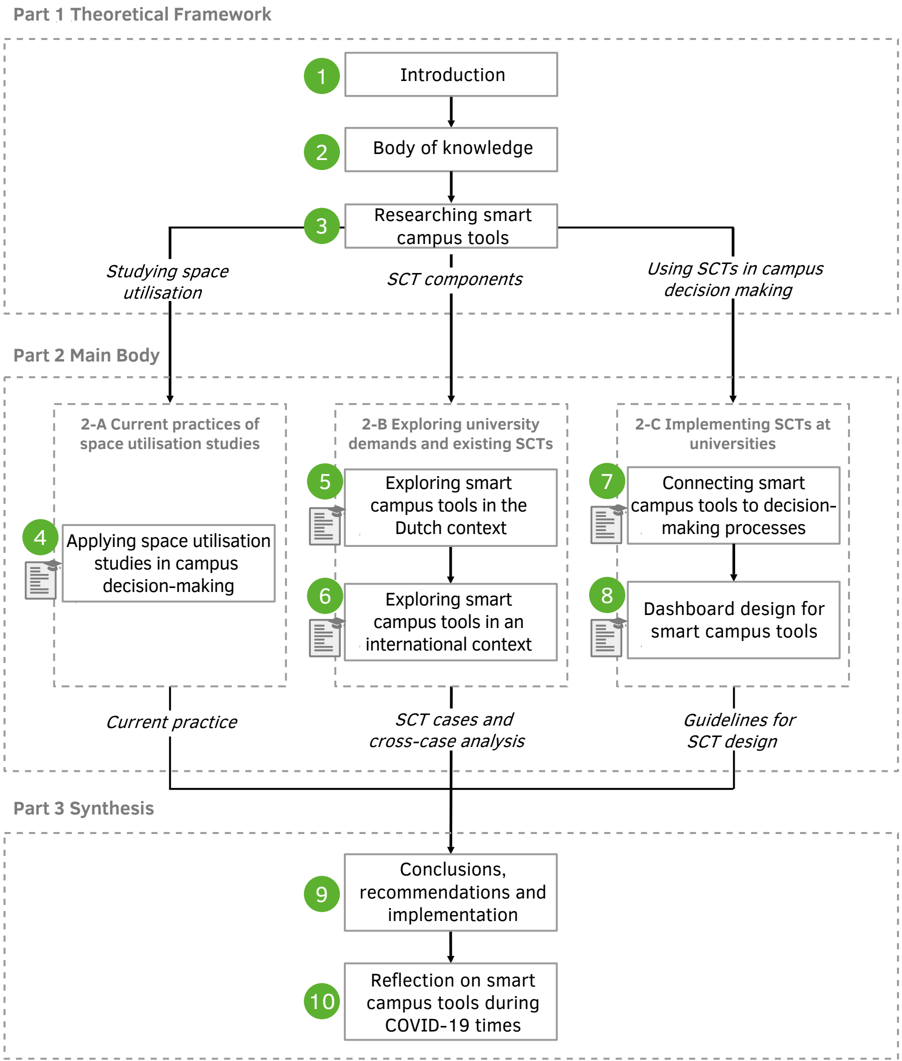

FIG. 1.7 Research design, showing the structure of this dissertation: from theoretical framework (input), through the main body (throughput) to the synthesis (output). Chapters published as papers are indicated by icons.

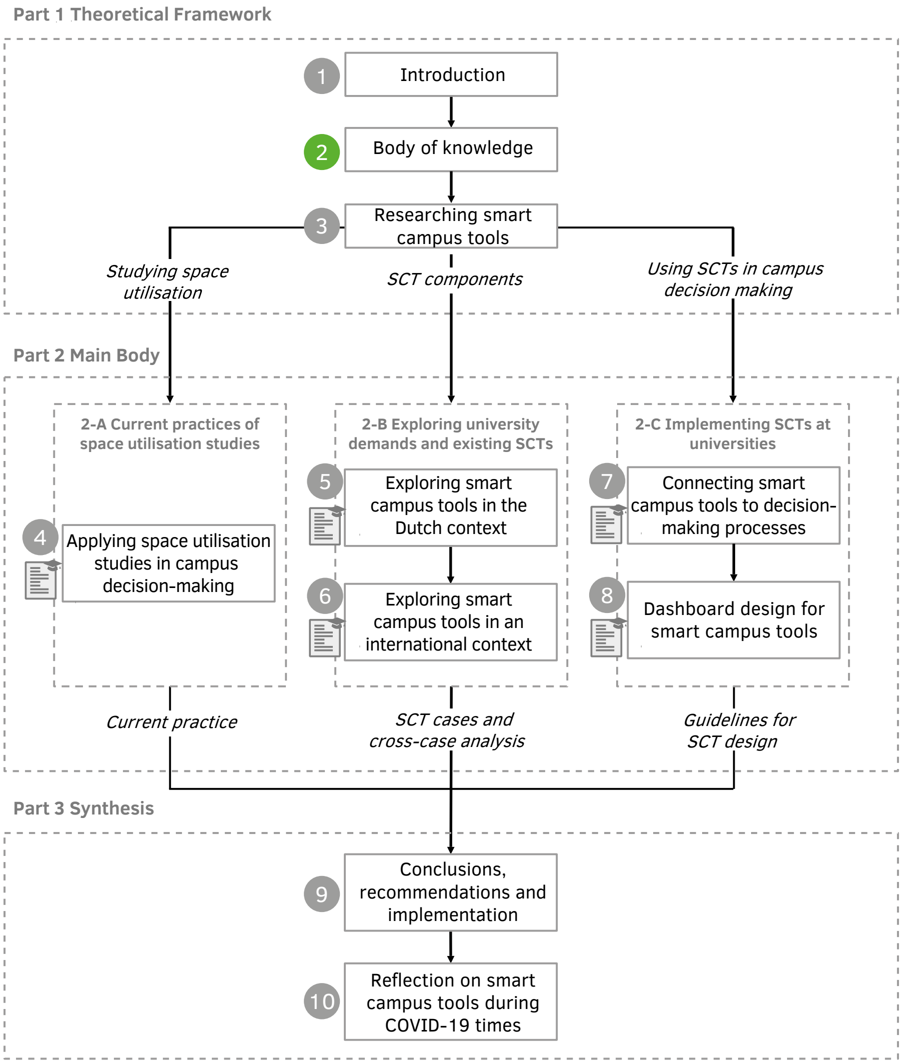

FIG. 2.1 Position of Chapter 2 in this research.

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2 Body of knowledge

This chapter describes input from previous research as the scientific foundation of this PhD dissertation. The following research question will be answered:

RQ1: Which theories are relevant to implementing smart campus tools at university campuses?

To answer this research question, three separate sections each elaborate on a part of the research question: see Figure 2.2. Therefore, the research question is first translated into a conceptual model. The conceptual model displays the relationship between the concepts that are studied in the research (within the context outlined in chapter 1):

- the objective: improving the match between demand and supply;
- the means to achieve the objective: SCTs;
- the use of the means to achieve the objective: how to enable its optimal contribution.

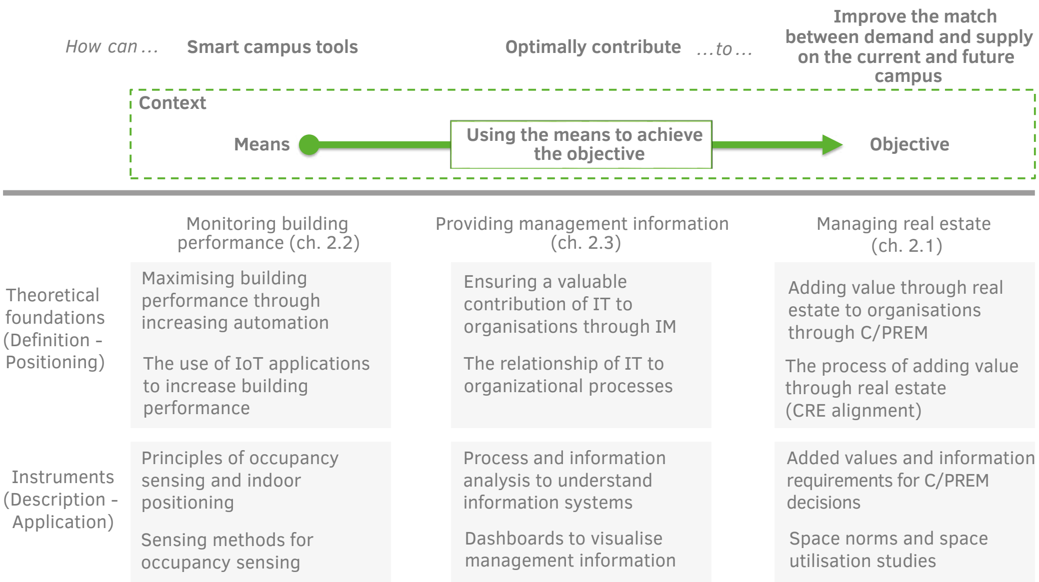

FIG. 2.2 Contents of this chapter related to the conceptual model.

Each of these concepts is discussed in its own section (2.1, 2.2, 2.3). Each of these sections is organised in a similar way. The first two subsections (e.g. 2.1.1, 2.1.2) of each section discuss the theoretical foundations of each component. The objective of these subsections is to provide definitions and present the ongoing development in various fields, which allows for positioning of the results of this research in part III. Then, the second two subsections (e.g. 2.1.3, 2.1.4) of each section discuss instruments which are relevant for the purpose of this research. Here, the focus is on the description of these instruments; further detail is provided in chapter 3 in order to apply them. Each section is summarised in a final subsection.

2.1 Managing real estate

The first body of knowledge relevant to this research is the management of real estate, specifically at university campuses. This PhD research is part of the research programme of Management in the Built Environment (MBE) and is conducted in the chair of Public Real Estate. The application of SCTs on university campuses is for the benefit of its users and managers. The literature in Real Estate Management first introduces the field and its objectives (subsection 2.1.1), followed by the management processes to achieve the objectives (subsection 2.1.2). Then, it specifies the information requirements for decision making (subsection 2.1.3), and the use of space utilisation measurements (subsection 2.1.4). This section (apart from subsection 2.1.4) draws heavily on prior research within MBE, particularly De Jonge et al. (2009) and Den Heijer (2011).

2.1.1 Real Estate Management

The basis of Real Estate Management is the presumed added value of real estate on the performance of a society, organisation or individual (Den Heijer, 2011, p. 91). Real estate, i.e. portfolios, buildings, spaces are inputs, which through a process – its use and management – adds value (throughput) to the performance (output) of societies, organisations and/or individuals (see Figure 2.3). The objective of real estate management is to maximise the added value of real estate to performance. However, there are different specialisations with different notions of added value (distinguished in De Jonge et al. (2009)):

- In portfolio management, or real estate from an investor's point of view, management focuses on adding financial value.
- Corporate real estate management (CREM), real estate management by owner-occupiers of real estate, is defined as "the management of a corporation's real estate portfolio by aligning the portfolio and services to the needs of the core business (processes), in order to obtain maximum added value for the business and to contribute optimally to the overall performance of the corporation" Krumm, Dewulf, and De Jonge (2000, p. 32). This definition reflects a broader view on performance as being not only financial, but a wider range of goals.

- In Public Real Estate Management (PREM), performance is elaborated further: PREM is “the management of a government’s real estate portfolio by aligning the portfolio and services to (1) the needs of the users, (2) the financial policy of the treasury, and (3) the political goals that the government wants to achieve.” (Van der Schaaf, 2002, p. 6).

For university campuses, both CREM and PREM theories apply (Den Heijer, 2011).

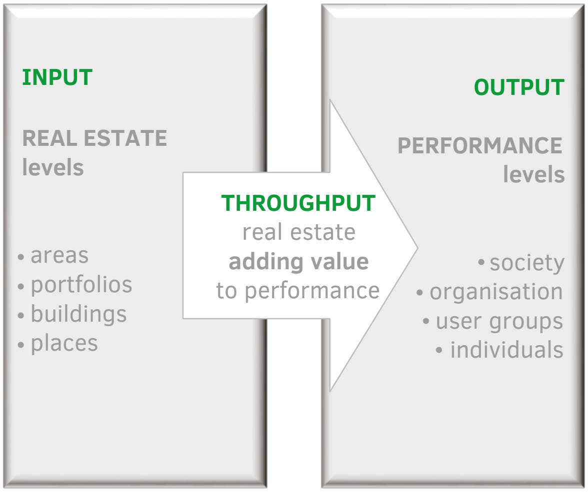

FIG. 2.3 Real estate adding value to the performance of an organisation (Den Heijer, 2011).

Over the years, CREM and PREM have changed from monitoring the technical condition of buildings and reducing costs to effectively supporting primary processes and adding value (De Jonge et al., 2009; De Vries, 2007; Den Heijer, 2011; Joroff, Louargand, Lambert, & Becker, 1993). This development was described by Joroff et al. (1993) in five competency shifts (Figure 2.4): including a more diverse set of individual and organisational objectives over time. Additionally, CREM research (De Jonge et al., 2009; Krumm, 1999) elaborated on the management perspectives to connect to CREM, distinguishing four quarters: stakeholders either focused on the institution (demand) or real estate (supply) on the horizontal axis and focused on a strategic level or an operational level on the vertical axis. These have developed into four stakeholder perspectives to inform or involve in decision-making processes (Den Heijer, 2011): see Figure 2.5. These stakeholders are policy makers (strategic), campus users (functional), controllers (financial) and technical managers (physical).

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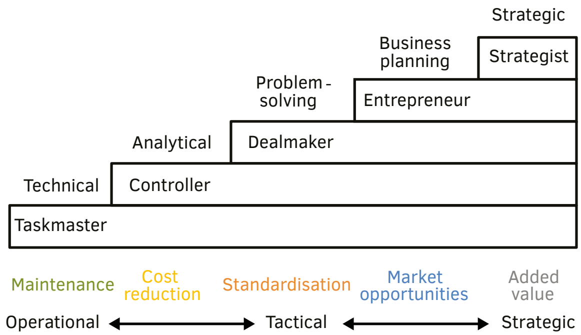

FIG. 2.4 Evolutionary stages of real estate (Joroff et al., 1993); adapted to show the connection to figure 2.5.

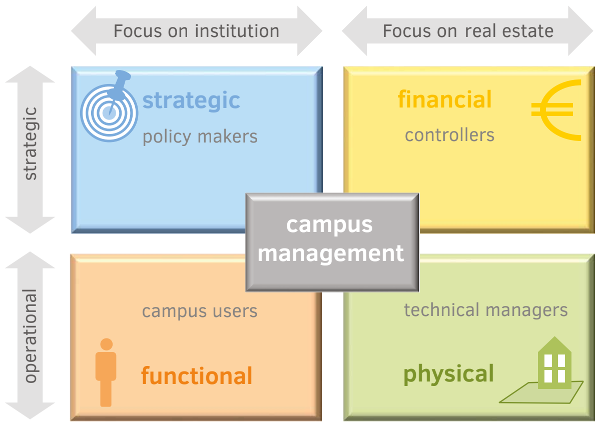

FIG. 2.5 The CREM Model, connecting CREM with four perspectives (Den Heijer, 2011).

2.1.2 Adding value through real estate management

In order to add value through real estate to organisational performance, organisations manage their real estate. In real estate management, real estate is therefore positioned as the fifth resource to manage by organisations, the other four being capital, human resources, IT and communication (Joroff et al., 1993). The alignment of the corporate real estate portfolio to the needs of the core business is positioned by some authors as the main activity of CREM – even its raison d'être (Heywood & Arkesteijn, 2017). In this PhD research, we follow Arkesteijn (2019, p. 58): "CREM will be seen as a wide range of activities that must be performed by the corporate real estate manager, while the alignment of CRE with the business will be seen as one of CREM's activities and is referred to as CRE alignment."

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In CREM literature, CRE alignment is researched by many authors. Alignment is found to be a long-standing issue in CREM theory (Heywood, 2011). Heywood and Arkesteijn (2017, 2018) provide the most recent examination of the current CRE alignment theories and models. Firstly, they found that CRE alignment was found to more complex and pluralistic than assumed by the individual models. In addition, few alignment models explicitly define alignment. In CRE alignment these complexities and pluralities must be addressed. The authors then provide a map of the modelling requirements for CRE alignment, which is based on an analysis of fourteen alignment models: see Figure 2.6. The map of the modelling requirements for CRE alignment gives insight into the various building blocks, components, relationships and variables that are needed (Arkesteijn, 2019).

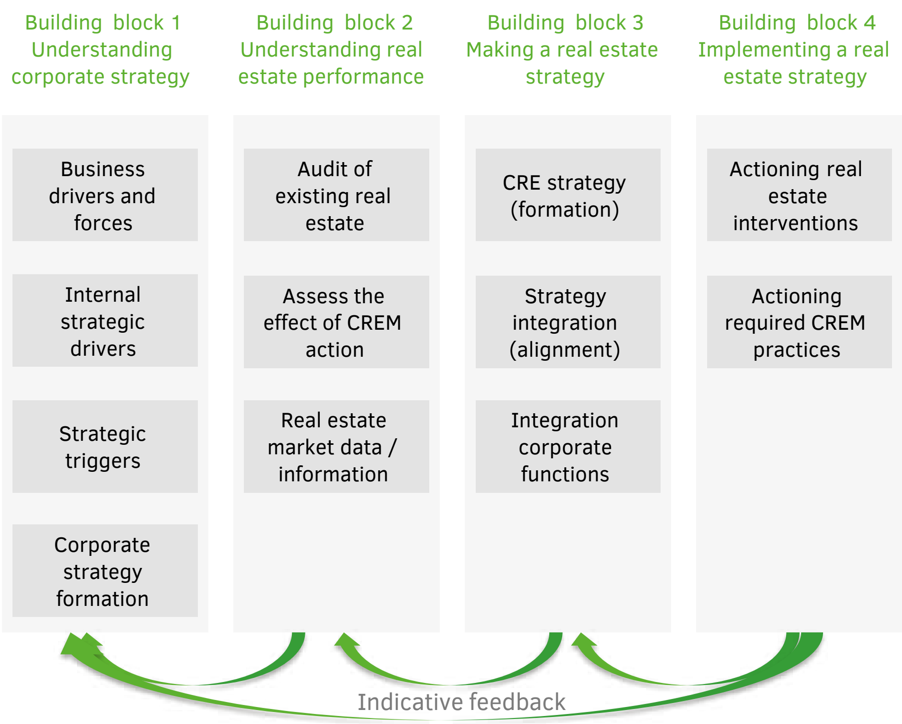

FIG. 2.6 CRE alignment building blocks and components (Arkesteijn, 2019), based on (Heywood & Arkesteijn, 2018).

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CRE alignment is displayed in a process-oriented way in the more abstract and flexible model provided by De Jonge et al. (2009): the framework for designing an accommodation strategy (Figure 2.7). Alignment is displayed as a continuous, iterative process along two axes, from demand to supply and from the present to the future. The scope of the process can be a campus, a building or the floor area used by a department; the timeframe of the decision can likewise also be different. As a graphical representation, such a flexible framework seems more useful as organisations have different strategies, over time and even in the same market (Arkesteijn, 2019).

The model has four coordination points (De Jonge et al., 2009):

1. ‘What we need’ versus ‘what we have’: determines the mismatch between current demand and current supply;

2. ‘What we need in the future’ versus ‘what we have now’: determines the mismatch between future demand and current supply;

3. ’Alternatives of what we could have’: design, evaluate and select solutions for the mismatch;

4. ‘Step-by-step plan to realize what we want to have in the future’ i.e. how to transform the current supply into the selected future supply.

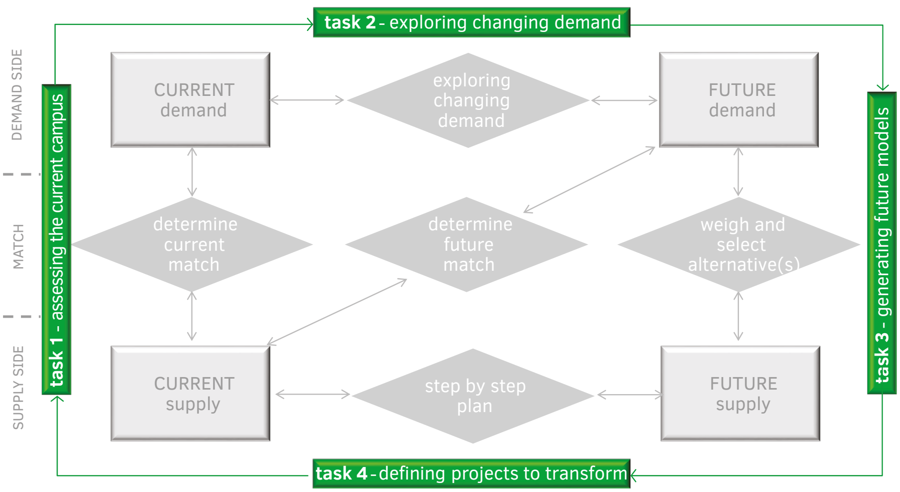

FIG. 2.7 De Jonge et al. (2009), adapted by Den Heijer (2011); Framework for Designing an Accommodation Strategy – DAS Frame.

2.1.3 Added value and management information requirements

Management information is needed to inform CRE alignment processes and to add value through real estate to institutional performance. In CREM, the ways in which real estate adds value to the performance of organisations has been studied extensively (De Jonge, 1994; De Vries, De Jonge, & Van der Voordt, 2008; Den Heijer, 2011; Lindholm & Levainen, 2006). Den Heijer (2011) merged the added values and insights from previous research and positioned them in the CREM model (see subsection 2.1.1): see Figure 2.8.

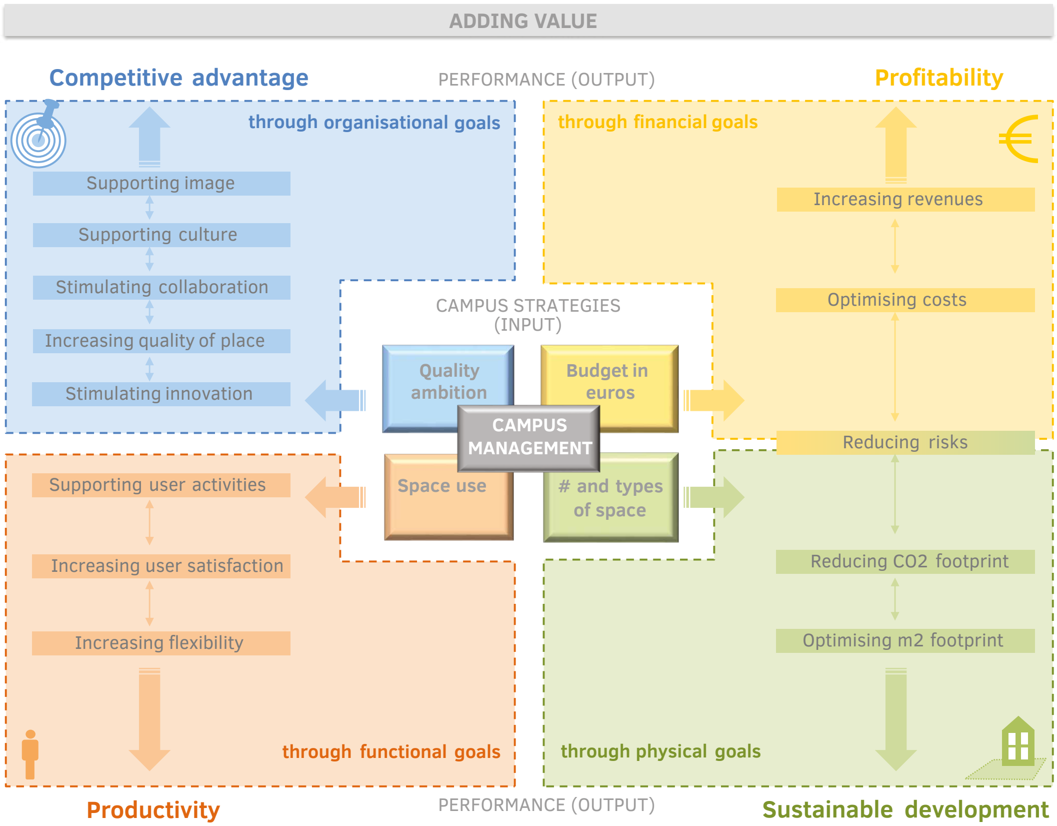

FIG. 2.8 Adding value to the university through real estate (Den Heijer, 2011).

This figure includes the following added values per perspective:

- Strategic objectives: real estate interventions can (a) support the image or (b) support the culture of the organisation to current users or external parties e.g. by designing open, transparent spaces, (c) stimulate collaboration between users e.g. by creating more meeting spaces, (d) stimulate innovation e.g. by designing spaces that allow for planned and unplanned encounters, and (e) increasing the quality of place through the design;

- Functional objectives: real estate interventions can (a) support user activities e.g. by creating functional spaces, (b) increase user satisfaction e.g. by responding to user demands, and (c) increase the flexible use of facilities, e.g. by making them accessible to more users;

- Financial objectives: real estate interventions can (a) optimise (operating) costs of the real estate portfolio e.g. by reducing floor area, (b) increase revenues e.g. by making buildings or spaces rentable or marketable, and (c) reduce risks e.g. by allowing easy adjustment of the size or characteristics of the building;

- Physical objectives: real estate interventions can (a) reduce the CO_2 footprint e.g. by investing in double glazing, and (b) optimise the m^2 footprint e.g. by accommodating more users on the same floor area.

Next, the understanding of real estate performance related these added values is relevant. Although other studies on management information requirements exist (for example Lavy, Garcia, and Dixit (2014a, 2014b), only Den Heijer (2011) is considered here as specifically developed for and applied at universities, and connected to the four stakeholder perspectives. In Den Heijer (2011) and TU Delft (2016), management information is collected on the performance of the real estate portfolios of fourteen universities, using the four stakeholder perspectives (see subsection 2.1.1) as a basis for data collection.

In Figure 2.9, Den Heijer (2011) provided an overview of the management information connected to stakeholder perspectives and their objectives. Here, the management information is presented as key performance indicators (KPIs) that describe relationships between perspectives: e.g., matching strategic goals and financial resources, or weighing financial costs against the benefits of physical resources. It also includes KPIs to measure the added value of campus decisions on multiple scale levels: from a department or faculty scale to an urban scale.

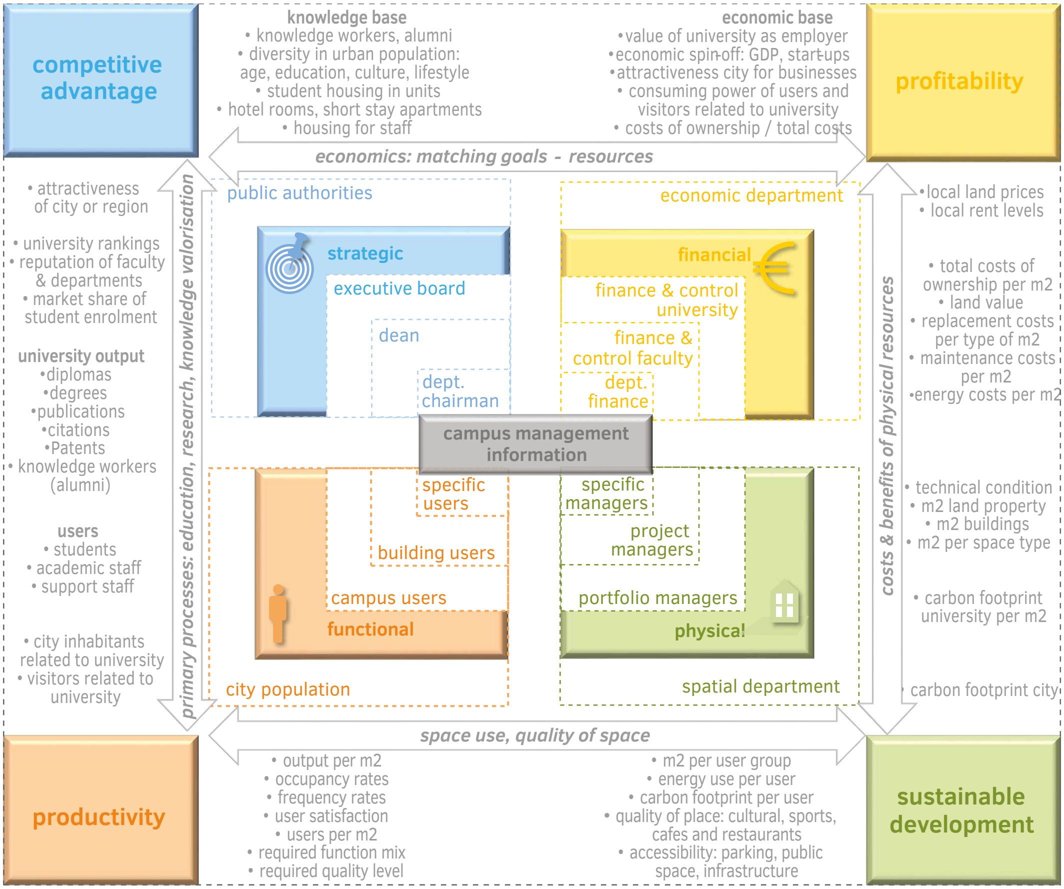

FIG. 2.9 Management information required to support campus decision making (Den Heijer 2011).

2.1.4 Space planning, space management and space utilisation studies

When making strategic choices about which functions to accommodate and/or about sharing spaces on and off campus, frequency and occupancy rates are important information to collect. Traditionally, space utilisation studies are used to collect this information. Various sources exist that document how to conduct space utilisation studies and how to use them, particularly from the United Kingdom (NAO, 1996; Space Management Group, 2006a, 2006b). As these sources are also commonly referenced by academic literature, this thesis will use them as a point of departure.

In Space Management Group (2006b), space utilisation studies are identified as having a strategic role. They provide information on how space is being used, thereby helping to inform decisions about the type and scale of facilities that are needed. Space utilisation can inform decisions on different time horizons. Beyrouthy et al. (2008) distinguish three time horizons (regarding education space): space planning to design new campuses and buildings (5-50 years), space management to remodel existing space (1-5 years) and course timetabling to allocate events to times and rooms (immediate).

In Space Management Group (2006a) the practice of space planning in the UK is elaborated. Traditionally space planning and allocation in the UK Higher education sector was done according to space norms, which are still in use in modified forms (Downie, 2005). The space norms in the UK are established by UGC (1987). Space norms in this document are expressed in a usable area in m^2 per FTE student for 20 different subject areas, e.g. humanities and engineering (Space Management Group, 2006a, p. 19). These norms were drawn up based on numerous 'coefficients':

1. total hours of on-campus contact or learning hours per week per student;
2. breakdown of those hours into different types of activity, for instance lecture theatre hours, seminar hours and laboratory hours;
3. total hours that space is available per week to be used, for instance 40 hours;
4. predicted frequency and occupancy rates for space use, that is planned utilisation;
5. space standards per workplace in teaching, learning, research and support spaces;
6. definition of discrete subject groups or disciplines;
7. staff: student ratios by discipline or subject group;
8. professorial: other academic staff ratios by subject group;
9. academic: support staff ratios by subject group.

(Space Management Group, 2006a, p. 10).

Space Management Group (2006a) reviewed these space norms, comparing the norms in place in 1991-92 to those in place in 2003-04, based on the size of the estate and the student and staff populations. The study found that in 2003-04 the sector was operating at 80 percent of the space norms set in the UGC report. This suggests that over time the coefficients that underpin the norms have changed, allowing a more efficient use of space. Space utilisation studies may help to inform decisions on the values of several of these coefficients and consequently the space norms themselves.

Next, in space management, space charging is a common method applied to maintain an efficient match between the demand for and supply of spaces is space charging. In NAO (1996, p. 36), space charging is defined as “a budgetary mechanism where a charge for space is levied on departments according to the amount of space they occupy.” Space charging addresses the match between demand for and supply of spaces in the middle-term, as space charging takes place annually. In Griffith (1999) two alternative models are described:

1. Space is allocated to each organisational unit (e.g. a faculty or department). For each organisational unit, the amount of required space is calculated, based on space norms or by assessing space needs. Each unit is either charged for the space they occupy in excess of the allocation, or given a pay-out for occupying less space.
2. Space is allocated to each cost centre (e.g. a department). Based on the total amount of space that each organisational unit occupies, the total costs of the estate are divided between them. Usually, the costs are expressed per m^2, perhaps with differences between space types.

These models are usually applied to ‘departmental spaces’ such as office spaces, meeting spaces and laboratories; centrally shared spaces such as education spaces are charged differently (Shove, 1993). According to Shove (1993), organisational units can hire these spaces using a budget allocated to them, which is determined using factors such as their number of FTEs. This approach is aligned with the first model described above, as the space need is predetermined in some way. Alternatively, organisational units are charged a percentage of the total costs of all education spaces, based on their relative use according to the timetable. This approach is in line with the second model.

Theoretically, both models give organisational units an incentive to reduce space and a disincentive to increase space. If all units make proper use of space charging, they will accommodate themselves as efficiently as the stated space norms, vacating space that the university can repurpose or dispose of. Also, the use of accommodation becomes more flexible as growth in one unit can be accommodated in space that has been vacated because of shrinkage in another unit. However, in practice, space charging does not always lead to higher efficiency. In a study among UK higher education institutions, Downie (2005) found no convincing evidence that space charging leads to increased efficiency, other than increased vacancy levels. Similarly, Shove (1993) suggests that the effects of space charging are unpredictable. In space charging, space utilisation studies can help organisational units to determine if they are occupying the appropriate amount of space, or if they need to make adjustments.

One of the earliest publications on space management in higher education is the Good practice guide by NAO (1996), often referred to by later publications. The publication states that in order to effectively manage space an organisation needs good information, which comes from estate management information systems (EMIS) and space utilisation surveys. The NAO publication is often referred to for its definition of space utilisation:

(% frequency x % occupancy) / 100 = space utilisation rate

The *frequency rate* is the number of hours a room is in use as a proportion of total availability (the timetabled week).
The *occupancy rate* is the average group size as a proportion of total capacity for the hours the room is in use.

Space Management Group (2006b, p. 6) adds to this definition the notion that "utilisation may be calculated as planned utilisation based on assumptions about how space will be used, for instance using data from timetables or assumptions about projected levels of use in a new building. Alternatively, it can be a measure of how space is actually being used, based on observation."

2.1.5 Summary

In this section the theories, processes and instruments in real estate management needed to researching SCTs have been studied. The most important insights are summarised below.

On Real Estate Management (2.1.1)

- Adding value to organisational performance is the basis of corporate and public real estate management (CREM / PREM), which also applies to the management of the university campus;
- Campus management can add value to strategic, functional, financial and physical stakeholder perspectives.

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On CRE alignment (2.1.2)

- CRE alignment is one of the (most important) activities within CREM;
- CRE alignment is conceptualised in four building blocks, each of which has several components. CRE alignment is a continuous, iterative process with four coordination points, matching demand for and supply in real estate now and in the future.

On Added value and management information requirements (2.1.3)

- The way in which CREM / PREM add value through real estate is specified in twelve added values, which are connected to the four stakeholder perspectives;
- Management information connected to the added values of campus management is required to inform and steer campus development.

On Space planning, space management and space utilisation studies (2.1.4)

- Universities use space norms to plan and allocate space, which are based on numerous coefficients. Space norms determine space use and are in turn informed by it through feedback;
- Some universities use space charging to incentivise faculties or departments to make efficient use of their spaces. However, its effects are unpredictable;
- Space utilisation studies measure frequency and occupancy rates, which can reflect either the scheduled use or the actual use.

In this research, SCTs are applied in the context of campus management. Campus managers strive to add value to the university campus through the process of CRE alignment. To do so, they require management information. Space use – frequency and occupancy rates – is a component of the required management information. Traditionally space use data is collected through space utilisation studies, but in this research the use of SCTs is proposed for that purpose. The next section will illustrate how technology can be used to collect space use data, understood through the wider development of increasing automation in buildings.

2.2 Monitoring building performance

The second body of knowledge relevant to this research is termed ‘Monitoring building performance’. This body of knowledge combines the knowledge and insights from various scientific domains that address the application of information technology (IT) to buildings. The application of SCTs on university campuses requires the use and interconnection of multiple IT components. The literature in this section provides grounding for the use of IT in buildings by introducing the field of building automation and its objectives (2.2.1), followed by a discussion of how these objectives are achieved, i.e. the Internet of Things and Smart campus (2.2.2). Then, it specifies how space use is measured real-time (2.2.3), and which methods are available to do so (2.2.4).

2.2.1 Building automation

A starting point for the application of IT to buildings is the field of building automation. Building automation is concerned with the control of building services (Kastner et al., 2005, p. 1179). Building automation is thus strongly linked to the use of control systems, which are based on control theory (Kalman, 1960). Fundamentally, there are two types of control systems: open-loop and closed-loop control systems. Both types are used in building automation. To illustrate the difference, an example of a closed-loop control system is given in Figure 2.10. In this example, a sensor measures the state of a variable (in this case temperature), which is compared to a reference value. The control takes the difference between these values to change the input to the system, i.e. which action to take. Through actuators the system sets the action in motion; it continues its action until the control tells it otherwise. In this system, the control acts based on the same variable as the output of the system (temperature). Contrary to this, in open-loop systems, the control acts on an independent variable, for example a time schedule.

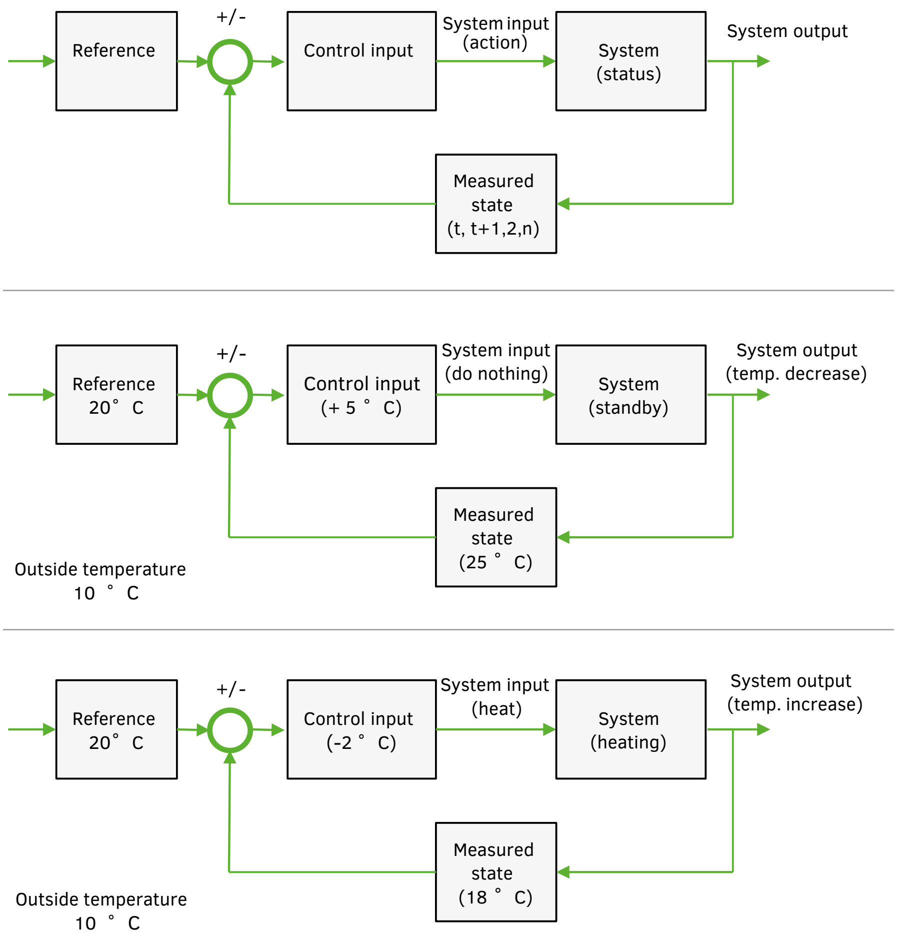

FIG. 2.10 An example of automated control for a heating system, showing the components (top), a state in t_0 (middle) and a state in t_{0+1} (bottom).

The use of control systems in building automation has evolved over time. Initially, each control system had its own name e.g. (building) energy management systems ((B)EMS), central control and management systems (CCMS) and building management systems (BMS). Later, the term integrated building management systems (IBMS) was used as various systems integrated with the BMS as base. More recently, the term building automation systems (BAS) is generally used, although the international standard uses building automation and control systems (BACS) as an umbrella term. These three stages are roughly distinguished by various literature reviews as automated buildings, intelligent buildings, and smart buildings. (Kastner et al., 2005)

The objective of building automation is to increase building performance. In the automated buildings phase, performance focused on heating, ventilation and air conditioning (HVAC) systems, (Kastner et al., 2005) in order to provide a comfortable indoor environment. Gradually building automation progressed towards intelligent buildings, and previously separate automation systems (e.g. EMS, CCMS, BMS) were integrated into the IBMS (Arkin & Paciuk, 1997). According to Wong, Li, and Wang (2005), early definitions (from the 1980s) focused on the technology aspect (i.e. the automation of systems) and not user interaction; later, this was included. Buckman, Mayfield, and Beck (2014, p. 96) write about these definitions that “as the definitions expand[ed], the term intelligence loses both meaning and focus, which is contrary to what the updated definitions were trying to achieve.” Parallel to the increase of user interaction the term ‘smart building’ is increasingly used instead of ‘intelligent buildings’. In smart buildings the drivers for increasing performance are longevity, energy and efficiency, and comfort and satisfaction (Buckman et al., 2014, p. 93).

Similar to intelligent buildings, multiple definitions exist for smart buildings. Buckman et al. (2014, p. 96) define smart buildings as “Intelligent Buildings but with additional, integrated aspects of adaptable control, enterprise and materials and construction.” They give the following examples of applications in smart buildings (Buckman et al., 2014, p. 93):

- Use real time environmental information to direct occupants to an area within their personal comfort preferences;
- Input the number of expected attendants to e.g. a meeting room booking into an enterprise system, adjusting operational system requirements to accommodate that specific number of people. This means controlling the HVAC systems in order to maximise productivity and achieve conditions which are most likely to be comfortable;
- Make suggestions tailored to occupants in e.g. hot-desking office buildings for environments that are likely to be comfortable to them, based on their previous feedback;
- Close zones of the building when there is low occupancy, based on occupancy data.

The difference between these examples and those given in automated and intelligent buildings is either the use of real-time occupancy data or the use of indoor climate data to interact with occupants. The occupant thus becomes part of the control system (see Figure 2.10); he/she is either sensed by the sensor, through which the control directs the action of the system; or he/she effectively replaces the 'system' component, as the control now suggests action to the user rather than controlling the system. Thus, as Buckman et al. (2014) write, smart buildings offer additional control strategies based on occupant interaction.

2.2.2 Internet of Things and Smart campus applications

The developments in building automation are being pushed further in large part through general advances in computing: low cost, high computing power and low power consumption together with omnipresent networks. These advances in computing are also termed the 'Internet of Things', which encompasses both the development of many technologies and their convergence. The concept of IoT was first proposed in 1999 by Kevin Ashton; however, the definition of IoT is still in development and dependent on the perspective taken (Li, Xu, & Zhao, 2015). Gubbi, Buyya, Marusic, and Palaniswami (2013, p. 1647) define IoT as:

"Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework".

The system architecture of IoT addresses the requirements set in this definition. Li et al. (2015) use the following division of layers in IoT system architecture: see Figure 2.11. Each layer has distinguished functionalities (Li et al., 2015, p. 247):

- The sensing layer: includes and integrates hardware objectives to sense the status of things. Examples of sensors are Temperature, Humidity, Pressure, Gas, Light, Sound, RFID, NFC, Ultrasonics, Flow Meter, Fluid, Cameras, etc.;
- The networking layer: is the required infrastructure to support wired or wireless connection among things. This includes gateways for protocol translation, data processing/storage/filtering, and device security, as well as network protocols for reliable, efficient, and secure transmission of data;
- The service layer: is to create and manage the services required by users or applications. Services are device-oriented: they can be seen as "a collection of data and associated behaviours to accomplish a function of feature of a device" (Li et al., 2015, p. 251);

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- The interface layer: consists of the interaction methods with users or applications e.g. in healthcare, industry, security and surveillance.

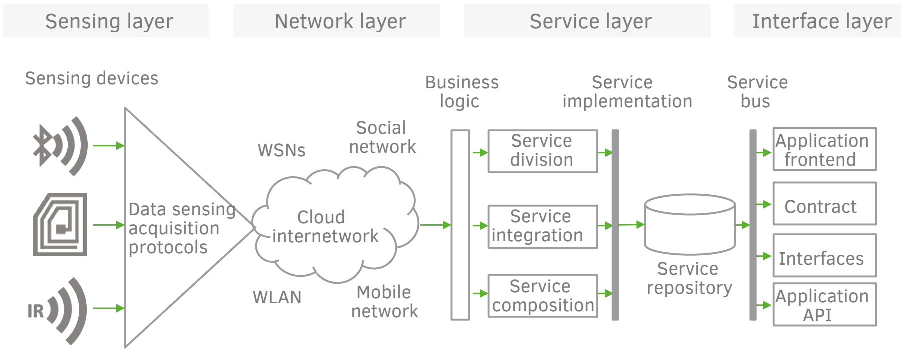

FIG. 2.11 Generic system architecture for IoT (Li et al., 2015).

Universities have taken notice of the potential of IoT applications, applying them both in single buildings and whole campuses, thereby realising the 'smart campus'. The smart campus is often compared to smart cities, as universities are in many ways similar to small cities (Mattoni et al., 2016; Vasileva et al., 2018). In a review, Alghamdi and Shetty (2016) highlight the research areas in existing smart campus research: intelligent buildings, smart energy grids, learning environments, and waste and water management, have received the most attention.

In smart campus research there is also a strong connection with tests in physical environments through case studies, living labs or demonstrators. Mattoni et al. (2016); Pagliaro et al. (2016) provide a framework for the development of a smart campus at Sapienza University in Rome. De Angelis, Ciribini, Tagliabue, and Paneroni (2015) report on energy strategies used to improve the energy performance of buildings through a test in a building of Brescia University; similarly, Gomes et al. (2017) conduct a pilot at Lisbon University. These examples reflect not only a growing academic interest in smart campuses, but also suggest a relation to a smart campus ambition of the universities themselves. Examples of universities that have formulated ambitions for smart campuses exist throughout the world (Basu, 2016; DTU, 2018; Glasgow University, 2017; IMDA, 2017; Temasek Polytechnic, 2014; University of Nottingham, 2015; University of Twente, 2016).

Just as is the case for smart buildings, no common definition of the smart campus exists (Prandi, Monti, Ceccarini, & Salomoni, 2019). The variability in approaches to the smart campus can be observed in the examples above, as well as in academic literature: for example, Y. Wang et al. (2017) distinguish different approaches to the smart campus. Gil-Garcia et al. (2015) suggest that with regard to smart cities 'smart' should not be seen as a dichotomy in terms of being smart and not being smart, but as a continuum in which managers think and make decisions to make the city into a better place. This will likely also apply to research on SCTs – although a definition can include thresholds such as the use of sensing technology, comprehensive networking infrastructure and/or the use of cloud technology, these may not be the thresholds which practitioners use to determine whether a SCT is indeed smart.

2.2.3 Occupancy sensing and indoor positioning

Enabling the interaction with building occupants in smart buildings and campuses requires IoT applications to sense building occupancy and/or to position users. These are slightly different concepts. The main difference in positioning and building occupancy is that in positioning, determining the position of the user is the main objective, whereas in building occupancy determining the use of the building, room or floor by occupants is the main objective. However, as we will see later, similar sensing methods are used to determine building occupancy and for indoor positioning. Here the following definitions are used:

Positioning: "Positioning is the general term for determination of a position of an object or a person. It is particularly used to emphasize that the target object has been moved to a new location." (Mautz, 2012, p. 25)

Building occupancy (sensing): Christensen, Melfi, Nordman, Rosenblum, and Viera (2014) define building occupancy along resolution and accuracy. The first component, i.e. resolution is determined along the dimensions time, space and occupant knowledge: see Figure 2.12. Regarding occupant knowledge, the four resolutions are:

- Occupancy: there is at least one person in a zone;
- Count: how many people are there in a zone;
- Identity: who are the people in the zone;
- Activity: what are the people doing in the zone.

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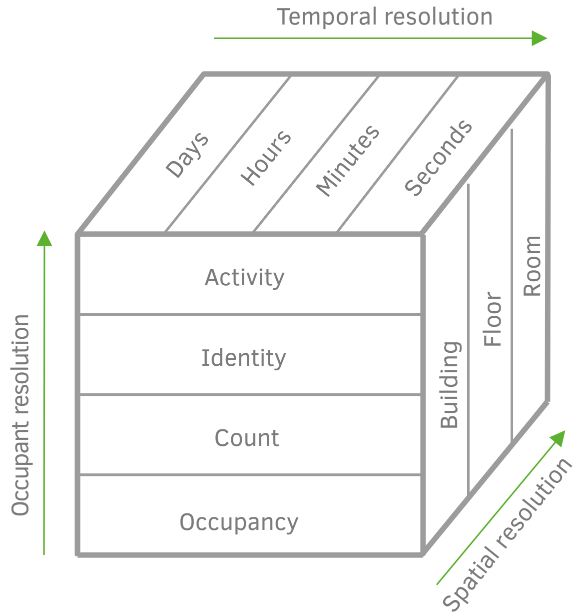


FIG. 2.12 Building occupancy resolutions (Christensen et al. 2014, p.8).

The second component of the definition by (Christensen et al., 2014, p. 8) is accuracy: “Occupancy error, or accuracy, indicates how far from the ground truth any occupancy measurement is” - ground truth being the actual occupancy at a given moment. Improving the accuracy of building occupancy is the objective of much academic research. However, Kjaergaard and Sangogboye (2016) note that researchers in the field use different methods and metrics to evaluate accuracy, which poses questions over reported evaluations and improvements.

In a practical survey of 10 sensing technologies, Serraview (2015) observes that there is not one technology that can be used to get a 100 percent accurate picture of the utilisation across a real estate portfolio. In their review of sensing approaches, Kjaergaard and Sangogboye (2016, p. 9) find a wide range of reported accuracies, both among individual systems and systems studied under different conditions and parameters. Trivedi and Badarla (2019, p. 11) write that the “sole use of any approach is unable to provide impeccable, complete, easily accessible and robust solutions for occupancy detection.” Furthermore, occupancy detection that has proven optimal for one environment may perform differently in another setting (Trivedi & Badarla, 2019; Yang, Santamouris, & Lee, 2016). Indoor positioning technologies are found to have similar issues regarding accuracy and performance (Brena et al., 2017; Mautz, 2012). A possible solution to overcome the limited accuracy of sensing methods is by combining complimentary sources

(Serraview, 2015). Trivedi and Badarla (2019) find that the combination of occupancy sensing methods with the sensing of indoor climate variables delivers a more reliable occupancy estimation.

Another relevant concept in both building occupancy sensing and indoor positioning is implicit sensing: Implicit occupancy sensing is the use of existing building infrastructure that is not originally intended for occupancy detection to measure occupancy (Christensen et al., 2014, p. 9). Conversely, explicit sensing uses new building infrastructure intended for occupancy detection.. Implicit occupancy sensing can be thought of as having three tiers:

- Tier 1 requires no modification to existing systems other than a data collection and processing point;
- Tier 2 involves the addition of software to existing infrastructure to make existing occupancy related data available;
- Tier 3 involves the addition of software and hardware to introduce new sources of occupancy data to existing systems.

Implicit occupancy sensing is of interest due to the costs associated with various sensing technologies. Shen, Newsham, and Gunay (2017) found that existing implicit occupancy sensing methods have the potential of delivering an acceptable accuracy for the purposes of building energy management against lower costs than explicit sensing methods. Furthermore, the development of the Internet of Things may lead -through a combination of sensing methods- to more accurate occupancy data that is usable for other purposes (Shen et al., 2017).

The discussion about implicit occupancy sensing shows that there is a balance between requirements such as cost and accuracy, and that this balance can differ per application. The same applies to the resolutions of building occupancy: not every application requires data collection on the activity resolution. In order to match the requirements for and capabilities of different technologies, Mautz (2012) provides a framework: see Figure 2.13. The selection of a sensing technology depends on many factors, not only requirements for costs and accuracy, but also with regards to e.g. privacy, scalability, and update rate.

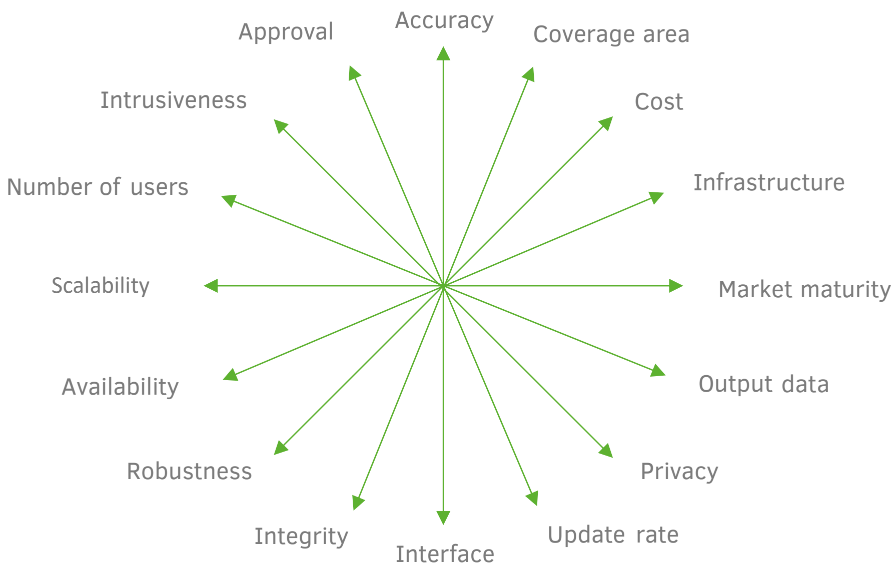


FIG. 2.13 User requirements of indoor positioning applications (Mautz 2012).

2.2.4 Sensors

Building occupancy sensing (and/or indoor positioning) may involve various sensing methods. Here, several important occupancy sensing methods are discussed. Other methods listed by Trivedi and Badarla (2019) include CO_2 sensors, ultrasonic sensors, vibration sensors, sound sensors, wearables, and smart devices for occupancy sensing. In addition, Mautz (2012) discusses the use of ultra wideband (UWB). Because these methods are almost not used for occupancy sensing in the literature or cases studied in this research, they are not discussed here.

Wi-Fi (network)

The Wi-Fi network can be used to estimate the location of a mobile device within a network (Mautz, 2012). As such it is used both for indoor positioning and occupancy sensing. The use of the Wi-Fi network is increasingly of interest: it is an implicit sensing method, and its accuracy is continuously increasing due to the increasing presence of mobile devices (smartphones, laptops, tables) and network infrastructure (access points).

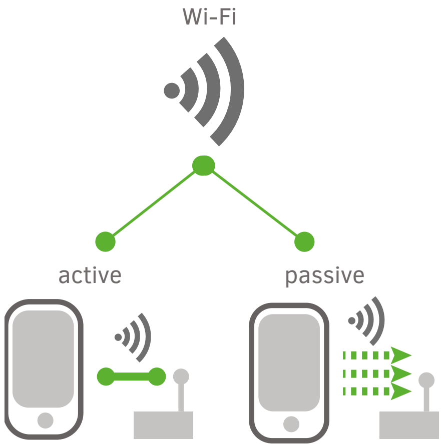


FIG. 2.14 Wi-Fi as a sensing method.

The received signal strength indicator (RSSI) value of a connection of a device to an access point is of key importance in many sensing methods using Wi-Fi. The RSSI value indicates the proximity of the user to an access point. During the presence of a user in a building, his/her device periodically searches for network connectivity or continuously communicates with the access points in a building to maintain sufficient connectivity. Therefore, a database will show many entries of the same device (represented by a unique MAC address), communicating with and connected to various access points through time and with various RSSI values.

Two common techniques, RSSI localisation and fingerprinting, make use of RSSI values to determine the location of a device (Mautz, 2012). In RSSI localisation, various RSSI values from a device to multiple access points are used to estimate the location of the device; this is called trilateration. In fingerprinting, a separate database is made of fingerprints, which are RSSI values to certain access points in various positions in a building. Then, each RSSI value can be compared to the values in this database to estimate the location. After determining the location, a conversion is needed to translate the number of devices to the number of users. Both techniques require data of the *connection attempts* of a device. However, approaches also exist in which established connections are used to determine occupancy: for example Balaji, Xu, Nwokafor, Gupta, and Agarwal (2013) associate devices with workplaces and nearby access points to determine workplace occupancy, and thus only require knowledge of when a device is connected to an access point.

The use of Wi-Fi as a method has some advantages and disadvantages (Serraview, 2015). Its main advantages are that it is economical and easily scalable. Its disadvantages are that occupancy on a room or workplace level are not achievable, and that its accuracy depends on many variables that are subject to change over time and per environment, e.g. the number of access points and their location in a building, the number of devices per person, their use of the network infrastructure, the specific layout and materials used in each building. In addition, due to the use of data from personal devices privacy is an issue that needs to be addressed in its design.

Bluetooth

Bluetooth is a wireless standard that is designed to transmit data over short distances, in the use of so-called 'personal area networks.' (Mautz, 2012). Bluetooth will be familiar to many people as the technology used for device-to-device connection, e.g. mobile phone and headphones or mobile phone and television. Similar to Wi-Fi, the use of Bluetooth has also attracted increasing interest due to the increasing presence of Bluetooth-enabled devices in indoor environments.

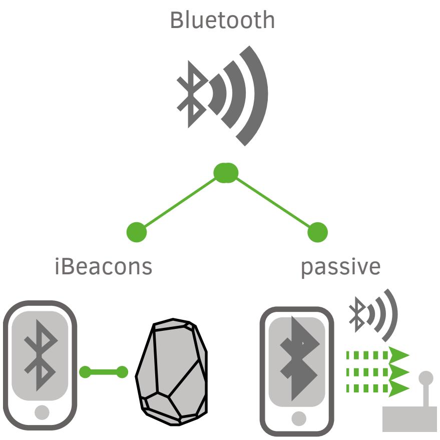


FIG. 2.15 Bluetooth as a sensing method.

A common approach to measure occupancy using Bluetooth is by installing Bluetooth emitters (such as iBeacons) in spaces, which establish connections with Bluetooth-enabled devices present in those spaces (see e.g. W. Wang, Chen, Huang, and Lu (2017)). The Bluetooth or Bluetooth Low Energy (BLE) emitters can be configured to cover a small room or zone in a building, thus allowing a more precise estimation of occupancy than Wi-Fi. However, an important condition of using Bluetooth is that the user has Bluetooth enabled on his/her device; in most cases this is automated through some mobile application.

Alternatively, methods exist to collect space use data via Bluetooth in a similar way as with Wi-Fi; i.e. making use of the periodic searches of a Bluetooth-enabled device for other devices in its environment. Here RSSI values are also used to estimate the position of a device. The extent to which users are detected depends on if their Bluetooth is active. Research shows that the percentage of total users detected by Bluetooth scanners is estimated to be between 5 to 11 percent (Daamen, Van den Heuvel, Ton, & Hoogendoorn, 2015; Versichele, Neutens, Delafontaine, & Van de Weghe, 2012).

The advantages of Bluetooth are that it can provide more accurate occupancy information than Wi-Fi. However, it requires the installation and configuration of new infrastructure, and in order to provide accurate information it requires every user to install a mobile application (Serraview, 2015). The privacy issues are similar to Wi-Fi.

RFID

RFID, which stands for Radio Frequency Identification, is a system that consists of (1) a chip with information and an antenna and (2) a reading device. Here we consider passive RFID systems, in which the chip is activated by the reading device. Passive RFID systems are inexpensive, robust and require little maintenance; however, their detection range is limited (Mautz, 2012). A familiar example of this technology is the theft prevention system used in libraries and in retail; at the entrance of the building there is a gate that detects when objects with tags cross it.

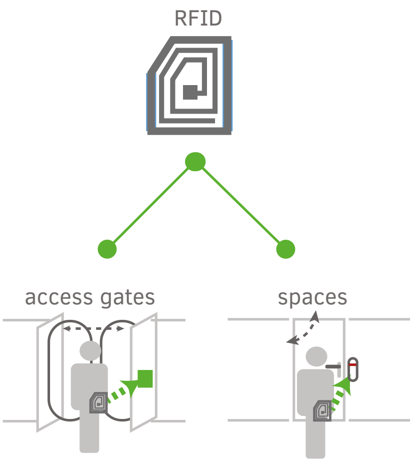


FIG. 2.16 RFID and its applications.

Two different methods that have been identified to measure space use with RFID (Serraview, 2015). The first method is using access control systems: these grant access to buildings or restricted sections through access cards. The use of access cards as a viable method depends on the system. When access gates restrict access to a person (e.g. Van den Heuvel and Hoogenraad (2014)), its accuracy is considerably higher than when this is not the case. Access gates that require access per person are also used in many corporate environments. When access per person is not required (for example in meeting rooms), tailgating prevents the accuracy of the data.

The second method of using RFID is by installing reading devices throughout building floors, or by placing them in desks (Mautz, 2012; Serraview, 2015). This allows for very accurate occupancy information but is relatively expensive to deploy.

The advantages of RFID depend on the type of deployment. On a building level, access gates that grant access per person may generate accurate building-level occupancy data at a low cost. However, the access systems used within buildings for restricted zones, elevators, meeting rooms etc. are not suitable as tailgating will occur more at these systems. Installing reading devices throughout floors or desks will enable accurate zone or workplace-level occupancy data, but at significant costs. Furthermore, in all cases the tags or access cards may be linked to identity, requiring the addressing of privacy issues in the design.

Cameras

The application of cameras to measure space use can be done in many ways. They are dependent on the deployment of cameras, the type of camera and the software installed to process the images. Camera footage is usually not saved but analysed real-time via the use of software.

Two main methods are distinguished: video cameras and infrared cameras. Video cameras are used in situations when there is sufficient light. Infrared cameras register an image based on infrared radiation (heat) of objects. Cameras can deliver data on various occupancy resolutions: presence, count, location, activity, and tracking (Trivedi & Badarla, 2019).

Trivedi and Badarla (2019) further identity the use of security cameras to deliver occupancy information – this could be similar to the use of access gates to deliver building-level occupancy information – and the indoor deployment of cameras to deliver more detailed occupancy information.

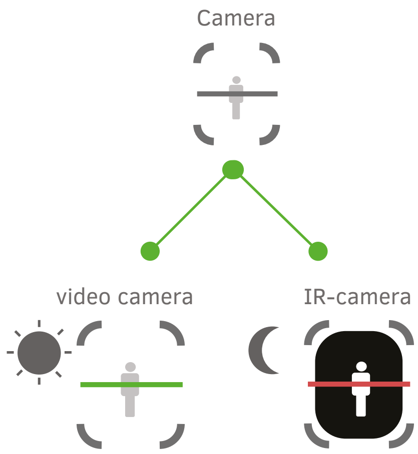


FIG. 2.17 Cameras as sensing method.

Similar to RFID, the advantages and disadvantages of cameras depend on their deployment. Potentially, cameras can deliver high-detail occupancy information; however, the cost of such a system is very high and it requires extensive image-processing (Trivedi & Badarla, 2019). In addition, the presence of cameras may give users the feeling that they are being monitored even if privacy issues are sufficiently addressed.

Infrared sensors

Infrared sensors are sensors that make use of infrared light or detect infrared radiation. The application of infrared to measure space use can be done in multiple ways. Within infrared applications active infrared (AIR) and passive infrared (PIR) can be distinguished (Mautz, 2012). AIR works with a transmitter and a receiver, in which the transmitter sends a continuous beam to the receiver. The system registers each time the beam is interrupted. This type of application can be used to measure the number of in- and outgoing users of a room (e.g. Sutjarittham, Gharakheili, Kanhere, and Sivaraman (2019)) and can deliver accurate room-level occupancy information at a relatively low cost.

In contrast to AIR systems, PIR systems sense energy variances in the environment within range of the sensor. Thus, when a user enters the environment, it is sensed. Three different methods of PIR sensors to (potentially) measure space use have been identified, but many more might exist.

1 The use of PIR sensors that are integrated in lighting systems. Here the PIR sensor triggers the lighting based on the presence of one or more persons in the area beneath the lighting. The use of these systems to measure space use is limited. Firstly, they measure frequency and not occupancy; secondly, they are prone to false positives e.g. a person passing through the space and not occupying it and to false negatives e.g. a person that is stationary for a long period and thereby not registered. In order to generate a more accurate picture of occupancy, many more sensors would need to be installed than required to control the lighting. (Serraview, 2015; Trivedi & Badarla, 2019)

2 The use of PIR sensors underneath desks. This sensor determines for each workplace when the desk is occupied or not. The accuracy of these sensors is very high – however, they are also very costly to deploy as each workplace requires a sensor (Serraview, 2015). Furthermore, it is sensitive to changes in the environment (moving of furniture) and more susceptible to accidental damage by users.

3 The use of PIR sensors to measure the space use in meeting rooms. Here the PIR sensor registers the presence of people in the meeting room, which can be compared to data from booking systems. This method is perhaps most used – it is cost efficient and helps to effectively determine if meeting rooms are used.

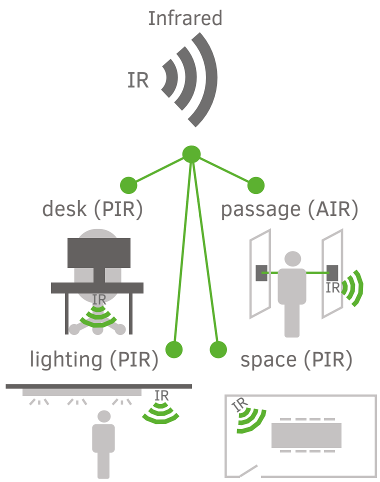


FIG. 2.18 Infrared as sensing method.

The main advantages of PIR systems are that they are relatively low-cost (except for PIR sensors underneath desks) and that the data they collect is anonymous. However, they do require the installation and configuration of new infrastructure.

Use of other devices

It is also possible to sense building occupancy through device use on a wired network (Serraview, 2015). For example, the use of workplaces can be determined by logging if the personal computer (PC) on that workplace is in use. Alternatively, if users make use of laptops, the use of the docking station on the workplace can be monitored. Of course, the accuracy of these solutions depends on the extent to which these facilities are used. For example, sensing methods that rely on the use of desktop PCs will not register occupancy if the workplace is occupied by a user who is using a laptop. Similarly, a method relying on the use of a docking station will not register occupancy if the user's laptop is not compatible with the docking station.

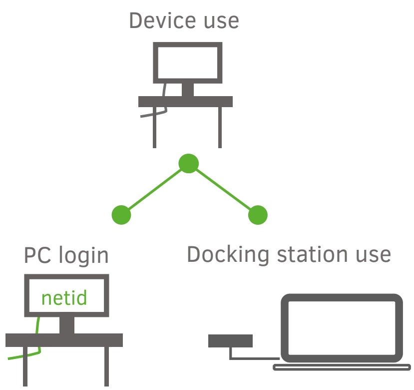


FIG. 2.19 Devices as sensing method.

The advantage of monitoring device use is that it is a very low-cost solution that may deliver building occupancy data on a workplace level. However, monitoring the device use through the network may raise privacy issues. Furthermore, the accuracy of the data may be limited and it cannot extend to all types of spaces.

Related use of sensors

In addition to occupancy sensing, the data collection revealed that sensors are also used in the built environment for other measurement purposes. A few additional purposes are discussed here:

1 Indoor climate variables are measured in order to optimise the comfort of users, or to combine with other occupancy data. Employees or students can submit their preferences and a system can (a) help them to find a place that matches

their preferences, (b) enable them to adapt a workplace to their preferences or (c) automatically adjust the environment to their set preferences. Temperature, luminance, noise and CO_2 sensors are a few relevant examples.

2 Various approaches can measure the user's vital signs in order to support them in tracking their health, productivity, etc. (Trivedi & Badarla, 2019) For example, wearables, smartphones, and laptops can inform users when they are stressed, are not moving enough, are not being productive, etc. Such insights may also be linked to workplace design but are of course very privacy sensitive.

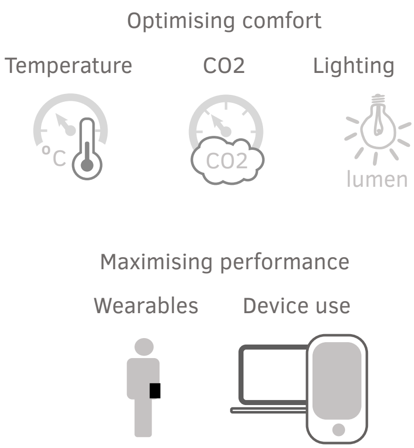


FIG. 2.20 Sensing methods linked to optimising comfort and maximising performance.

2.2.5 Summary

In this section the relevant theories, processes and instruments from various fields describing the monitoring of building performance have been studied. The most important insights are summarised below.

On building automation (2.2.1)

— The objective of building automation is to maximise performance, i.e. energy efficiency, longevity, comfort, and satisfaction. This is achieved through increasingly advanced open-loop and closed-loop control systems;

- Smart buildings offer additional control strategies based on occupant interaction, which distinguishes them from automated and intelligent buildings.

On the Internet of Things and Smart campus applications (2.2.2)

- Recent advances in computing have been termed the Internet of Things. The IoT can be divided into four layers: sensing, network, service, and interface layers;

- IoT applications have enabled the application of a 'smart campus' at universities, which is a similar concept to smart cities. For smart campuses, cities and buildings no universal definitions exist; although thresholds may be set in definitions, what constitutes as 'smart' according to practitioners may be different and develop over time.

On indoor positioning and occupancy sensing (2.2.3)

- Building occupancy is defined along resolution and accuracy. The resolutions of occupant knowledge (next to time and space) are occupancy, count, identity, and activity. Indoor positioning methods can be included in this definition;

- Improving the accuracy of sensing methods is the main objective of research – e.g. through the combination of multiple sensing methods. However, not every application requires maximum accuracy – rather, it should be seen as one of the requirements which together determine the appropriate sensing technology for a specific application.

On sensors (2.2.4)

- Different sensors can be used to sense occupancy, such as Wi-Fi, Bluetooth, RFID, Infrared, and Cameras. Each sensor has its own advantages and disadvantages;

- In addition to occupancy sensing, sensors can also be used to measure indoor climate variables or support users in monitoring their health and increasing their productivity.

In this research SCTs are positioned within the ongoing automation in buildings and the larger development of the Internet of Things. Different sensing technologies measure space use and/or position users in space. Thus, SCTs will yield newly available information once implemented. The next section will discuss how to ensure a valuable contribution of use SCTs and their information in organisations.

2.3 Providing management information

The third and final body of knowledge to be studied is ‘Providing management information’. This body of knowledge in this section provides grounding for the connection of SCTs to real estate management. First, by introducing Information Management and its objectives (2.3.1), and then by specifying where these objectives are achieved, i.e. on the level of organisational processes (2.3.2). Then, it details the use of process and information analysis to connect IT to organisational processes (2.3.3), and the use of dashboards within this connection (2.3.4). This section draws heavily on the work of Bytheway (2014), Koutamanis (2019), and Few (2006).

2.3.1 Information Management

The use of information technology to achieve organisational benefits is at the intersection of two worlds: the realm of information and information technology, and the realm of management. Bytheway (2014) refers to Lee (1999), who explored the intersection of these two worlds and underlined the difficulty of managing the place where they meet. Effective management of this intersection would make sure that “information technology makes a good and proper contribution to society at large and organisations in particular” (Lee (1999), in Bytheway (2014, p. 15)).

In the Information Management Body of Knowledge (IMBOK) framework (Bytheway, 2014) information technology, society and organisations[6] meet. It decomposes the relationship between these areas into six management segments, which each require different skills, competencies and techniques but share the common goal i.e. a valuable contribution of IT to society and organisations: see Figure 2.21. The six management segments are (Bytheway, 2014, pp. 29-31):

- Information technology describes the components that make up an information system – one can think of hardware, software, and communications, but due to the fast pace of development in IT reality is much more complicated. The pace of change requires staying up to date with the latest developments and choosing when to invest in information technology;

6 Bytheway refers to organisations as businesses in the IMBOK framework. The term organisation is chosen here because universities are better classified as such.

- Information systems describe the engineering of IT into a working system which includes the human capabilities to work with the system in order to deliver output. Nowadays, many software packages have been developed to fulfil routine information systems needs across organisations. Exceptions exist where there are unique requirements or new opportunities;

- Organisational processes and organisational information are where information systems are applied in order to deliver outcomes. The data that information systems deliver becomes useful as organisational information. Here, ideas such as business process management and business information management are relevant ideas, though relatively new;

- Organisational benefits deal with the question which benefits are achieved through any action, but here specifically with regards to the investment in information technology. Although there is a large interest in business performance management, but its relation to the benefits of information technology is not well understood;

- Organisational strategy deals with the strategies that direct the activities of organisations and how these strategies may be informed when they are implemented.

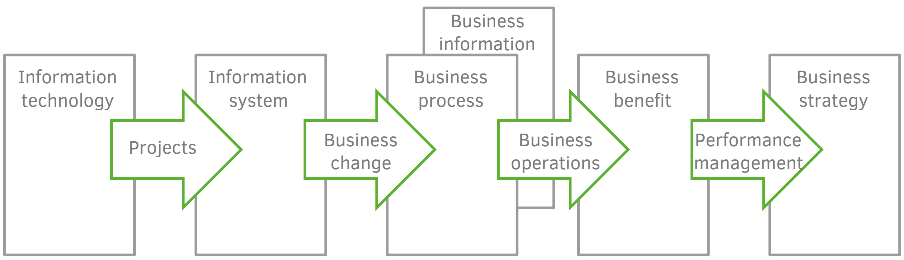


FIG. 2.21 The IMBOK framework (Bytheway, 2014).

Then, at the intersection of the segments are four information management processes that ensure the delivery of value from each segment to the next (Bytheway, 2014, pp. 32-33):

- Projects deal with the engineering of information technology into information systems, meeting the needs of business processes and information. In project management, the challenge is not only to steer on project delivery variables such as cost and time, but especially to the organisation-level outcome;

- Organisational change is the management of the change resulting in the new capabilities of an information system, which may change the way organisational processes work and the skills required of employees. Good management of organisational change is required for a successful implementation of information technology in organisations;

- Organisational operations are the use of the new organisational information in organisational processes over time to deliver organisational benefits; the organisation at work;

- Performance management deals with weighing the various organisational benefits against each other to maximise performance. Revenues, internal efficiency, customer satisfaction, and competitive advantage are all examples of benefits that must be balanced in an organisation.

In information management, the contribution of IT to organisations is split up into six interacting segments, which require four processes in order to ensure the added value of IT to organisations. Each element has their distinct activities, requirements, and skills. The connection with systems thinking is also noted by Bytheway (2014), who considers in particular its relation to business processes: he notes the view of business process management as an extension of systems thinking and its contribution to the ideas of business process redesign.

2.3.2 Organisational processes

Organisational (or business) processes and information systems are of specific interest at this point of the conceptual model. The other components of the IMBOK have already been discussed in previous (sub)sections: the information technology in section 2.2, and the organisational benefits and high-level management process in subsection 2.3.1. Here, organisational processes will be discussed in more detail.

Bytheway (2014, p. 97) defines organisational processes as:

"An organisational process is a logical envelope that coordinates and gives purpose to organisational activities; generally, whereas an activity delivers an output, a process delivers an outcome—a result that is evident to stakeholders outside the organisation as well as those within."

In this definition, Bytheway makes a distinction between higher-level processes, which consist of multiple lower-level activities:

- “An organisational process is a high-level component of a business that is comprised of a number of lower-level business activities; it delivers value to organisational stakeholders;
- A organisational activity is a low-level component of a business that makes up a part of a business process; it consumes resources and drives costs.” (Bytheway, 2014, p. 98)

When viewing alignment (subsection 2.1.2) in real estate management in the context of these definitions, alignment can be thought of as a process and its building blocks as activities (or outputs of activities). To deliver their outputs, the activities make use of information systems. As a result of new information made available through new information systems, these business processes and activities may change. It is useful to identify this change in terms of depth and scope.

There are three levels of depth of change (Bytheway, 2014, pp. 105-106):

1. Assessing current activities with regards to efficiency and time consumption. The activities that are identified to be particularly inefficient or time-consuming are explored in terms of the application of IT to them;
2. Taking a broader view of the organisation, also looking at the way activities combine into processes and their visibility to other stakeholders. Here, change can be to eliminate redundant activities, redeploy inventory and/or to share information with stakeholders. These changes are a view of what people regard as ‘business process redesign’;
3. A whole new view of the business process is taken and designed from a ‘clean sheet’. This may happen in some cases of radical change, or in case an organisation needs to find a solution to a completely new problem.

Bytheway (2014) defines the scope of change in four levels: (1) change within one organisational unit, (2) change within multiple organisational units, (3) change that requires links with external parties, and (4) change that results from being excluded from the chain of industry activity.

2.3.3 Information systems

Information systems are the place where information technology and business processes meet. Bytheway (2014, p. 47) defines information systems as follows:

“An information system is not the same as the technology upon which it is based: it is the totality of technological and human components that work together to produce the information services that are needed, for organisational purposes.”

Bytheway’s ways to classify information systems provide further understanding of what an information system is and is not (Bytheway, 2014):

- Formal or informal – there is a large range of formality in information systems, ranging from informal information systems relying on face-to-face communication and e-mail to very formal information systems such as systems that process orders or payments;
- Automated or non-automated – the extent to which processes can be automated, which relies not only on information technology but for example also on structures and protocols;
- Relation to decision-making – Bytheway distinguishes strategic decisions (long term), control decisions (daily, weekly) and operational decisions (daily, hour-by-hour);
- Value – consider a system only deployed for regulatory purposes versus a system that delivers value across multiple organisations.

Information systems can be understood through process analysis and information analysis. First, in order to identify, structure and connect information in a way that supports and anticipates the needs of a process, the process itself must be understood. The additional benefit of having a process model as background is that it helps people understand why and how information should be managed. (Koutamanis, 2019)

Process diagrams, which consist of lower-level activities towards a specific outcome, can be visualised through basic flow charts (Koutamanis, 2019). Flow charts are directed graphs, in which different kinds of nodes are connected to each other by arcs. The arcs direct the graph from start to end. Flow charts are useful because of their consistency (Koutamanis, 2019), which results from the rules that govern how they are drawn and how they relate to each other (Bytheway, 2014). Koutamanis (2019) gives the following rules:

- There is a predefined set of nodes and arcs that may be used in the graph (see Figure 2.22);

- Bidirectional arcs should be avoided and rather described as e.g. evaluation and feedback;

- Each object (activity) should appear only once in the diagram.

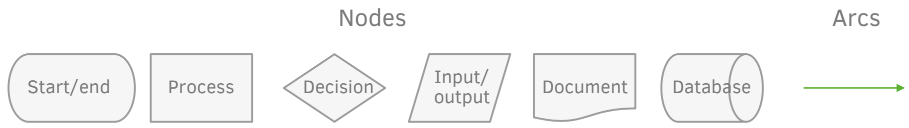


FIG. 2.22 Nodes and arcs in a flow chart.

Next, in information analysis, the process diagram is used as a foundation for an information diagram. The information diagram makes the information and its flow through the process explicit (Koutamanis, 2019). The following rules should be followed (Koutamanis, 2019):

- The diagram should make explicit what takes place in terms of input, process and output;

- The start (actor) nodes can be abstracted or replaced by the input each actor contributes to the process;

- Each node in the process diagram must be examined regarding its required inputs, and which information is produced as its output.

Information diagrams serve many potential needs. They can be used by managers to guide and control the process; and by actors to understand the scope and significance of their actions. They can be used to indicate responsibilities and actions, to clearly establish actor needs and what they must produce, and to evaluate the completeness, coherence and consistency of the output produced through the process. (Koutamanis, 2019)

2.3.4 Dashboards

Dashboards deal with the specific points within information systems where IT delivers input to organisational processes. Here, dashboards transfer the essential information to the actors involved in a particular step or activity in the process in order to deliver an outcome. Dashboards are an increasingly popular instrument in the field of performance management (Bremser & Wagner, 2013; Yigitbasioglu & Velcu, 2012). Over time, dashboards have evolved from stand-alone displays of KPIs to interactive enterprise-wide decision support systems (Yigitbasioglu & Velcu, 2012). This is cause for some confusion: some distinguish dashboards as instruments for operational decision making from scorecards as instruments for strategic decision making (Cokins, 2010), while others define a dashboard more broadly as an instrument to be tailored to a specific type of decision or objective (Eckerson, 2009; Few, 2006, p. 26). This research uses a more broad interpretation of dashboards, following Few (2006, p. 34): “A visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance”.

The main problem in the design of dashboards is that they fail to communicate effectively (Few, 2006). The causes for this problem are: poorly designed implementations that are overly focused on flashy displays rather than what clients need and widespread confusion about what dashboards actually are (Few, 2006).

To clarify what dashboards are, Few (2006) outlines the characteristics of dashboards (Table 2.1). These characteristics can be used to remove confusion in the design phase of dashboards by clarifying the objectives of the dashboards and its intended use. For example, a strategic dashboard should contain enterprise-wide data, containing data suitable to make decisions on a longer term. A quick update frequency is thus less relevant. Furthermore, it should be able to communicate which areas need attention, hence the dashboard should be static and not refer to additional data. Conversely, an analytical dashboard should enable the user to shift between views, compare data to each other, allow the data analyst to make notes, etc. Here, interactivity is of vital importance.

TABLE 2.1 Dashboard Characteristics (Few, 2006).

Variable	Values
Role	Strategic, Operational, Analytical
Type of data	Quantitative, Qualitative
Data domain	Sales, Finance, Marketing, HR, Manufacturing
Type of measures	Balanced scorecard, Six-sigma, Non performance
Span of data	Enterprise-wide, Departmental, individual
Update frequency	Monthly, weekly, daily, hourly, real-time
Interactivity	Static, Interactive
Mechanisms of display	Graphical, text, hybrid
Portal functionality	Conduit to more data, no conduit

To clarify how dashboards communicate data effectively, dashboards must support the following sequence of activities (Few, 2006):

1. Present a consolidated overview that can be quickly scanned to see what's going on at a high level and to rapidly identify any items that need attention;

2. Provide enough information when particular items demand attention to help the person viewing it determine if further investigation and potential action is required;

3. Provide the means to quickly access additional information about those items that need further investigation to determine if action is required and what action to take.

Few (2006) gives various considerations to achieve effective communication, regarding (1) the type of data that is shown and (2) how the data is visualised. The considerations with regard to data selection are displayed in Table 2.2, based on several variables listed by Few (2006). First, a choice needs to be made which information needs to be included on the dashboard in order to show an overview of the situation at hand. Next, the comparison of information based on time or other comparisons allows for the identification of which items demand attention. Visual indicators are added to rapidly identify which items those are. Finally, one may consider adding non-quantitative data to the dashboard to provide additional information.

TABLE 2.2 Dashboard data considerations, based on Few (2006).

Variable	Values	Considerations
Common dashboard information per business practices	E.g. for sales: sales volumes, revenues, profits, …	-
Dashboard information comparison in time	Year-to-date, Month-to-date, Week versus same week in the last year, etc.	Determined by the nature of the objectives supported by the dashboard
Dashboard information comparison – further enrichment.	Comparison to past point in time, comparison to norm, comparison to other business units, etc.	Text usually suffices for comparison (instead of visual); especially time series provide rich context.
Use of visual indicators to draw attention	Visual indicators that indicate when performance on a criterion is poor	Indicators need not be binary, but too much distinct states will become too complex
Non-quantitative data: Additional data on dashboard	Top 10 customers, issues to investigate, etc.	-

With regards to data visualisation, Few (2006) argues for the use of specific types of graphs over others. Traditional bar and line graphs work well for comparison of magnitudes of different values and comparison of values over time, respectively. Pie charts, doughnut charts, and 3D charts should be avoided for various reasons. For comparison of values to an objective or norm, Few (2006) proposes the use of bullet graphs over gauges and radar diagrams to fit the specific requirements of dashboards. The advantage of bullet graphs is that they take up less space and have no loss in information, clarity, or efficiency: see Figure 2.23 for an example. Here, the performance of different types of workplaces is shown with regards to the average area each of them requires. The underlying shades of grey show whether this average area falls within a poor, average or good performance range. In this case, the average for all types of workplaces falls within a good performance.

Furthermore, Few (2006) argues to limit the use of colour in dashboards as otherwise the dashboard will not point to those items that need attention as effectively. Furthermore, the use of different colours may not be suitable for colour-blind users. When using markers to highlight attention Few (2006) suggests the use of different shades of the same colour rather than different colours, such as in the example in Figure 2.23. In this example, the average cost per type of workplace is shown. The markers, shown to the right of the graph, highlight that all items require some attention based on their performance, and study places in particular because of their poor performance.

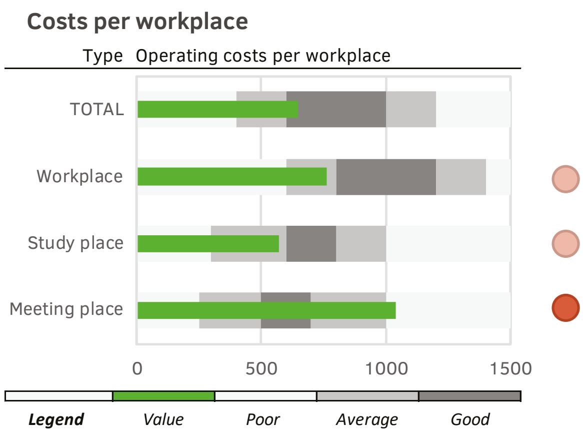


FIG. 2.23 Example of a bullet graph.

2.3.5 Summary

In this section the relevant theories, processes and instruments describing the provision of management information have been studied. The most important insights are summarised below.

On Information Management (2.3.1)

- The Information Management Body of Knowledge (IMBOK) describes six management segments: information technology, information systems, organisational processes, organisational information, organisational benefits and organisational strategy;

- Each segment in Information Management requires specific management and skills, and four processes that ensure the delivery of value from one segment to the next: Projects, business change, business operations, and performance management. Their shared objective is a valuable contribution of IT to society and organisations.

On Organisational processes (2.3.2)

- Organisational processes can be divided into higher-level processes that deliver value to the organisation, and the lower-level activities within processes that consume resources and drive costs. Activities make use of information systems;

- Changes to the organisation or changes in IT systems may necessitate changes to organisational processes; this change can be thought of in different scopes and depths.

On Information systems (2.3.3)

- Information systems consist not only of IT, but the totality of technological and human components that work together to produce the information services that are needed;

- Information systems are understood through process analysis and information analysis. These analyses identify the activities that make up a process and the flow of information through these activities, respectively.

On Dashboards (2.3.4)

- A dashboard is a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so the information can be monitored at a glance;

- To ensure effective communication of a dashboard, careful consideration must be given to (a) the alignment between the contents of the dashboard and its objective and intended use, and (b) the presentation and visualisation of data.

2.4 Conclusion

This chapter has discussed various theories, frameworks, models and instruments that together form the scientific foundation of this PhD dissertation. The body of knowledge has been divided into three interrelated fields: real estate management, building automation, and information management. The summaries of each section (2.1-2.3) provide a concise overview of the insights gained from studying literature. From the first two subsections of each section, foundations summarising the findings are derived. These are input for part II of this PhD dissertation, and will be used in part III to discuss its contribution to the existing body of knowledge.

Managing real estate:

- SCTs add value to the performance of the university through strategic, financial, functional and physical campus perspectives, as an instrument in campus management.

- SCTs support campus management organisations in their CRE alignment in specific building blocks / process steps, resulting in added value

Monitoring building performance:

- SCTs are components of smart buildings, which increase performance primarily through increased interaction with building occupants.

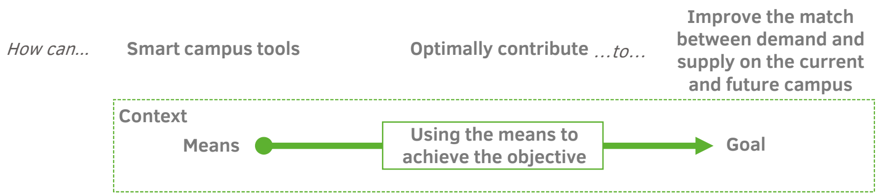
- SCTs (or the broader IoT applications) enable smart buildings, campuses and cities, where the meaning of 'smart' is not narrowly defined and continuously developing.

Providing management information:

- SCTs require Information management in order to ensure a valuable contribution of its output to campus management.

- The implementation of SCTs may lead to changes in both higher and lower-level organisational processes within the university.

In addition, each section has also described several instruments which will be used in part II of this dissertation. Chapter 3 details how these are implemented in the research. Figure 2.24 shows the position of the foundations in relation to the conceptual model.



	Monitoring building performance (ch. 2.2)	Providing management information (ch. 2.3)	Managing real estate (ch. 2.1)
Theoretical foundations (based on chapter 2)	SCTs are components of smart buildings, which increase performance primarily through increased interaction with building occupants.	SCTs require information management in order to ensure a valuable contribution of its output to campus management.	SCTs add value to the performance of the university through strategic, functional, financial and physical campus perspectives, as an instrument in campus management.
INPUT for this research; **to evaluate in Part 3**	SCTs (or the broader IoT applications) enable smart buildings, campuses and cities, where the meaning of 'smart' is not narrowly defined and continuously developing.	The implementation of SCTs may lead to changes in both higher and lower-level organisational processes within the university	SCTs support campus management organisations in their CRE alignment in specific building blocks / process steps, resulting in added value.

FIG. 2.24 Overview of the body of knowledge relevant to study the application of SCTs to university campuses.

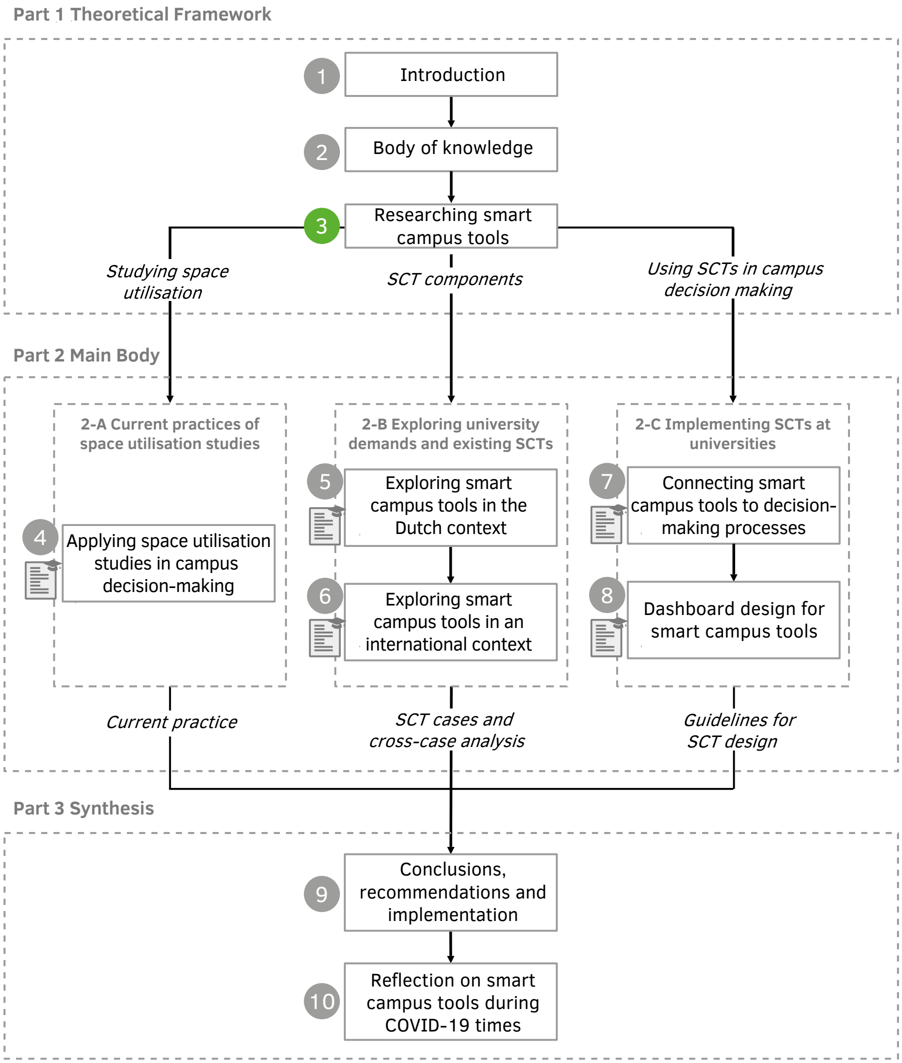


FIG. 3.1 Position of chapter 3 in this PhD dissertation.

TOC

3 Researching smart campus tools

The previous chapter gave an overview of the relevant knowledge to research the application of SCTs at university campuses. It divided the body of knowledge in three fields: real estate management, building automation, and information management, resulting in two summarizing foundations for each of them. These statements were primarily related to the more theoretical parts of the chapter.

This chapter discusses how the mostly instrumental parts of chapter 2 are combined in order to research SCTs. The research question answered in this chapter is:

RQ2: How are the theories discussed in chapter 2 applied to research smart campus tools?

The chapter contains three sections, each of which discusses a different angle through which SCTs are studied:

- Studying space utilisation (section 3.1);
- Components of SCTs (section 3.2);
- Utilizing SCTs in campus decision making (section 3.3).

Each section is used in one or two chapters in Part B of this dissertation: see Figure 3.1.

3.1 Studying space utilisation

In chapter 4, the use of space utilisation studies in decision making in real estate is studied. When positioned in the conceptual model introduced in chapter 2 (see Figure 3.2), manual frequency and occupancy data are used here rather than SCTs. While manual measurement of space utilisation is fine, automation has several advantages that are described in chapter 4. Additionally, the chapter focuses on decision making in real estate, i.e. only improving the match between demand and supply on the future campus and not on the current campus.

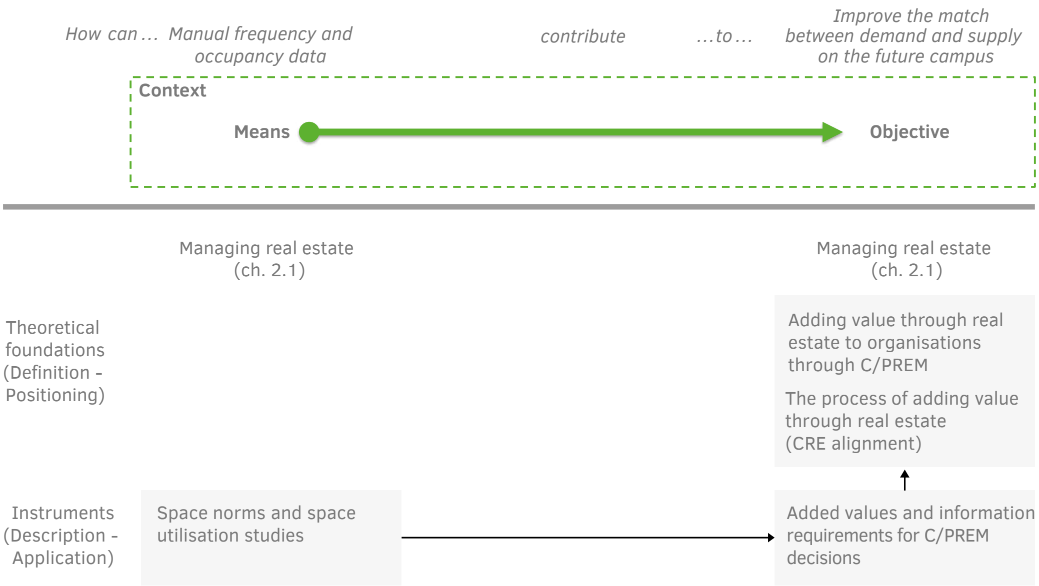


FIG. 3.2 Using space utilisation studies to inform campus management decisions, as input for chapter 4 (adapted version of the conceptual model).

In section 2.1, the use of space norms in space planning, space charging and space utilisation studies were positioned as an instruments within the body of knowledge of real estate management.

Space charging is not considered further as a (part of the) solution to the problem statement of this dissertation. This is because space charging is an approach to optimise departmental or faculty space use on an annual basis using space norms, whereas the problem statement requires an approach to optimise individual space use using real-time information, such as SCTs. If the solution does not provide real-time information to students and employees, they will not be able to make better use of the available spaces on campus.

Though not in the scope of this research, it may be possible to combine SCTs with space charging. However, in its current form this seems undesirable. Because each unit is charged for its use of space, space charging promotes territorial behaviour: a unit will not want to be charged for the use of its space by another unit. Furthermore, because units can determine how efficiently they are accommodated, there may be differences in the quantity and quality of the units' accommodation, further increasing territorial behaviour. With SCTs, the more spaces are shared across campus, the higher the benefits are. And the more equal the quality and quantity of the spaces is across campus, the more likely users are to make use of spaces all across the campus.

The use of space norms and space utilisation studies can be connected to the previous theories and instruments in real estate management:

- Users per m^2 and frequency and occupancy rates are indicators in the framework of management information requirements by Den Heijer (2011). Though they are positioned as functional / physical indicators, decisions on the amount of space offered per user can influence added values in all four perspectives such as supporting image, stimulating collaboration, user satisfaction, supporting user activities, reducing costs, and reducing m^2 footprint;

- Collecting information on users per m^2 and frequency and occupancy rates can be positioned in the CRE alignment building blocks (Heywood & Arkesteijn, 2018) as components of the 'audit of existing real estate';

- Collecting information on users per m^2 and frequency and occupancy rates serve the purpose of supporting campus management decisions that maximise the performance of the university.

In section 2.1.4, the space norms (UGC, 1987), their underlying coefficients (Space Management Group, 2006a) and guidelines for space utilisation studies (NAO, 1996) were discussed. In this dissertation, these space norms and space utilisation rates are related to each other, as illustrated in Figure 3.3, where they are connected to the time horizons distinguished by Beyrouthy et al. (2008). The space norms, which are used to plan spaces, determine space utilisation. In turn, space utilisation informs the refinement of these space norms. A high rate of m^2/user will likely lead to a low space utilisation; similarly, a low m^2/user will likely lead to a higher space utilisation.

Over time, the coefficients that underpin the space norms may change. These coefficients can affect the way space is being used, but also how work is organised, which then consequently affects space use. Therefore, depending on the observed space utilisation rates, organisations may decide to adjust their space norms. The extent to which the space norms and (changes to the) coefficients are understood can improve the accuracy of this relation. Feedback from space use to space planning enables an organisation to set effective space norms that express the demands of the organisation and lead to effective and efficient space use.

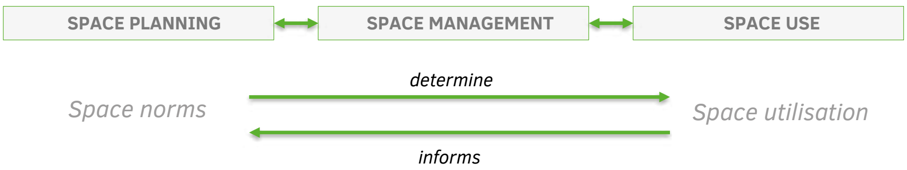


FIG. 3.3 Relationship between space planning and space use (own illustration).

Additionally, this dissertation specifies the existing content regarding space utilisation studies prior to conducting them in chapter 4. Subsection 2.1.4 discussed the four variables used to measure space use: (1) scheduled frequency, (2) scheduled occupancy, (3) actual frequency and (4) actual occupancy (NAO, 1996; Space Management Group, 2006b). These four variables are the basis for the data collection in chapter 4 (Figure 3.4).

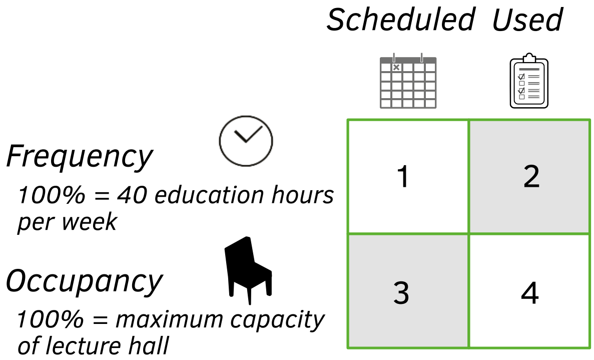


FIG. 3.4 Scheduled and actual frequency and occupancy (based on SMG 2006b).

If all four variables are measured, they give a comprehensive insight into the use of a room:

1 The scheduled frequency rate is the primary variable to steer on: it describes how many of the available education spaces or meeting rooms have been booked prior to the survey. The performance on this variable gives a strong indication to if there is enough space available in the portfolio;

2 The scheduled occupancy rate is the secondary variable to steer on: it indicates the group size for each reserved room. The performance on this variable gives a strong indication of whether the available spaces are of the right size, if there are many over- or undersized spaces in the portfolio that are consequentially poorly utilised;

3 The actual frequency rate can be compared to the scheduled frequency rate to show which bookings do not take place ('no-shows') or where unscheduled meetings take place. For education spaces this comparison pinpoints where no-shows occur, which can serve as input to improve the schedule in the next academic year. For meeting rooms, it also shows where unscheduled meetings take place and how large this demand is, thereby refining the initial indication of space needs;

4 The actual occupancy rate can be compared to the scheduled occupancy rate or measured standalone. In comparison, it shows the actual number of participants compared to the expectation. This information can be used to improve planning assumptions, especially in education spaces.

It is important here to note that although both NAO and SMG do not state this explicitly, the definition of space utilisation assumes the room as the object of measurement (hence ‘space’ utilisation): frequency describes its availability and occupancy describes its use of capacity. This approach can be followed for surveys of education spaces or meeting rooms. However, in office areas and study spaces, the object of measurement is a workplace. Here, the frequency and occupancy are essentially the same because the value of the capacity is binary: 0 (free) or 1 (occupied). In measurements where workplaces are the unit of measurement, the measured variable is referred to as scheduled or actual *occupancy*.

In literature, different targets are set for frequency and occupancy rates, and these are not always explicit about whether they pertain to actual or predicted use. This distinction is relevant, as the difference between the two can be significant (Space Management Group, 2006b). NAO (1996) writes that the PCFC set targets of 80% frequency and 80% occupancy for education space. Whether this pertains to predicted or actual use is not stated explicitly, although their relation to the auditing of space implies actual use. TEFMA (2009) provides targets for a range of space types, of which the most have targets of 75% frequency and 75% occupancy. It is stated that these targets are for an average week of 67,5 hours and they seem to relate to actual use. NAO writes that, in practice, achieving frequency and occupancy rates above 70% may already be challenging. The variability in targets is consistent with the previous observation that space utilisation is dependent on space norms and coefficients: it suggests that the suitability of targets depends on the specific organisational context.

3.2 Components of smart campus tools

In chapter 5 and 6 the components of the SCTs are studied. The initial definition of SCTs gives a starting point for the components to be studied:

"A smart campus tool is a service or product that measures space use real-time in order to support students and employees in making better use of spaces on campus today, whilst also supporting campus managers in making better decisions on the future campus."

This definition was split into three aspects: objectives in real estate management (WHY), the measurement of space use (HOW) and the methods to measure space use (WHAT).

Figure 3.5 shows how these components relate to the conceptual model. Here, both the use of information by campus users and campus managers is studied, i.e. the current and future campus. The sensing methods, principles of occupancy sensing / indoor positioning, and added values are used in the data collection as the components of SCTs that are studied, i.e. the means and the objectives. During the research the components studied as well as the understanding of these components have evolved.

These findings can then be linked to the theoretical foundations from chapter 2:

- Occupancy sensing methods are a component of a class of IoT applications, applied in the smart campus with the objective of maximising building performance;
- SCTs contribute to various added values via either CRE alignment processes, or directly by providing users with actionable information, thereby maximising the performance of the university.

Furthermore, the results of this part of the research inform the first research assumption:

SCTs add value to the university campus and enable universities to simultaneously support increasing user demands (including health and safety) and increase their resource efficiency.

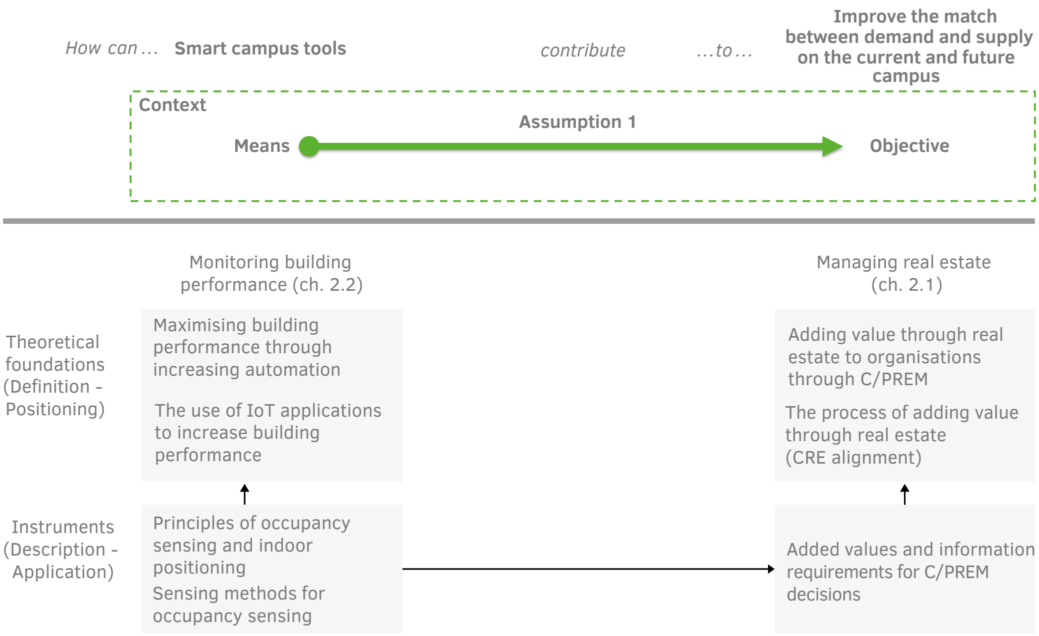


FIG. 3.5 Using various frameworks to understand the components of SCTs, as input for chapter 5 and 6 (adapted version of the conceptual model).

In the data collection, the objectives (or added values) of the SCTs are based on the added value model by Den Heijer (2011), as presented in subsection 2.1.3. The methods used to measure space use focus on the application of sensors, i.e. the sensing layer in IoT applications (see subsection 2.2.2). The overview in Figure 3.6 is based on previous research by Mautz (2012) and Trivedi and Badarla (2019) and an overview of sensors by Serraview (2015). In the inner circle, it shows the type of sensor used to measure space use, while in the outer ring it shows the specific application of that type of sensor. Subsection 2.2.4 provides a more detailed explanation on sensing methods.

TOC

The measurement of space use is based on traditional space use frameworks of NAO (1996) or Space Management Group (2006b), which defined frequency and occupancy rates (see subsection 2.1.4), complemented by the framework of Christensen et al. (2014) for building occupancy resolutions (see subsection 2.2.3). The occupancy and count resolutions in this definition are identical to the previously defined frequency and occupancy. To avoid confusion, the terms frequency and occupancy are used in this dissertation instead of occupancy and count. The identity and activity resolutions provide further detail on how space is used. Positioning methods may also be categorised in these resolutions: positioning is either used to determine a specific user or object, which is a measurement on the identity resolution, or to determine the movement of that user to a new location, which is a measurement on the activity resolution.

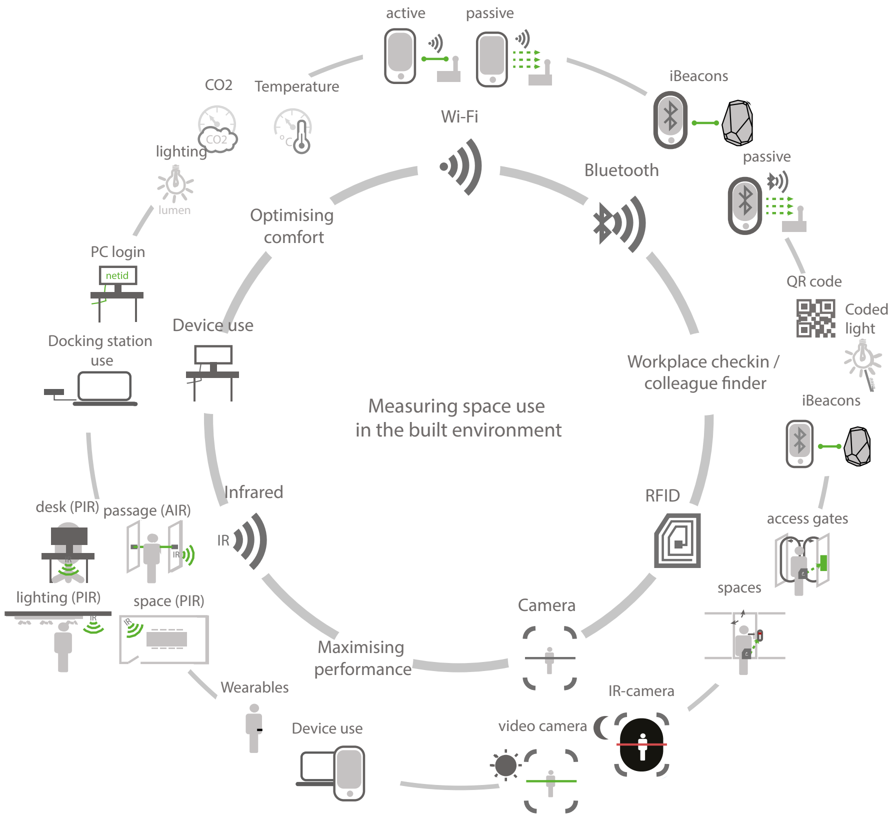


FIG. 3.6 Overview of sensing technologies to measure space use in the built environment (own illustration, based on (Mautz, 2012; Serraview, 2015; Trivedi & Badarla, 2019).

These three aspects form the basis of studying SCTs. A fourth aspect that was studied is what makes a SCT ‘smart’. Initially three user requirements were used, based on the overview of user requirements by Mautz (2012) (see subsection 2.2.3). These are displayed in Figure 3.7:

- Number of users: defined as a range from internal, i.e. few select users, to open access;
- Accessibility: on a scale from on location to everywhere;
- Update rate: defined as a range from on demand (in case an update can be made) to real time.

In this form, these four aspects were translated into the questionnaires and interview schedules used at universities for the research of chapter 5 (see Appendix 2). After the initial data collection, additional user requirements, such as market maturity, cost, coverage area, privacy and interface, were considered in more detail. Together with the previously mentioned data, these were merged in a single overview per SCT. This overview was used as a template for further data collection in chapter 6: each case was documented within this structure - see Figure 3.8 for an example.

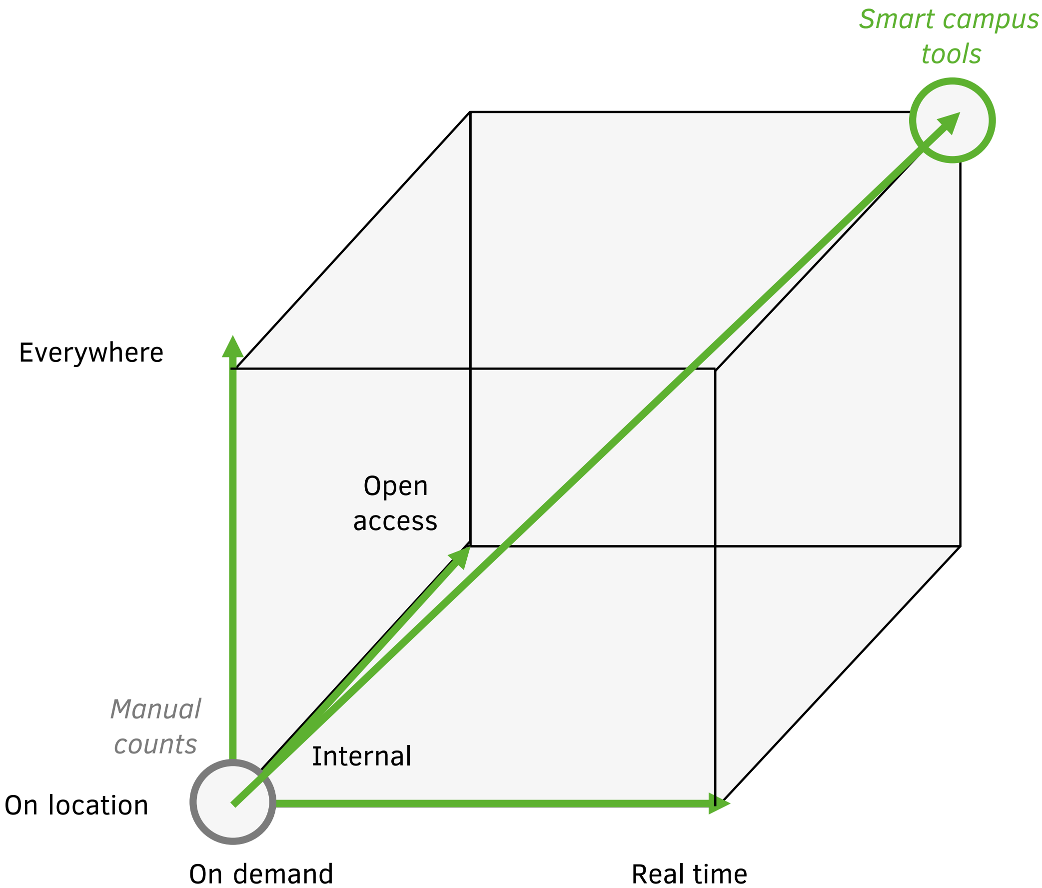


FIG. 3.7 From manual counts to SCTs (own illustration).

TUD-2 TU Delft Pilot education spaces

phase
Pilot

scale
1 building
2.500 m2

duration
Q3 2016 - present

Project description

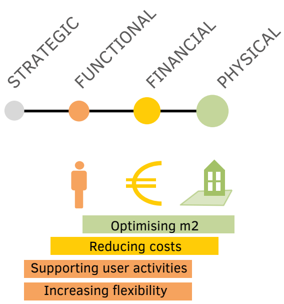
The initiative has been taken because TU Delft wants to get better insight into the use of facilities on campus. The university has been growing in terms of student population for years and that results in pressure on the education spaces. Four years ago we had 1 seat in an education space per student; now we have about 0,85 seat per student. In order to monitor what the effect of this change is on the use of space and to be able to schedule more efficiently in the future, the university decided to start measuring the frequency and occupancy rates real-time for education spaces. Wi-Fi has been selected as preferred method.

Foreseen developments

The next step in this project is to measure frequency and occupancy in education spaces on a campus level.

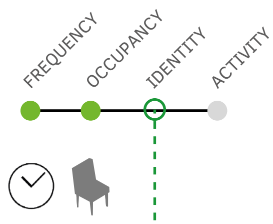
Profile

Why: Objectives



Optimising m2 has priority. On the long term this is achieved because schedulers receive information about the actual use of spaces by users. With that information it is possible to evaluate the space use and search for better solutions together with teachers.

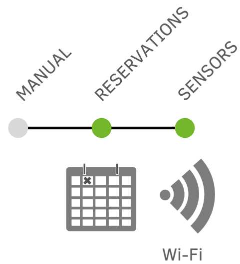
What: Measurement



Wi-Fi data is anonymised on-site before it goes to the cloud. In addition a different encryption is used so users can never be tracked for longer than one day if anyone is able to deanonymise the data.

The amount of devices in the building at a certain moment. That is converted via algorithms to an amount of people.

How: Measurement method



Wi-Fi registers both the amount of connected devices and connection attempts. Based on the signal strength between device and access point the location of a device in the building can be pinpointed.

FIG. 3.8 Example of a case documented within the template for data collection.

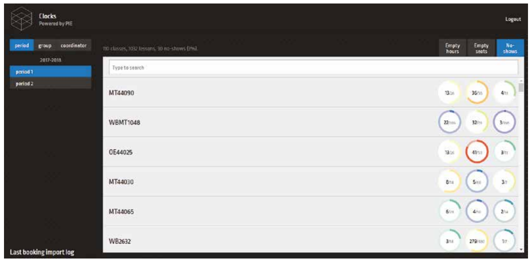
TUD-2 TU Delft Pilot education spaces

functionalities
Monitoring space use

space types
Education spaces

User information

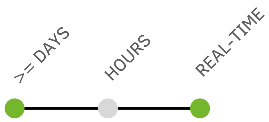
The user (scheduler) receives a report with in it per course the amount of bookings, the amount of no-shows, empty hours (partly used bookings) and the average occupancy. This makes the performance in relation to the schedule visible.



Management information

The manager can see the same reports as the scheduler and also the PIE dashboard in which the whole building is visible. PIE is not linked to the scheduling data, but shows real-time what the use of spaces in the building is in relation to their capacity.

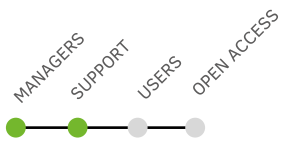
Actuality of the information



PIE displays real-time data.

The information in Clocks is visible real-time; for lectures currently underway a tentative frequency and occupancy is shown. The report shows data per period.

Access levels



The scheduling team has access to Clocks.

A few project team members and two people from the management of a faculty have access to Clocks and PIE.

Benefits

Implementing a system with which the schedulers can evaluate the space use of lecture halls has been identified as one of the measures that enable the university to move to a more efficient space use. The university intends to move from a policy of 0,9 education spaces/student to 0,81 education spaces/student. The pilot is not aimed at assessing what efficiency can be achieved, rather to get experience with the method and testing the results with Wi-Fi in a second building.

Side notes

The reason that this pilot is undertaken is because of the results in the proof of concept in the faculty of Industrial Design Engineering were not as positive as expected. The lecture halls showed promising results, but the other spaces in the building did not. Multiple causes were identified: an open central hall with multiple floors adjacent to it, the pedestrian flows in the hall and around the building, the layout of access points and the way in which the network allocates users to access points. The pilot in 3mE is a test to see if the results in another building are comparable.

3.3 Utilising smart campus tools in campus decision making

In chapter 7 and 8 the use of the information from SCTs in campus decision making is studied. Several methods and tools are used to structure and guide the use of SCTs in campus decision making. Those methods are applied sequentially, with each part of the research building on the results of the previous. Thus, the management information section (section 2.3) is added here to the conceptual model in between the means and the objective: see Figure 3.9. Because it focuses on campus decision making, the findings only inform how the match between demand and supply on the future campus can be improved, and not on the current campus. The output of this part of the research will inform the second research assumption:

A review of the required management information and its use in decision making processes enables SCTs to optimally contribute to the match between demand and supply in real estate.

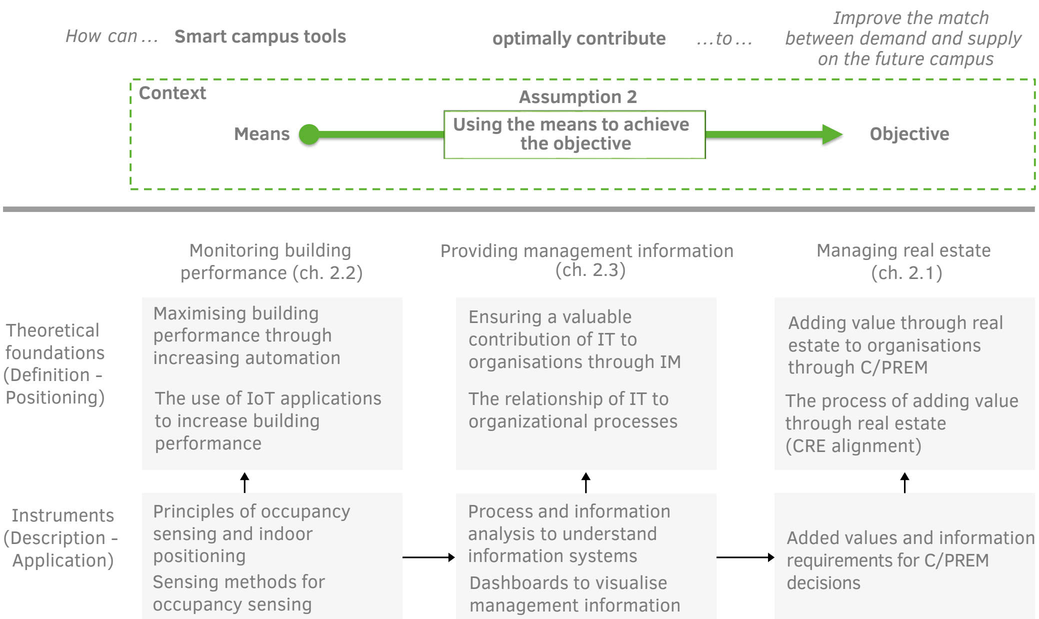


FIG. 3.9 Using process and information analysis and dashboards to connect SCTs to campus decision making, as input for chapter 7 and 8 (adapted version of the conceptual model).

In campus management, decisions are made with the objective to align the university campus to the needs of the organisation. The CRE alignment building blocks (Heywood & Arkesteijn, 2018) and components and the DAS frame (De Jonge et al., 2009) (subsection 2.1.2) describe the process and its information requirements on a high abstraction level.

In this part of the research, the objective is to understand exactly what these processes look like in practice and how information can be used to complete each process step. Therefore, process analysis and information analysis are used (see subsection 2.3.3). Figure 3.10 shows an example of a simple process diagram, showing the lower-level activities within a process in the context of campus management. The process shown here describes how a faculty within a university submits accommodation needs to a real estate department, where they are then matched to possible accommodation strategies. The outcome of the process is the start of a project. The diagram shows which activities are required to complete the process, and the stakeholders needed in order to complete each activity. From this diagram, each actor can identify in which activity their input is required.

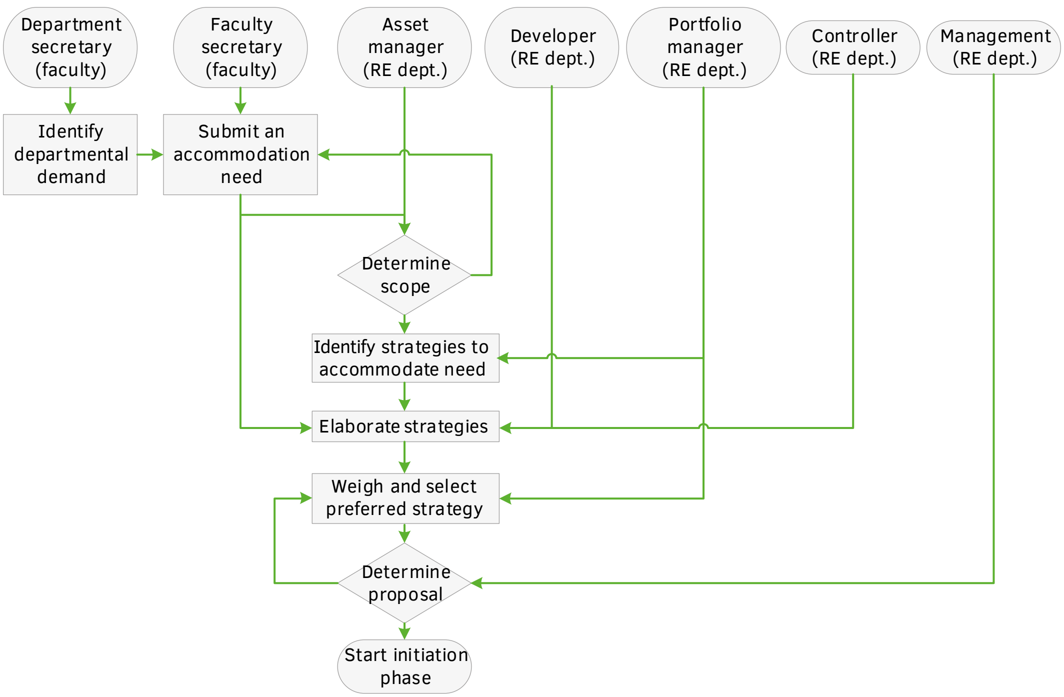


FIG. 3.10 Example of a process (activity) diagram.

Next, information analysis is conducted based on the process analysis, as described in subsection 2.3.3. The objective of information analysis is to determine which information is needed to complete each activity within the process and which information is expected as the output of each activity. Figure 3.11 and Figure 3.12 show the translation of the previously shown diagram into information diagrams. In these diagrams, the actor nodes (at the top) now describe the information inputs that are brought into the process by each stakeholder. Each activity node describes the required output of each activity. Here, it becomes specific which information is delivered at which point of the process. Now, each actor knows exactly which input is required of them and what the expected output is of the activity they contribute to. In addition, the diagrams show how various documents and databases are to be used in the process.

Information analysis can be used to design the contribution of SCTs in organisational processes: compare Figure 3.11 and Figure 3.12. In the latter figure, SCTs are used as input in designing strategies for the accommodation need. By collecting workplace occupancy data, SCTs deliver information on the current occupancy to be used in the activity. Rather than just comparing the required space and available space to determine strategies, the occupancy information can be used to assess if the current space is used well, or if there is an opportunity to use existing space better. The information of SCTs thus contributes to the formulation of effective strategies in this process.

As can be seen in these (simple) examples, but also in subsection 2.1.3, SCTs are expected to deliver only a part of the information required to make decisions. The campus manager therefore needs an overview that combines this information to other important information. In order to make such an overview, dashboards are designed based on dashboard design principles Few (2006) – see subsection 2.3.4. These principles of dashboard design are combined with principles from campus management, based on Den Heijer (2011):

- The basis of Real Estate Management is the presumed added value of real estate on performance, either negatively or positively. Real estate is positioned as input, organisational performance as output, and the process of adding value as throughput;

- In order to make decisions about the university campus, a dashboard must combine four perspectives on the campus: the strategic, functional, financial and physical perspective;

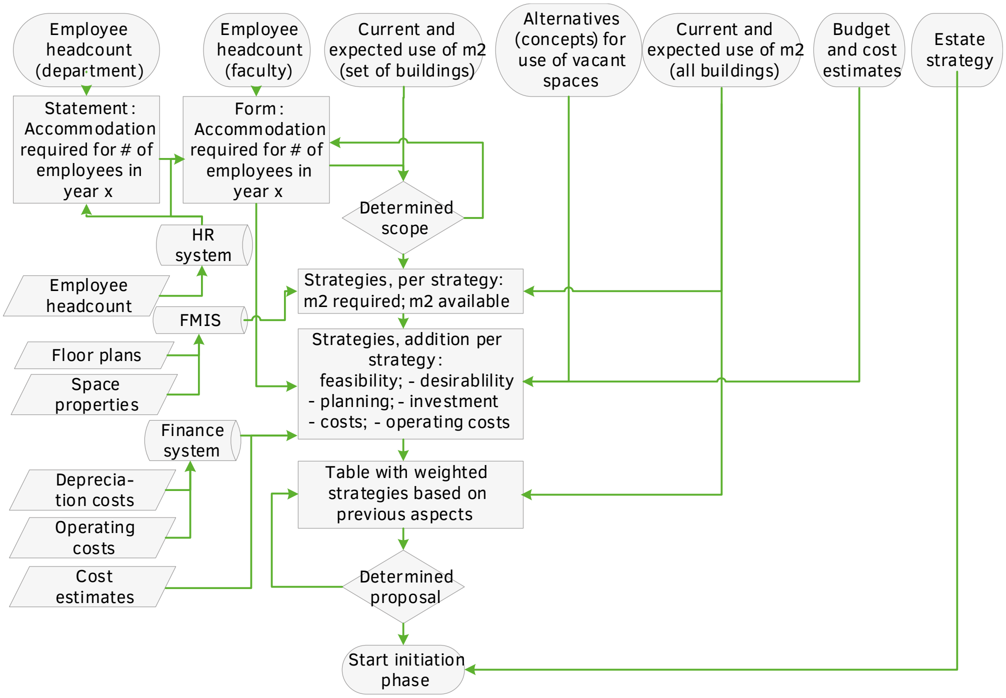


FIG. 3.11 Example of an information diagram.

- Each stakeholder views the campus primarily from their own perspective. Dashboards for campus management can be tailored to support a specific group of stakeholders. However, following the previous point these dashboards should also always include information on the other perspectives. In an overview of management information to support campus decisions, various indicators are grouped by the four perspectives. This overview (see figure 3.13) can be used as a source of indicators to consider for inclusion in the dashboards;

- The four stakeholder perspectives are applicable on multiple abstraction levels: e.g. on the organisational level of the university, faculty or department and on the real estate level of a building portfolio, building or set of spaces. Designing dashboards will also involve making choices on which abstraction level to report each variable.

Because of these requirements, the colours corresponding to each stakeholder perspective by Den Heijer (2011) are also retained in the dashboard, as they are recognisable as such by practitioners. However, this conflicts with one of Few's (2006) guidelines for dashboard design, i.e. limiting the use of colours.

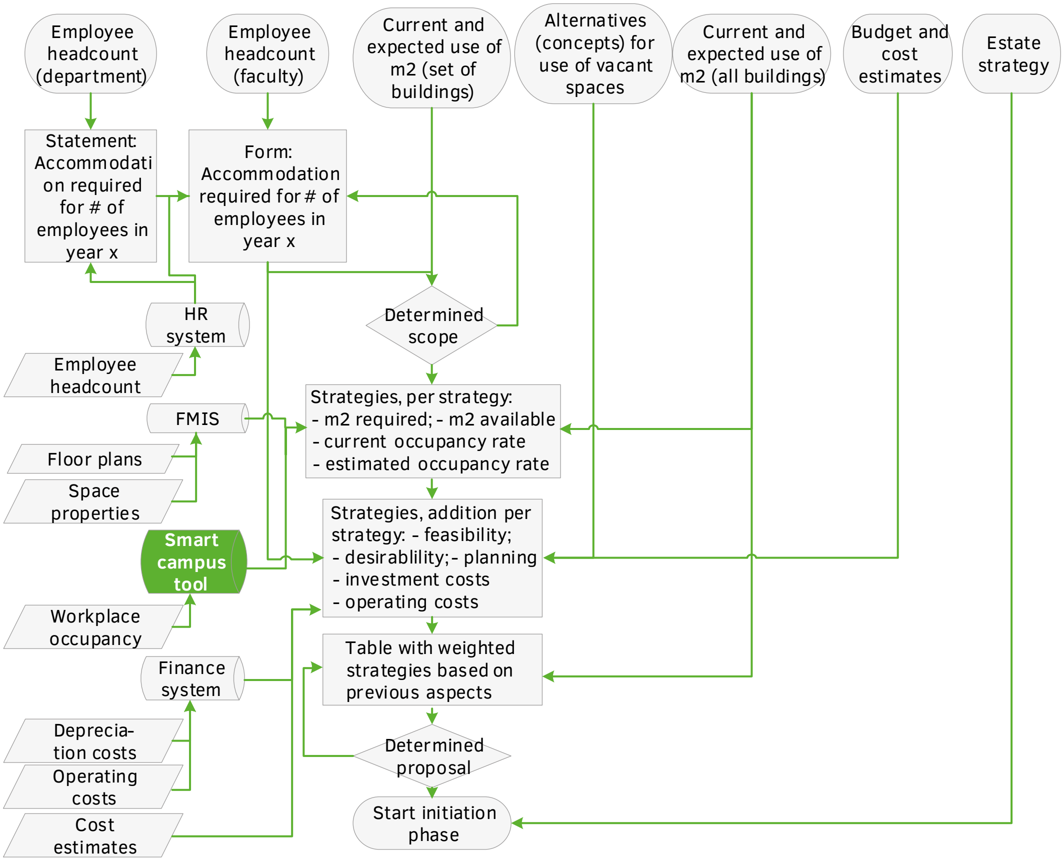


FIG. 3.12 Information diagram with SCT included (highlighted).

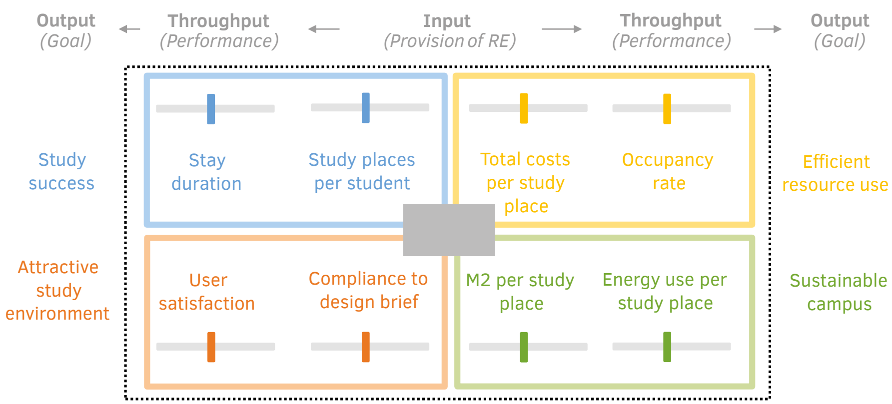


FIG. 3.13 Conceptual design for the structure of a campus management dashboard.

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3.4 Summary

This chapter has described three applications of elements from the body of knowledge in this research, making use of the conceptual model in three different ways. Each of these is described in a section:

- Section 3.1 discussed the relationship between space utilization studies and decision making. Specifically, the relationship between space norms and the outcomes of space utilization studies are important;

- Section 3.2 combined different tools and instruments from managing real estate and monitoring building performance to research SCTs. Over time, these have been integrated into a template that serves as a basis for data collection;

- Section 3.3 discussed process and information analysis and dashboards as instruments to support the use of information from SCTs in campus management decision making.

Figure 3.14 shows how the conceptual model will be used, step by step, throughout the main body. Together, these three different ways of applying the conceptual model will answer the main research question:

- First, chapter 4 will research how the current use of frequency and occupancy data informs campus management decisions to improve the match between demand and supply on the future campus;

- Next, chapter 5 and 6 will research how SCTs contribute to improving the match between demand and supply on the current and future campus, thereby informing assumption 1;

- Last, chapter 7 and 8 will research how SCTs can be connected to decision-making processes in campus management in order to improve the match between demand and supply on the future campus, thereby informing assumption 2.

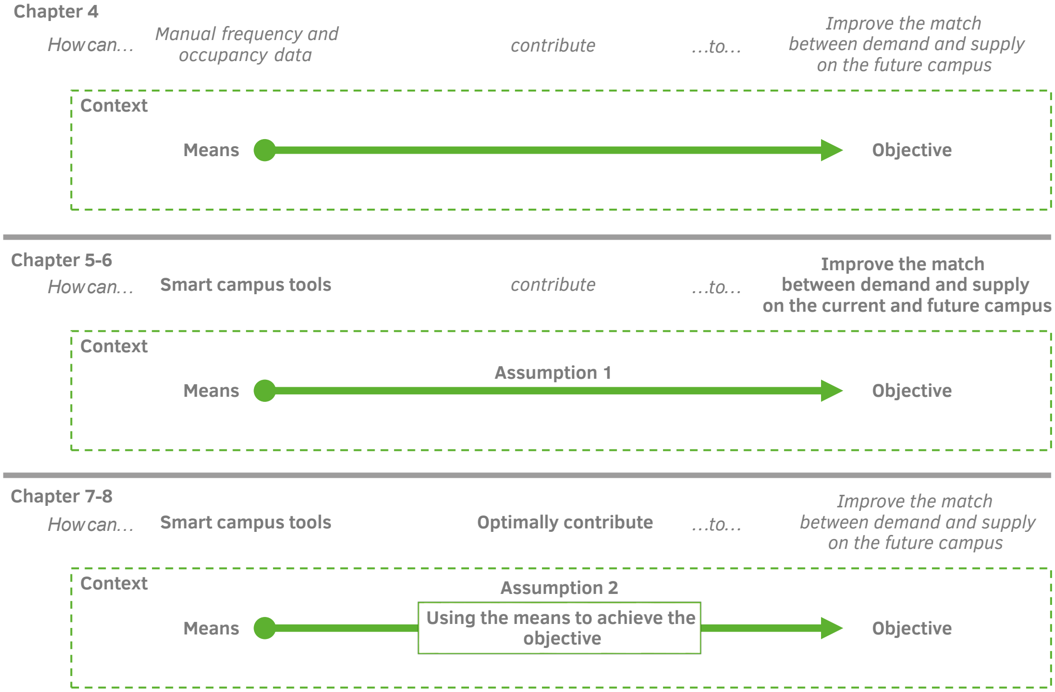
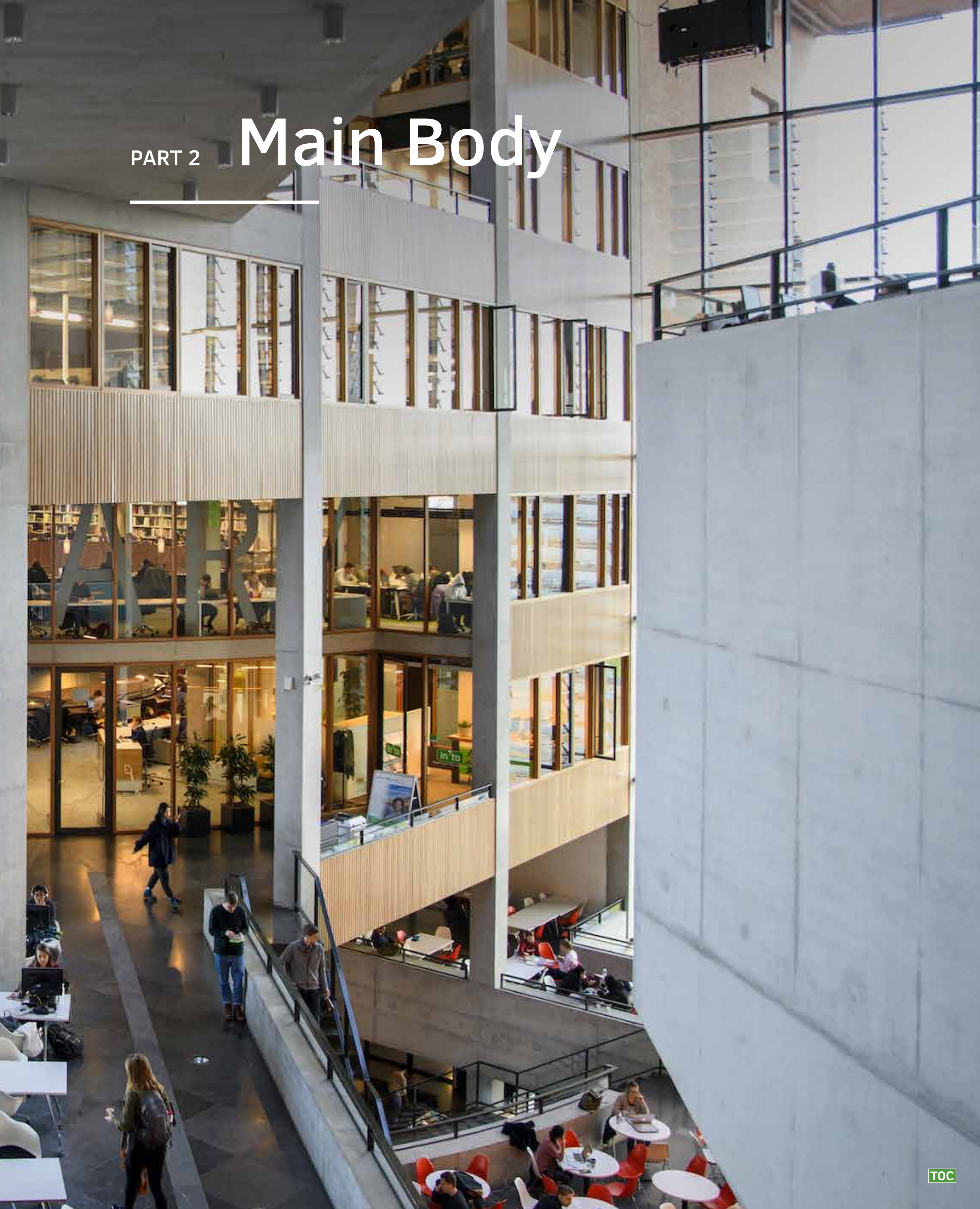


FIG. 3.14 The contents of Chapter 3 as input for the research in subsequent chapters of this dissertation.

Forum building Wageningen University. Photo: Sicco van Grieken, copyright Wageningen University & Research.

PART 2

Main Body



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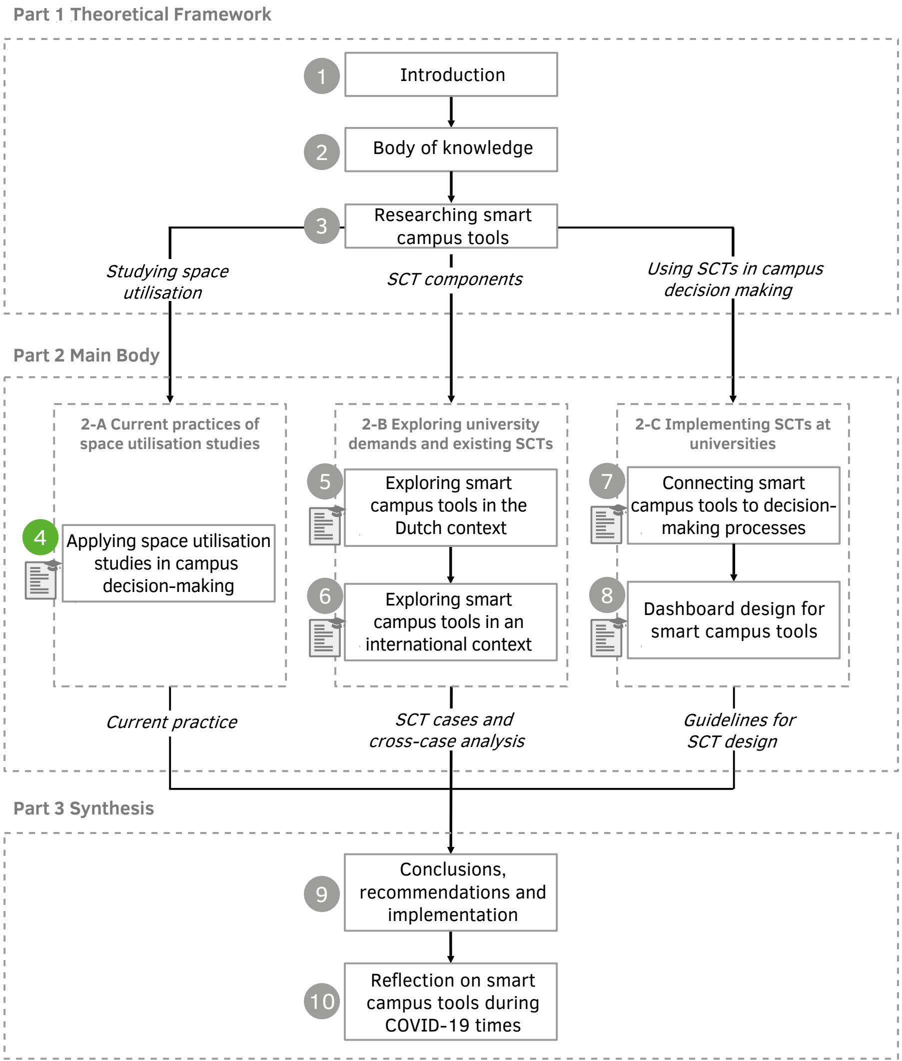

FIG. 4.1 Position of this chapter within the PhD research.

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4 Applying space utilisation studies in campus decision-making

This chapter is an adapted version of a research paper. The introduction has been abbreviated to omit contents already discussed in section 1.1. Furthermore, the conceptual model has already been discussed in section 3.1 and is therefore omitted in this chapter. Small textual changes have been made for the purpose of overall consistency in this dissertation.

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4.1 Introduction

This chapter marks the move to part II of the dissertation by considering the use of frequency and occupancy rates to inform campus decision-making. Prior to involving SCTs for the calculation of these rates, this chapter makes use of manual data collection through space utilisation studies in order to illustrate both relevance and information needs.

Space utilisation studies have a strategic role in campus planning (Space Management Group, 2006b): they provide information on how space is being used, and help to inform decisions about the type and scale of facilities that are needed. Space utilisation studies have already been detailed in part I of this dissertation:

- In chapter 2, subsection 2.1.4 discussed the main use of space norms and coefficients for space planning, and the measurement of frequency and occupancy rates in space utilisation studies.

- In chapter 3, section 3.1 further specified the concepts ‘space norms’, ‘coefficients’, ‘frequency rates’ and ‘occupancy rates’. It then discussed the relationship between space norms and coefficients on the one hand, and frequency and occupancy rates on the other hand, as input for this chapter.

Existing academic studies detailing space utilisation studies are subject to several limitations (see section 4.2). Existing studies either do not cover all spaces in a portfolio, have difficulty connecting results of space utilisation studies to space planning assumptions, or do not clearly report the setup of their study. By removing these limitations, this study is novel in three ways:

- it covers a whole portfolio across multiple years;

- it relates the outcomes of the study to the space norms of the institution, and reports the decision-making based on the outcomes of the study;

- it clearly states the setup of the utilisation study.

The space utilisation study reported in this chapter is conducted as a case study. Its objective is to understand how information on the space use of a portfolio is used to make decisions. Therefore, the main research question of this chapter is:

RQ3: What is the space use of education spaces and study places at TU Delft, and how does it inform campus decision-making?

The remainder of this chapter is structured as follows. First, the limitations of existing space utilisation studies are discussed (4.2). This is followed by the research methods which discuss how the survey is set up and how its relation to decision making is analysed (4.3). Then, the case is introduced, together with the spaces which are surveyed and relevant policies on those spaces (4.4). This is followed by an analysis of the space use of the education spaces and study places (4.5) and how these results informed decision making at the university (4.6). Finally, the chapter is concluded (4.7).

4.2 Space utilisation studies in academia

There has only been limited research documenting space utilisation at universities, even though there is a clear need to share and benchmark data across institutions. This need is identified both by campus managers (Den Heijer, 2011) and by researchers. Alghamdi (2017) gives two explanations for the limited availability: the high costs of conducting utilisation studies and a belief by practitioners that other variables are more useful indicators than space utilisation. A third possible explanation is that there is a lack of sharing space utilisation studies outside of the own organisation.

Table 4.1 shows the space utilisation studies found in literature and their characteristics. Four of these studies were conducted in education spaces and two in study spaces. Only two studies were done across multiple buildings. Because utilisation levels can vary greatly between buildings, studies across whole portfolios are expected to deliver more value in terms of benchmarking.

TABLE 4.1 General characteristics of space utilisation studies.

Authors	Year	Country	Space type	Study object	Objective	Space norms	Space coefficients
(Organ & Jantti, 1997)	1997	Australia	Study places	Library building	Recommend strategies to accommodate future growth and development	Yes	Other coefficients
(Khoo et al., 2014)	2014	England	Study places	Library building	Understanding if the Library supports student's goals	Not mentioned	None
(Ibrahim et al., 2011)	2011	Malaysia	Education space	One building	To develop a space charging model for the university	Not mentioned	None
(Kasim et al., 2012)	2012	Malaysia	Education space	One building	To provide a guideline for future space provision	Not mentioned	None
(Abdullah et al., 2012)	2012	Malaysia	Education space	University Campus	A basis for action to improve space efficiency and effectiveness	Not mentioned	None
(Alghamdi, 2017)	2017	Saudi Arabia	Education space	Five buildings (one per campus)	To identify how space can be effectively and efficiently operated	Yes	None

Furthermore, Table 4.1 shows each study's objective and the mention of space norms (m^2 per user or workplaces per user) in the article. The objectives show that the reasons to conduct the studies are different. The studies focusing on study places seem to be more user-centric, focusing on how future growth can be accommodated and if the spaces support students. Conversely, the studies on education spaces are more real estate-centric, focusing on improving effectiveness and efficiency, providing guidelines for future space provision or developing a space charging model. Surprisingly, only two studies make mention of space norms. Organ and Jantti (1997) make note of both the current number of seats per 100 FTE students, and the figure that was used during discussions of extension of the Library building. Alghamdi (2017) lists the current space area per FTE student. Similarly, with regards to the coefficients, only Organ and Jantti (1997) make mention of some coefficients that underpinned the space norms for their Library building, but they are other coefficients than identified in section 2.1. This is a surprising finding – even though many authors have the objective of relating the outcomes of their studies to decisions about accommodating growth or increasing efficiency and effectiveness, they have difficulty connecting it to the planning assumptions that are the basis for those decisions.

Next, Table 4.2 shows the specifications of the space utilisation studies provided by the authors. First, it shows if the studies make a distinction in their measurements between frequency and occupancy, scheduled and actual. For the studies conducted in study places, only the actual occupancy is relevant. For the studies in education space, none of the studies measure both scheduled and actual space use. Abdullah, Ali, and Sipan (2012) and Kasim, Nor, Masirin, and Idrus (2012) study space use based on scheduling data. Ibrahim et al. (2011) imply the use of scheduled frequency in their definition of frequency (hours used / hours booked)[7], but do not specify what the scheduled frequency rate is, nor how it is collected. Only Alghamdi (2017) addresses the distinction between scheduled and actual use, although his experiment is based on scheduling data and thus only reflects scheduled frequency and occupancy rates.

7 Note that this definition of actual frequency deviates from the earlier given definition, which is the number of hours used / total number of available hours.

TABLE 4.2 Data collection specifications of space utilisation studies.

Author	Scheduled Freq.	Actual Freq.	Scheduled Occ.	Actual Occ.	Measure-ment period(s)	Measure-ment duration	Observa-tions per day	Maximum availability
(Organ & Jantti, 1997)	n/a	n/a	n/a	Yes	One	3 months	3 per day	~40 hours
(Khoo et al., 2014)	n/a	n/a	n/a	Yes	One	Unclear	Unclear	Unclear
(Ibrahim et al., 2011)	Implied	Yes	No	Yes	Two	Unclear	Unclear	Scheduled frequency
(Kasim et al., 2012)	Yes	No	Yes	No	Four	A semester	Not applicable	65 hours
(Abdullah et al., 2012)	Yes	No	Yes	No	One	A semester	Not applicable	35 hours
(Alghamdi, 2017)	Yes	No	Yes	No	One	A semester	Not applicable	40 hours

Table 4.2 further shows the measurement period, duration, number of observations and the maximum availability used to calculate frequency. The table shows that often these details are not provided to full extent. Either the measurement duration, the number of daily observations or the maximum availability are unclear. In Khoo, Rozaklis, Hall, Kusunoki, and Rehrig (2014) all of these details are absent: although they state a total of 112 surveys are carried out, the division of those surveys into observations per day and duration of the measurement in days is not specified. Only the measurement period is clear in all studies, e.g. four semesters or a one-time study of three months. Organ and Jantti (1997) are an exception – they provide clear statements on all aspects. As has been observed by Space Management Group (2006b), the variability in conducting space utilisation studies makes comparison difficult. Table 4.2 confirms this variability amongst academic studies.

To conclude, this section demonstrates that past utilisation studies have some limitations: most studies do not cover a whole portfolio, most studies do not relate the outcomes to planning assumptions (and consequently decision-making), and most studies are not clear about the setup of their utilisation study. The study reported in this chapter satisfies all these requirements: it covers a whole portfolio over multiple years, it relates the outcomes to planning assumptions and decision-making, and it details the study setup.

4.3 Research methods

In order to answer the main research question, a case study design is chosen, as it focuses on the extensive exploration and understanding of a phenomenon rather than confirmation or quantification of it (Kumar, 1999). The case that is studied in this chapter is the portfolio of education spaces and study places at TU Delft. What is studied is the space use of this portfolio and how this information informs decision making with regards to the portfolio.

Because the match between the demand for and supply of education spaces changes every year, it is necessary to collect data over a long period of time and use quantitative and qualitative research methods. Data on space utilisation is collected each year via surveys and analysed and compiled in reports. These surveys follow the guidelines for space utilisation studies which can be found in NAO (1996) and Space Management Group (2006b) (see subsection 2.1.4). Then, the relationship of the surveys to decision making is studied ex post through document analysis.

This study adheres most to Yin's (2002) conceptualisation of a case study design, as described by Yazan (2015). However, with regards to epistemology and validity a constructivist perspective is followed, as in Stake (1995) and Merriam (1998). Ultimately, the objective of the chapter is to present a case of an organisation that uses space utilisation studies to inform its decision making. When it comes to space utilisation studies, the objective of the study is to determine the space use as objectively as possible. However, the registration of this data is done by humans and subject to interpretation and mistakes. To ensure reliability and validity of the survey and its results, the data collection and analysis are based on prior work on the subject and applied consistently throughout the survey. To increase external validity, a detailed description of the data collection is provided here, as this was found to be a limitation in prior research. The survey includes measures to reduce surveyor bias. In the analysis, comparison to scheduling data and to previous studies provided additional checks. Finally, when reporting the survey outcomes, various university stakeholders were involved before finalising the outcomes.

When it comes to analysing how these surveys inform decision making, the notion of reality is more subjective. Here, document analysis is used as primary method with the purpose of tracking the development in decision making (Bowen, 2009). The studied documents are policy documents and memoranda. The resulting text has been checked with several co-authors of this chapter, who together with the main author have worked together on the university's policies for education spaces and study places as well as the initiation and development of projects.

The survey is set up as follows. Each year, all the university's shared education spaces are surveyed during peak periods. The number of study places surveyed differs throughout the years (see subsection 4.4.2), and surveyed during exam weeks. The objective of both surveys is not to infer the use of the spaces throughout the whole portfolio for the whole year, but to understand the space use during the busiest time of the year. Throughout the years, the measurement duration and the number of daily observations have changed: due to additional information demands the measurement duration was increased, and later due to budget constraints the measurement duration and observations were decreased. Table 4.3 summarises the properties of the space utilisation studies.

TABLE 4.3 Properties of the reported study.

Properties	Education space					Study places		
Measurement period	2015	2016	2017	2018	2019	2017	2018	2019
Scheduled frequency	Yes					N/A		
Actual frequency	Yes					N/A		
Scheduled occupancy	No					N/A		
Actual occupancy	Yes					Yes		
Measurement duration (weeks)	6	9	8	4	4	3	2	2
Observations per day	8	8	8	8	4	8	8	4
Frequency baseline	40					40		

The following steps were taken in the data collection process:

1 First the spaces to be surveyed, the number of daily observations, and the measurement duration are determined. A template is made in MS Excel for recording observations;

2 During the measurement period, several surveyors (students) are tasked to walk past all the education spaces or study places to make observations. Each surveyor covers several buildings within a set observation period (1 hour or 2 hours) and repeats this 4-8 times a day depending on the observations per day;

3 Each observation is either a 0 (empty), a NS (no-show), or a count of the number of students in the room. Empty means that there is no event scheduled. A no-show means that an event was scheduled in the space, but the space was empty. This only applies to education spaces. In case no observation is made, a "no registration" is indicated.

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The data collection and analysis of the space utilisation studies evolved throughout the years. The data collection varied in measurement duration and observations, and the data analysis expanded by tailoring to specific needs. To make the connection to the use of the data in decision making, the data analysis in this chapter is done based on a document analysis. Both the reported data and comparable data across years are shown. The steps in the data analysis are the same each year:

1. Determine the Scheduled Frequency and Occupancy. The timetable of each space for the duration of the measurement period is downloaded after the measurement period ends. The scheduled frequency is determined per education space per week, by dividing the sum of the duration of all activities in a week in a space by the number of hours that the space is available. The scheduled occupancy could also potentially be extracted from this document; however, using the data of the estimated group sizes for this purpose was deemed unreliable by the scheduling department. Because the university does not require students to enrol for activities and there is no required attendance, group sizes are estimated using different methods.

2. Determine the Actual Frequency. For each education space, the number of no-shows that is counted for one week is subtracted from the scheduled frequency during that week.

3. Determine the Actual Occupancy. The actual occupancy is determined by taking the average count of students for all counts that are equal or larger to 1: these are all activities which have taken place, or the moments that study places were occupied during a week. The average of these counts divided by the maximum capacity of a space is its actual occupancy.

4.4 Case TU Delft

4.4.1 Case introduction

The TU Delft is a technological university in Delft, The Netherlands. The university was founded in 1842 and consists out of eight faculties which organise the university's education and research. The support services provide supporting functions for the faculties – relevant to this chapter are the departments of Campus and Real Estate (CRE), Education and Student Affairs (ESA) and Information and Communication Technology (ICT). Both the faculties and the support services are headed by an Executive Board which oversees the daily operation of the university and which makes most decisions at the university, and a Supervisory Board that supervises the Executive Board.

The TU Delft houses most of its activities on its campus, located south of Delft's city centre. The university's campus comprises of 161 hectares of land. The distance between the northernmost and southernmost faculty building is around 2 kilometres. Most faculties have their own main building, and in some cases they have additional buildings. The university's education spaces and study places are located both within faculty buildings and within shared education buildings.

TU Delft organises all its education in an academic year that starts in September and ends in July: see Figure 4.2. The academic year is divided into two semesters, which are each split into two quarters. A quarter consists out of ten weeks. Education takes place from week 1 to week 7 or 8; week 8, 9 and 10 are focused on exams and preparation.

At TU Delft different types of education spaces and study places are distinguished. Figure 4.3 shows the four types of education spaces suitable for general use. These spaces are grouped together in the sense that they are scheduled centrally and used by all faculties. Within types there are some variations depending on group sizes and spatial configurations. Figure 4.4 shows the three types of study places. There are spaces for longer periods of self-study (categorised as type A, or A2 if it has a desktop PC), short periods of studying ('touchdown') (type B, or B2 if it is in a classroom), or collaboration (type C). The functional and technical requirements of these spaces are outlined in a Program of Requirements called the 'Cookbook' (TU Delft 2018).

Week no.	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4	5
Type	C	C	C	C	CT	C	C	CW	CWT	T	C	C	C	C	CT	C	V	V	C	CW	CWT	T
Teaching week	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.10	2.1	2.2	2.3	2.4	2.5	2.6			2.7	2.8	2.9	2.10
Mon.	2	9	16	23	30	7	14	21	28	4	11	18	25	2	9	16	23	30	6	13	20	27
Tues.	3	10	17	24	1	8	15	22	29	5	12	19	26	3	10	17	24	31	7	14	21	28
Wedn.	4	11	18	25	2	9	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29
Thurs.	5	12	19	26	3	10	17	24	31	7	14	21	28	5	12	19	26	2	9	16	23	30
Fri.	6	13	20	27	4	11	18	25	1	8	15	22	29	6	13	20	27	3	10	17	24	31
Sat.	7	14	21	28	5	12	19	26	2	9	16	23	30	7	14	21	28	4	11	18	25	1
Sun.	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2

Sept **Oct** **Nov** **Dec** **Jan**

C	=	Lectures and other teaching activities
CT	=	Lectures and examinations BSc programmes
CW	=	Lectures / free week; varies per programme
CWT	=	Lectures / free week / examinations
T	=	Tentaminations /Resits
V	=	No teaching; vacation or public holiday

FIG. 4.2 A typical academic year calendar for one semester (TU Delft). [8]

FIG. 4.3 Different types of educations spaces: frontal didactics (top left), mixed didactics (top right), collaboration (bottom left), examination (bottom right).

8 https://www.tudelft.nl/en/student/education/academic-calendar/

FIG. 4.4 Different types of study places: self-study places (left), touchdown places (middle) and meeting places (right).

4.4.2 Policy developments

This subsection summarises the relevant developments in policy making at the university. The policy making on this topic is a collaboration between ESA, CRE and ICT, supported with analyses and by feedback from students and lecturers.

In July 2014 the ‘Roadmap Education Spaces’ was established. This document is a framework for decision-making on renovation, disposition or construction of education spaces. It outlines the university’s forecast for the student population, the expected future demand for education spaces, requirements for education spaces and scheduling, and the governance. Relevant conclusions are:

- The student population will continue to increase to a peak and stabilise around 20.000 students in 2020;
- There will be an increased demand for classrooms suitable for active learning as education programs will move towards interactive forms of teaching;
- To facilitate active learning and ease of use for lecturers there is a need for standardisation of the audio-visual facilities in education spaces.

Based on these recommendations, a ‘Transformation plan’ was made, a plan outlining the adjustment of education spaces to fulfil these requirements. This document was established in February 2016. The transformation plan builds on the Roadmap:

- It contains an analysis that shows for which types and sizes of education spaces there is a shortage. The two largest shortages are in classrooms for 90-120 people and lecture halls for more than 600 people. It proposes an investment to build spaces to reduce these shortages;

- A program of requirements ('Cookbook') is made together with lecturers, describing the requirements of each education space (by type and size)– see subsection 4.4.1;

- It contains an investment plan to transform all existing spaces to meet these requirements;

- For study places a similar plan is made together with the student council. The number and type of study places on campus is determined – see subsection 4.4.1. For each type, requirements are set. An investment is proposed to transform existing study places.

In February 2017, the Transformation plan was adjusted to account for an updated student population forecast: it was aligned to an increase towards 25.000 students in 2025 rather than the previous forecast which predicted a stabilising population of 21.500 in 2020. In June 2017, a proposal 'Terms of Reference education spaces and study places' was made, outlining the opportunities to optimise education logistics (and thus reduce the demand for education spaces). This proposal was made in reaction to the updated student population forecast, which required an estate strategy that made more efficient use of existing spaces on campus. The proposal outlines several improvements to the education logistics, which are expected to reduce the demand for education spaces by 10 percent: from 0.9 to 0.81 seats in education spaces per student and from 0.25 to 0.23 study places per student.

Since 2018, a document called the Progress monitor is made each year, describing the progress on the ambitions stated in the Transformation plan. It reports on three components: satisfied users, efficient space use, and sufficient space for growth. Specifically relevant for this chapter is efficient space use. Here, the stated goals for all shared education spaces are 75% scheduled frequency, a 5% no-show rate, and at least 60% scheduled occupancy. No targets are mentioned for study places.

4.5 Results of the space utilisation studies

4.5.1 Education spaces

The space utilisation studies of the education spaces were originally reported per component of space utilisation. Here, we report per space type. The data per component of space utilisation can be found in Appendix 1. First, Table 4.4 displays the survey characteristics. In each year the student population and the capacity in education spaces are different from the previous year, resulting in a gradual decrease in the number of seats / student. Furthermore, the composition of the portfolio has changed over the years. Each of these changes affects the reported results.

TABLE 4.4 Survey characteristics compared to portfolio characteristics.

	2015-16	2016-17	2017-18	2018-19	2019-20
Portfolio vs. Survey					
Seats / students	*0,87*	*0,86*	*0,82*	*0,83*	*0,82*
Total number of seats in education spaces	*18.300*	*18.532*	*18.539*	*19.306*	*19.555*
Percentage of portfolio covered in survey	*69%*	*67%*	*69%*	*72%*	*71%*
Survey					
Education spaces (number of spaces)	130	136	144	157	157
Lecture halls	36	31	31	31	31
Classrooms	67	80	91	104	104
PC halls	21	19	18	18	18
Exam halls	6	6	4	4	4
Education places (capacity in seats)	12.711	12.448	12.859	13.869	13.869
Lecture halls	7.056	6.262	6.272	6.268	6.268
Classrooms	2.924	3.908	4.408	5.422	5.422
PC halls	1.471	1.232	1.324	1.324	1.324
Exam halls	1.260	1.046	855	855	855

First, the overall performance across different space utilisation metrics is shown in the weeks that all studies can be compared: see Table 4.5. Over the past five years the space use has generally increased, with peaks in 2016-17 and in 2019-20. The scheduled frequency has increased from an average of 68% to 77%, enabled by more efficient scheduling. The actual frequency has increased even more – from 59%

to 74%, due to an increase of scheduled activities and a reduction of no-shows. The actual occupancy has been fairly consistent around 50% in these specific weeks. When compared to the target rates of the university, the portfolio performs adequately in terms of frequency, but not in terms of occupancy. Unfortunately, the absence of scheduled occupancy data obscures what improvements may be made. It is not possible to identify whether the movements in the actual occupancy are caused by a better 'match' of estimated attendance and capacity, by a higher student attendance, or both. It is also possible that they cancel each other out: students attend more scheduled activities, but the match between estimated attendance and capacity has worsened, or vice versa.

TABLE 4.5 Space utilisation across surveyed education spaces (week 1.3-1.4).

Portfolio	2015-16	2016-17	2017-18	2018-19	2019-20
Scheduled Frequency	68%	81%	70%	66%	77%
Actual Frequency	59%	75%	66%	61%	74%
No-shows	9%	6%	4%	5%	3%
Scheduled Occupancy	-	-	-	-	-
Actual Occupancy	49%	52%	48%	48%	52%

In Table 4.6 and Table 4.7 overviews are specified for lecture halls and classrooms. These tables show that the use of both space types differs from the portfolio average. Lecture halls have even higher scheduled and actual frequency rates than the average, of 90% and 87%, respectively. The no-show percentage in these spaces is very consistent. When compared to space utilisation targets, the scheduled and actual frequency at times exceeds the objective of 75%. This is not a desirable situation, as it may lead to less desirable outcomes in the scheduling process. Therefore, more capacity is needed. Similar to the whole portfolio, the actual occupancy rates can be improved.

In classrooms scheduled and actual frequency rates are less consistent, varying from 18 percentage points in scheduled frequency to 22 percentage points in actual frequency between years. The no-show percentage has declined since the start of the studies. This is presumably because schedulers estimate the group sizes of activities split across multiple classrooms more accurately. The actual occupancy is higher than in lecture halls, which is likely because it is easier to match group sizes to capacities in classrooms. When compared to space utilisation targets, scheduled and actual frequency rates in classrooms have at times met the objective of 75% and at other times not. Various factors have influenced these rates: the increasing student population, the space use of the shared education spaces, the addition of newly built classrooms, the introduction of new education programmes, etc. Again, the actual occupancy rates of classrooms may be improved.

TABLE 4.6 Space utilisation across all lecture halls (week 1.3-1.4).

Lecture halls	2015-16	2016-17	2017-18	2018-19	2019-20
Scheduled Frequency	79%	87%	82%	80%	90%
Actual Frequency	74%	82%	77%	75%	87%
No-shows	5%	5%	5%	5%	3%
Scheduled Occupancy	-	-	-	-	-
Actual Occupancy	48%	49%	49%	45%	50%

TABLE 4.7 Space utilisation across all classrooms (week 1.3-1.4).

Classrooms	2015-16	2016-17	2017-18	2018-19	2019-20
Scheduled Frequency	63%	81%	67%	64%	75%
Actual Frequency	52%	74%	63%	58%	72%
No-shows	12%	7%	4%	6%	4%
Scheduled Occupancy	-	-	-	-	-
Actual Occupancy	54%	55%	47%	51%	53%

Finally, the variability of the space utilisation across weeks is relevant. Figure 4.5, Figure 4.6, and Figure 4.7 show the average scheduled frequency rate, actual frequency rate, and actual occupancy rate across all education spaces for each survey. The x-axis displays the week numbers; the y-axis displays the rate. Each of these graphs allows comparison per week across years. The scheduled and actual frequency show a specific pattern: after a slightly less busy first week, week 1.2 until 1.8 follow a similar pattern with a slight peak in week 1.4. Week 1.9 and week 1.10 show very low frequency rates, as they are exam periods. With regards to occupancy, a steady decrease is observed from week 1.1 until week 1.8, reflecting a decreasing attendance as the quarter progresses. The decrease continues in week 1.9-1.10 for education activities. This does not include exams, as they were excluded from the survey to minimise disturbance. Furthermore, surveying exams was found to be less relevant, as the scheduled and actual use of exam halls is very comparable.

These graphs can also be used to explain several considerations with regards to the setup of the utilisation studies. When the first study was conducted in 2015-16, the shared view was that it should take place in the busiest period of the year. Therefore, the study was done in the first six weeks of the year. In the next years, there was a need to understand the space use across a whole quarter. These measurements have shown how the education spaces are used in exam weeks (1.9 and 1.10) when compared to regular education weeks. Those measurements also revealed that the pattern of week 5-8 was comparable to week 2-4. Interestingly, week 1 follows a specific pattern due to the start of the academic year and the start-up of some courses in week 2 instead of week 1. Therefore, since 2018-19, the study has only been conducted from week 1 until week 4.

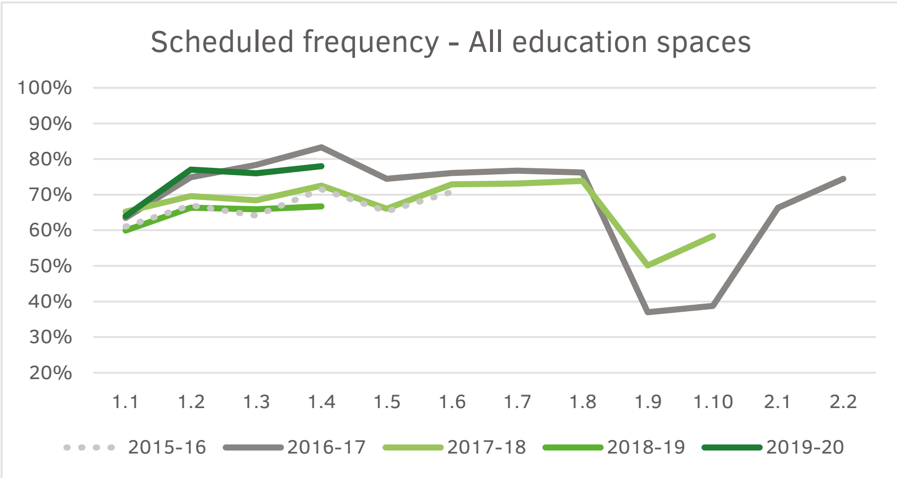

FIG. 4.5 Average scheduled frequency of the zalenpoule; per year.

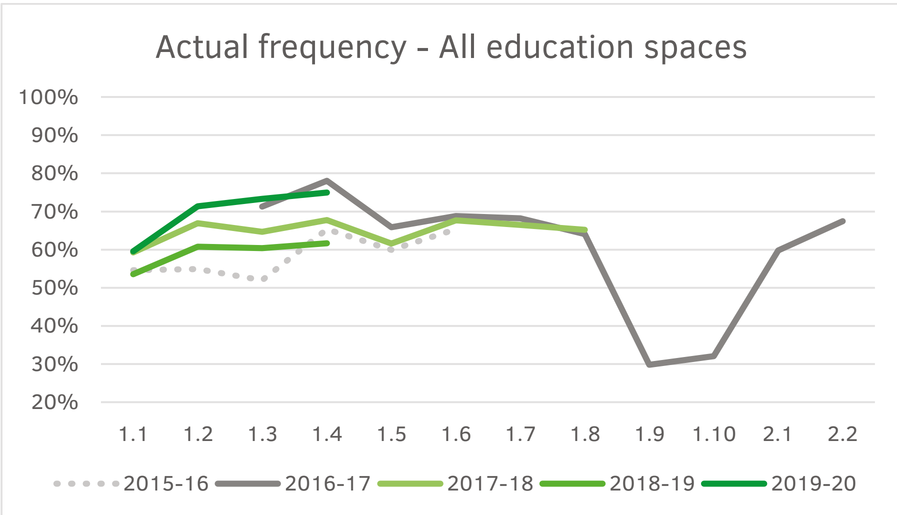

FIG. 4.6 Average actual frequency of the zalenpoule; per year.

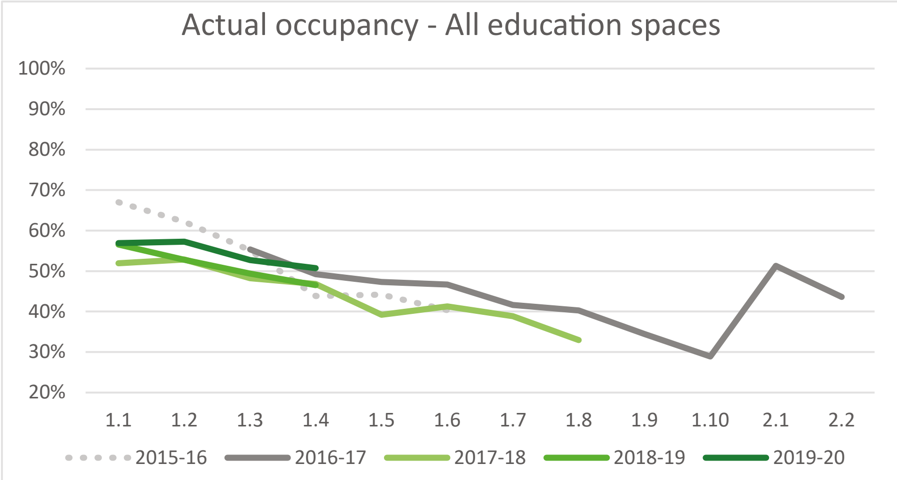

FIG. 4.7 Average actual occupancy of the zalenpoule; per year.

4.5.2 Study places

The space use of study places has been reported in different ways throughout the years. Different analyses were made: e.g. per location, per hour of the day, per calendar week, per type of study place. Here, we report the occupancy per type of study place. Like the education spaces, the student population and number of study places change each year, and thus the study places / student ratio. This development is shown in Table 4.8 together with the part of the portfolio that is surveyed. As the table shows, the study places / student ratio only includes type A, B and half of type C. Type B2, and a part of A2 are education spaces that are partly used as study places during exam periods, and not counted during education weeks. The total number of available study places is thus much larger during exam periods, and thus the percentage of the portfolio covered is larger than 100%.

The 2017-18 study differs significantly in the number of study places covered, but also in other aspects of its setup. In this study a sample of study places in faculty buildings was surveyed, as there was a need to know how well these study places were used. In the 2018-19 and 2019-20 studies the space use was surveyed across the whole portfolio. Furthermore, these studies did not measure week 1.10 (only week 1.8 and 1.9) and they divided occupancy into ‘occupied’, ‘not occupied’ and ‘occupied by belongings’. Given the differences between 2017-18 and the subsequent years, only 2018-19 and 2019-20 will be used for comparison.

TABLE 4.8 Survey characteristics compared to portfolio characteristics.

Study places	2017-18	2018-19	2019-20
Portfolio vs. Survey			
Study places / students	0,25	0,25	0,24
Total number of study places (A+B+0,5*C)	5.650	5.900	5.900
Percentage of portfolio covered in survey	45%	>100%	>100%
Survey			
A - Self study	743	823	919
A2 – Self study in PC halls		1.287	1.279
B - Touchdown	1.374	3.982	3.896
B2 - Touchdown in education spaces		1.437	1.437
C - Informal	889	2.070	2.141
Total	3.006	9.599	9.672

The occupancy for self-study places is shown in Figure 4.8, plus additional data for the other types in Table 4.9. There are large differences in the occupancy patterns of the different types – so much so that it does not make much sense to report an average. Self-study places are occupied the highest, around 70% (occupancy + belongings) most of the day. Next is type A2 with rates between 50-60%, then type B between 45-50%, then B2 and C with rates around 20-25%. Given these results, it makes sense to compare the occupancy rates for type A, A2 and B to a target of ~70%. The space use in type A2 and type B can be improved further by improving wayfinding to these study places and/or improving the study places themselves. For type B2 and C study places another target may be considered given their multi-purpose use.

A commonly observed phenomenon is that occupancy is below average in the early morning. Furthermore, as spaces become busier, the behaviour of leaving belongings to occupy study places increases. Aside from these observations, the further analysis of study places has yielded many insights. It shows which buildings are popular study locations and which are not. For the Library, the analysis delves down to a room-level to show which study places are not fully used. Also, occupancy patterns per day of the week and per week have been reviewed.

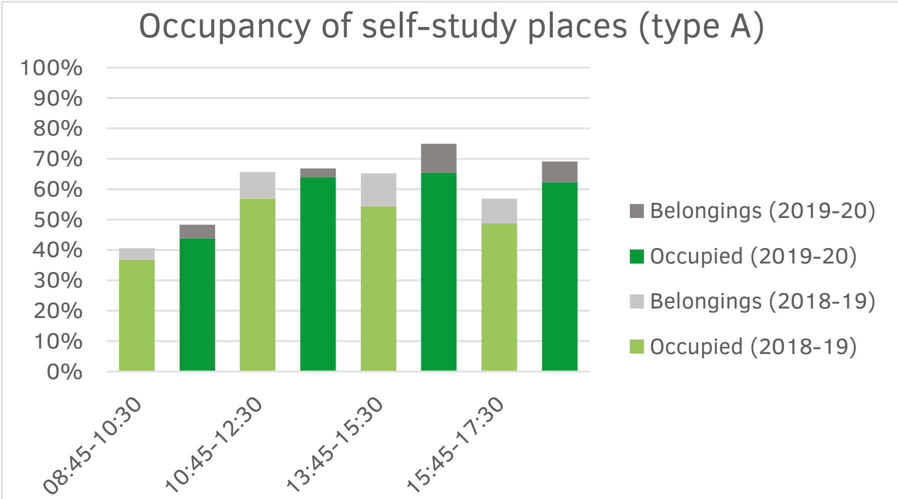

FIG. 4.8 Average occupancy for self-study places (week 1.8-1.9).

TABLE 4.9 Occupancy per type of study place (week 1.8-1.9).

Type	Year	Occupied				Occupied by belongings			
		08:45-10:30	10:45-12:30	13:45-15:30	15:45-17:30	08:45-10:30	10:45-12:30	13:45-15:30	15:45-17:30
A	2018-19	37%	57%	47%	55%	4%	9%	17%	9%
	2019-20	44%	64%	66%	62%	4%	3%	9%	7%
A2	2018-19	31%	43%	39%	44%	4%	8%	13%	7%
	2019-20	33%	44%	50%	45%	3%	2%	8%	5%
B	2018-19	20%	39%	39%	40%	3%	7%	9%	7%
	2019-20	21%	43%	46%	42%	2%	2%	5%	3%
B2	2018-19	11%	24%	22%	27%	1%	2%	2%	2%
	2019-20	8%	19%	21%	21%	0%	3%	1%	1%
C	2018-19	7%	21%	31%	18%	1%	3%	4%	3%
	2019-20	6%	20%	22%	18%	0%	3%	1%	1%

4.6 Informing decision making

The policies on education spaces and study places and the space utilisation studies together have greatly impacted the university's campus strategy. The two figures below illustrate this impact. When the Roadmap was established as the framework for the management of education spaces and study places, plans were made to move a faculty from multiple buildings to one new building, and to renovate two large buildings between 2013 and 2022: see Figure 4.9. One of these renovations would lead to a large temporary capacity reduction (2.300 seats), before resulting in a slight increase. Given the norm of seats/student at the time (see subsection 4.4.2) and the increasing student population, this reduction was not feasible. The adjustment to the high population forecast coupled with the insights into which space types and sizes were needed changed this strategy.

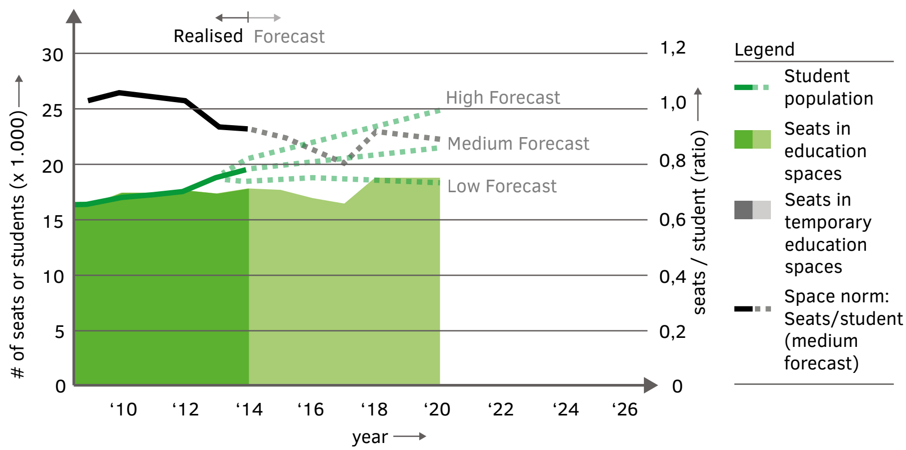

FIG. 4.9 Student population and forecast vs. the education space capacity and forecast (December 2014).

Next, Figure 4.10 shows the development up to 2019: the student population has increased more than expected, student population forecasts have changed, and more education spaces have been realised. By realising education spaces of the right sizes and making adjustments in the education logistics process, the capacity is gradually decreasing towards 0,8 seat / student. To accommodate increasing numbers of students two education buildings were planned: in 2018 (Pulse) and 2022 (Echo). Both Pulse and Echo were initiated during the adjustment of the campus strategy.

During this adjustment it was very helpful that information on the demand for education spaces could be quickly provided. Currently, it is being assessed if another building is needed around 2025.

The space utilisation studies deliver mostly additional insights to this process. In the past years the ratio in seats / student has declined and a further decline is expected. Year-by-year monitoring of the space use helps to understand the effects of this decline and provides input to discuss which ratio is desirable and achievable. Currently, the scheduled and actual frequency are mostly used in this analysis; however, in the future the scheduled occupancy rate may further detail how the match between estimated attendance and capacity may improve or worsen when the student population changes.

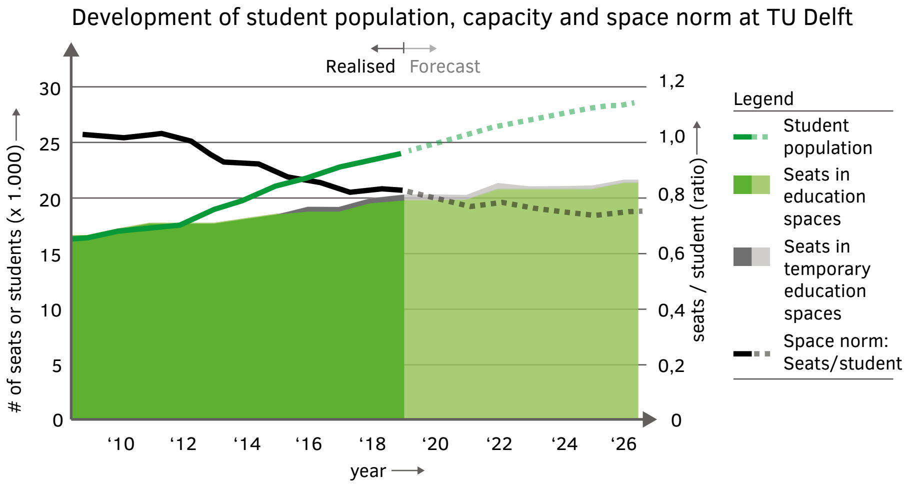

FIG. 4.10 Student population and forecast vs. the education space capacity and forecast (December 2019).

The planning of the university's study places is less strongly linked to the space utilisation studies and to the student population. In addition, space utilisation studies focusing on the use of education buildings in evenings and weekends are conducted. In consultation with the student council, the adequacy of the current capacity is determined and interventions are defined. The space utilisation studies provide necessary input for these discussions as evidence on the actual use of study places. As a result, various upgrades of existing study places on campus were realised, and opening hours of facilities adjusted to demand. A consistent count of capacity of study places and a seats/student ratio for exam weeks would improve the usability of the space utilisation studies for decision making.

More recently, the space utilisation studies have also become important input for the planning of short-term interventions. Figure 4.11 shows the planning of these processes and Table 4.10 gives an overview of the planned and additional measures per year. When the first estimations on the estimated number of students for the next academic year become available (in January), it is compared to the forecast and available capacity. If the growth is higher than expected, then additional measures may be necessary. Here, the data from the space utilisation studies shows to which extent the current spaces are used and where improvements can be made. Together with the data on the use of flexible capacity (spaces hired on demand by the university), it is determined which extra measures are needed. These are then realised during the summer months to minimise disturbance.

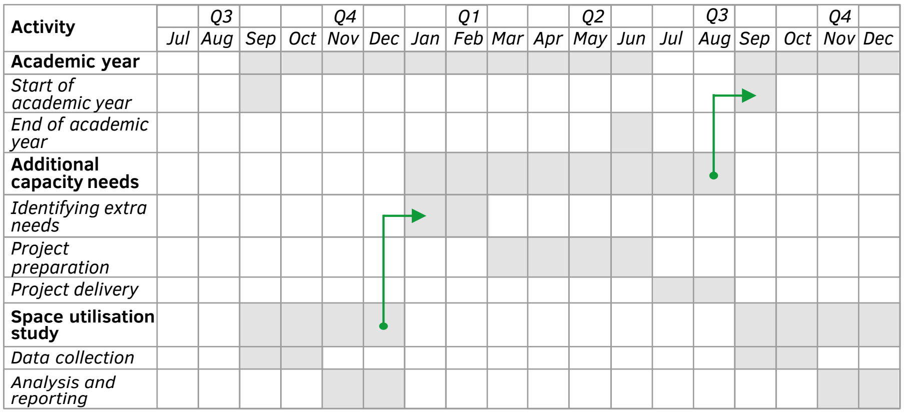

FIG. 4.11 Relation of space utilisation study to Programme Education Spaces.

TABLE 4.10 Planned mutations and additional measures per academic year.

Utilisation study	Academic year	Planned mutations	Additional proposed measure(s)	Measures
2015-16	2016-17	+200 seats -400 seats	Increase use of flexible capacity 200 seats in existing stock	Increase use of flexible capacity 200 seats in existing stock
2016-17	2017-18	-	Increase use of flexible capacity Increase use of evening hours Back-up plan for extra capacity (200 places)	Increase use of flexible capacity Increase use of evening hours
2017-18	2018-19	+1.000 seats -400 seats	Back-up plan in case of delay	-
2018-19	2019-20	-	-	-
2019-20	2020-21	-	Temporary units	T.b.d.

4.7 Conclusion and Discussion

This chapter reports on the space utilisation studies conducted at TU Delft. The study is unique as it spans a whole portfolio across multiple years, it connects the outcomes of the study to space norms and organisational decision-making, and it clearly states the setup of the study. Over the years, it has supported campus managers with evidence to make decisions about the campus of the future.

The research question posed at the outset of this research was:

RQ3: What is the space use of education spaces and study places at TU Delft, and how does it inform campus decision-making?

For education spaces, data is collected on the scheduled and actual frequency and the actual occupancy. On average, the scheduled and actual frequency rates of all education spaces fall within the university's targets. In lecture halls, it is exceeded, suggesting additional capacity is required. The actual occupancy rates are well below the target of 60% scheduled occupancy. However, due to the absence of scheduled occupancy data it is impossible to accurately determine which measures will lead to a substantial improvement of the occupancy rate. This is a limitation of the study. The information on the use of education spaces has helped to understand which number of seats/student is achievable and desirable, and thus supported decisions to increase the education capacity both on the short-term and long-term to accommodate the increasing student population.

For study places, a range of occupancy rates is reported, from 65-70% occupancy rate for type A study places to 20-25% for type B2 and C study places. The results suggest that the occupancy rates for type A, A2 and B study places can be compared to a target of ~70%, but for type B2 and type C this is difficult due to their multi-purpose use. When compared to the target, the occupancy of type A2 and B study places may be improved. The studies support continuous discussion to determine which interventions are needed and if the current capacity meets student's needs. However, more studies are needed to understand the relation between the space norms and space use of study places to set accurate targets and support decision making.

In addition to the data for scheduled occupancy not being available, a limitation of this research is the absence of data on the underlying coefficients (see subsection 2.1.4). Although it is connected to space norms for education spaces and study places (0,81 and 0,23 seats per student, respectively), these norms are not well connected to underlying coefficients. Further research connecting the space norms to underlying coefficients for e.g. planned frequency and occupancy rates or on-campus contact and learning hours is needed.

Another issue for further research is data collection and analysis. In this study, and the studies discussed in section 4.2, data collection is done via manual counts. However, manual counts are expensive, time-consuming to collect and analyse, and deliver only a snapshot of the actual space utilisation during the time of the study. Sensing methods (see chapter 5 and 6, and many other studies) offer a more complete picture of space utilisation, may improve reliability of the studies. Still, the aspects which make this study unique should also be observed in future work based on real-time counts, as they improve the reliability and external validity of these kinds of studies. Another avenue for further research is data analysis of these studies. In this study, the data analysis is fairly simple as most attention is paid to comparing year-by-year data and connecting it to decision making. However, the application of in-depth analysis of these studies can yield many other useful insights for campus managers.

Finally, an issue underlying space utilisation studies is the exact determination of capacity, particularly for study places. Not only does it influence the results of the studies, but also the determination of space norms. Especially the question how to count spaces that are not fully available as a study place needs to be addressed, both in terms of determining capacity and counting them during observations.

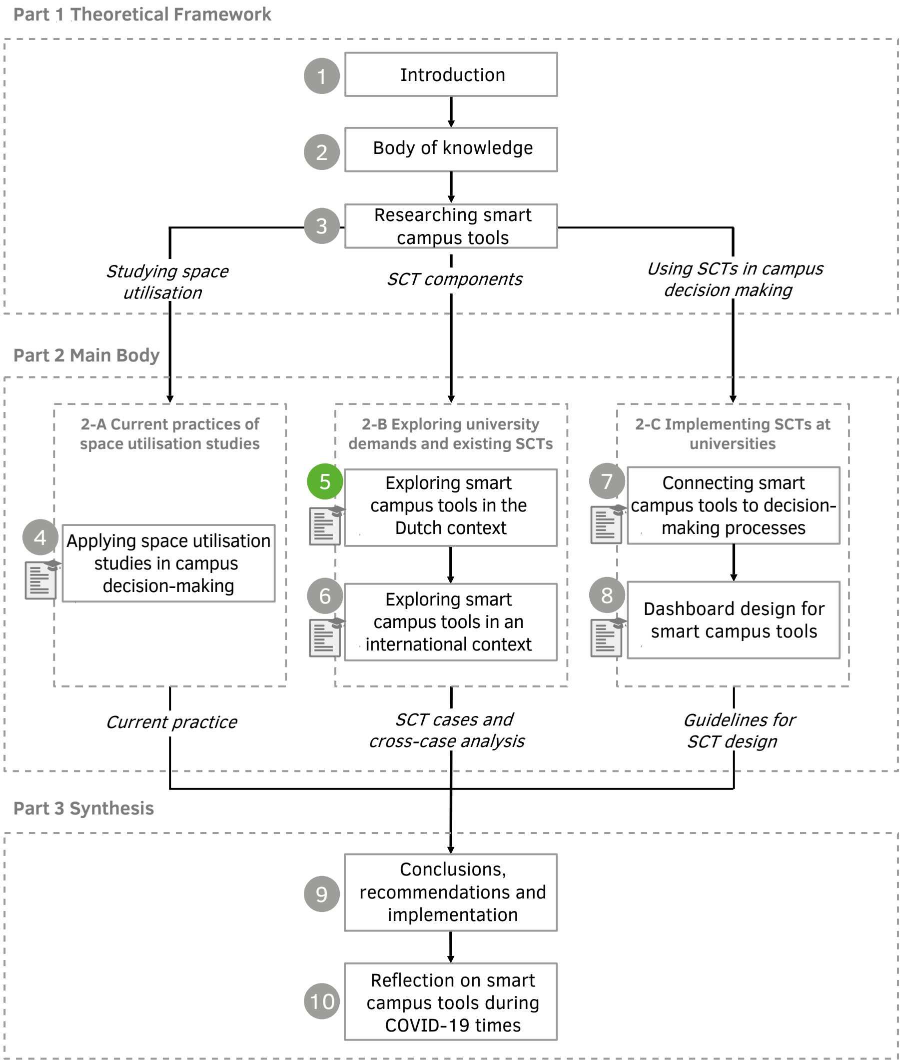

FIG. 5.1 Position of chapter 5 within the PhD research.

5 Exploring smart campus tools in the Dutch context

This chapter is an adjusted version of a research paper. The introduction has been abbreviated to omit contents already discussed in section 1.1. Although the conceptual model is already discussed in section 3.2, it is also displayed here to show in which way it was applied to this part of the research. Small textual changes have been made for the purpose of overall consistency in this dissertation.

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5.1 Introduction

This chapter presents the first explorative study of this research into the use of SCTs. The research conducted in this chapter is the outcome of a research project commissioned by thirteen campus managers of the Dutch universities (in October 2015) to explore the use of SCTs for improving space use on campus. In contrast to chapter 4, the focus of this chapter is the use of real-time data collection for frequency and occupancy rates (via SCTs) rather than manual counts.

Increasing the effective and efficient use of space has been a driver for various research initiatives. Much research has been done in the subject of timetabling approaches for courses and exams, although there is still a gap between theoretical work and the practical applications by educational administrators (Johnes, 2015). In research on the energy use of buildings, approaches have been developed to reduce the energy use by controlling lighting and/or HVAC systems via occupancy sensors, based on the variability in occupancy – see for instance Garg and Bansal (2000);

Martani, Lee, Robinson, Britter, and Ratti (2012). At the time of this study there was, to the best of the authors' knowledge, no research addressing the problem of spaces that are reserved, but not in use (see section 1.1), from the viewpoint of either the user or the campus manager.

Because there are many different ways to improve the effective and efficient space use on campus, this research focused on (1) exploring the available SCTs and (2) studying campus managers' demands regarding those SCTs. The main research question of this chapter is:

RQ4: What is the demand for smart campus tools of Dutch universities and what smart campus tools are available? [9]

To answer the research question, a survey was conducted at universities and similar organisations. Universities were surveyed regarding their demands and available SCTs; organisations were only surveyed regarding the available SCTs. At the outset of this research, SCTs were defined as follows:

"a *smart campus tool* is a service or product with which information on space use is collected real-time to improve utilization of the current campus on the one hand, and to improve decision-making about the future campus on the other hand."

A broad definition was chosen in order to survey as many SCTs as possible before analysing and structuring the results. As a result, the survey results were not only used to analyse the SCTs currently applied at universities, but also to discuss the development of SCTs and the variations in what is called a 'smart campus tool'.

The rest of this chapter is structured as follows. Section 5.2 discusses the set-up of the survey. Section 5.3 discusses the conceptual model used to structure the survey and analyse the results. The survey results at Dutch universities and at similar organisations are reported in section 5.4 and 5.5, respectively. Finally, section 5.6 concludes the chapter.

9 Though the research question of this chapter pays equal attention to the demand for smart campus tools and the available smart campus tools, the chapter places much heavier emphasis on reporting the available smart campus tools than on the campus managers' demands. In the book publication (Valks et al. 2016), the campus managers' demands are elaborated more than in this chapter.

5.2 Research methods

The survey at Dutch universities consisted of both a questionnaire and interviews and was conducted in the spring of 2016. Two interviews per university were conducted: one with a policy advisor and one with a real estate manager. A semi-structured interview approach was chosen in order to balance between providing comparable data for the universities, whilst also allowing room for further exploration. Prior to the interviews, a questionnaire was administered to collect the first results: data on occupancy and frequency rates, which SCTs are currently in use, what the objectives of the SCTs are, etc. In the interviews these results were elaborated: how were these SCTs selected, which developments are currently going on, what future demand could be expected, etc.

The questionnaire contained the following questions:

1. Which SCTs are currently in use at your university? (max. 5 entries)
   - (Per entry) What are the objectives of the SCT?
   - (Per entry) What measurement method is used in the SCT?
   - (Per entry) For which space type is the SCT used?
   - (Per entry) In which implementation phase is the SCT?

2. For which space types does your university measure frequency and occupancy rates?[10]
   - (Per space type) Which variables are measured – frequency and occupancy, scheduled and in use?
   - (Per space type) What data is reported for each variable?
   - (Per space type) What is the target for each variable?

10 The objective of this part of the questionnaire was to collect input for the problem statement of this research (see section 1.1). The outcomes of this part of the questionnaire can be found in Appendix 1.

The objective of the questionnaire was to collect the first results on the subject. With these results the interview protocol for the interviews was further specified towards the results of each university.

For the main interviews the questions were specified per SCT. Interviewees were asked to provide specifics of each tool: to show the dashboard or report, to indicate what results have been achieved, what measurement methods were used, what the reasons were to implement the tool, what the costs were, etc. Then the interviewees were asked if they were satisfied with the use of SCTs at their university, how the information from the SCTs is used in their decision-making processes and what decisions have been taken as a result, and what the desired situation regarding the use of SCTs would be in the future. Per main question a number of possible follow-up questions were drawn up. The questions were not administered in a particular order.

After the survey at the universities the interview protocol was slightly adjusted for the interviews with other organisations. First a short introduction of the research was given, after which the results at the universities are discussed. In the interview questions more emphasis was placed on the SCTs currently in use at these organisations and the specifics of these SCTs. Furthermore, rather than asking what the desired situation regarding SCTs was for their organisation, interviewees were asked what the next step should be in the development of SCTs at the universities.

5.3 Analytical framework

“The basis of Corporate Real Estate Management is the presumed added value of real estate on performance, either negatively or positively. If real estate had no impact on performance, no organisation, society or individual would spend resources on it” (Den Heijer 2011, p. 91). For universities this also applies: the land and buildings on campus should contribute to, align with or at least not hinder the institutional goals. Therefore, for campus management and CREM the use of SCTs should add value to performance.

In her dissertation on managing the university campus Den Heijer (2011, p. 245) developed a model to assess the added value of real estate decisions, from project to performance. This model is based on evolving insights on the stakeholder perspectives to connect in CREM and the different aspects in which value can be added by real estate. Figure 5.2 shows an adaptation of the model, which is used to position the reasons to implement a SCT, also in the survey and interviews with universities. The use of this model is used to assess which objectives are achieved both directly and indirectly.

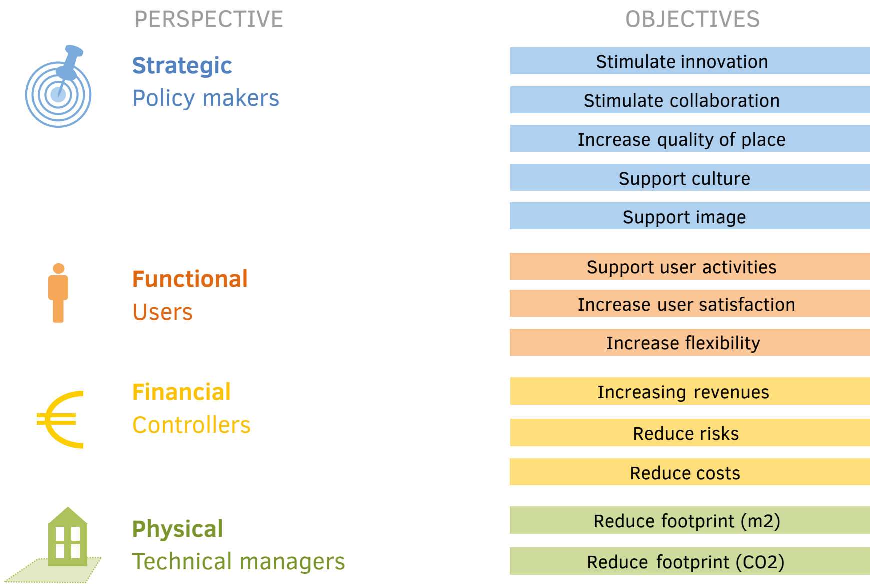

FIG. 5.2 Objectives per stakeholder perspective to add value to the campus (adapted from Den Heijer 2011).

The means to achieve these ends in the case of SCTs is to measure space use. The traditional framework used for measuring space use in CREM can be extracted from numerous reports. Space utilisation studies in academia (Beyrouthy, 2007; Ibrahim, Yusoff, & Sidi, 2011; Kasim, Nor, Masirin, & Idrus, 2012) commonly refer to NAO (1996) or Space Management Group (2006b) for a definition of space utilisation. Space Management Group (2006b) writes:

"Space utilisation is a measure of whether and how space is being used. The utilisation rate is a function of a frequency rate and an occupancy rate. The frequency rate measures the proportion of time that space is used compared to its availability, and the occupancy rate measures how full the space is compared to its capacity. Utilisation rates can be assessed in terms of both actual use and predicted use."

The utilisation rate can be expressed as follows:

Utilisation rate [%] = frequency rate [%] * occupancy rate [%]

Traditionally space use measurements are done by means of manual counts. Because this study focuses on measuring space use real-time, a definition from the perspective of indoor positioning is used. This is provided by Christensen et al. (2014, pp. 7-8) – they determine four levels in which the use of a space can be measured. Each of these levels can be aggregated in space and time. The four levels are described with four terms and questions they answer:

- Frequency: (when) is there at least one person in a zone;
- Occupancy: how many people are in the zone;
- Identity: who are the people in the zone;
- Activity: what are the people doing in the zone.

Space use is measured real-time by using various methods. In an overview of current positioning technologies, Mautz (2012, p. 107) writes that practically every type of sensor can be used for indoor positioning. Initially the survey focused on the use of Wi-Fi, passive infrared sensors, RFID, Bluetooth and Cameras based on the technologies reviewed by Mautz (2012) and a white paper by Serraview (2015).

In conclusion three aspects of SCTs are central in this study:

- The why: what are the drivers for the university to implement the SCT?
- The what: what information does the SCT collect in order to achieve the objectives?
- The how: what measurement method is used to collect the data?

5.4 Results of the survey at Dutch universities

In this section the results of the survey are summarized, starting with the current use of SCTs at Dutch universities and ending with their future demands for the development and functionality of these tools.

Current use of smart campus tools

In total 26 SCTs were identified by the 13 Dutch universities during the survey, summarised in Table 5.1. A number of SCTs are found at multiple universities, though they can differ slightly in aspects such as reporting. These SCTs are grouped together in the rows of the table.

The results in the table show that the majority of SCTs are implemented in education spaces: either in education spaces such as lecture halls and classrooms or in learning spaces such as study places, student meeting rooms or PC study places. Two types of applications are dominant: applications that help users to find or reserve available spaces and applications that monitor the use of education spaces. For the first application the users are the target group; for the second application the target group is the timetable staff or real estate managers.

The applications that help users to find available spaces on campus are mainly a result of the increasing number of students and employees on campus. Because especially the number of students has increased, universities have sought to provide information on the availability of learning places. This is done largely by monitoring the use of shared desktop PCs and by using self-booking systems for small rooms. Some universities have even started to share other space types such as classrooms and meeting rooms for studying purposes.

Furthermore, a few examples of SCTs in the office environment have been found. These applications have all been implemented on a small scale – in one case because a particular department or faculty moved from individual workplaces to shared workplaces and in the other two cases because the university wanted to gain experience with the application itself. This is in contrast with the existing applications for students, which have been implemented on larger parts of the campus.

TABLE 5.1 Summary of the 26 existing SCTs at Dutch universities, identified in the survey.

#	Space type	Application	Target group	Measurement method	Occupancy resolution	Main CREM objective
1	Lecture halls, classrooms (1x)	Real-time monitoring of space use in education spaces	Timetable staff Real estate managers	Wi-Fi	Frequency, Occupancy	Optimising (reducing) m^2 footprint
2	Lecture halls, classrooms (1x)	Ex-post monitoring of space use in education spaces	Real estate managers	Manual counts linked to each booking	Frequency, Occupancy	Optimising (reducing) m^2 footprint
3	PC classrooms (1x)	Real-time monitoring of space use in PC classrooms	Timetable staff	PC login	Frequency, Occupancy	Optimising (reducing) m^2 footprint
4	Lecture halls, classrooms (1x)	Ex-post monitoring of space use in education space	Real estate managers	Video camera (manual counts)	Frequency, Occupancy	Optimising (reducing) m^2 footprint
5-11	PC study places (7x)	Availability of desktop PCs	Users (students)	PC login	Occupancy	Supporting user activities
12	Study places (1x)	Real-time indication of availability of study places in a building	Users (students)	Video camera	Occupancy (building)	Supporting user activities
13-16	Student meeting rooms (4x)	Booking system for small meeting rooms	Users (students)	Room bookings	Frequency	Supporting user activities
17-19	Lecture halls, classrooms (3x)	Real-time indication of availability of education spaces for self-study	Users (students)	Timetable	Frequency	Supporting user activities
20	Office workplaces, meeting rooms (1x)	Real-time availability of workplaces and meeting rooms	Users (employees)	Desk sensors (Infrared)	Frequency (meeting rooms), Occupancy (desks)	Supporting user activities
21-22	Meeting rooms (2x)	Real-time availability of meeting rooms on location	Users (employees)	Room bookings	Frequency	Supporting user activities
23-24	Lecture halls (2x)	Attuning energy, lighting, ventilation based on timetable	-	Room bookings / key access	Frequency	Reducing CO_2 footprint
25	Parking spaces (1x)	Real-time availability of parking spaces	Users	Infrared	Occupancy	Supporting user activities
26	All space types (1x)	Indoor navigation via maps	Users	-	-	Supporting user activities

The second group of applications is the group that monitors the use of education spaces. As a result of the growing student and employee numbers at universities these spaces have become shared between faculties, which has resulted in the monitoring of the quality and quantity of these spaces on a campus level. In order to help campus managers and timetablers to determine if the portfolio is used effectively and efficiently some SCTs have been introduced. In addition almost all universities periodically audit the space use of their education spaces via manual counts. Two universities have mentioned these as a SCT in the survey. In one case the data from the manual counts is linked to each activity in the booking system and can therefore be reported quickly in each desired cross-section: portfolio-wide, per building or per space, but also university-wide, per faculty or per course. In the other case the university included their application as SCT because the manual counts are done via cameras that are installed in the education spaces, which makes the data collection process more efficient.

What is interesting with regard to the SCTs identified in Table 5.1 is that the universities do not require the measurement method to be real-time in order for them to be smart. Almost half of the identified SCTs do not collect data on space use real-time but via timetables, room bookings and manual counts. Rather, they seem to categorise tools as smart when they lead to an improved space use and also when they measure or report on space use in a more efficient or effective way than manual counts. All universities measure on the space use levels of frequency and occupancy.

Finally, the universities were asked to state the objectives with which the SCTs were implemented, both in the questionnaire and the interviews. In the survey the universities were asked through what objectives each SCT adds value to the campus: the results are shown in Figure 5.3. Each score in Figure 5.3 is a sum of the number of times that a SCT adds value to that objective – e.g. of the 26 existing SCTs 20 contribute to supporting user activities, whilst only 2 contribute to supporting image. This was further elaborated in the interviews based on the reasons to implement SCTs. The interviews revealed that all SCTs were implemented based on a main objective (see also Table 5.1): either to better support users, optimise the m^2 footprint or reduce CO_2 emissions. Each time a main objective is stated in Table 5.1, it is also counted in the score in Figure 5.3. Figure 5.3 shows that aside from these objectives, SCTs are also found to add value – directly or indirectly – to the campus via other objectives. Especially the strategic objectives can be seen as objectives through which value is added indirectly, which explains why they are not mentioned as main objectives. Furthermore, cost reduction is seen more as an outcome rather than an objective to steer on. The main result of Table 5.1 and Figure 5.3 is that the current SCTs have a strong emphasis on strategic and functional goals rather than financial and physical goals – adding value by improving the effectiveness of space use on campus rather than the efficiency.

The question if universities were satisfied with their use of SCTs also delivered a number of interesting insights. The tools which monitor availability of study spaces based on desktop PCs are usually implemented by the ICT department, which means that campus managers are less familiar with the cost-benefit relation in these tools. Generally, it is recognised that these tools do meet the needs of students. For self-booking systems the universities are satisfied with the use of the tools: they are relatively cheap and are very well received by users. With regard to frequency and occupancy measurements most universities are satisfied with their current practice and the results that are achieved with it, although they are interested in the option of using SCTs for this rather than manual counts. Finally there are a few universities that have recently implemented new systems – these universities indicate that they are very satisfied thus far. However, they also indicate that their implementation is still in development, and that the cost-benefit relation cannot yet be assessed because the effects of the SCT need to be measured over a longer term.

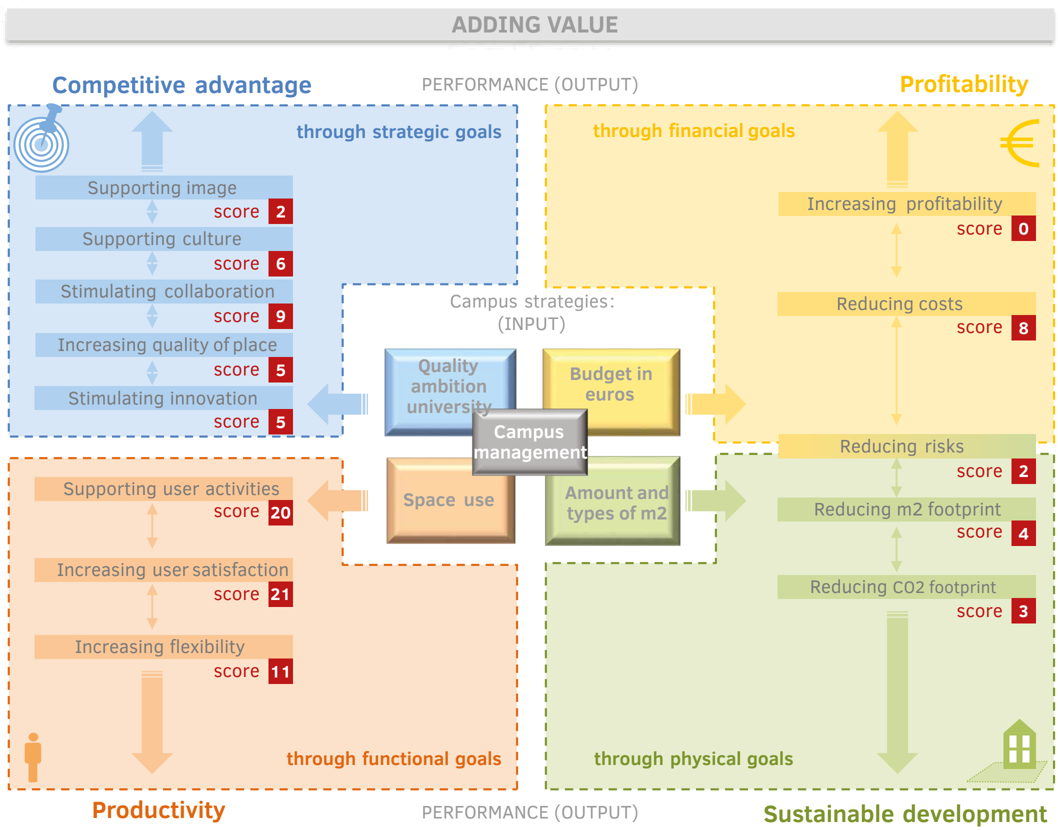

FIG. 5.3 Objectives through which the current SCTs add value to the campus, (adapted from Den Heijer 2011).

Future demand: development of smart campus tools

In addition to the existing tools universities were asked in the interviews about their future demands for SCTs. With regard to the existing tools the foreseen development is mainly to change or improve the way space use is measured. For the current SCTs that are used for education spaces about half of the universities are considering to measure frequency and occupancy rates real-time rather than via manual counts, or already researching possible solutions. For the study places a large number of current tools provides students with information on where to study via booking systems or desktop PCs. Because more and more students bring their own laptop to study on campus, the information via desktop PCs will decrease in utility; firstly, students might use the places equipped with a desktop PC without using the PC and secondly, universities are reducing the number of PCs on campus because of the reducing demand. Notably, only one university is working on a system that measures the occupancy of study places with another measurement method. For booking systems, the shortcoming is that they do not reveal actual use. Especially for the existing applications where the availability of large rooms is given to students based on a schedule, real-time information on the occupancy of these rooms is considered.

Finally, a few other additional demands have been mentioned by one or two universities: the measurement of user movements on campus to determine which users use which facilities, an indoor navigation app that shows evacuation routes in case of emergencies and an application that enables third parties to book meeting rooms on campus. The future demands stated in the interviews reveal that similar to the current demand, campus managers are focused on using SCTs to increase the effectiveness of space use on campus.

5.5 Interviews with organisations in other industries

In the interviews a number of other organisations were interviewed: two Universities of Applied Sciences (UAS), two organisations with office portfolios and the Netherlands railways. The results are displayed in Table 5.2.

TABLE 5.2 Summary of the results identified through the interviews at other organisations, per interviewee.

Space type - Organisation	Application	Target group	Measure-ment method	Occupancy resolution	CREM objective
Meeting rooms: University of Applied Sciences (1)	Interactive Room booking tool based on real-time proximity	Users	Wi-Fi	Identity	Supporting user activities
Classrooms, meeting rooms: University of Applied Sciences (2)	Combined tool – real-time space use monitoring and availability / room booking	Real estate managers Users	iBeacons (Bluetooth)	Identity	Reducing m^2 footprint (optimising space use), supporting user activities
Office buildings: Office user (1)	None	-	-	-	-
Office buildings: Office user (2)	Ex-post monitoring of building use	Real estate managers	Access gates PC login	Occupancy (build-ing level)	Reducing m^2 footprint, reducing costs
Train station: Netherlands Railways	Studying passenger behaviour to determine station capacity	Real estate managers Operational managers	Wi-Fi / Bluetooth Smart card data Cameras	Activity - movement	Increasing user satisfaction (enhancing safety, increasing ease and speed of travel, etc.)

The first interviews conducted in this series of interviews were at the Universities of Applied Sciences. The first UAS is currently developing a room booking tool that allows a user to book only when he/she is nearby the room. This is done to solve the problem that rooms on campus are booked, but not in use. By only allowing bookings based on proximity, the user is more often able to find a nearby room and the demand for space is not influenced by unused bookings. The location of the user is determined via the Wi-Fi network. By positioning the user the app is able to determine if the user is nearby and if he/she can book the room. According to this interviewee the next step for the universities would be to develop apps that interact with the user, like this example. Another example of interactiveness is to help users find spaces based on the attributes of the spaces on campus and the users' preferences for these attributes (Priestner, Marshall, & Modern Human, 2016). Interactive apps make the user aware of their behaviour – in this case claiming space – and help to solve the problem because users change their behaviour as a result.

The second UAS is in the process of implementing a SCT which is used both for room booking and monitoring of space use based on real-time measurements. The main objective of the tool is to close the planning and evaluation cycle of the timetabling process at the university. With the tool the university is able to determine to what extent the timetable is actually used in practice: not only in terms of frequency and occupancy, but also if a booking is used by the right group of students. By doing so the UAS hopes to minimise the gap between predicted (timetabled) use and actual use. This is done via iBeacons that are placed in each room. The students and employees connect to these iBeacons via the Bluetooth connection of their smartphones. This is enabled via an app, which users can install to book rooms and find study places on campus. The next step for universities according to the interviewee is a similar application – improving the efficiency of space use further on campus is possible through SCTs, but they should also contain benefits for the users on campus.

The other two applications of SCTs, at the office user and Netherlands Railways (NS), are both tools, which collect real-time information on the building in order to inform real estate managers and/or operations. At Netherlands Railways a number of SCTs based on pedestrian flows are compiled in a programme called Smart Stations (Daamen et al., 2015). These SCTs measure how large numbers of users use the train stations in the Netherlands: via Wi-Fi, Bluetooth, cameras and smart card data movements are analysed to determine where congestion occurs. The objectives of Netherlands Railways are not only to make better decisions on investment in stations, but also to monitor if safety regulations in station areas are met. However, Netherlands Railways defines the performance of stations in terms of their value towards the user – therefore supporting the user is mentioned as primary objective in table 5.2 (Van den Heuvel & Hoogenraad, 2014, p. 643). Adjustments are made if necessary – e.g. changing train stopping positions can help to reduce congestion on platforms. Netherlands Railways also determines occupancy on a high level (activity), and has set very high requirements to ensure the privacy of the users tracked.
The organisation with a large portfolio of offices monitors the use of these office buildings by combining multiple data sources: the data of access gates and pc login, combined with data on the number of employees registered per location are used to determine which buildings are used efficiently and which are not. Both organisations suggest that the next step for the universities could be to implement solutions that use multiple sensors to better determine space use on campus.

The interviews with end users in other industries show that the implemented SCTs are directed more towards informing management – to improve the efficiency of operations and/or the efficiency of the real estate portfolio – than towards supporting users, which is more common at universities. This is a type of tool that is demanded by numerous Dutch universities – especially for education spaces. In addition, all interviewees indicate the importance of addressing privacy issues.

5.6 Conclusion and discussion

Both the current SCTs and the future demand the Dutch universities are focused on using space more effectively through SCTs. The primary function of the existing SCTs is to support users – mostly students – to find available spaces on campus. A few SCTs are also aimed at monitoring the use of education spaces. In other industries the results of the interviews suggest a larger emphasis on efficient use of space.

In the future Dutch universities foresee an increase in use of real-time measurements: both in SCTs that help users to find available spaces on campus and in monitoring the use of education spaces, which is currently still done manually at most universities. Of the solutions found in other industries -especially the SCTs of the UAS- provide helpful alternatives for this demand.

The development of SCTs at Dutch universities is displayed in Figure 5.4. Initially universities monitored their space use via FMIS and timetabling systems. Then most universities started auditing the use of their education space because - due to the increase of students - education spaces had to be shared on a campus level. Also they started to provide systems to show the availability of desktop PCs and project rooms to help students find an available space. Recently – in 2015 and 2016 – SCTs have been introduced at some universities in which classrooms and meeting rooms are made available for studying when not in use; additionally, one university has started to monitor the space use of education spaces real-time.

The future demand is that these developments will continue – real-time information will be used more to monitor the use of education space, but also to provide information on available study places. The organisations in other industries give a number of suggestions for the next phase: to develop SCTs that interact with the user, to integrate the functions of monitoring space use and helping users to find spaces, and to combine multiple data sources. However, as the interviewees from other industries indicate, these solutions will raise questions on how privacy issues are dealt with. Just like most of the interviewed parties, universities are very sensitive on this topic and as public organisations they set high requirements regarding the use of personal data. The implementations at the UAS using iBeacons and the university using Wi-Fi provide interesting cases on how the end users perceive this development and if the benefits outweigh the costs.

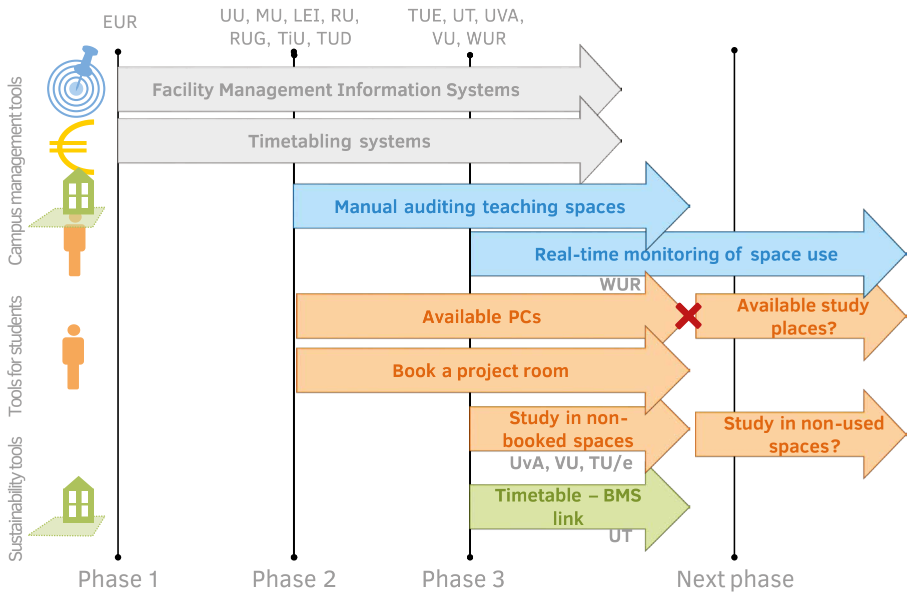

FIG. 5.4 Development of SCTs at Dutch universities.

At the outset of this research the definition for SCTs was: “a *smart campus tool* is a service or product with which information on space use is collected real-time to improve space use on the current campus on the one hand, and to improve decision-making about the future campus on the other hand.” During the research different uses of the term SCTs were found. To explain how these definitions differ, the process of improving space use via SCTs has been outlined in Figure 5.5.

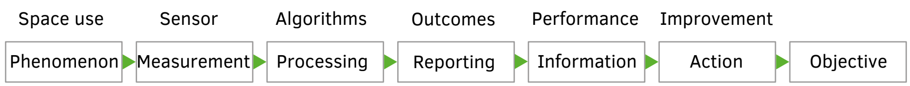

FIG. 5.5 Components of improving space use via SCTs.

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The steps taken in this process are:

- Space use is measured– e.g. by Wi-Fi which measures x devices with y locations;
- The data is processed via algorithms – e.g. a conversion factor for devices per user, triangulation to determine location;
- The results are reported – e.g. x users in y1 education space;
- The results are converted to information – e.g. 50% frequency rate during the year in education space y1 as opposed to 75% in the timetable;
- An action is taken based on the information to achieve the objective – e.g. the bookings in the education space are reviewed critically with the users.

The tools identified as SCTs in this research can be categorised into three types. The first types are SCTs that do not measure space use real-time, but are an improvement when compared to manual counts because they improve on specific aspects of measurement or reporting. This type of SCTs measures space use manually, but the measurement of data, processing, reporting and/or resulting information are done more efficiently or effectively than in traditional utilisation studies. The second types are SCTs that measure space use real-time or near real-time (certain booking systems) and which process and report these measurements to deliver information to the user or manager. The user then determines what action to take in order to achieve the objective. This definition applied to almost all SCTs found during this research. The third types are SCTs that measure space use real-time, which process and report these measurements to deliver information to the user and which actively influence the action taken by the user or automate an action. One example of such a SCT was found, at one of the UAS. The variability in the definitions of SCTs used reflects the ongoing development of the matter at both universities and other institutions.

Summarizing, the results suggest that SCTs contribute to university goals and have even more potential to improve CREM at universities. Therefore the research continues to explore SCTs, supported by Dutch universities who acknowledge the (potential) role of real-time space use information in decision making about today's campus and the campus of the future. Further research could be done on the use of SCTs in other countries, but also on the development of the existing SCTs at Dutch universities. Special attention needs to be paid to how organisations deal with privacy issues and how users perceive different SCTs with regard to their measurement methods and benefits.

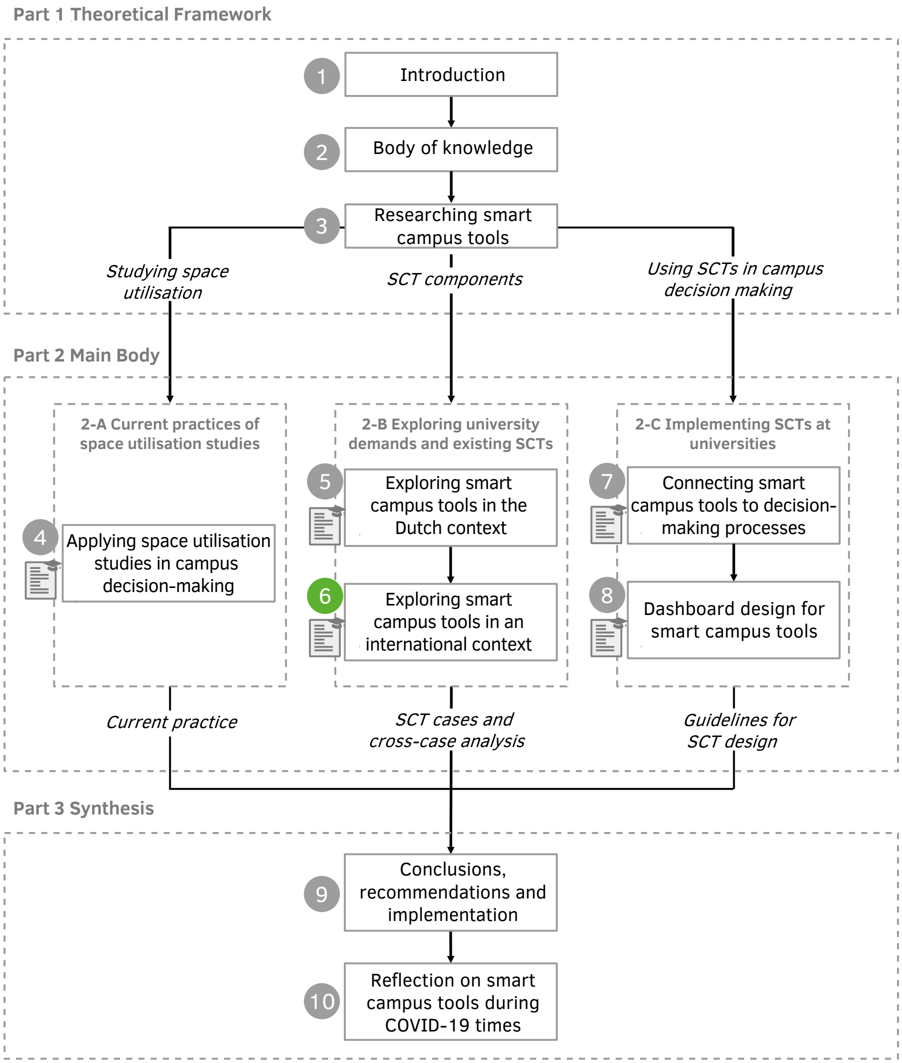

FIG. 6.1 Position of chapter 6 in this research.

TOC

6 Exploring smart campus tools in an international context

This chapter is an adjusted version of a research paper. The introduction has been abbreviated to omit contents already discussed in section 1.1. Although the conceptual model is discussed in section 3.2, it is displayed here to show in which way it was applied to this part of the research. Small textual changes have been made for the purpose of overall consistency in this dissertation.

Valks, B., Arkesteijn, M.H. and Den Heijer, A. (2019), “Smart campus tools 2.0 exploring the use of real-time space use measurement at universities and organizations”, Facilities, 37(13), pp. 961-980. https://doi.org/10.1108/F-11-2018-0136

6.1 Introduction

This chapter reports on the second study of SCTs at universities and other organisations, following the first study as discussed in chapter 5. Based on the findings of chapter 5, a second research project, Smart campus tools 2.0, was commissioned by the campus managers of Dutch universities. The aim was to explore the use of SCTs at international universities and other CRE organisations. In this research project the development of the conceptual model is expanded, not only viewing the studied cases of SCTs in isolation but also looking at the surrounding context.

Perhaps typically for the current stage of development of SCTs, most scientific publications present the development of new or improved systems. Therefore, applications are essentially small-scale tests and most papers consider performance criteria such as accuracy and apply the systems on a relatively small scale – e.g. a room or floor. Similarly, studies in semi-outdoor environments report experiments done during an event of a few days. Mathisen, Sorensen, Stisen, Blunck, and Gronbaek (2016) argue that the limited scale is an issue from a technical perspective: because there is a lack of extensive evaluations of systems in large-scale real-world environments, system performance results (i.e. accuracy and related metrics) may differ when transferring systems from a small controlled setting to a large environment. Furthermore, another issue is that systems are still primarily evaluated from a technical perspective and not yet from a functional perspective (this is further detailed in chapter 7). In order to know if and how SCTs actually support users, save energy or help make better decisions on the future campus, data needs to be collected on real-life implementations.

To resolve the above problems, this study has collected data of 27 real-life cases, which illustrated how SCTs are implemented in practice, thereby providing valuable knowledge to researchers developing new systems. Simultaneously, it helps to develop knowledge on SCTs from a FM/CREM perspective – a subject still sparsely researched. Therefore, the research question of this chapter is:

RQ5: Which smart campus tools are being used by international universities and CRE organisations and how do they compare to the wider use of SCTs in the Dutch context?

The remainder of this chapter is structured as follows: first, section 6.2 discusses the research strategy and interview set-up. Then, section 6.3 discusses the conceptual model used to structure the interviews and interpret the results. Section 6.4 discusses the results of the data collection, first reporting the results on the structured aspects of the data collection and then the results on the semi-structured aspects. Finally, section 6.5 discusses additional findings, followed by the conclusion in section 6.6.

6.2 Research methods

The SCT research can be framed within a naturalistic system of inquiry. The researchers recognise that there is an inherent dynamic between the researchers, the practitioners and the object of study (Groat & Wang, 2002, p. 33); this is reflected in the explorative nature of the study and the objectives. SCTs can be viewed as a concept that is constantly developing – because of advances in technology, changing demands of campus users and managers, and because of increasing insight on the part of the researchers.

In order to answer the research question a qualitative research strategy is chosen. Qualitative research studies things in their natural settings, focuses on interpretation and meaning, focuses on how respondents make sense of their own circumstances and uses multiple tactics (Groat & Wang, 2002, p. 176). SCTs are part of a very complex system in which organisational, technological and behavioural factors together determine if real estate is used more effectively and efficiently. In order to understand if SCTs add value to the university campus, they must be understood within this complex system. In addition, because SCTs are relatively new, collecting quantitative data on their added value would be premature. Table 6.1 shows how the qualitative research strategy is applied in this research.

TABLE 6.1 SCT 2.0 research and characteristics of qualitative research.

Characteristics of Qualitative research	SCT 2.0 research
Studying things in their natural settings	By studying SCTs from the perspective of campus managers the data collection focuses on SCTs when 'in use'
Focus on interpretation and meaning; Focus on how respondents make sense of their own circumstances	By addressing aspects such as the relationship between SCTs and the development of the university and its campus, experiences during implementation etc. ; Developing the interview protocol and reviewing results together with practitioners
Use of multiple tactics	(Semi) structured interviews, with a differentiation in structured and semi-structured data collection.

The research consists of three major components: (1) a survey of international universities, (2) a survey of other organisations (e.g. governments, companies, hospitals, etc.) and (3) a survey of Dutch universities. For the surveys an interview schedule is developed and used to fill in a standardised 'template' describing the case and all the relevant aspects. The schedule has been developed based on the findings of the previous year and by consulting practitioners on their information requirements, and it contains both a structured and a semi-structured part. The structured interview questions are used to collect information on the aspects of SCTs that are understood, whereas the semi-structured questions are formulated in a more open way to allow for new insights to the conceptual model.

For the survey of international universities and other organisations the interviews are administered in one or two sessions, either physically or by telephone. An organisation can fill in multiple templates if they have multiple SCTs implemented. For the survey of Dutch universities, the interview schedule is filled in with the data from the previous research (see chapter 5) and sent to the universities with the request to update the data. The update of the data is done either individually or together with the researcher and the results are discussed during an expert meeting of the Dutch universities in November 2017 for which all interviewees are invited.

The case selection for each of the surveys is based on various methods. For the international universities desk research was done to find universities that were using SCTs for study places. For other organisations news alerts were used to discover cases in which SCTs were applied. Furthermore, 'snowballing' was used to increase the sample size: by asking fellow researchers and practitioners for suggestions and by asking interviewees for suggestions. For the survey of Dutch universities there was no case selection process; all universities were requested to fill in the survey and update the data recorded in the previous research.

6.3 Constructing the conceptual model

The development of a conceptual model has been an ongoing process from the outset of the SCT research, building theory as the research progressed. First, an initial definition was formulated: “a smart campus tool is a product or service that collects real-time data to improve space use on the current campus and decision-making about the future campus.” This definition was further elaborated in a why, how and what. These are shortly explained below; for further information see chapter 5:

- The why: why would a university implement a SCT? Just as with real estate, the basic assumption with SCTs is if they would not add value to the university campus, no university would invest in it. In order to understand how SCTs add value, a model of Den Heijer (2011) is used that identifies the added value of real estate decisions. Four stakeholder perspectives are defined, each with their own objectives through which added value can be measured;

- The what: what data must the SCT collect in order to achieve the objectives? In order to understand what data is collected, traditional space use frameworks of NAO (1996) or Space Management Group (2006b) are complemented by an indoor positioning framework provided by Christensen et al. (2014, pp. 7-8). Four levels of space use are defined, which Christensen et al. term ‘occupancy resolutions’: frequency, occupancy, identity and activity, which can each be aggregated in space and time;

- The how: how can space use be measured real-time? A study on indoor positioning methods by Mautz (2012) and a white paper by Serraview (2015) are used to generate a list of possible technologies that can be applied.

During the survey of Dutch universities reported in chapter 5 the question of what makes a tool ‘smart’ arose. Despite the assumptions in the data collection about what constituted ‘smart’ –measuring real-time rather than on demand, accessibility via the internet rather than locally and open access rather than restricted access to campus managers- some interviewees regarded different aspects to be ‘smart’. The observation that SCTs are subject to varying definitions and interpretations aligns with literature on smart buildings; Buckman et al. (2014) write that there is confusion about what is an intelligent building and what is a smart building. The development of these interpretations is also described by Kastner et al. (2005) and Wong et al. (2005). With regard to smart cities, Gil-Garcia et al. (2015) observe that there is not a dichotomy between ‘being smart’ and ‘not being smart’ but that it is a continuum in which managers think about how to improve the city to a better place and that the concept of smart city is still in full development. The same observation applies to smart campus (tools): it is a continuum or mindset used by various stakeholders on campus to make the campus a better place.

As the research progressed, more aspects were found to be relevant to study and integrate into the conceptual model of SCTs. Practitioners wanted to know if and how the EU’s General Data Protection Regulation (GDPR) would affect SCTs, what the costs and benefits of different types of SCTs were, what the interfaces of different SCTs look like and what management information is generated. SCTs –and whether they are ‘smart’ or ‘not smart’- can be viewed from many different perspectives, which is visualised in Figure 6.2. The aspects in the inner circle will be elaborated further in the results section of this chapter.

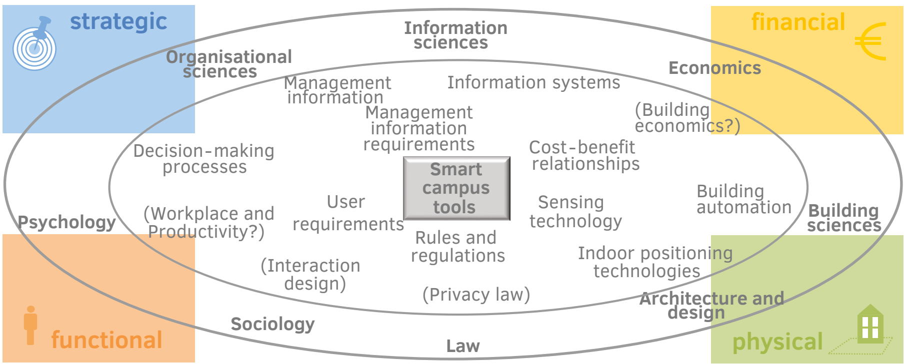

FIG. 6.2 SCTs and related fields of (applied) research (based on an adaption of Den Heijer (2011)), reflecting the multidisciplinary nature of the research topic.

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6.4 Survey results

This section is divided into three parts. The first part discusses the results and analysis of each case. Then, the structured data collection is reported, focusing on the aspects of SCTs. Finally, the results of the semi-structured data collection are reported, and the focus will shift to understanding SCTs in their respective contexts. The data collection yielded much information that is not discussed in this chapter – for a more detailed analysis we refer to the book publication (Valks, Arkesteijn, & Den Heijer, 2018).

6.4.1 Case studies

In the survey of international universities a total of 26 universities were approached to participate. 12 universities responded which resulted in 9 cases at universities (one university delivered two cases of SCTs, four universities did not have any SCTs in use). In the survey of other organisations a total of 14 other organisations were approached to participate. 8 other organisations responded, which resulted in 9 cases at other organisations (one organisation delivered two cases of SCTs). In the survey of Dutch universities all 14 Dutch universities were approached to participate. All universities responded, resulting in 9 cases (one organisation delivered two cases of SCTs). In summary, 54 universities and organisations were approached to participate, leading to a total of 27 cases.

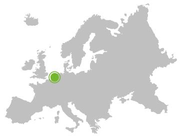
In order to illustrate the results of the case studies, we provide an example in Figure 6.3 and 6.4. The case shown here is the development and implementation of a SCT called 'Plekchecker' by the Dutch government. It was initiated after the government had implemented a new policy for the governmental workplace. In order to help employees find a workplace, the Plekchecker was developed. At the time of the interview, it was just being implemented in a major office building.

NLG-1 | Dutch government | Plekchecker

phase: Implementation

scale: 80.000 m2, 1 building

duration: July 2017-present

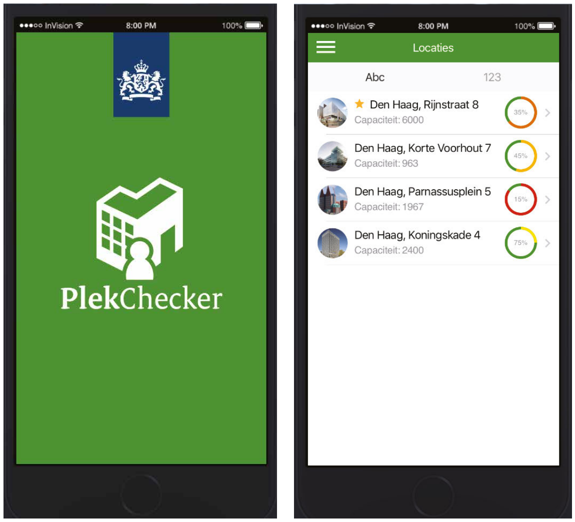


Project description

The initiative was started because of the implementation of the I-strategy of the government, the governmental accommodation system and the furbishing of the office at the Rijnstraat. In that building the norm will be 0,7 workplace per 1 employee. The development of the smart tool was started to help users find a workplace. First this was done within the organisation, but later an external party was added. The Plekchecker is foremost developed by the government and partly by an external party.

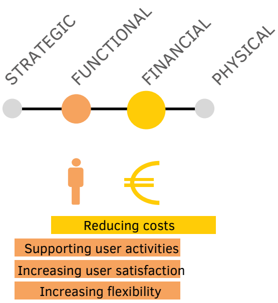
Foreseen developments

The foreseen developments are (1) complying with all our requirements; (2) expanding to more buildings; (3) determining if investment is needed in current and future wishes with regard to the smart tool.



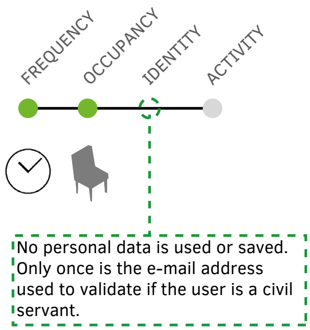
Profile

Why: Objectives



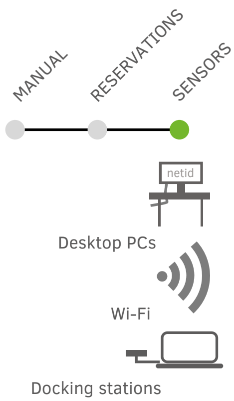
Financial objectives have priority, they are achieved by reducing the amount of offices and using the existing space more effectively.

What: Measurement



Via the Wi-Fi network an indication is given of the occupancy on floor-level. On zone level the data of port replicators and desktop PCs is used.

How: Measurement method



Wi-Fi measures the amount of devices inside a building that tries to connect with the network. Via desktop PCs and port replicators/docking stations the use of these devices can be detected, and thereby the frequency.

FIG. 6.3 Overview of the results for one of the cases in the research; page 1.

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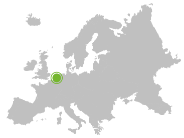
NLG-1 Dutch government Plekchecker

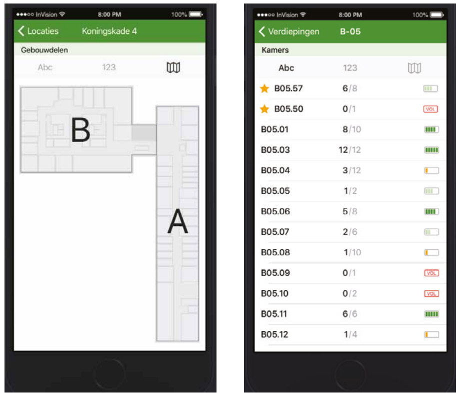
functionalities
Find a workplace, monitoring space use

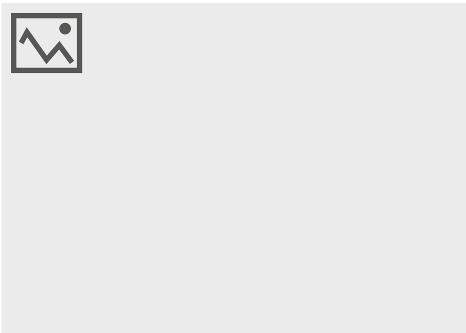
space types
Whole building



User information (employees)

The user sees a list with buildings, in which it it possible to click further to lists of floors and defined zones per floor. Per floor an indication of the occupancy is visible. There are also floor plans available, but they are still separated from the real-time data.

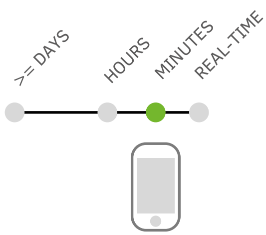




Management information

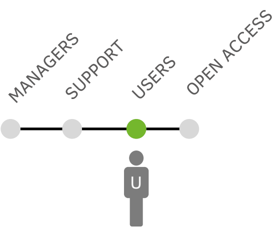
The occupancy reports based on the collected Plekchecker data has not been developed yet. At the moment there are talks with facility services providers about the form of these reports. This functionality will then be developed in a separate development process.

Actuality of the information



The information is updated every few minutes (ca. 3 minutes) in the Plekchecker.

Access levels



Employees that are serviced by the government's ICT shared service centre.

At the moment we are exploring how to shape different roles in the tool.

Benefits

In the business case a calculation has been made of the time that a civil servant spends on finding a workplace to indicate the potential savings. It is not possible to report on that yet - in the future the savings will be in the adjustment of spaces with low utilisation or in adjusting the way we work (e.g. spreading meetings over the week).

Side notes

Wi-Fi makes it possible to show the occupancy within 5-10 meters. With algorithms this information is displayed in zones, with a reliability of 90 percent. That determines the size of the zone, which in some cases can become too large to offer the users the level of detail they desire.

FIG. 6.4 Overview of the results for one of the cases in the research; page 2.

For each case, the result of the interview(s) was a completed table containing both short, concise answers to structured questions and textual descriptions and images to semi-structured questions. This table underlies the two-page overview displayed in Figure 6.3 and 6.4. Analysis of the structured output mainly reveals how far along each case is in the development of SCTs: how many objectives are achieved, is the SCT already implemented, how many m^2 are covered by the SCT, etc. By comparing these aspects across cases, the development of the cases relative to each other is assessed. Analysis of the semi-structured output gives additional contextual information next to the progress in the development: why was the project initiated, what are the next steps, what user information is available, etc. By comparing these aspects across cases, the development of the SCTs phenomenon can be put into context. In the book publication the cross-case analysis is done across cases; here, the cases are grouped in international universities, other organisations and Dutch universities.

6.4.2 Results of the structured data collection

In Table 6.2 the aggregated results on the most relevant aspects of the structured data collection are displayed. When studying the functions of the SCTs in the cases the following observations can be made. With regard to functions the SCTs at international universities are highly diverse; furthermore each case tends to focus on one specific function. Other organisations have a more unified approach to SCTs, in the sense that find a workplace and monitoring space use are present in most cases. However, organisations tend to combine multiple functions in their SCTs. Dutch universities have the most unified approach, focusing on either monitoring space use or supporting users through a combination of finding a study place, room booking and/or wayfinding. With regard to the phase in which the SCT project finds itself, the Dutch universities and other organisations are often further when compared to international universities. Also, at universities in both the Netherlands and abroad research initiatives related to SCTs are included as cases.

TABLE 6.2 Cross case analysis showing the aggregated results per survey.

	International universities	Other organisations	Dutch universities
Functions			
Monitoring space use	4	6	6
Find a study place	4		5
Find a workplace		7	
Room booking		4	5
Optimise workplace comfort	1	2	
Wayfinding	1	1	3
Other	2 (People finding, linking systems to reduce energy use)	1 (Increasing employee productivity)	
Phase			
Implementation	2	4	5
Pilot	2	2	1
Design brief	3	1	2
Research project	2		1
Unknown		2	
Sensors and functions			
Monitoring space use	Infrared sensors (1) Wi-Fi (1)	Wi-Fi (3) PC login (2) Infrared (2) Cameras (1) Access gates (1)	Wi-Fi (4) Schedule data (1) T.b.d. (1)
Find a study place	iBeacons (1) No measurement (1) Multiple sensors (1) Access gates (1)		Infrared (2) Schedule data (3) PC login (2) T.b.d. (1)
Find a workplace		Wi-Fi (4) PC login (2) Workplace check-in (2)	
Room booking		Infrared (3) Workplace check-in (1)	Infrared (2) Schedule data (3) T.b.d. (1)
Optimise workplace comfort		Temperature, CO_2 (2) * Coded light (1) ****	
Wayfinding			Not applicable ***

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TABLE 6.2 Cross case analysis showing the aggregated results per survey.

	International universities	Other organisations	Dutch universities
Occupancy resolution and functions			
Monitoring space use	Frequency (2) Occupancy (2)	Frequency (4) Occupancy (6)	Frequency (6) Occupancy (5)
Find a study place	None (1) Occupancy (4) Identity (1)		Frequency (4) Occupancy (4)
Find a workplace		Occupancy (6)	
Room booking		Frequency (4)	Frequency (5)
Optimise workplace comfort		N.a. **	
Main CREM Objective(s)			
Supporting user activities	6	7	3
Reducing m^2 footprint	2	2	4
Reducing CO_2 footprint	1	2	
Optimising costs		1	
Not specified			2

* *One case also measures these values but has not yet linked them to a specific function*

** *Temperature and CO2 values are not used to infer frequency or occupancy but to relate to indoor climate preferences.*

*** *The possible relationship of sensors to determine positioning for wayfinding purposes is not studied.*

**** *Coded light is a technology that communicates with the device of a user his/her position in the building and the amount of emitted lighting which the user can adapt.*

When looking at the sensors and occupancy resolutions, cases are comparable if they have the same functions. This is possible for finding study places, monitoring space use, room booking, optimising workplace comfort and wayfinding. At international universities it is quite simple to make this analysis, as each case usually focuses on one function. For other organisations and to a lesser extent Dutch universities this is more complicated: there are more cases of SCTs that provide a range of functions, which makes it more difficult to link the findings of sensors and occupancy resolutions to the functions within these SCTs. Table 6.2 shows the sensors used per function, and shows that for each function and within each survey there are multiple types of sensors that are used rather than there being very dominant sensor-function relationships. The most dominant relationships present are the use of Wi-Fi for monitoring space use (and for finding a workplace at organisations, which they combine in the same SCT) and the use of infrared sensors in meeting rooms.

For occupancy resolutions the following rules generally apply to each function:

- For finding a study place or workplace occupancy is measured, with the exception of sharing other spaces (classrooms) for studying, in which case scheduling data is used to indicate if the room is free or not (frequency);
- For the monitoring of space use in education spaces both frequency and occupancy are measured;
- For the monitoring of space use in workplaces occupancy is measured;
- For room booking and monitoring space use in meeting rooms the frequency is measured.

Finally, with regard to the main CREM objectives stated by the interviewees the majority of the cases at international universities and other organisations mention supporting user activities as the main objective. At Dutch universities reducing the m^2 footprint has the highest priority. However, when compared to the functions provided in the SCTs it seems that there is a slight misbalance; at other organisations one would expect a more equal priority for supporting user activities and reducing the m^2 footprint, and at Dutch universities a slight majority for supporting user activities. Based on the more elaborate findings on CREM objectives (see the book publication) one can conclude that at international universities functional objectives are dominant; at Dutch universities functional and physical objectives are equal; and at other organisations strategic and functional objectives are dominant, whilst physical and financial objectives are often mentioned.

6.4.3 Results of the semi-structured data collection

The aggregated results of the semi-structured data collection are shown in Table 6.3. In the project description the interviewees indicated the reasons for initiating the SCT and why they chose a specific solution. At international universities, the responses show a very high diversity in terms of what problems were indicated by the interviewees, as well as a high diversity in the solutions that they intend to develop or have already implemented. At organisations, the solutions are more alike and similar in what they measure and their objectives, although the reasons for initiating the SCTs vary slightly. A possible explanation for this is that organisations commonly have the office as their primary type of space, for which more standardised solutions already exist than for education spaces. However, at Dutch universities, both the problems mentioned by the interviewees and the solutions that are intended or implemented are very similar. What could play a role here is that the Dutch universities have previously conducted research as a group on SCTs, and that there is a lot of knowledge exchange between colleagues working in real estate management of Dutch campuses.

In the foreseen developments, interviewees make mention of what next steps are intended with the SCT if applicable. The fact that many cases indicate some form of development shows how topical the application of SCTs is and how fast-paced the development is going. With regard to foreseen developments, the components mentioned amongst the different surveys are very similar.

TABLE 6.3 Cross case analysis showing the aggregated results per survey.

	International universities	Other organisations	Dutch universities
Initiation and chosen solution (project description)	There is a diversity in the problems that the universities are facing (or rather focusing on) and the intended or implemented solutions. Even for similar problems the surveyed universities tend to develop different solutions.	The solutions seem relatively similar in the sense that they measure space use to support users and optimise space use and in some cases also to save energy. However the interviewees have stated different reasons for initiating their SCTs, and solutions differ slightly in if they focus on workplaces, meeting rooms, or both.	The cases displayed reveal that the Dutch universities are focusing on two main problems in their portfolios for which they have implemented similar solutions.
Foreseen developments	**6/9**	**7/9**	**7/9**
Expansion (more buildings)	2		3
Adding additional functions, sensors, information to the SCT	2	3	5
Development of a user app		3	
Other	2 (Analysing space use data in relation to study success)	2 (use of data for further optimisation of the building)	3 (Linking the SCT to other information systems)
Costs	Anonymised comparison; 9 cases indicate investment costs / m^2, ranging between € 0,7-18 / m^2. 5 cases indicate operating costs per m^2, ranging from € 0-1,9 / m^2.		

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TABLE 6.3 Cross case analysis showing the aggregated results per survey.

	International universities	Other organisations	Dutch universities
Benefits	**6/9**	**7/9**	**7/9**
Optimising m² use	1; evaluation through occupancy data of different locations	1; through informing the estate strategy and advising users 1; evaluation of target set in design brief. 1; evaluation through frequency and occupancy data. Exact figures are not provided. 1; evaluation will be based on frequency and occupancy rates.	1; evaluated through increase in space efficiency (5-10%) 1; evaluated through increase in frequency and occupancy rates (+13%) 1; target set at 10% improvement of space efficiency
Supporting users	1; no evidence will be collected 1; no metrics defined yet 1; evaluation through qualitative interviews and anecdotal evidence	1; evaluated by measuring how groups of people work together	1; evaluated through the number of reservations in the system (3400 per month) 1; evaluated through short surveys with students 1; SCT enables a transition to a different way of scheduling 1; evaluated through anecdotal evidence
Saving energy	1; evaluation via calculation of achieved energy savings (17,8%)	1; not yet evaluated because building has just been opened.	
Improving user comfort	1; evaluation via user interaction data		
Attracting talent		1; evaluation through an increase in job applications and % of applicants that want to work in the building (65%)	
Privacy	**6/9**	**6/9**	**9/9**
Anonymous data	1		4
Direct anonymization	3	2	4
Opt-in	2	2	
Personal data ownership		2	
Unknown			1
User information	**9/9**	**9/9**	**9/9**
Interactive (app, interactive display)	4	7	7
Passive (display or website with user information)	2	1	1
Unknown	1	1	1
None	2		

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TABLE 6.3 Cross case analysis showing the aggregated results per survey.

	International universities	Other organisations	Dutch universities
Management information	**9/9**	**9/9**	**9/9**
Interactive (interactive reporting tool)	3	5	5
Passive (automated reporting)	1		2
Passive (on-demand reporting)	1		
Unknown		4	
None	4		2

Gathering data on the costs of SCTs was quite complex. Some interviewees preferred to not share data on costs at all, whilst other interviewees would share data if it remained anonymous. There were also interviewees that were willing to share costs, but did not have insight in the exact costs. Especially for operating costs this was an issue. Furthermore, the costs depend largely on the extent to which sensors are used in the SCT –more sensors means a more expensive solution- and the scale on which they are applied –generally more m^2 means a slight decrease in costs per m^2. This is reflected in the large bandwidth that is found in the collected data on costs.

The data collection on the benefits of SCTs was also more difficult than expected. The responses received from the interviewees can generally be split into three parts:

- What is the main objective that is stated;
- In what way is the objective evaluated;
- Is there concrete evidence of an improvement with regard to the stated objective.

The results in Table 6.3 show that most interviewees can indicate the main objective and some form in which the objective is evaluated (or will be evaluated), but that there is very little concrete evidence of improvement with regard to the stated objective. The concrete evidence is marked bold in the table; there is some evidence of energy savings, of an increase in space efficiency and of the extent to which users are supported. The main reason that there is little concrete evidence is mainly because many SCTs have only been implemented for a very short time, if they have been implemented at all – Table 6.2 showed that only 11 of the 27 cases are implementations.

With regard to the way privacy is addressed in the SCTs, different solutions are observed. The solution that is used most, is the use of direct anonymization of data; this is most often used in solutions that make use of Wi-Fi data. Direct anonymization means that after collection of the data it is directly anonymised before it leaves the network of the university of organisation. Furthermore, the opt-in principle is used in multiple cases. Here, users can give or revoke permission to share their data in order to make use of the service. Finally, personal data ownership is applied at two other organisations. In these cases employees have access to a personal page in which they can determine how their personal data is used in the SCT.

In the data collection phase a large amount of data was collected with regard to the user information and the management information that is contained in the SCTs. When analysing the data after the data collection, the responses could be roughly grouped into four categories:

- Information is provided to users or campus managers interactively, via an app or website. Users can book rooms, find workplaces or set comfort preferences; campus managers can adjust the reports to suit their needs;

- Information is provided to users or campus managers passively; usually via a display or website. Users can see information, but not take actions within the SCT. Campus managers can see automated reports, but not adjust them;

- Information is provided to users or campus managers passively via occasional reports. For example, users are informed occasionally of the space utilisation of an office department or campus managers receive occasional reports generated by a researcher or analyst;

- None; no information is provided.

Table 6.3 shows the number of times these types of delivery of user information and management information were inferred from the data collection. In some cases not enough information was available to categorise the response of the interviewee. For example, a lot of interviewees provided a description of the management information and an image of a chart, but did not specify if this was the output of a dashboard or if an analyst generated it. In other cases it was simply not known yet how the information would be delivered to the user or campus manager. However, the data that is collected shows that the majority of cases focus on interactive delivery of information for both users and campus managers. The book publication contains many images and descriptions that elaborate on the information.

6.5 Additional insights on smart campus tools

Over the course of this research we experienced how topical the problem of ineffective and inefficient space use is and how much interest there is amongst students, employees, policy makers, and campus managers for the topic. As discussed in the paragraph on the conceptual model, the data collection approached SCTs as a construct which is continuously developing. This has allowed us to include a number of new aspects in the data collection, through which new insights have been developed that increase the understanding of SCTs within their context.

Understanding the development of smart campus tools

Over the course of the research, the interviews and analysis led to a further development of two frameworks presented in chapter 5. The first framework displayed the development of SCTs at Dutch universities where each phase stands for a phase in which the Dutch universities are working on SCTs: see Figure 6.5. During the previous year, the results of the interviews were continuously positioned in this framework which led to the realisation that in terms of objectives SCTs were becoming increasingly integrated. The figure was then reworked to its current form in Figure 6.6, containing the following phases:

Phase 1 – No SCTs, but separate systems for operational purposes which can be used to generate management information: the facility management information system (FMIS), building automation system (BAS) and scheduling system.

Phase 2 – Basic SCTs, which are aimed at individual objectives: usually supporting users and to a lesser extent saving energy and reducing m^2. Real-time measurement of space use is optional.

Phase 3 – Advanced SCTs, which collect real-time data of space use. It is possible, but not necessary that multiple objectives are achieved in this phase.

Phase 4 – Development of innovative SCTs, which collect real-time data of space use via multiple ways (e.g. registering space use via infrared sensors, but also collecting indoor climate data via CO_2 and lighting sensors).

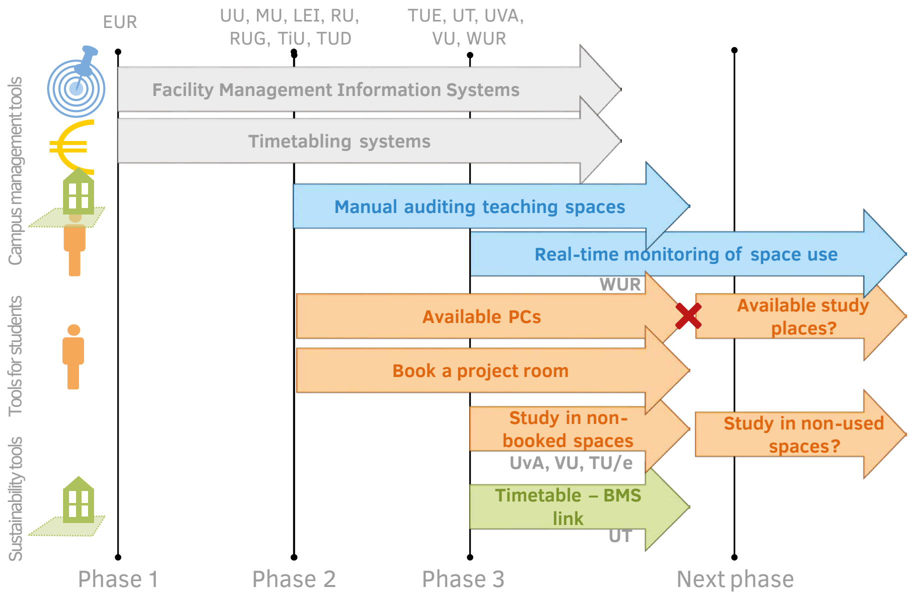

FIG. 6.5 Overview of the available SCTs at Dutch universities in 2016, positioned in time to indicate the development of SCTs.

Generally speaking each phase costs more than the previous phase in terms of sensing costs, but also generates more information and delivers more benefits to the organisation. Most of the cases discussed in this chapter can be positioned in phase 3, and some cases can be found that belong in phase 4. The cases in phase 4 are especially interesting, as they can help to answer the questions that belong to the advancement of SCTs: Do the benefits of such a SCT outweigh the costs? Is it achievable to implement such a solution on the scale of a whole portfolio, or should we wait for technology to become cheaper? And are the benefits sufficiently clear to warrant a large-scale implementation already? Is the increasing integration of functions not also a risk in terms of vulnerability to hacks and system failures? And how do organisations deal with privacy issues in these implementations?

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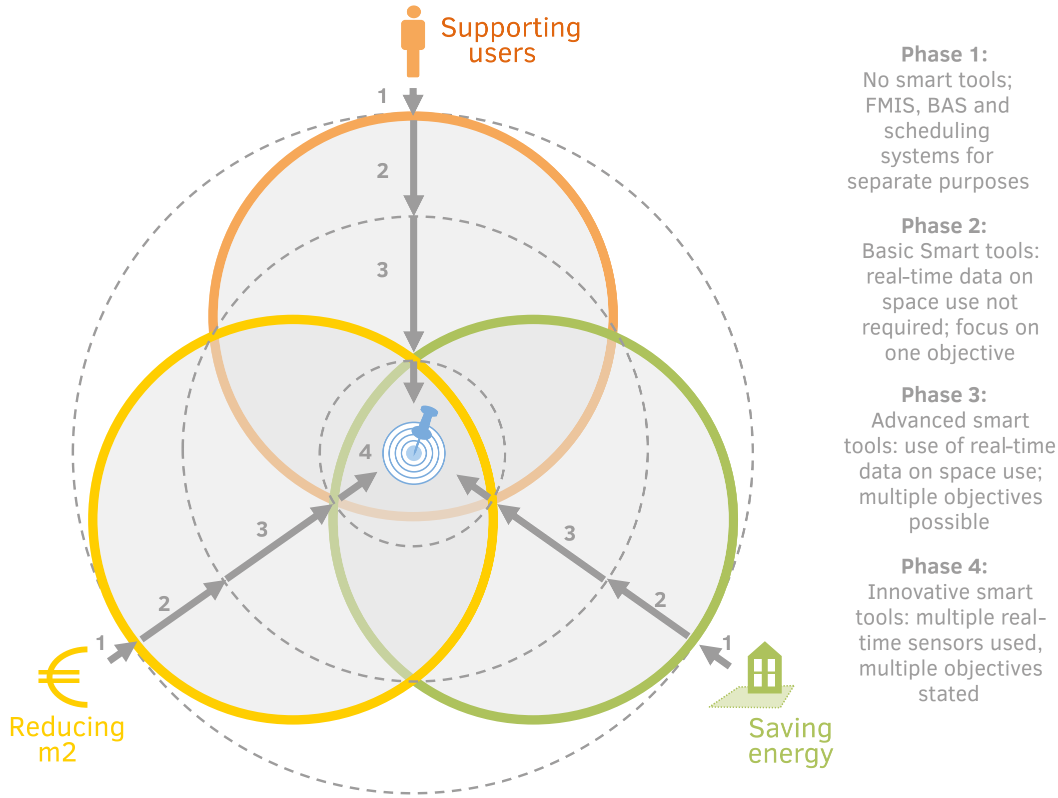

FIG. 6.6 Adjusted overview of available SCTs based on the findings of this research.

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Directions for further research based on the data collection

The data collection on SCTs gives many directions for further research on SCTs. As shown in Figure 6.2, the data collection can be connected to separate (applied) research fields. In this study a multitude of data has been collected to explore what SCTs are available. The following opportunities for further research have been identified by practitioners:

- A detailed study of 2 or 3 cases that focuses on the total costs of ownership of their SCTs and their stated and achieved benefits can help academics and practitioners to better understand the business case for SCTs; However, especially when a reduction of m^2 is desired it is necessary to wait until a SCT has been implemented for a sufficient amount of time (5-10 years);

- A detailed design study that focuses on defining the management information requirements for a SCT and using the generated management information to make investment decisions could be very useful for practitioners. This seems to be a gap in practice and anecdotal evidence suggests that research could help to provide guidelines for practitioners;

- Case studies that study the relationship between the provision of certain information to the user and the effect on user satisfaction can help academics and professionals understand the impact of providing certain information to users as well as the added value of SCTs in relation to other variables of the workplace;

- Case studies that study the relationship between the intended benefits of a SCT and the internal processes of an organisation. For example, in order to optimise the use of education space not only a SCT is necessary, but also identifying what needs to be changed in the organisation and its work processes.

These examples, in combination with the positive response of many universities and stakeholders to participate in the research and their interest to learn from each other, illustrate how topical the research topic is and that there is significant interest from CREM/FM practitioners in further understanding and documenting the use of SCTs at organisations.

6.6 Conclusion

The research question to be answered in this chapter was:

RQ5: What smart campus tools are being used by international universities and organisations and how do they compare to the use of smart campus tools in the Netherlands?

In order to answer the research question, a total of 27 cases have been recorded, expanding and complementing the findings reported in chapter 5. The results of the structured data (subsection 6.4.2) can be used to answer the main research question.

At international universities two implemented SCTs are found to help students find study places and one pilot project to optimise education space. The other six cases are in a pilot stage or design brief, revealing that many universities are busy with the subject. New SCTs are being considered, researched, developed and tested to support students and employees, optimise space use and save energy.

At other organisations most cases reveal that organisations are working on SCTs that both monitor their space use and help their employees find available workplaces and/or meeting rooms; and in two cases also to align energy use to building use. Most SCTs are in the implementation phase. Organisations are generally further along than universities with their implementations. Multiple cases are found that use multiple types of sensors in their SCTs.

At Dutch universities SCTs are aimed at either real-time monitoring of education space or on SCTs that support students, in which multiple functions are brought together. Previous research concluded that by looking at all available SCTs –which includes more room booking apps and available PC apps- the focus of SCTs was for the largest part to add value by supporting students. The cases at Dutch universities are generally further along than those at international universities in terms of their implementation.

Aside from answering the main research question, one of the main objectives of the chapter was to increase the understanding of SCTs through development of the conceptual model. In order to achieve this a number of additional elements were added to the data collection; these have been discussed in subsection 6.4.3. The most important insights –both for academics and for practitioners- from this part of the data collection are:

- That the problems and reasons for initiating SCTs and the solutions chosen are found to be diverse, especially amongst international universities;
- That many universities and other organisations will move forward with their SCTs by expanding in size, adding sensors and functionalities, or using the data for new types of analysis;
- That cost data is hard to collect and very variable, depending primarily on the use of sensors;
- That most organisations know what their main objective is and how they evaluate it, but that there is still very little concrete evidence that demonstrates the added value of SCTs;
- That most universities and organisations deal with privacy in similar ways, i.e. via direct anonymization, the opt-in principle and to a lesser extent personal data ownership;
- That the delivery of user information and management information is to a high extent interactive, via apps and websites in which users can book rooms, find workplaces or set comfort preferences and campus managers can adjust the reports to suit their needs.

In the discussion multiple suggestions for further research have been identified. The observed results and the foreseen development towards integration of functions in SCTs suggest that in the future, SCTs have a high potential to further improve the use of spaces and the campus management at universities. Further research should aim to translate this potential into actual results by connecting the collection of data in SCTs to the decision-making process of campus management, in order to optimally support the university's primary processes.

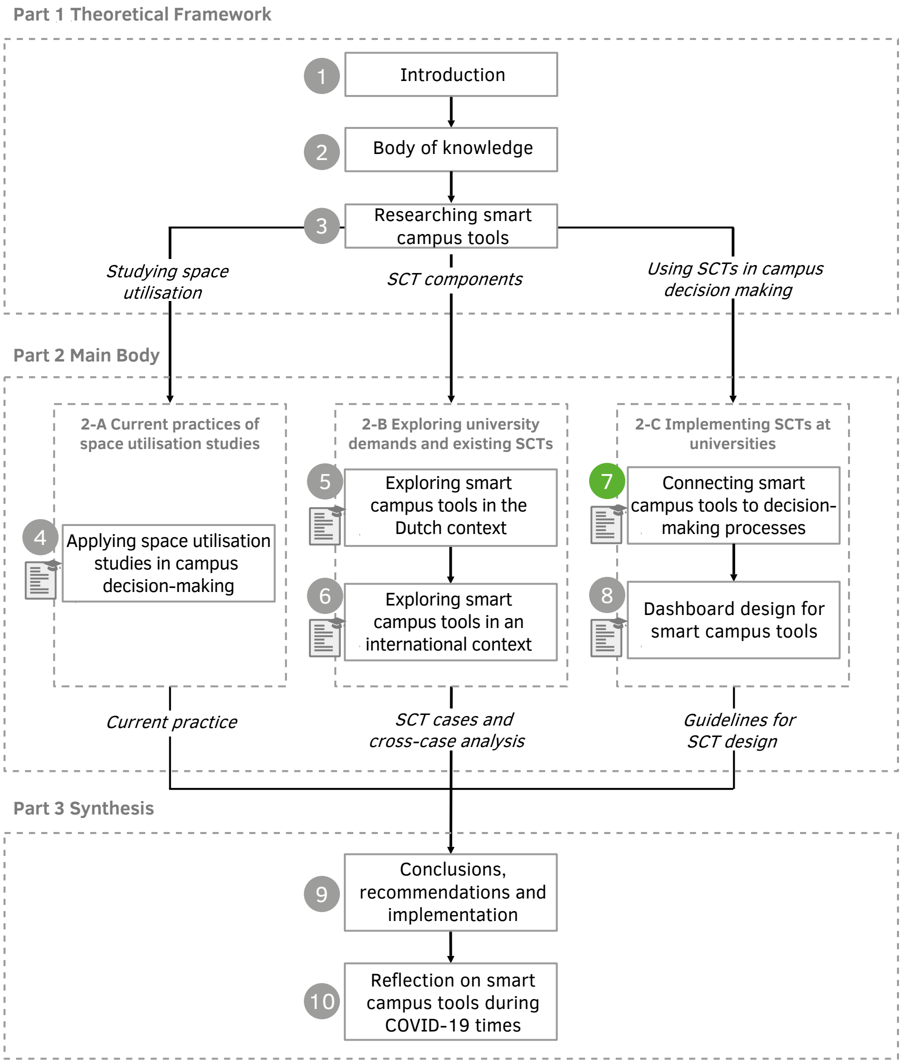

FIG. 7.1 Position of chapter 7 in this research.

7 Connecting smart campus tools to decision-making processes

This chapter is an adjusted version of a research paper. The introduction has been abbreviated to omit contents already discussed in section 1.1. Although the conceptual model has been discussed in section 3.3, it is displayed here to show which part was applied to this chapter. Small textual changes have been made for the purpose of overall consistency in this dissertation.

Valks, B., Arkesteijn, M.H., Koutamanis, A., and Den Heijer, A.C. (2021), "Towards a smart campus: Supporting campus decisions with Internet of Things applications", Building Research and Information, 49(1), pp.1-20. https://doi.org/10.1080/09613218.2020.1784702

7.1 Introduction

This chapter moves away from the studies on SCTs and their characteristics in chapter 5 and 6, towards the connection of SCTs to decision making in campus management. As previous chapters show, universities can achieve short-term improvements by the effective and efficient use of their spaces through the use of SCTs, by measuring the use of these spaces in real time and guiding students and employees to available spaces that match their needs. Real-time data on space use are also used to optimise the delivery of building services (heating, ventilation, lighting), resulting in energy savings (Balaji, Koh, Weibel, & Agarwal, 2016; Balaji et al., 2013). Over the past years, significant research attention has been given to the development of information technologies that can measure space use in real time, focusing mostly on these operational applications.

However, at the same time, information on the utilisation of spaces, user satisfaction, and energy consumption can be used to support various strategic and tactical campus management decisions. Strategic decisions (with a long-term focus) are e.g. building renovation, construction and disposal and tactical decisions (with a mid-term focus) are e.g. optimisation of cleaning schedules, building opening hours and purchase quantities of food facilities. These decisions are outcomes of organisational processes within the university. As this chapter will show, the use of the information delivered by SCTs and their application in organisational processes has received little attention in research.

To investigate information delivery and application in organisational processes, an information management perspective is adopted, using process and information analysis: see section 3.3. Furthermore, SCTs are referred to as 'IoT applications' in this chapter, as the term 'IoT applications' better covers the broad scope of the literature study presented in this chapter. SCTs are understood to be a subset of IoT applications, falling within the definition of the Internet of Things (see subsection 2.2.2).

The main research question of this chapter is:

RQ6: How can IoT applications be used to effectively support (strategic) decision making in university campus management?

The remainder of this chapter is structured as follows. First, section 7.2 details the set-up of the literature study and the case studies. Then, section 7.3 discusses the results of the literature study: first, by presenting an overview of IoT applications, and then by analysing how they support organisational decision-making processes. This is followed by section 7.4, which discusses the context of the four studied cases and their decision-making processes. Then, in section 7.5 the overview of IoT applications is connected to decision-making processes at universities, showing how their information needs can be satisfied. Finally, section 7.6 concludes the chapter.

7.2 Research methods

In order to answer the research question, a mixed methods approach is adopted. First, literature is studied to understand which IoT applications are available and how these relate to decision-making processes. Then, a strategic decision-making process in campus management is studied. For this a case study approach is used. Finally, the outcomes from both studies are combined to answer the research question.

7.2.1 Literature study

The literature study focuses on the potential use of IoT applications in campus management. In the field of CREM surprisingly little has been published regarding IoT applications: a scan of the 2014-17 issues of the Journal of Corporate Real Estate, Facilities and the Journal of Property Research did not yield any relevant articles to the subject matter. Therefore, a search query in Scopus (Figure 7.2) was developed to extend the scope to any relevant studies, linking sensors to either added values of CREM, real estate domains, occupancy measurements or different types of real estate. A limitation of this search query is that some relevant papers were not identified through it; these papers have been added through other searches. This study was first done in 2016 and reiterated in 2018 and 2020. Figure 7.3 shows the steps that were taken to select the 60 studied papers; Table 7.1 shows the inclusion and exclusion criteria used in the studies.

```
( TITLE-ABS-KEY(
{Wi-Fi} OR {Wi-Fi monitoring} OR {Bluetooth} OR {WLAN} OR {Geospatial data} OR
{automated people counters} OR {Indoor RSSI} OR {tracking technology} OR UWB OR {Wi-Fi sniffers}
OR {indoor positioning} OR {outdoor positioning} OR {occupancy sensors} OR {localisation}
                                                                                              )
AND TITLE-ABS-KEY(
{building energy efficiency} OR {building energy consumption} OR {facility utilization} OR
{building costs} OR {building footprint} OR {quality of place} OR {supporting user activities} OR
{facility management} OR {real estate management} OR {real estate} OR {crowd data collection} OR
{event monitoring} OR {tracking people} OR {human presence} OR {human movement} OR
{building occupancy} OR {room occupancy} OR {occupancy profiles} OR {occupancy rate} OR
{hospital complex} OR {university building} OR {campus building} OR {building use} OR
{non-residential buildings} OR {airport building} OR {airport terminal} OR {hotel building} OR
{residential building}
                                                                                              ))
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FIG. 7.2 Scopus query.

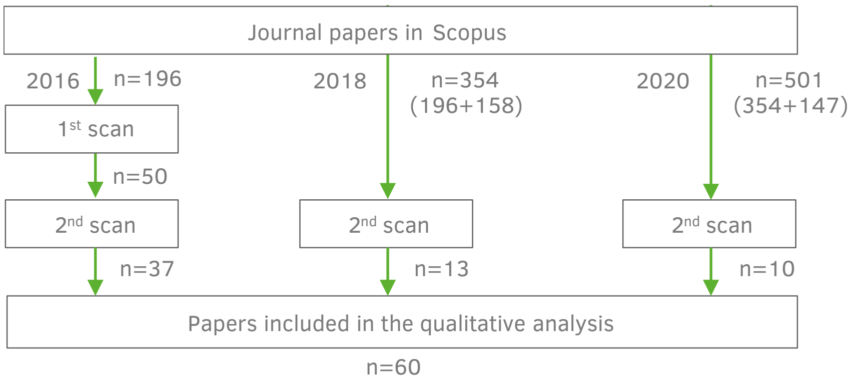

FIG. 7.3 Scanning steps of the literature review.

TABLE 7.1 Criteria to include and exclude papers.

	Study	Criteria	
		Excluding	Including
First scan	2016		- Citation count; 50 papers with highest citation score
Second scan	2016, 2018, 2020	- The study is not linked to an object (a type of real estate) - The study is a discussion paper, survey or literature review	- The study measures space use within an object

The results are organised in a study-and-concept matrix in which the articles are listed in rows and the categories in columns. Initially, the literature study focused on the IoT applications presented in the papers. The following aspects were documented and analysed: sensors used, type of space use measurement and CREM objectives. In the 2018 iteration, more aspects were added to the matrix in order to identify the perceived research gap concerning IoT support to decision-making processes. The following fields were added: the research field of the authors, the type and scale of the space that the study was applied to, granularity of results, reported outcomes, and the way in which those outcomes are used.

7.2.2 Case studies

Through four case studies an understanding is gained of current campus management practices, including the current contribution of IoT applications. The cases are actual decision-making processes of campus (re)development at different

Dutch universities (henceforth the ‘strategy process’). The main components of each decision-making process are the involved actors, the activities, and information flow through the process. In two cases IoT applications are implemented and in the other two cases not. This allows the identification of changes in the business processes as a result of IoT applications.

For each case study the following procedure is followed:

1 A first interview is conducted with a campus manager in which he/she is asked to go through a recent adjustment of the university’s campus strategy. For this interview, customer journey mapping (Halvorsrud, Kvale, & Folstad, 2016) is used to structure the interview protocol and visualise the results. This method was chosen because it is a customer-centric method - the customer being the campus manager- and because it provides a comprehensive, visual overview;

2 The customer journey map is translated into diagrams. According to Bytheway (2014), process analysis and information analysis are the two principal ways of visualising an information system; in our cases, the information system serving campus management. For the process analysis, a high-level process diagram shows the relationship of campus management to other business processes, and a more detailed activity diagram shows the activities in campus management. For the information analysis an information diagram shows the information flow that supports campus management. The diagrams are visualised as basic flow charts, as these suffice in practically all cases (Koutamanis, 2019). Figure 7.4 displays the elements of these flow charts;

3 A second interview is conducted with the campus manager to validate the activity diagrams. In three cases, extra input was collected for the information diagrams as well;

4 The activity and information diagrams are adjusted accordingly. These diagrams form the basis for the analysis of IoT connectivity to strategic processes.

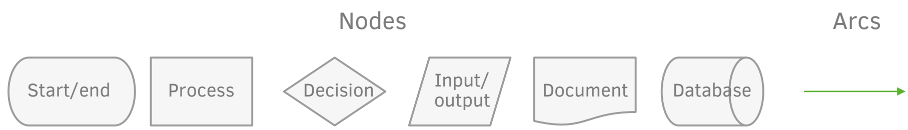

FIG. 7.4 Nodes and arcs in a flow chart.

7.3 Studying IoT applications in academic literature

7.3.1 Overview of IoT applications

Literature shows that IoT applications are applied to a wide range of built environments. Although our focus was mostly on academic buildings and offices, the studied literature also covers hospitals (Prentow, Thom, Blunck, & Vahrenhold, 2017; Ruiz-Ruiz, Blunck, Prentow, Stisen, & Kjaergaard, 2014; Stisen et al., 2017), outdoor settings (Abedi, Bhaskar, & Chung, 2013; Chang, Wolf, & Burdick, 2010; Versichele et al., 2012), sports venues (Liebig, Andrienko, & Andrienko, 2014; Stange, Liebig, Hecker, Andrienko, & Andrienko, 2011), residential buildings (Chuah, Li, Jha, & Raghunathan, 2013; Pesic et al., 2019; Villarrubia, Bajo, De Paz, & Corchado, 2014), train stations (Daamen et al., 2015; Van den Heuvel & Hoogenraad, 2014), and airports (Schauer, Werner, & Marcus, 2014).

The literature has been categorised by type of application. We distinguish between nine types of IoT applications (Table 7.2[11]). The application types most frequently present in literature are location-based user applications (18 times), optimising building services (13 times), and monitoring user flows (13 times). Other application types are monitoring space use (5), building energy simulation (5), telecare (4), user detection (2), social sensing applications (2), and emergency response (1). There are three papers that report on multiple application types. Dave, Buda, Nurminen, and Främling (2018) discuss the development of a platform that contains numerous location-based user applications, but also provides opportunities to optimise

11 Table 7.2 is complemented by a table in the appendix listing all the literature per application type. The following references are not cited in the main body of this chapter, but are included in the literature review: Castro, Chiu, Kremenek, and Muntz (2001), Chen and Ahn (2014), Chen, Chen, and Luo (2019), Chung and Burnett (2001), D'Souza, Wark, Karunanithi, and Ros (2013), Dodier, Henze, Tiller, and Guo (2006), Jiang et al. (2012), Kilic, Wymeersch, Meijerink, Bentum, and Scanlon (2014), Kjaergaard, Wirz, Roggen, and Troster (2012), Kosba, Saeed, and Youssef (2012), Labeodan, Aduda, Zeiler, and Hoving (2016), C. H. Lim, Ng, and Da (2008), Liu, Makino, Kobayashi, and Maeda (2008), Lopez-Novoa et al. (2017), Maraslis, Cooper, Tryfonas, and Oikomonou (2016), Nyarko and Wright-Brown (2013), Orozco-Ochoa, Vila-Sobrino, Rodríguez-Damián, and Rodríguez-Liñares (2011), Rachuri, Efstratiou, Leontiadis, Mascolo, and Rentfrow (2014), Rodríguez-Martín, Pérez-López, Samà, Cabestany, and Català (2013), Shrestha, Talvitie, and Lohan (2013), Sutjarittham, Gharakheili, Kanhere, and Sivaraman (2019), Talvitie, Renfors, and Lohan (2015), Tekler, Low, Gunay, Andersen, and Blessing (2020), Toh and Lau (2016), Utsch and Liebig (2012), Vu, Nahrstedt, Retika, and Gupta (2010), and W. Wang et al. (2017).

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building services. Sutjarittham, Gharakheili, Kanhere, and Sivaraman (2018) discuss four different pilots of IoT applications, which offer benefits to users via location-based user applications, as well as monitor the use of space. Romero Herrera, Doolaard, Guerra-Santin, Jaskiewicz, and Keyson (2018) make use of a platform that measures indoor climate and occupant comfort, which contains a location-based user application, and which can support optimisation of building services. Each of these examples is considered separately under each row, which is why the total number of IoT applications is 63 instead of 60. For each of these applications, the table shows which objectives are intended, which occupancy resolution is measured, which sensors are applied, and at which granularity the system delivers results.

Application type is closely linked to the type of objectives. As expected, location-based user applications are mostly aimed at supporting users, e.g. in wayfinding or improving comfort, just as optimising building services is mostly aimed at energy savings. Monitoring user flows and monitoring space use are equally aimed at supporting users and optimising costs. Similarly, most application types favour a specific occupancy resolution. For example, applications that monitor space use mostly measure on the resolution of occupancy, and telecare applications mostly measure on the resolution of activity.

With respect to granularity, most application types favour room level granularity or higher. The only exception is monitoring user flows, where results on floor and building level are found. Furthermore, in monitoring user flows and user detection, the granularity of outdoor settings is not always compatible to the indoor scale used in the table. In location-based user applications, there are also a few instances where the granularity is unknown; in these cases, experiments are conducted on a small scale (Chapre, Mohapatra, Jha, & Seneviratne, 2013; Deak, Curran, & Condell, 2010), making it difficult to determine the granularity.

TABLE 7.2 Types of IoT applications and their properties; in Appendix 4, the references are listed per application type.

No. of IoT applications	Type of IoT application	Objectives	Occupancy resolution	Granularity *(of results)*	Sensors
18	Location-based user applications	Supporting users (11) Enhancing safety (4) Energy savings (3) Optimising costs (2)	Identity (12) Occupancy (4) Frequency (1) Activity (1)	Room (8) Unknown (5) Sub-room (2) Floor (1) Workplace (1) Building (1)	Wi-Fi (10) Multiple (4) Wearables (1) Illuminance (1) Observations (1) FM radio signals (1)
13	Optimising building services	Energy savings (13) Supporting users (5) Optimising costs (1) Enhancing safety (1)	Occupancy (10) Frequency (2) Activity (1)	Room (10) Workplace (2) Sub-room (1)	Multiple sensors (10) PIR (2) Ultrasonic sensors (1)
13	Monitoring user flows	Supporting users (7) Optimising costs (7) Enhancing safety (5) None (1)	Activity (12) Occupancy (1)	Building (5) Floor (3) Unknown (3)	Multiple (5) Bluetooth (4) Wi-Fi (3) Access gates (1)
5	Monitoring space use	Supporting users (3) Optimising costs (3) Energy savings (1)	Occupancy (4) Activity (1)	Room (4) Workplace (1)	Multiple (2) Wi-Fi (2) PIR (1)
5	Building energy simulation	Energy savings (5)	Occupancy (3) Frequency (1)	Sub-room (1) Room (2) Floor (1) Building (1)	Wi-Fi (2) Bluetooth (2) PIR (1)
4	Telecare	Supporting users (4)	Activity (2) Identity (1) Frequency (1)	Workplace (2) Room (1) Floor (1)	Wi-Fi (2) Wearables (2) Bluetooth (1)
2	User detection	Enhancing safety (2) Supporting users (1)	Frequency (2)	Unknown (2)	UWB (2)
2	Social sensing applications	Supporting users (2) Stimulating collaboration (1) Enhancing safety (1)	Activity (2)	Workplace (1) Floor (1)	Wi-Fi (1) Multiple (1)
1	Emergency response	Enhancing safety	Occupancy	Room	Multiple

Finally, when comparing application type to the sensors used, the diversity in sensing approaches becomes apparent. While some applications, such as location-based user applications and optimising building services, seem to favour a certain sensing approach (Wi-Fi and multiple sensors, respectively), in other areas one type of sensor is not predominant. Furthermore, a significant number of papers make use of multiple sensing methods. In applications that optimise building services, researchers make use of sensors that measure aspects of the indoor environment, such as temperature, CO_2, luminance, humidity, acoustics (Ekwevugbe, Brown, Pakka, & Fan, 2017; Ioannidis et al., 2017; Saralegui, Anton, Arbelaitz, & Muguerza, 2019; Schwee et al., 2019). In two recent studies, these are combined with the collection of user feedback (Dave et al., 2018; Romero Herrera et al., 2018). Together with space utilisation data, data on the indoor environment and user feedback can provide valuable information to support decision making.

7.3.2 Supporting decision-making processes

An important question in the literature study was how IoT applications can affect decision making in real estate management. For an answer, we first looked at the results presented in each paper: these results describe the performance of the IoT application itself (i.e. is the measurement of the technology accurate), the performance of the environment, or both. Measurements of the environment are for instance occupancy measurements, user flows, noise levels. With regards to the performance of the IoT applications, Mautz (2012) named the performance benchmarking of implemented systems as one of the recommendations for further research. More recently, Mathisen et al. (2016) have observed that few extensive evaluations of positioning methods have been reported in large-scale environments. For the purpose of this chapter, results that measure the performance of the environment are especially relevant, as they can potentially inform organisational decision-making: Among the studied papers, we find that 46 out of 60 papers report on the performance of the IoT application, whilst only 28 out of 60 papers report on the performance of the environment. 14 papers report both types of results. This suggests a tendency in literature to focus on the performance of the IoT application when reporting results; however, recently the literature has also reported more on the performance of the environment: see Table 7.3.

TABLE 7.3 Overview of the number of papers by year, and the type of results they report.

No. of papers	Year	Results related to performance of the IoT application (No. of papers)	Results related to the performance of the environment (No. of papers)
17	2017-20	11	11
23	2013-16	18	10
14	2009-12	12	5
6	<2008	5	2

In literature that reports results related to the performance of the environment, we looked for links to decision making. These fall under four categories. In the first category, the results improve understanding of what is studied. This does not necessarily mean that decision making is considered. For example, Stange et al. (2011) have involved decision makers in their research and report that they have gained new insights on the movement behaviour of their customers. However, they do not mention what these insights are. Nor do report on any of the three other categories: improvements they may lead to, what they recommend based on the findings or how the decision makers used this information. In total, 10 out of 28 papers fall in this category.

In the second category, the results can be used for a specific improvement. These improvements can be realised through automation or through organisational processes. For example, Garg and Bansal (2000) conclude that through automation “about 5% more energy can be saved by using smart occupancy sensor as compared to non-adapting fixed TD sensors”. Abedi, Bhaskar, and Chung (2014) write that “by identifying the peak periods of utilisation, the facility management team can optimise their performance by selecting critical periods for inspection and providing facilities. Also, this team can be aware of people’s response to space design change or new facility setup such as upgraded coffee machine, adding a TV and entertainment facilities.” Here, opportunities to use the results to improve the environment are identified, but it is not made more specific what that improvement is. In total, 15 out of 28 papers fall in this category.

In the third category, the results include advice for specific improvements in the environments. There are only two papers that contain such an advice. Zhang, Izato, Munenoto, Matsushita, and Yoshida (2010) advise enlarging the spaces along the windows in the studied office because use of these spaces was found to be suboptimal in their IoT-based measurements. Y. Wang and Shao (2017) write that their results “revealed that the current 24-hour opening policy for the library during term time did not correlate with usage. On the other hand, the eight-hour library-opening duration during the summer holiday period could be extended to include the early evening hours to benefit user productivity.” In these examples, the authors show how the data may be used in decision-making processes, as they provide their interpretation of the data for decision making.

Finally, in the fourth category, the authors report on the use of results in real-life decision-making processes. There is only one paper in this category. Van den Heuvel and Hoogenraad (2014) report that “our analysis of passenger route choice in Amsterdam Central station illustrate that planners should be careful with assumptions about pedestrian route choice inside train stations.” They then report which assumptions hold and do not hold, followed by the relation to decision making: “These findings have had significant implications for a major overhaul that is being planned.” Additionally, the authors also refer to a separate paper that discusses in more detail how the results are used in decision-making. In this example, the authors show the actual use of data in a decision-making process.

Almost all papers (25 out of 28) belong to the first two categories. In our view, this constitutes a research gap: when making strategic or tactical decisions in real estate management, it is not always apparent how the information from IoT applications are, could or should be used. Therefore, it is useful to analyse existing practices in organisations that already use IoT applications in decision-making and compare it to others that do without. This research gap complements the previously stated research gaps regarding the performance of IoT applications: both of them obstruct successful delivery and implementation of IoT applications.

7.4 Strategic decision making in campus management

7.4.1 Contexts of the four case studies

The organisational processes, their activities and information flows are studied in four Dutch universities. To show the similarities across the four cases, a summary is provided in Table 7.4. In all cases, the universities have experienced a significant increase in student population. The organisation of the executive branch and faculties is also similar but there are slight differences in the responsibilities of the real estate (RE) departments. In three of the four cases, the RE department is not responsible for facility management. In the fourth case, the RE department is not only also responsible for facility management, but moreover for other services: IT, the university library and procurement.

Table 7.5 shows the use of IoT applications in each case. At two universities, IoT applications are implemented to monitor the occupancy of education spaces, with an additional functionality of booking the study spaces. In the two other cases, pilots have been conducted with IoT applications and with the same goals and functionalities, as exploration of further steps towards IoT implementation.

TABLE 7.4 Case studies and their characteristics; At RU, the supervisory board is responsible for both the university and the hospital.

	Wageningen University (WU)	TU Eindhoven (TUE)	TU Delft (TUD)	Radboud University (RU)
University characteristics				
Type of university	β (Agriculture)	β (Engineering)		αβγ (Arts, Social Sciences, Sciences)
Student population	11.944 (2007: 5.240)	11.966 (2007: 7.190)	23.508 (2007: 13.680)	21.675 (2007: 15.280)
Student growth (2007-18)	+127%	+66%	+79%	+42%
Executive organization	Executive board, Supervisory board			Executive board, Supervisory board*
Faculty organization	5 science groups (faculty department + research institutes), headed by directors.	9 faculties, headed by deans	8 faculties, headed by deans	7 faculties, headed by deans
Real estate department responsibilities				
Portfolio,asset management	RE department			
RE development	RE department			
Project management	RE department			
Facility management	RE department	FM department	FM/ICT department	FM department
Maintenance management	RE department			
Other activities RE department	IT, Library, Procurement	-		

TABLE 7.5 The use of IoT applications in case studies.

Use of IoT applications	Wageningen University (WU)	TU Eindhoven (TUE)	TU Delft (TUD)	Radboud University (RU)
Implementation of IoT	Yes; implemented		No, although numerous pilots exist	
Implementation period	2015-present	2016-present	Two pilots in 2017	Pilots in 2016, 2019
Function	Monitoring occupancy of education spaces	Booking and monitoring occupancy of education spaces and study spaces	Booking and monitoring occupancy of education spaces and study spaces	Booking and monitoring occupancy of education spaces and study spaces

7.4.2 Analysis of decision-making processes

The first step of the analysis of the four cases is the comparison of the four process diagrams. In these diagrams, the processes of (re)developing a campus strategy are shown in relation to the involved actors and other organisational processes. This gives a high-level overview of what a university does (Bytheway, 2014). The four processes were so similar, that they could be generalised in the process diagram in Figure 7.5. This diagram illustrates that planning the development of a campus requires many different stakeholders, as well as their specific inputs.

At the heart of the diagram (Figure 7.5), the main process is shown ('planning the campus development'). The outcomes of this process are used to initiate projects. In the four cases the projects described are the construction of a new education building, the renovation of a faculty building, the decision to retain and repurpose a building for education spaces, and the relocation of a faculty. Providing input to the main process are four separate processes: determining financial boundaries, the university strategy, forecasting student population, and forecasting education and research activities. Each of these processes can trigger the initiation of the main process. In the main process, the stakeholders responsible for the other processes provide the necessary input: for example, when the process is triggered by a changing forecast in student population, it also requires input with regards to the university strategy, financial boundaries and education and research activities. Each of these inputs can have a major impact on the decision; in order to understand those impacts a more detailed analysis is required.

The second step of the analysis is the comparison of the activity diagrams of the four cases. Activity diagrams show how the high-level process of 'planning the campus development' consists of lower-level activities. As such, they provide a fruitful starting point in understanding the overall function of a business application in relation to a business process (Bytheway, 2014). These activity diagrams closely reflect the actual practice at the four universities. Consequently, they formed the main output of the interviews and have been validated with the interviewees.

The first thing that one notices is that the four activity diagrams seem quite different: TU Eindhoven (Appendix 4) is similar to Wageningen University, and TU Delft (Appendix 4) is similar to Radboud University but there are significant differences between the two pairs. Business processes may seem very similar in a high-level analysis, but these lower-level analyses illustrate how different they can be in implementation. A comparison between two cases illustrates the most important differences.

At Wageningen University, the process of redeveloping the campus strategy was triggered by an adjustment of the student forecast. The activity diagram (Figure 7.6) details how first scenarios for the forecast were made, after which they were combined with policy measures to arrive at a definitive student forecast. Note that these activities are related to a separate business process in the process analysis, i.e. forecasting student population. Then, with the definitive forecast, a specification was made per education program. This is necessary in order to determine the demands for education spaces on campus, which were compiled in an overview. This overview was compared with an overview of the available and planned education spaces in order to match the demand to supply. The matching returned a surplus or shortage of education spaces on campus. Finally, after deciding on the match, strategies were defined in order to address the surplus or shortage. In an iterative process, these were combined with requirements and other demands for spaces on campus to create a framework for weighing and selecting strategies. The process was finalised by deciding on a strategy, after which a project was initiated.

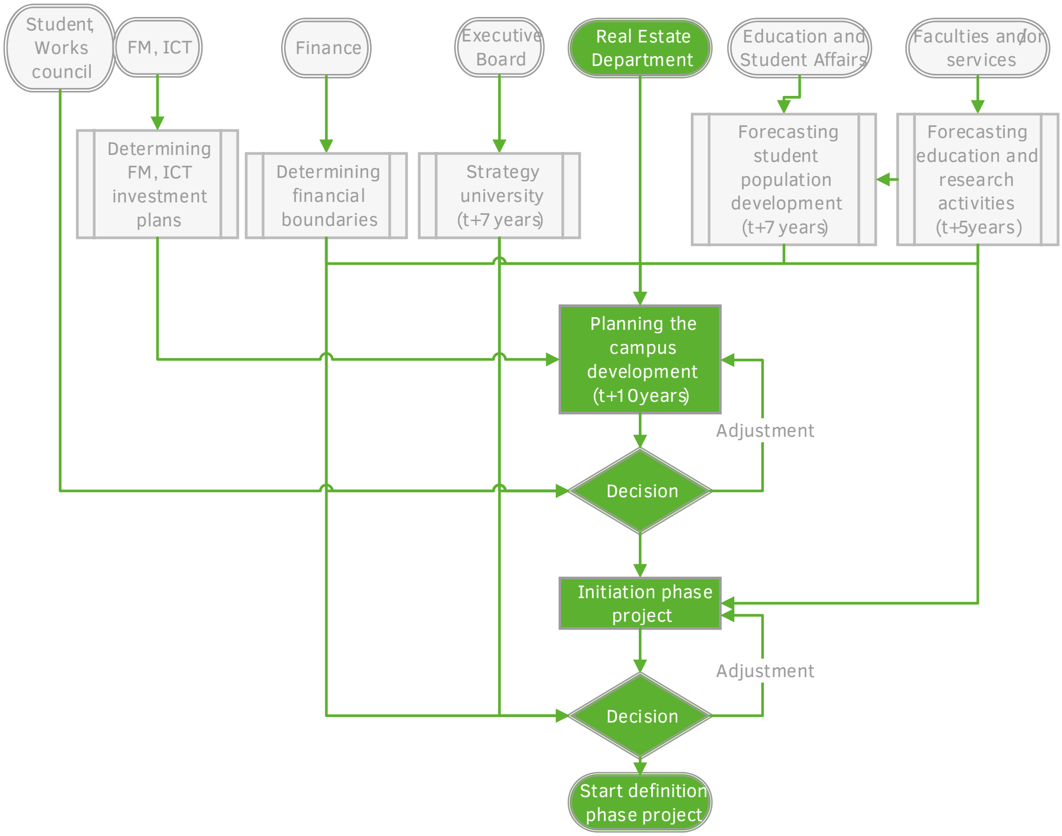

FIG. 7.5 Process analysis: Process diagram displaying the generic strategy process in campus management in relation to other business processes. The responsibilities of the real estate department are emphasized.

At Radboud University, the activity diagram (Figure 7.7) describes a regular update of the campus strategy. The Real estate department initiated the process by determining requirements for the strategy: these requirements were financial and real estate constraints (i.e. building age, condition level). Next, an investment plan was drawn up based on these requirements. This was translated into a draft plan, in consultation with the Finance department and the Executive Board. After determining this plan, a project was initiated for the relocation of a faculty. In this project, the growth or shrinkage of the faculty's student and employee populations were identified, whilst at the same time determining the requirements for the building envelope and location. The forecast for the faculty's population was translated into a demand for space (in m^2 and space types), which together with the aforementioned requirements were compiled into a project brief. After fixing the project brief, the next phase of the project was started.

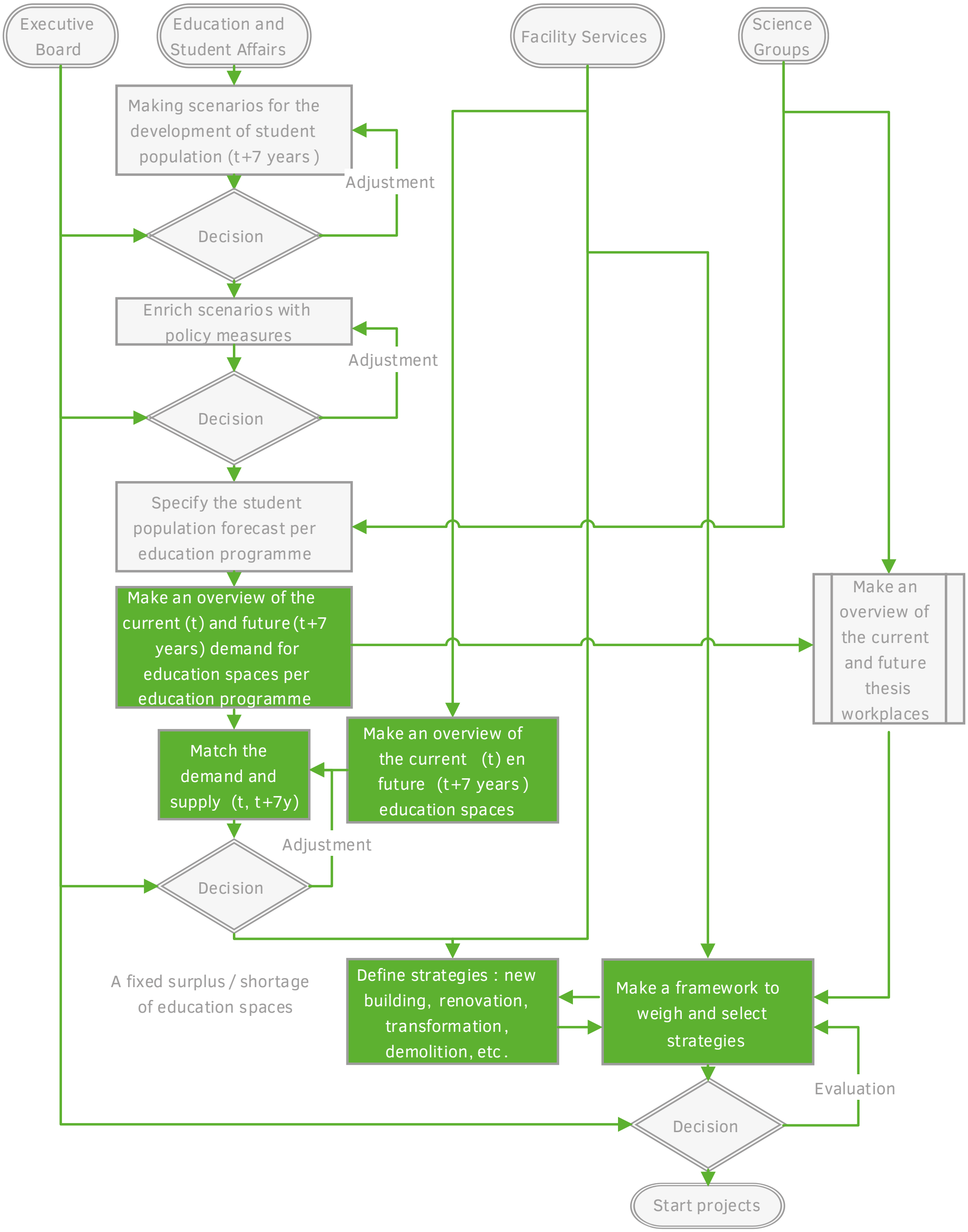

FIG. 7.6 Activity diagram Wageningen University. The matching of supply and demand on a portfolio level and the subsequent definition of strategies are emphasized. (Note: Facility Services is the name of the RE department)

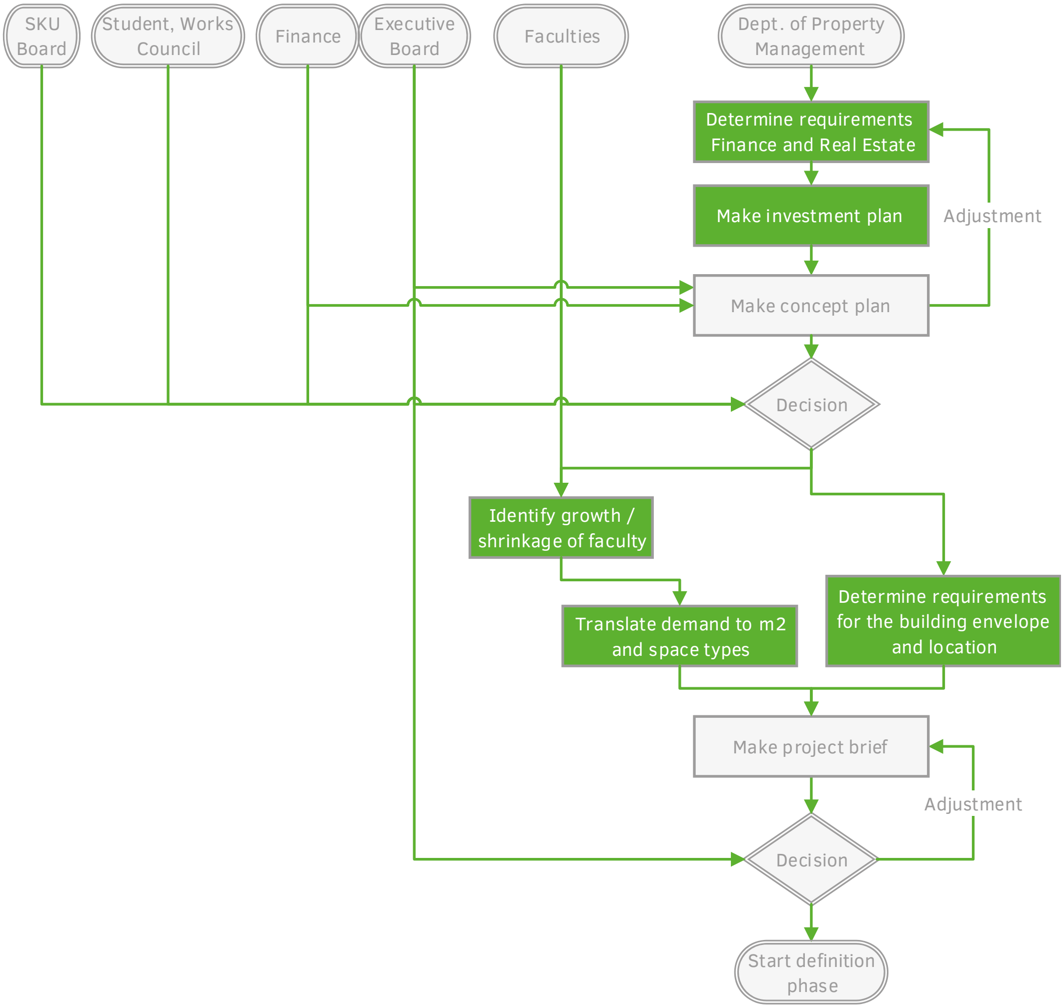

FIG. 7.7 Activity diagram Radboud University. The definition of strategies and the subsequent matching of demand and supply on a building level are emphasized.

The first thing that must be noted is that the start and end of the activity diagrams are different. The activity diagram of Wageningen University partially describes activities in the process of forecasting the student population and does not describe the steps taken in the initiation of projects, whereas the diagram of Radboud University starts at the development of the campus strategy and ends with the conclusion of the initiation phase. Furthermore, unlike Radboud University, Wageningen University has implemented IoT technology. The first aspect in which the (re)development of the campus strategies differ, is how the process is started. As mentioned earlier, the 'triggers' are different in each case.

Next, the activities required to determine the campus strategy differ significantly in both cases. As a result, the content of the strategies is likely to be different as well. At Radboud, financial and real estate requirements are drawn up in order to make an investment plan. This plan is likely to be a sequence of building-level interventions. The demand for space is only determined after determining the campus strategy, in the initiation phase of a project. At Wageningen, the approach is the other way around. First, the demand for education spaces is determined on a portfolio (or campus) level, after which strategies are defined to satisfy this demand, given requirements and other demands for spaces.

The difference observed here is of major importance. As the complexity of decision making is increasing at the university, matching demand and supply only on a building level poses numerous risks. Firstly, an incomplete picture on a portfolio level may result in a wrong prioritization of building-level interventions. Secondly, accurately determining the demand in a building-level intervention is increasingly difficult due to the increasingly shared use of facilities on a campus level, possibly leading to a wrong estimation of the demand. As universities continue to move towards a more uncertain 'match' between demand for space and supply of spaces, a portfolio-level approach is desirable. In a portfolio-level approach, demand and supply are matched for each specific space type (education spaces, offices, laboratories, etc.) across the whole portfolio in order to inform the definition of strategies.

7.5 Matching IoT potential to campus management processes

Next, we combine the findings from the previous two sections. In the literature study, various IoT applications have been described and categorised. Through various sensing technologies, room-level data can be delivered not only on various occupancy resolutions, but also on environmental aspects, as well as user feedback. Through the case studies, we identify a need to match demand for spaces and supply of spaces per space type, on a portfolio level, in order to inform the definition of strategies. By using information analysis, it is possible to match the capacities of IoT applications to the information needs of the cases. According to Bytheway (2014), information analysis focuses on entities and the information that is needed about them. Here, we try to understand how the information potentially available from IoT can support current processes; our information diagrams are thus to be understood as designs.

In Figure 7.8, the result of the analysis is shown in an information diagram. This information diagram is based on the activity diagram of an existing case, Wageningen University. Information diagrams follow a similar structure to activity diagrams, with some slight differences. The parallelogram node is introduced as an element to show all the relevant information input into the process. Furthermore, the descriptions in the start/end nodes and the process nodes have changed: instead of showing descriptions of the stakeholders and the activities, they now show the input delivered by each stakeholder and the resulting output of each activity.

The highlighted parts of the information diagram show the intended relationship between the entities, i.e. the output of each activity, and the input directed towards it, i.e. its information needs. As can be seen in the diagram, the process requires two lists of all education spaces through two separate activities. In the first list, the information needs are the type of education space, the level of amenities of those spaces, their capacity, and the current and future number of hours that these spaces are required for education in each period. These are the information needed in order to determine the demand for education spaces: in number and characteristics. In the second list, the information needs are the type of education space, the area, capacity, length-width ratio, condition level, as well as frequency and occupancy rates, user satisfaction, energy performance, CO_2 concentration, luminance, noise, etc. These are the information needed in order to determine the supply of education spaces: in number, characteristics and performance.

IoT applications thus deliver information to the overview of supply (together with scheduling and facility management information (FMIS) systems). In order to make use of this information, the overview of demand requires additional information: in Figure 7.8, this is termed ‘performance requirements’. These requirements state for the minimum user satisfaction, maximum CO_2 concentration, minimum occupancy rate, etc. They are not determined by the education programs, but shown as a separate input to the overview. Through the addition of IoT applications, information is added to the decision-making process that is essential for the subsequent definition of strategies. On the supply side, IoT helps to obtain a reliable overview of the current supply, which can be monitored and permanently evaluated. On the demand side, this helps to overcome issues in the definition of the demand, which may be limited in scope or erroneous due to the absence of performance assessment.

Without the information from IoT applications, the match between demand and supply may be evaluated wrongly. Without information on actual frequency and occupancy rates, it is likely that the required number of spaces is incorrectly determined: actual frequency rates may be lower than those scheduled due to overbooking, or higher if there are many ad hoc activities. Without information on the user satisfaction, it is likely that incorrect assumptions are made about which existing spaces perform well and which do not. A high space utilisation may be unjustly equated to mean a high user satisfaction, leading to disposition of spaces with low utilisation, which do meet user requirements. Without information on the indoor climate, it is likely that incorrect assumptions are made about why existing spaces underperform. For example, poor lighting, noise issues, or high CO_2 concentrations may cause low user satisfaction or user utilisation.

In addition to the relationship between the entities and information needs, Figure 7.8 also states the position of a ‘platform’ in a database node. This is because in strategy processes, it is very time consuming to create an overview of the performance of each space in order to inform portfolio-level decisions. As it is displayed in the figure, the platform brings together the inputs from various IoT applications, other databases and sources in order to automate such an overview of the performance. The closer the overview in the platform adheres to the output stated by the activity, the more it will support the needs of the process.

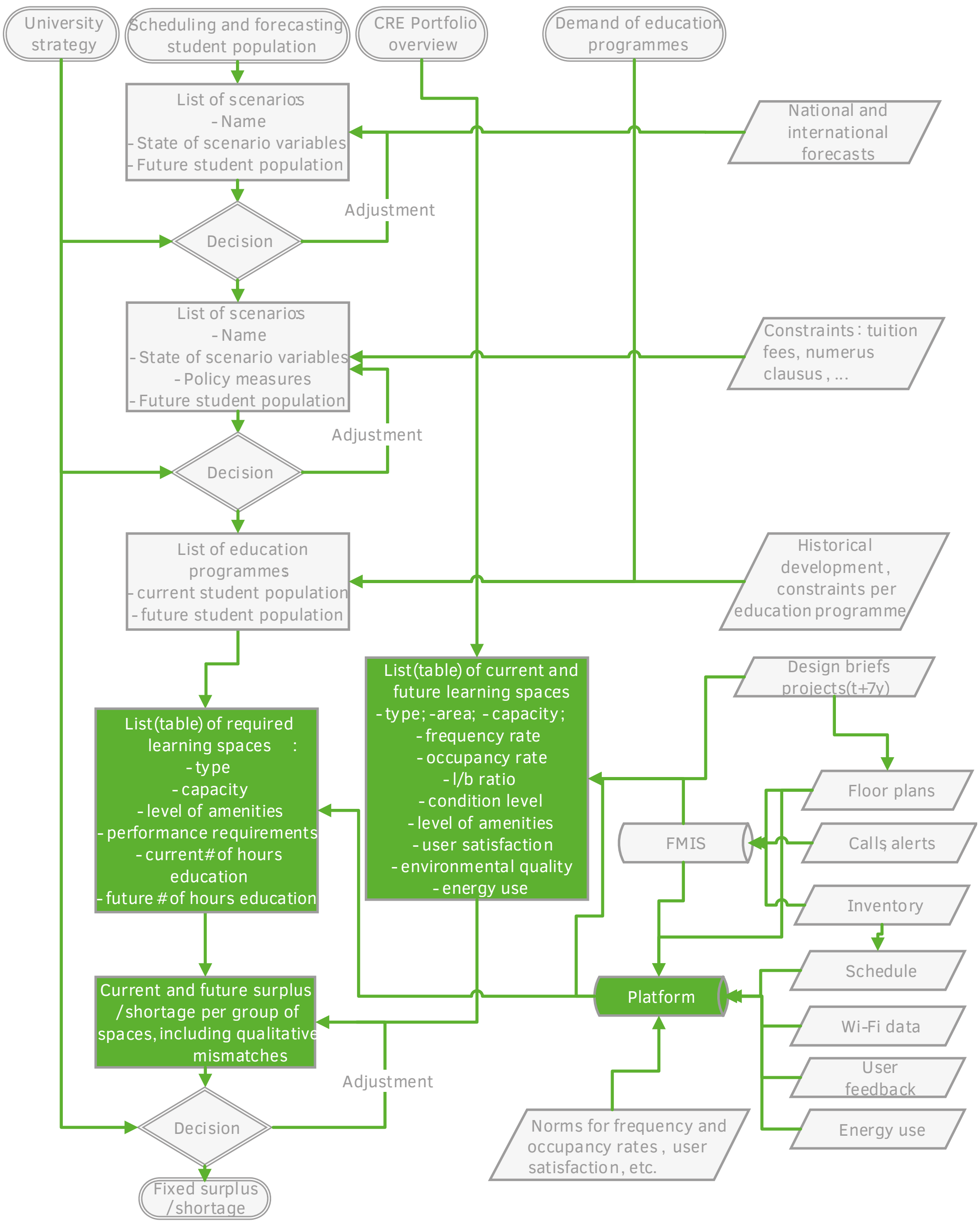

FIG. 7.8 An information diagram showing the proposed information flow through the first part of the portfolio-level process at Wageningen University. The information needs of the entities and the IoT platform which delivers the required input are emphasized.

7.6 Conclusion and Discussion

The increasingly dynamic allocation and complex use of spaces at universities requires sharper tools not only in operation but also in strategic processes. Information on real-time space utilization is one of the foundations of such tools. The main question this chapter set to answer was:

RQ6: How can IoT applications be used to effectively support (strategic) decision making in university campus management?

Through a literature study of 60 papers, we identified nine types of IoT applications. These nine types all use various types of sensing methods and measure a specific type of occupancy resolution. Most applications favour a room-level accuracy or higher. Other variables such as environmental aspects and user feedback are also measured. Then, through a study of the process of (re)developing a campus strategy in four cases, we identified activities to which IoT applications can deliver value. Through a cross-case comparison, we show that two cases 'match' their demand for space and supply of spaces prior to developing strategies (on a portfolio level), whereas two other cases do this after determining their strategy (on a building level). We argue that given the problem statement, a portfolio-level approach for each specific space type is preferable. Finally, we matched the capabilities of the IoT applications to the processes of the case studies. Here, we provide in detail the information needs of a portfolio-level process.

The activity and information diagrams provide a solid basis for integrating the IoT in campus management. Currently, many universities do not yet utilize IoT applications on their campus, or they focus on collecting a specific type of information: in the studied cases this was frequency and occupancy rates for education spaces. Given the multitude of information they can collect with IoT and the different space types they can collect it for, choosing which IoT applications to implement is a complex decision. Additionally, these implementations can be costly and uncertain. It is important to support campus managers and universities in choosing an appropriate IoT solution, especially given the growing number of IoT providers (see Figure 7.9).

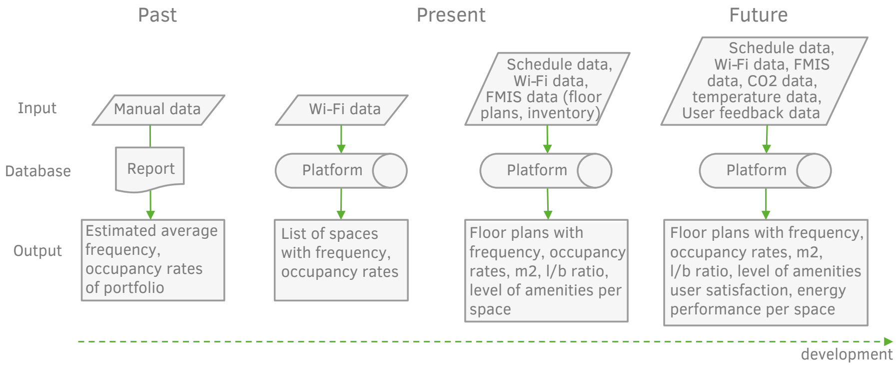

FIG. 7.9 Development towards SCT effectively supporting campus management with big data / use patterns.

There are many potential areas for further research. Firstly, the literature study has shown that there is a research gap between research on information technology and its application in the REM domain. There is enough knowledge about the available technologies, but not about the demands from a REM perspective. This chapter has studied how IoT can support a strategic process in campus management. Further research also needs to identify how IoT can effectively support tactical and operational decision-making processes on the university campus.

Secondly, there is also a need for more research on the potential impact of IoT applications on campus performance, and for large-scale experimental evaluations of IoT applications. Without it, universities may implement the wrong applications or not make effective use of the information resulting from it. A limited understanding of how IoT is integrated into campus management processes may lead to failures in IoT implementations: Cisco (2017) reports that 60 percent of all IoT initiatives do not move past the proof-of-concept stage, and that only 26 percent of initiatives are considered a success; collaboration between IT and business was cited as the primary success factor.

Towards the future, there are many trends that will possibly influence the future demand of spaces at universities. Online education, changing funding mechanisms and life-long learning are but a few of these. Furthermore, the recent Coronavirus pandemic has shown to what extent unforeseen changes can disrupt the demand for space, and its effects are likely to impact the use of spaces at universities and many other places long after. With IoT applications in place, users of the current campus will be enabled to use the campus more effectively, and campus managers will be better positioned to assess the effects of these demands on space usage and adapt their campus strategies accordingly.

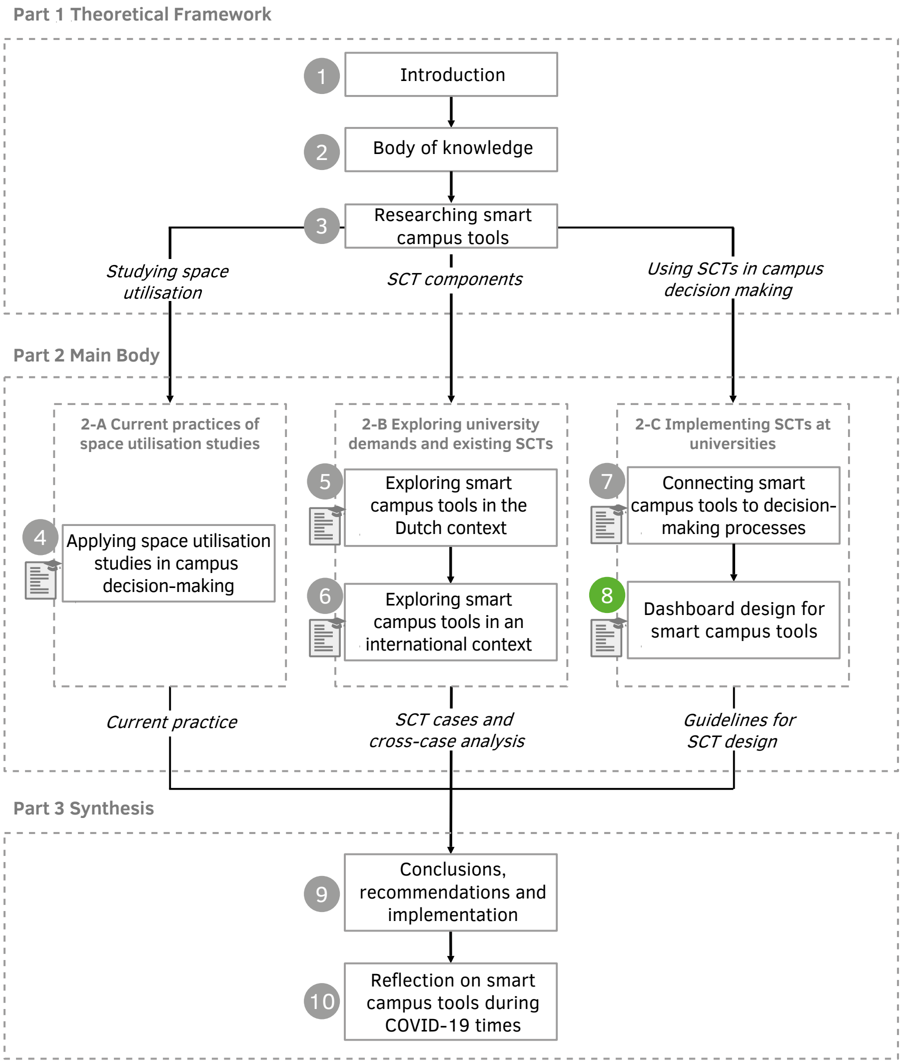

FIG. 8.1 Position of chapter 8 in this research.

8 Dashboard design for smart campus tools

This chapter is an adapted version of a research paper. The introduction has been abbreviated to omit contents already discussed in section 1.1. Although the conceptual model has been discussed in section 3.3, it is displayed here to show which part was applied to this chapter. Small textual changes have been made for the purpose of overall consistency in this dissertation.

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8.1 Introduction

This chapter reports on two cases in which organisations are supported in defining information needs for their decision-making processes. In the previous chapter, we studied strategic decision-making processes in campus management and explored how information from the Internet of Things (IoT) can support them. The conclusion was that the IoT can deliver valuable information to the overview of real estate supply and its performance. However, as this overview normally requires information from many different sources, its creation tends to be very time-consuming. A more efficient and reliable alternative is to bring together data from various IoT applications, other databases and sources in a platform that supports automated production of overviews, as proposed in chapter 7.

Based on that, the main objective of the present research is to develop an appropriate connection of IoT applications and their data to real-life decision-making processes. The paper reports on two cases (Radboud University and TU Delft) in which organisations are supported to determine the information needs for their decision-making processes by de-signing dashboards.

In addition to the managerial results, the design outcomes (the dashboards) are also of interest for the case study organisations: they provide examples of the performance re-quired in strategic decision making. Therefore, the secondary objective of this research is to design usable dashboards for campus managers. The research question of this chapter is thus:

RQ7: How can the information demand of campus management be matched to the capabilities of IoT applications, and optimally displayed in a dashboard?

Design research is chosen as the strategy to answer the research question, as the subject calls for an operational exploration of the fundamental principles and conditions of dashboards that contain information from the IoT. The dashboard designs presented in this paper express indicators and relations relevant to campus management, which are first designed, and then refined and tested together with users. The novelty of this research lies in this use of design research. To the best of the authors' knowledge, there is no research that fulfils the following conditions: (a) it discusses dashboard prototyping as a needs analysis method for IoT applications in campus management (see subsection 8.2.2), and (b) the dashboard designs report a combination of indicators from the IoT and legacy systems related to all four stakeholder perspectives in campus management (see subsection 8.3.1).

The rest of this chapter is structured as follows: first, section 8.2 discusses the research methods, detailing the use of design research to answer the main research question, introducing the use of dashboard design to elicit requirements, and introducing the cases. Then, section 8.3 discusses the results regarding the design of the dashboards, followed by the section 8.4, which discusses the determination of requirements through dashboard design. Finally, section 8.5 concludes the chapter.

8.2 Research methods

8.2.1 Design research strategy

In order to answer the research question, design research is conducted as described in Van Aken (2004, 2005), and Hevner (Hevner, 2007; Hevner, Martch, Park, & Ram, 2004): prototypical dashboards are designed for specific campus questions and the design process as well as the performance of the design results is studied.

Figure 8.2 shows the parts of the research positioned in the framework of Hevner (2007). This framework consists of three cycles:

- In the relevance cycle a problem is formulated for which an artefact needs to be designed, as well as requirements to design and test the artefact;
- In the design cycle the researcher iterates between designing and testing the artefact that is designed to solve the research problem;
- In the rigor cycle the problem and the design outcomes are grounded in the scientific knowledge base.

In this research, both cases formulate their own specific problems. The dashboard prototypes are designed in the design cycle and tested together with relevant stakeholders. By grounding the dashboard design in existing theory and research, the cases are grounded in relevant theories and the knowledge generated through the design outcomes are added to the knowledge base.

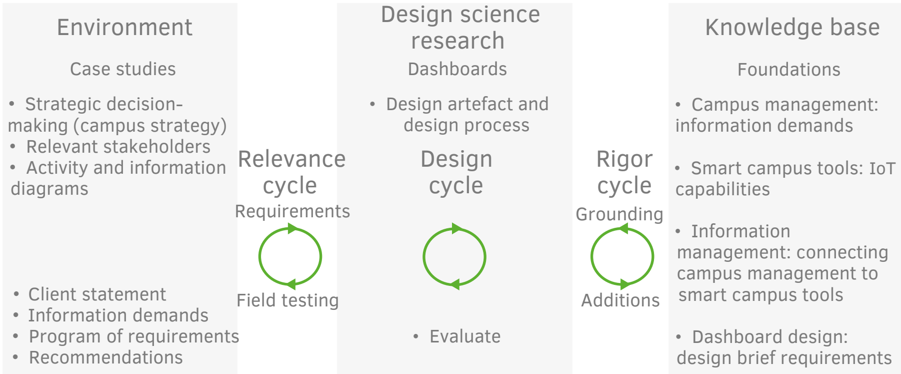

FIG. 8.2 Design research cycles in this research (adapted from Hevner (2007)).

Accordingly, the design research leads to multiple design outcomes: an object design, a process design, and an implementation design (in accordance with Hevner (2007). In this research, those design outcomes are as follows:

- The process design is the sequence of activities to realise the object design. The process design describes which steps should be taken to determine information requirements for campus decision making. Testing the process design is the main objective of this research.
- The object design is the dashboard prototype. The dashboard is based on previous research, and is designed to support campus managers in determining the match between the demand for and supply of real estate and subsequent steps in making a campus strategy. The two resulting object designs and their usability are the secondary objective of this research.
- The implementation design is a brief, which specifies (a) practical use requirements for the dashboard, (b) which information the dashboard needs to show to support the specific decision process, and (c) which steps need to be taken to organise the dashboard accordingly. The implementation design thus reports the outcomes of the main and secondary objectives to each case.

TOC

The research design of a case is shown in Figure 8.3. Following a client statement describing the problem faced by the case and its requirements for a solution, the authors design dashboard prototypes on the basis of principles for dashboard design from the knowledge base. The results are tested in two workshops, which took place online (due to COVID-19 restrictions) with a group of stakeholders. In each case, six participants are selected in consultation together with the client. These participants are professionals who are involved in strategic campus decision-making processes. The design of the dashboard prototypes is implemented in Microsoft Excel, a program (1) with sufficient facilities for combining various data sources and visualising data, and (2) familiar to participants. The goal of the workshops is to determine the information requirements for the dashboard, which moves from what is maximally possible (workshop 1) to what is required by the participants (workshop 2). Prior to the use of the dashboard in the first workshop, users are introduced to the dashboard through a presentation and a short instruction video. Observers record the interactions during the workshops, which are then coded and analysed in three ways:

- A1: The number of interactions with each indicator: this is used to select which indicators are actually required in the dashboard.

- A2: The quality of the interactions with each indicator: this is used to (a) determine if participants understand the contents of the dashboard and (b) to identify opportunities to improve the dashboard.

- A3: The interventions decided by the participants on the basis of the dashboard: this is used to understand if participants can use the dashboard to complete the assignments.

As Figure 8.3 shows, the outcomes of analysis A1 and A2 are used to refine the design of the dashboards. They are thus part of the process design that is proposed and tested as the main objective of this paper. The dashboard designs and analysis A3 give information about the object designs and how they are used by participants, and are thus connected to the secondary objective of this paper.

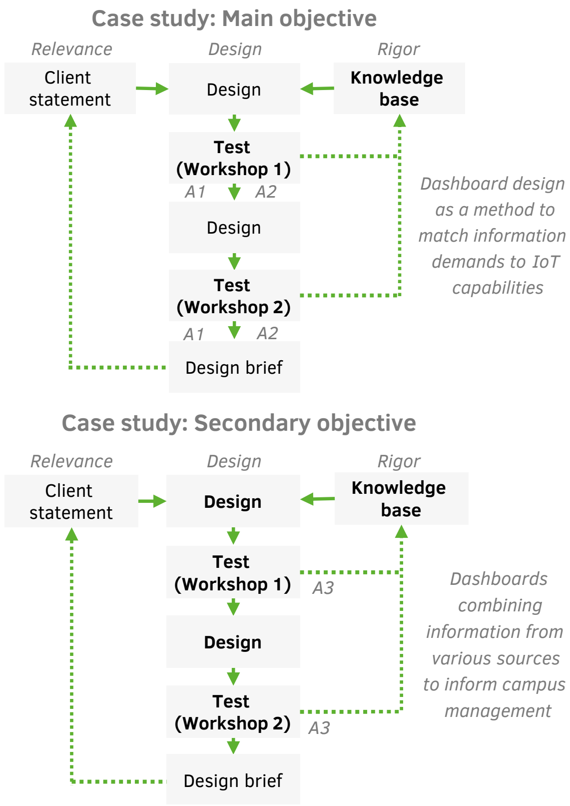

FIG. 8.3 Research design for one case, displayed twice to show the relationship between the analyses and main and secondary objectives. The resulting design brief answers the client statement. The analyses of the testing phase inform the knowledge base. A1, A2 and A3 denote the three analyses reported in the paper. Emphasis in bold denotes relevance to each objective.

8.2.2 Dashboards and dashboard design

The use of dashboard design in this chapter needs to be grounded from two perspectives. Firstly, dashboard design is one of several methods to determine information requirements, i.e. the main objective of this paper. Secondly, dashboards are one of several methods to present information in decision making in campus management, i.e. the secondary objective of this paper. First this section discusses the use of dashboards as a means to present information in decision making, after which it moves to determining information requirements through their design.

Dashboards are an increasingly popular instrument in the field of performance management (Bremser & Wagner, 2013; Yigitbasioglu & Velcu, 2012). Over time, dashboards have evolved from stand-alone displays of KPIs to interactive enterprise-wide decision support systems (Yigitbasioglu & Velcu, 2012) This is cause for some confusion: some distinguish dashboards as instruments for operational decision making from scorecards as instruments for strategic decision making (Cokins, 2010), while others define a dashboard more broadly as an instrument to be tailored to a specific type of decision or objective (Eckerson, 2009; Few, 2006, p. 26). This research uses a more broad interpretation of dashboards, after Few: “a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance” (Few, 2006, p. 26).

This broader definition of dashboards requires further specification and alignment with their objective. Table 8.1 describes the characteristics of the dashboards designed in this research for the purposes of informing strategic decision making processes in campus management.

TABLE 8.1 Dashboard characteristics (based on Few (Few, 2006, p. 26)).

Properties	Values (Main dashboard)	Values (Further dashboards)
Role	Strategic	Analytical
Type of data	Quantitative	Quantitative
Data domain	Real estate management	Real estate management
Type of measures	KPIs	KPIs
Span of data	Enterprise-wide	Enterprise-wide
Update frequency	Monthly	Monthly
Interactivity	Static	Interactive (drill-down, filters etc.)
Mechanisms of display	Primarily graphical	Integration of graphics and text
Portal functionality	No portal functionality	Conduit to additional data

Dashboards can also be positioned against multiple criteria decision analysis (MCDA) approaches. Here, dashboards and MCDA approaches are seen as complementary rather than competing. MCDA deals with the structuring and solving of problems involving multiple criteria, such as the problems studied in the cases of this research. There is a broad range of MCDA approaches available, which have also been applied to problems in real estate management (Arkesteijn, Valks, Binnekamp, Barendse, & De Jonge, 2015; Zadavskas, Turskis, Sliogeriene, & Vilutiene, 2021). Following the results of our previous research, we focus on a specific activity in the decision-making process: the overview of the supply of real estate and its performance. Dashboards are well-suited to provide such an overview in a visual display, on a single screen. The objective of this overview is to create a basis for subsequent actions. In subsequent steps of this decision-making process (defining strategies and weighing and selecting strategies), MCDA approaches are usable. A dashboard combining information from the IoT with other campus management indicators actually provides provide a reliable basis for MCDA modelling of decisions and their impact on the criteria displayed in the dashboard.

Following the discussion about the use of dashboards to present information, the next issue is the use of dashboard design as a method to determine information requirements. Within Information Management this is related to the activity of requirements analysis for (information) systems development (Bytheway, 2014), also termed needs analysis or requirements engineering. The first step of requirements analysis is requirements elicitation, which concerns itself with gathering and organising information requirements from stakeholders (Tuunanen, 2003). The use of prototyping (in our case, dashboard design) is a common method to achieve this (T. Lim, Chua, & Tajuddin, 2018; Tuunanen, 2003).

Other methods to elicit requirements are traditional techniques e.g. surveys and interviews, group techniques e.g. brainstorms and focus groups, or contextual and cognitive techniques (T. Lim et al., 2018; Tuunanen, 2003). Tuunanen (2003) review these techniques in order to find a method that (1) has the possibility to reach a wide range of users, i.e. a community, and (2) has two-directional communication, allowing for interaction and understanding of the users. In this research, the intended users of the dashboards are a small, homogeneous group; hence, its development does not have to involve many users. Furthermore, the real-time communication by IoT devices distributed in an environment affects the way users interact with it (Bergman, Olsson, Johansson, & Rassmus-Gröhn, 2018; T. Lim et al., 2018) which is another reason to use more interactive, two-directional elicitation methods such as prototyping and iterative design (Bergman et al., 2018).

8.2.3 Case descriptions

Two case studies were included in this research: Radboud University (RU) and TU Delft (TUD). The case selection was based on the following reasons:

- Both cases were included in the previous study (chapter 7), in which the information requirements for their processes of creating a real estate strategy were studied;
- Key stakeholders have indicated that it is difficult to produce an overview of their real estate portfolio and its performance for use in strategic decision making;
- They have expressed a desire to make more decisions on a portfolio level, which would require such information;

- Currently they do not have any IoT applications implemented but wish to do so in the future.

In both cases, the dashboards display information derived from the available data on the real estate portfolio and complemented with fictive data where the sources would have been IoT applications. Further case-specific information on the use of the available data is given in the case descriptions.

Radboud University Nijmegen

Radboud University (RU) is a university with around 22.000 students located in Nijmegen, the Netherlands. The university has concentrated its activities on its campus, which was formerly an area in the periphery of Nijmegen, but now it has become immersed by the city. At the start of 2020 the university established a new real estate strategy. The strategy focuses on sustainability and optimal use of the existing buildings on the one hand, and on the other hand on further developing towards a livelier campus. RU wants to accommodate growth maximally in the existing area and further increase the utilisation of the buildings. Rather than longer opening hours across the campus, it chooses for a synergy of existing functions. A higher utilisation is achieved by implementing modern office concepts, improving the scheduling of education and implementing SCTs to show the available capacity within the existing spaces to the users.

In this research, the university chose to focus the case on its study places. In the existing situation, there are many types of study places in the various buildings of the university. Each student uses mostly the study places of their own faculty and the Library building. There is no overview of all the study places; furthermore, the management of the study places is organised in different ways. In the future the university wants to use all study places as flexible, shared facilities that can be used by any student at the university. At the time of the research, following the transfer of study place assets from the faculties to the department of Campus and Facilities, a project group was working towards a uniform way of managing them. This included stating the desired quality and quantity of study places, the use of personnel, and the required finances.

The RU campus has around 28 university buildings, six of which contain study places. Beyond their location, not much information on study places is available. The floor area per study place and costs of each building are known. However, the number and type of study places are not registered. In the dashboard, information is required on room level, including floor area, type, capacity and costs. Consequently, what was displayed in the dashboard prototypes had to be supplemented with hypothetical, plausible data, both for the real estate indicators and the information that would be delivered through IoT. This should not influence the quality of the results. Even with fictive data, workshop participants could assess the performance of a real estate portfolio and define interventions based on that. Any deviation from reality would not impede utilization of the indicators included in the dashboard and, therefore, the workshops would still provide the envisaged feedback.

TU Delft

TU Delft (TUD) is a university with around 26.000 students located in Delft, The Netherlands. TUD houses its activities on its campus, located south of Delft's city centre. In 2019 the university's Campus and Real Estate (CRE) department established a new campus strategy, which focuses on optimal use of the existing facilities and resources to realise the university's ambitions and accommodate growth. The campus strategy includes the construction of new buildings in the south of the campus, intensifying the use of existing buildings in the middle of the campus, and disposition of buildings in the north of the campus.

In this research, TUD chose to focus on dashboards for the whole portfolio and for separate buildings to be used in reporting and updating its campus strategy. A first version of this dashboard had been made to show the current performance of the portfolio and buildings, but which would also serve as a basis for showing the expected performance as a result of the campus strategy. The main issue with these dashboards is how to provide an overview of a building or portfolio at one glance. Furthermore, the case offers the opportunity to further develop the first version of the existing dashboards and develop a vision on which information from IoT is valuable to include in those dashboards.

There are around 60 buildings on the TUD campus. It was decided to focus on buildings, wholly or partially used for academic purposes, which included around 80 percent of the area in the portfolio. The floor area and space types were known for each space. The capacity was also largely known for each space. The number of users, quality, costs, and energy use were known for each building. Space utilisation data was known per room for education spaces and study places, based on a 2019 survey. The dashboard was thus based on real data, with the exception of the information to be delivered by IoT. Therefore, in contrast to the first case, it was expected that the participants would frequently relate the information in the dashboard to their existing knowledge of the campus.

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8.3 Design results

8.3.1 Principles for dashboard design

The design of the dashboards in this research is based on a knowledge base combining theories and instruments from corporate real estate management (CREM), building automation, the IoT, and Information Management (see chapter 2). The dashboard is further detailed using design principles for dashboards as outlined by Few (2006). Following the earlier definition by Few (see subsection 2.3.4), there are several requirements on dashboards - just as in a dashboard of a car: a dashboard should not display all information, but the information that is needed to perform a specific activity such as driving a car. This information is collected from multiple sources: a car dashboard obtains data from sensors in the tank, engine, transmission, etc. to report fuel levels, speed, rotations, etc. Finally, information is reported succinctly and meaningfully to the user, e.g. by showing a meter with thresholds for maximum speed or for fuel tank content, or simply by displaying an alert when a seatbelt is not used.

From CREM several principles are drawn for a dashboard to be used in university campus management, based on Den Heijer (2011). These principles direct choices on which type of indicators to consider and which to omit (to avoid information overload), and how to report them. The principles are:

1. The dashboard reports on the process of adding value through real estate. Real estate is positioned as the input, the use of the real estate as the throughput, and the organisational performance as output;

2. The four stakeholder perspectives must be present in the dashboard. If a dashboard is tailored towards a specific group, the dashboard should include information on the other perspectives. The question is, what are the key indicators per perspective;

3. Preferably, the indicators should be related to each other – e.g. euro / m^2, users / m^2, etc.;

4. The indicators in the dashboard are customised to the type of campus decision, and limited in number by the requirement to fit on a single screen;

5 The stakeholder perspectives are applicable on multiple abstraction levels: e.g. on the organisational level of the university, faculty or department and on the real estate level of a building portfolio, building or set of spaces.

From the IoT, lessons with regards to the sensing of properties of the environment with various technologies are drawn from previous chapters (5-7). This real-time data allows for better use of spaces on campus by users on a day-to-day basis. Furthermore, real estate managers can make better decisions about demand in the long term, when real-time data collection (supplied by the IoT) is used as a 'ground truth' (Sadd et al., 2015; Sadd et al., 2013) for actual space use. Previous research provides overviews of the management information that can be made available through IoT applications. From Information Management lessons on the use of information technologies (IT) are drawn, including those of the IoT, in order to deliver value in organisations. In chapter 7, process and information analyses were conducted for both cases presented here. These analyses match the demand for information from campus management and the supply of information from the IoT and other IT, and thus serve as a foundation for the information requirements to be satisfied in the dashboard.

Information requirements for an overview of existing spaces include various space characteristics such as type, area, capacity, condition level, and level of amenities. The IoT complements these with information on frequency and occupancy rates, user satisfaction, energy use and indoor environmental quality. These requirements are combined with the five principles from CREM to guide the conceptual design (see Figure 8.4). This conceptual design is the starting point of the cases: designing what is *possible* with IoT applications. Following that, the cases focus on selecting what is *desired* from IoT applications.

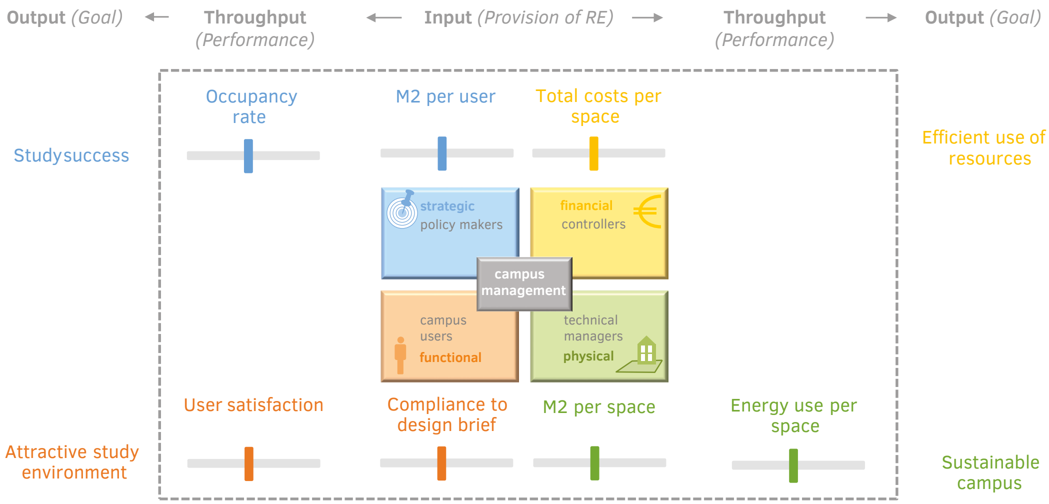

FIG. 8.4 Conceptual design for the structure of the dashboards, based on previous research.

After determining which information to display, the next issue is how to display it. Table 8.2 provides several considerations with regards to displaying information. Each property of a dashboard is matched with initial values for the real estate dashboards and matching indicators. The variations in timing depend on the type of information displayed. For the existing situation, the current performance of real estate indicators is shown. For IoT indicators this is the year-to-date performance. In addition, a comparison over the past five years is required because real estate indicators tend to change very slowly. The most important comparisons in the dashboard, aside from the comparison in time, are a comparison to norms determined by the organisation and a comparison across buildings. Visual indicators are used to draw user attention to poor performance. Finally, data on objects and past interventions are added to provide further context to the contents of the dashboards.

TABLE 8.2 Considerations for the display of information in dashboards (based on Few, 2006).

Properties	Values (Dashboards)	Considerations
Common dashboard information per business practices	Previously determined, to be refined through the workshops for each case	-
Variations in timing: year to date, month to date, etc.	Year-to-date or 5 years – to date	Determined by the nature of the objectives supported by the dashboard
Enrichment through comparison: relation to past, future, norm, average, etc.	Relation to past point in time Relation to norm Relation to other spaces/buildings/ average	Text usually suffices for comparison (instead of visual); especially time series provide rich context.
Enrichment through evaluation: use of visual indicators to draw attention	Visual indicators that indicate when a space /building performs inadequately	Indicators need not be binary, but too much distinct states will become too complex
Non-quantitative data: top 10 customers, issues to investigate, etc.	Addition of interventions, object data to support information in dashboards	-

An important choice drawn from Few (2006) is the use of bullet graphs for clear visual communication. The advantage of bullet graphs is that they enable the display of performance on an indicator across multiple divisions of the portfolio and compared to values for poor, medium and good performance. Figure 8.5 shows an example of a bullet graph used in one of the dashboards in this research. The overlay of measurement on requirements makes it easier to discern which parts of the portfolio perform well and which do not.

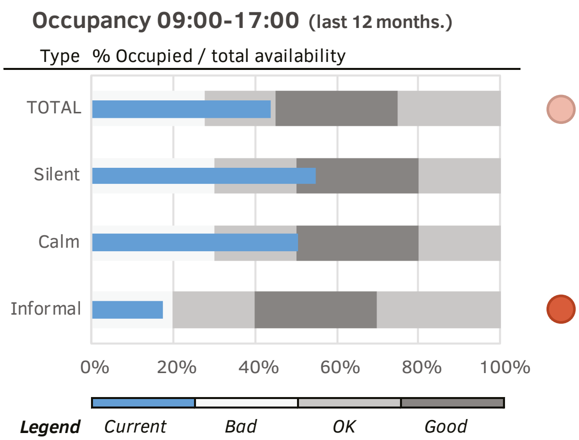

FIG. 8.5 Example of a bullet graph (own illustration).

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8.3.2 Dashboard designs and design outcomes

Radboud University Nijmegen

The dashboard design for RU was determined by two information needs that must be satisfied: (1) establishing the match between the demand for spaces and the supply of spaces and (2) identifying trends that may impact the future demand for spaces. This led to the initial division into two dashboards (Figure 8.6 and Figure 8.7). Each dashboard initially contained eight indicators, four related to the provision of real estate and four related to space use: *study places per student, average stay duration, the percentage of spaces that comply to the brief, user satisfaction, total costs per study place, occupancy, floor area per study place,* and *energy use per study place*. In the main dashboard, the performance on each indicator was visible for every type of study place and the whole portfolio. In the Trends dashboard, the performance on the whole portfolio over the past five years was visible. In both dashboards, the user could navigate between viewing the performance on a campus-level or selecting a specific building.

After the first workshop, the indicators *stay duration* and *energy use* were omitted as they were found to be of less importance to determine the performance of the study place portfolio (see subsection 8.4.1). Furthermore, two other dashboards were made (see appendix 5): one in which the main dashboard displayed the performance per building rather than per type of study place, and another that offered a more detailed insight into the performance on four criteria. These were tested in workshop 2.

The dashboard tested in workshop 2 complied to the requirements set in subsection 8.3.1: (1) it positioned traditional real estate indicators in the top row as input and indicators based on information from the IoT below them as throughput; (2) it contained indicators in each stakeholder perspective; (3) it defined the indicators in such a way that their values could be related to each other; (4) it was customised for decisions on the study places of the university; and (5) the dashboard could report on both a portfolio and a building level. Both the main dashboard and the alternative to the main dashboard were found to be useful by the participants. The additional dashboard was also found to be useful, but requires further development and testing.

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Radboud University Nijmegen
Study Places (dashboard)
Campus
Campus manager
Effective space use
Conclusion
Attractive study environment
Conclusion
Efficient provision of space
Conclusion
Study places per student (2020)
Type Number of seats / number of students
Spaces comply to design brief (2020)
Type % of spaces that complies to the policy
Total costs per study place (2020)
Type Operating costs + depreciation costs per seat
Area per study place (2020)
Type m2 / study place
Occupancy 09:00-17:00 (last 12 months.)
Type % Occupied / total availability
User satisfaction (last 12 months)
Type Average user satisfaction (0-10)
Legend Current Bad OK Good
Properties of objects
Campus 4925 seats
Selection
TOTAL 4925 seats 100% of total
Silent 2020 seats 41% of selection
Calm 2025 seats 41% of selection
Informal 880 seats 18% of selection
Construction year -
User
Strategy -
Energy label -
Energy use 491 kWh / study place / year


Radboud University Nijmegen
Study Pla
Campus
Effective space use
Conclusion
Attractive study environment
Conclusion
Study places per student (2020)
Type Number of seats / number of students
TOTAL
Silent
Calm
Informal
0,0 0,1 0,2 0,3 0,4 0,5
Legend Current Bad OK Good
Spaces comply to design brief (2020)
Type % of spaces that complies to the policy
TOTAL
Silent
Calm
Informal
0% 20% 40% 60% 80% 100%
Legend Current Bad OK Good
Occupancy 09:00-17:00 (last 12 months.)
Type % Occupied / total availability
TOTAL
Silent
Calm
Informal
0% 20% 40% 60% 80% 100%
Legend Current Bad OK Good
User satisfaction (last 12 months)
Type Average user satisfaction (0-10)
TOTAL
Silent
Calm
Informal
4 5 6 7 8 9 10
Legend Current Bad OK Good

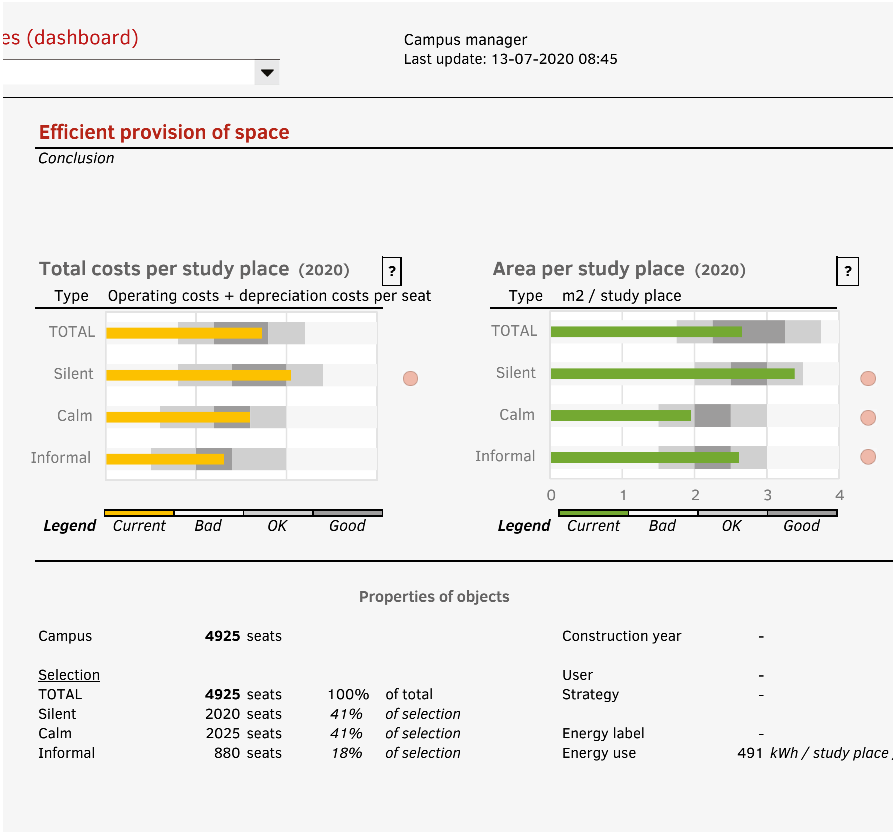
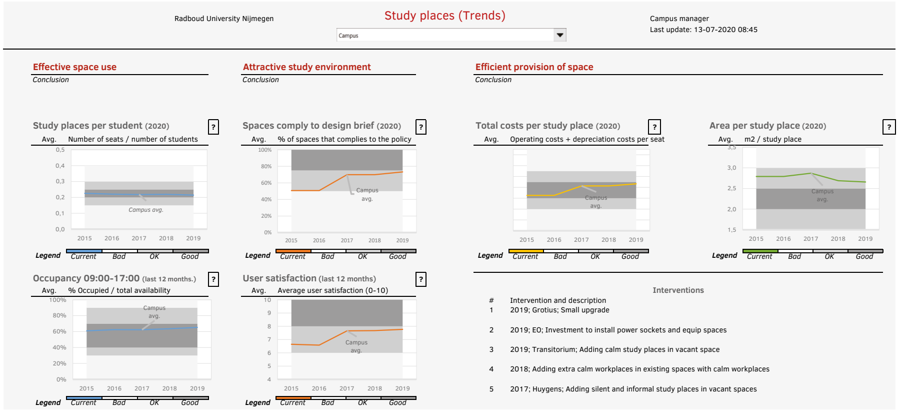


FIG. 8.6 Main dashboard ‘Study places RU’ (tested in workshop 2): overview, left side and right side.


Radboud University Nijmegen
Study places (Trends)
Campus
Campus manager
Last update: 13-07-2020 08:45
Effective space use
Conclusion
Attractive study environment
Conclusion
Efficient provision of space
Conclusion
Study places per student (2020)
Avg. Number of seats / number of students
Spaces comply to design brief (2020)
Avg. % of spaces that complies to the policy
Total costs per study place (2020)
Avg. Operating costs + depreciation costs per seat
Area per study place (2020)
Avg. m2 / study place
Occupancy 09:00-17:00 (last 12 months.)
Avg. % Occupied / total availability
User satisfaction (last 12 months)
Avg. Average user satisfaction (0-10)
Legend Current Bad OK Good
Interventions
Intervention and description
1 2019; Grotius; Small upgrade
2 2019; EO; Investment to install power sockets and equip spaces
3 2019; Transitorium; Adding calm study places in vacant space
4 2018; Adding extra calm workplaces in existing spaces with calm workplaces
5 2017; Huygens; Adding silent and informal study places in vacant spaces


Radboud University Nijmegen
Study place
Campus
Effective space use
Conclusion
Attractive study environment
Conclusion
Study places per student (2020)
Avg. Number of seats / number of students
0,5
0,4
0,3
0,2
0,1
0,0
Campus avg.
2015 2016 2017 2018 2019
Legend Current Bad OK Good
Spaces comply to design brief (2020)
Avg. % of spaces that complies to the policy
100%
80%
60%
40%
20%
0%
Campus avg.
2015 2016 2017 2018 2019
Legend Current Bad OK Good
Occupancy 09:00-17:00 (last 12 months.)
Avg. % Occupied / total availability
100%
80%
60%
40%
20%
0%
Campus avg.
2015 2016 2017 2018 2019
Legend Current Bad OK Good
User satisfaction (last 12 months)
Avg. Average user satisfaction (0-10)
10
9
8
7
6
5
4
Campus avg.
2015 2016 2017 2018 2019
Legend Current Bad OK Good

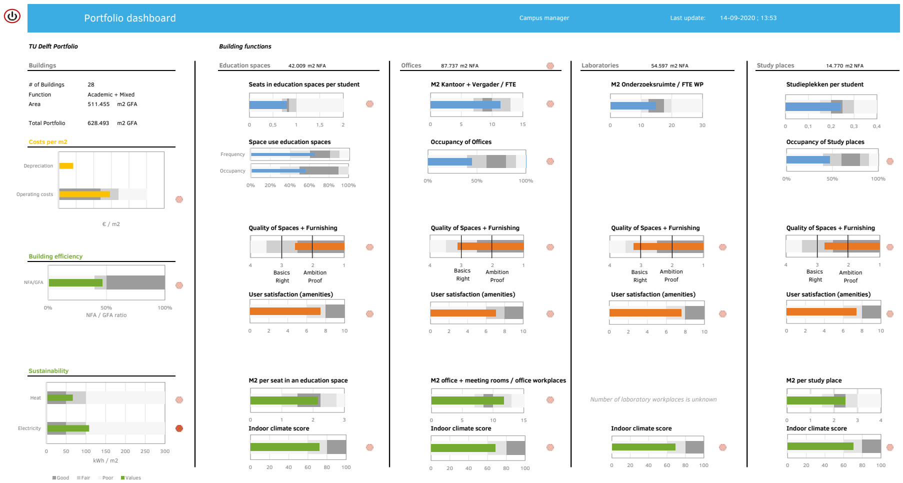
FIG. 8.7 Trends dashboard ‘Study places RU’ (tested in workshop 2): overview, left side and right side.

TU Delft

The dashboard design for TUD focused primarily on resolving the challenge of displaying the information in a clear way. Firstly, there was a challenge in what could be reported on a building level, i.e. *costs* and *energy use*, and information to be reported across the different space types of the building, i.e. education spaces, study places, offices and laboratories (and later meeting rooms). This led to the design of a dashboard showing the performance on the level of the whole portfolio or a selected building. The design of the dashboards was identical. To help navigate through the building dashboard, an overview was given of the buildings which required the most attention. Initially, the dashboard contained five building-level criteria (Figure 8.8): *operating costs, depreciation costs, building efficiency*, and *energy use* in warmth and electricity. For each space type, it contained six criteria: *seats (or* m^2*) per user, space utilisation* in *frequency* and/or *occupancy*, *quality, user satisfaction, floor area per seat,* and *an indoor environmental quality score.*

After the first workshop, the indicators *building efficiency,* m^2 *per seat, and the indoor environmental quality score* were omitted because they were deemed less important in determining the performance of the portfolio (see subsection 8.4.1). A financial criterion was added to reflect the use of resources during the year: *budget vs. expenditure.* The type of office spaces was further distinguished into offices and meeting rooms. After these amendments, a trends dashboard was made to show the development in past years (see Appendix 5). Finally, the overview to help navigate through the building dashboard was improved, based on feedback. In the first version, this overview included a ranking per space type to direct the user to the buildings requiring attention for each space type. This was adjusted to one overview with a list of the five buildings requiring the most overall attention. The dashboard tested in the second workshop is displayed in Figure 8.9.

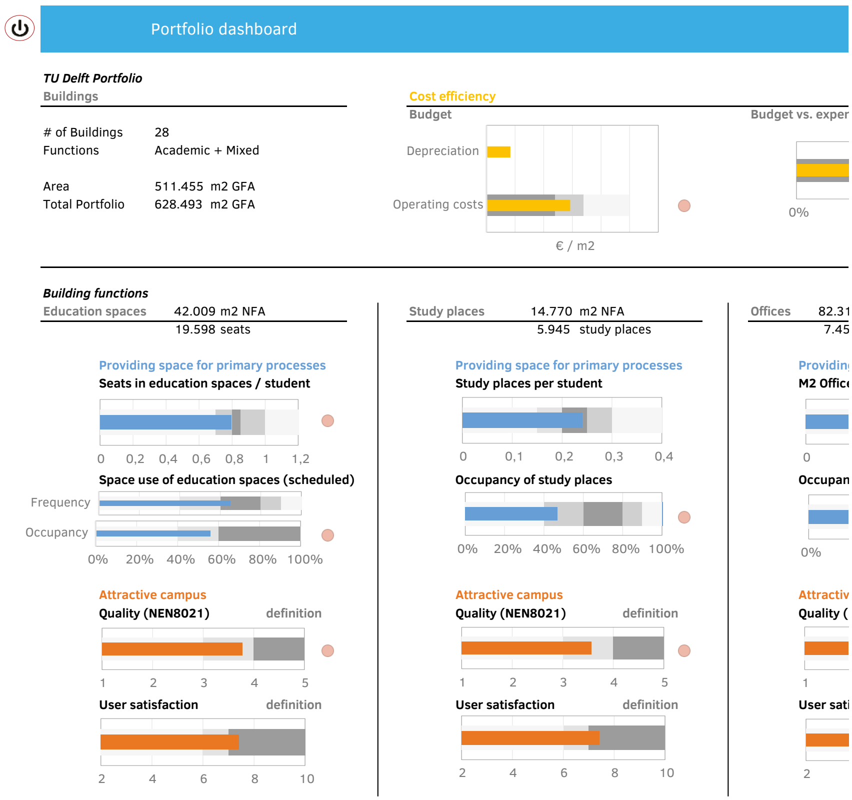
The dashboard tested in workshop 2 complied with the requirements set in section 8.3.1: (1) it positioned traditional real estate indicators as input and indicators drawing information from the IoT below them as throughput per stakeholder perspective and space type; (2) it contained variables from each stakeholder perspective; (3) it defined the indicators in such a way that their values could be related to each other; (4) it was customised for decisions on the buildings of the university; and (5) the dashboard reported on both a portfolio and a building level. The main dashboard was found to be useful by the participants. The trends dashboard and the overview for navigation were not sufficiently used in the workshops to evaluate thoroughly and require further development.


Portfolio dashboard
Campus manager
Last update: 14-09-2020 ; 13:53
TU Delft Portfolio
Building functions
Buildings
Education spaces 42.009 m2 NFA
Offices 87.737 m2 NFA
Laboratories 54.597 m2 NFA
Study places 14.770 m2 NFA
Seats in education spaces per student
M2 Kantoor + Vergader / FTE
M2 Onderzoeksruimte / FTE WP
Studieplekken per student
Space use education spaces
Occupancy of Offices
Occupancy of Study places
Quality of Spaces + Furnishing
User satisfaction (amenities)
M2 per seat in an education space
M2 office + meeting rooms / office workplaces
Number of laboratory workplaces is unknown
M2 per study place
Indoor climate score
Costs per m2
Building efficiency
Sustainability


Portfolio dashboard
TU Delft Portfolio
Building functions
Buildings
# of Buildings 28
Function Academic + Mixed
Area 511.455 m2 GFA
Total Portfolio 628.493 m2 GFA
Costs per m2
Depreciation
Operating costs
€ / m2
Building efficiency
NFA/GFA
0% 50% 100%
NFA / GFA ratio
Sustainability
Heat
Electricity
0 50 100 150 200 250 300
kWh / m2
Good Fair Poor Values
Education spaces 42.009 m2 NFA
Seats in education spaces per student
0 0,5 1 1,5 2
Space use education spaces
Frequency
Occupancy
0% 20% 40% 60% 80% 100%
Quality of Spaces + Furnishing
4 3 2 1
Basics Right
Ambition Proof
User satisfaction (amenities)
0 2 4 6 8 10
M2 per seat in an education space
0 1 2 3
Indoor climate score
0 20 40 60 80 100
Offices 87.737 m
M2 Kantoor -
Occupancy o
Quality of Sp
User satisfac
M2 office + n
Indoor clima

FIG. 8.8 Main dashboard 'Portfolio TUD' (tested in workshop 1): overview, left side and right side. The left and right side views have been slightly adjusted to optimise for viewing.


Portfolio dashboard
Campus manager
Last update: 14-09-2020 ; 13:53
TU Delft Portfolio
Buildings
# of Buildings 28
Functions Academic + Mixed
Area 511.455 m2 GFA
Total Portfolio 628.493 m2 GFA
Cost efficiency
Budget
Depreciation
Operating costs
€ / m2
Budget vs. expenditure (2020)
Sustainability
Energy use
Heat
Electricity
kWh / m2
Building functions
Education spaces 42.009 m2 NFA
19.598 seats
Study places 14.770 m2 NFA
5.945 study places
Offices 82.316 m2 NFA
7.451 workplaces (primary)
Meeting rooms 11.686 m2 NFA
3.506 meeting rooms
Laboratories 54.597 m2 NFA
Providing space for primary processes
Seats in education spaces / student
Study places per student
M2 Office space per FTE employees
Seats in meeting rooms per FTE employees
M2 Laboratories per FTE academic staff
Space use of education spaces (scheduled)
Occupancy of study places
Occupancy of office workplaces
Occupancy of meeting rooms
The use of laboratories is not measured
Attractive campus
Quality (NEN8021)
User satisfaction
definition


Portfolio dashboard
TU Delft Portfolio
Buildings
# of Buildings 28
Functions Academic + Mixed
Area 511.455 m2 GFA
Total Portfolio 628.493 m2 GFA
Cost efficiency
Budget
Budget vs. exper
Depreciation
Operating costs
€ / m2
0%
Building functions
Education spaces 42.009 m2 NFA
19.598 seats
Study places 14.770 m2 NFA
5.945 study places
Offices 82.31
7.45
Providing space for primary processes
Seats in education spaces / student
0 0,2 0,4 0,6 0,8 1 1,2
Space use of education spaces (scheduled)
Frequency
Occupancy
0% 20% 40% 60% 80% 100%
Attractive campus
Quality (NEN8021) definition
1 2 3 4 5
User satisfaction definition
2 4 6 8 10
Providing space for primary processes
Study places per student
0 0,1 0,2 0,3 0,4
Occupancy of study places
0% 20% 40% 60% 80% 100%
Attractive campus
Quality (NEN8021) definition
1 2 3 4 5
User satisfaction definition
2 4 6 8 10
Providin
M2 Office
0
Occupan
0%
Attractiv
Quality (
1
User sati
2

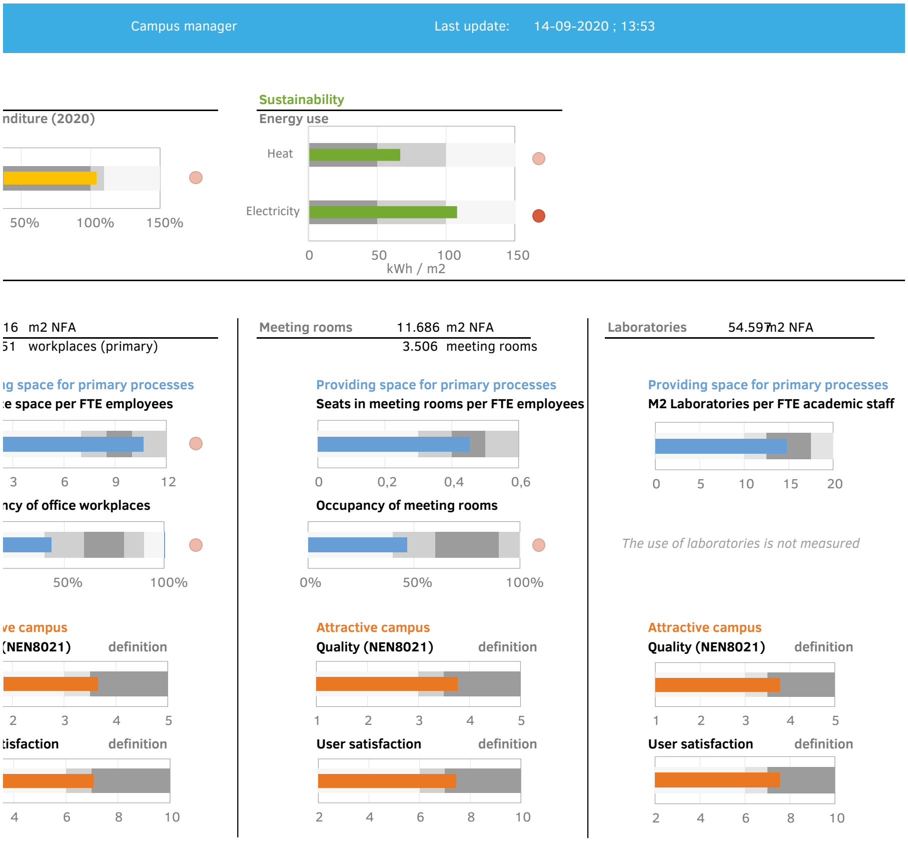


FIG. 8.9 Main dashboard 'Portfolio TUD' (tested in workshop 2): overview, left side and right side. The left and right side views have been slightly adjusted to optimise for viewing.

8.3.3 Design outcomes (analysis A3)

In each workshop, the participants were asked to complete two assignments using the dashboard: first, to assess the performance of the whole portfolio, and second, to determine interventions per building. This analysis discusses these interventions as the outcomes of using the dashboards. The proposed interventions for specific buildings are compared to initial conclusions drawn up by the main author. For each specific building, the three most important interventions are drawn up a priori and compared to the interventions proposed by the participants. Each intervention can occur multiple times across buildings, and they can be determined in separate occurrences by participants, as there are 3 outcomes of workshop 1 and 2 outcomes of workshop 2.

Table 8.3 lists the most important interventions drawn up in the RU case, the number of times they occur, and to what extent these interventions are also defined by the participants. Each intervention can occur six times at most, as there are six buildings which could potentially all require the same intervention. Then, the interventions determined by the participants are compared to the number of times these interventions could have been determined. Table 4 shows that participants were able to define multiple interventions. They were particularly focused on silent study places in workshop 1. In workshop 2, participants were focused more on identifying qualitative interventions. Furthermore, the table shows that the participants identified five interventions which were not identified in the author's main conclusions. These interventions show an ability to combine the information from the dashboard with knowledge about the campus, the buildings and its users that is not contained in the dashboard: e.g. discussing how to redevelop quality requirements, by sending students to other buildings or by naming the planned disposition of a building as an intervention.

Table 8.4 shows the results for the TUD case. Here, the number of possible occurrences of interventions is based on the buildings selected by the participants to study, as there are more than 40 buildings in the model. The selected buildings differ somewhat per workshop group. Similarly to the first case, participants were able to define multiple interventions. The conclusions show that participants were mainly focused on quantitative interventions (increase or reduction of a type of space), and less on qualitative interventions. Furthermore, the participants defined four additional interventions. These interventions and the additional comments reveal a need for more specific information on occupancy patterns, which can be delivered through drill-down dashboards (see case 1). Furthermore, they show the ability of participants to connect the information in the dashboards to existing knowledge of the portfolio, e.g. the current tenant's demands and satisfaction level.

TABLE 8.3 Interventions in Case RU.

	Case RU	Author's Main conclusions		Participants' Main conclusions		Additional comments
	Interventions	WS1	WS2	WS1 (3 groups)	WS2 (2 groups)	
		# of occurrences in the dashboard model		# of occurrences / possible occurrences		
I1	Add silent study places within existing m^2s (decreasing m^2/study place and costs/ study place)	3	3	7/9	2/6	Proposed in one additional building (WS 1)
I2	Reduce calm and informal study places / replace them for silent study places	1	0	1/3	-	
I3	Transform calm study places into silent study places	3	2	0/9	0/4	
I4	Invest in the quality of the study places	3	2	1/9	2/4	Specified to power outlets, ventilation, Wi-Fi (WS2)
I5	Take measures to reduce energy usage	2	0	0/6	-	
I6	Stimulate students to find the existing silent study places	1	0	1/3	-	
I7	Add informal study places within existing m^2s (decreasing m^2/ study place and costs/ study place)	1	3	1/3	0/6	
I8	Reduce silent and informal study places by removing study places (increasing m^2/place)	0	1	-	0/2	
I9	Discuss Quality requirements with students	-	-	2/3	-	
I10	Dispose of Building 2	-	-	2/3	-	
I11	Send students to another building	-	-	1/3	1/2	
I12	Further research in what intervention to choose for calm study places	-	-	-	2/2	
I13	Use other spaces in Building 4 to create extra study places	-	-	-	2/2	

TABLE 8.4 Interventions in Case TUD for the buildings that were selected by the participants in the assignments.

	Case TUD	Author's Main conclusions		Participants' Main conclusions		Additional comments
	Type of intervention	WS1	WS2	WS1 (3 groups)	WS2 (2 groups)	
		# of occurrences in the dashboard model		# of occurrences / possible occurrences		
I1	Increase the number of research spaces per user	1	0	1/2	-	Proposed at the expense of other space types (WS1)
I2	Reduce the energy emissions on campus	2	3	0/2	2/4	
I3	Reduce the number of study places (increasing the m^2/user)	1	1	1/3	2/2	Research the use in specific buildings to determine action (WS2)
I4	Increase the quality of all space types	1	0	1/2	-	Also consider styling and tenant's wish to invest in the entrance (WS1)
I5	Reduce the number of office spaces per user	1	3	2/2	1/4	Discuss where tenant's dissatisfaction comes from (WS1)
I6	Invest in the quality of offices and laboratories (and meeting rooms)	0	2	-	1/2	
I7	Increase the number of study places within existing m^2s	1	-	1/1	-	
I8	Reduce number of education spaces within existing m^2	-	-	1/3	-	
I9	Discussion about cost levels at the university	-	-	2/3	-	
I10	Spread students between study place locations	-	-	1/3	-	
I11	Further research on the use of study places to determine further action	-	-	-	1/1	

8.4 Refining and adjusting dashboard information requirements

8.4.1 Relative importance of indicators (analysis A1)

This analysis studies the use frequency of indicators during the assignments in order to determine which indicators to exclude from the dashboards. In each assignment, participants first completed the assignment and were then asked to state their conclusions. First, the number of mentions per indicator during the navigation was counted; then, the indicators were ranked from 1 to 8 based on those counts. The score indicates the average rank of each indicator during each workshop. The results of the workshops were averaged. Based on the average, rank indicators were categorised in terms of their importance and compared to the use of indicators mentioned by participants in their conclusions, also based on an average of counts.

The outcomes of both cases were also compared to the performance on each indicator according to the dashboards (i.e. where the dashboards draw the user's attention to). The comparisons showed that there is little to no relation between what the model draws attention to and what the participants look at. This suggests that the participants of the workshop used the model based on their own expertise and not just by what the model indicates. This is a positive finding with respect to usability, which is the subject of the third analysis.

The outcomes of the analysis for the RU case are reported in Table 8.5. In the first workshop, based on the use of the indicators in the assignments, *study places / student, occupancy, compliance to the brief* and *user satisfaction* were determined to be of high importance; *floor area per place* was of medium importance; *costs, stay duration* and *energy use* were categorised as low importance. The use of the indicators in formulating conclusions supported these findings. Based on these results, *stay duration* and *energy use* were omitted from the dashboard in the second workshop. Despite low importance, *costs* were not omitted, following the dashboard requirement of including information from each stakeholder perspective. The results of the second workshop were very similar to those of the first.

TABLE 8.5 Use of the indicators during the assignments and in forming conclusions. Asterisks (*) denote instances in which the importance based on the conclusions deviates from the importance based on the assignments.

Indicators	Workshop 1			Workshop 2		
	Assignments		Conclusions	Assignments		Conclusions
	Rank (1-8)	Importance	Importance	Rank (1-6)	Importance	Importance
Study places per student	2,5	High	High	1,3	High	High
Stay duration	6,2	Low	Low	-		
Total costs	6,0	Low	Low	6,0	Low	Low
Occupancy	2,3	High	High	3,5	High	High
Compliance to brief	3,5	High	High	3,3	High	High
User satisfaction	3,0	High	High	3,5	High	High
M^2 / place	5,2	Medium	Medium	3,5	High	Low*
Energy use	7,3	Low	Medium*	-		

The outcomes of the analysis for the TUD case are reported in Table 8.6. The table distinguishes building-level and space-type indicators because each space-type indicator is repeated per space type and is thus used much more frequently in the assignments. Consequently, these indicators were counted separately for each space type and averaged prior to their ranking. The use of indicators in formulating conclusions deviated slightly from the assignments, especially for *sustainability* and *user satisfaction*. Based on the results, *building efficiency* and *indoor climate score* were omitted because of low scores; additionally, *m^2 per seat* was removed to reduce the information load. On the other hand, *sustainability* remained in the dashboard following the requirement of including information from each stakeholder perspective.

The results of the second workshop are similar to the first workshop, except for *sustainability*. Furthermore, given the feedback of some of the participants, it should be considered to add the *m^2 per seat* indicator to the dashboard again.

TABLE 8.6 Use of the indicators during the assignments and in forming conclusions. Asterisks (*) denote instances in which the importance based on the conclusions deviates from the importance based on the assignments.

Indicators	Workshop 1			Workshop 2		
	Assignments		Conclusions	Assignments		Conclusions
	Rank (1-9)	Importance	Importance	Rank (1-6)	Importance	Importance
Building-level						
Costs	3,8	High	High	3,3	Medium	Medium
Building efficiency	6,7	Low	Low	-		
Sustainability	5,8	Medium	Low*	1,3	High	High
Space-type						
m^2 per user	2,0	High	High	3,0	High	Medium*
Frequency and occupancy	3,7	High	Medium*	3,0	High	Medium*
Quality	4,0	High	Medium*	5,5	Medium	Medium*
User satisfaction	6,0	Low	Medium*	5,0	Medium	Low*
m^2 per seat	5,7	Medium	Medium	-		
Score indoor climate	7,3	Low	Low	-		

8.4.2 Information quality and flow (analysis A2)

In this analysis, the quality of the use of indicators during the assignments is analysed. Based on observation, the use of an indicator was labelled as positive or negative. Positive uses, which suggest sufficient information quality and flow, react to a positive or negative situation in the model, seeking relations between indicators or seeking relations with the real-life context. Negative uses, which suggest insufficient information quality and flow, ignorance of the situation in the model, confusion about what is displayed, or a dead end (the user gets stuck in the interpretation of the model due to wrong interpretations). Each of these uses is counted in a transcript of the workshop, with the relationships between indicators counted as 0,5 point per indicator and all other types of uses as 1 point. Ignorance of situations in the model is determined by the points to which the model draws attention and by if the participants pay attention to those points.

In both cases, the number of positive interactions during the first workshop greatly outnumbered the number of negative interactions: see Table 8.7. At RU the ratio was 6,1:1, at TU Delft 5,2:1. This analysis supports the initial observations made during the workshops, namely that participants were able to use the model well to complete the assignments and form conclusions. Between the cases a difference can be observed in how the model was used: at RU participants made sense of the information by reacting to what was in the model and relating indicators to each other, while at TUD participants made more connections between what was in the model and the situation in reality. This is thought to be the effect of using fictive data in the first case, which forced participants to focus on what was in the dashboard.

The primary objective towards workshop 2 was to reduce the number of negative interactions by improving information quality. At RU there was some confusion about the definitions of *study places per student, stay duration,* and *occupancy*. To resolve this, pop-ups giving the definitions were added next to each indicator. In addition, for *study places per student* and *occupancy*, a 'drilldown' dashboard was made that enabled the users to see the differences in performance during education weeks and exam weeks. At TUD, there was confusion with regards to the definitions of *quality, user satisfaction*, and the *indoor climate score*. Here, pop-ups giving the definition of the latter two were added to remove confusion, while for *quality* a link led to the description of an existing framework for defining quality.

As a result of these changes, in workshop 2 the ratio of positive to negative interactions increased at TUD from 5,2:1 to 8,7:1. At RU, the ratio decreased from 6,1:1 to 5,4:1. However, the decrease is due to one new participant, who participated only in workshop 2. If this participant is excluded from the group, the ratio increased to 8,5:1. At RU, the confusion concerning indicators was reduced, which suggests that the adjustments to the model had effect. However, the alerts for the cost indicator were fairly often ignored, which suggested further improvement to the information quality of this indicator is needed. At TUD, the confusion with regards to costs increased as well. This is largely due to adding another financial indicator between the first and the second workshop. Furthermore, participants indicated that, to be able to reach conclusions, they needed additional information on indicators such as quality and user satisfaction, despite clarity in their definitions. Here a similar 'drilldown' dashboard as in the first case would be useful.

TABLE 8.7 Sum of positive and negative instances, comparing cases and workshops (see Appendix 5 for details).

Case	Workshop 1			Workshop 2		
	Positive instances	Negative instances	Ratio	Positive instances	Negative instances	Ratio
Radboud University	190	31	6,1:1	135	25	5,4:1
TU Delft	261	50	5,2:1	226,5	26	8,7:1

8.5 Conclusion

The research question to be answered in this chapter was:

RQ7: How can the information demands of campus management be matched to the capabilities of IoT applications, and optimally displayed in a dashboard?

This research question is connected to the main objective, i.e. to develop a connection between IoT applications and real-life decision-making processes, and a secondary objective, i.e. to design usable dashboards for campus managers.

With regards to the secondary objective, the results described the translation of various principles and the outcomes of process and information analysis into a conceptual design for dashboards. The designs for both cases were evaluated and were found to be compliant with the principles outlined in section 8.3.1. Next, the results of analysis A1 showed that the participants made use of indicators in all four stakeholder perspectives to formulate different kinds of interventions (see analysis A3). These results show that it is possible to design usable dashboards for a portfolio of study places and for an entire real estate portfolio at a university, combining data from existing systems and data to be delivered by IoT, based on the combination of principles from various fields (Bytheway, 2014; Den Heijer, 2011; Few, 2006).

Additionally, the findings from analysis A2 suggest that involving participants in the design process improved the usability of the dashboards, as the refined dashboards resulted in a higher ratio of positive to negative interactions. This is supported by participants, who indicated that the workshops enabled them to learn how to use the dashboards and work with their information. Specifically, the introduction of the dashboard in the first workshop was appreciated. Analysis A2 also showed that for some indicators such as *quality, user satisfaction*, but also *occupancy* and *m^2 per user*, participants may require definitions and explanations. 'Drilldown' dashboards were proposed as a solution (case 1) for analysts to determine interventions with precision.

With regards to the main objective, the results describe how the workshops resulted in the selection of indicators (analysis A1) and how improvements to the design resulted in improved usability in the second workshop (analysis A2). In the first case, the information requirements for IoT were determined to be *occupancy* and *user satisfaction*; in the second case, the dashboard was required to include data on *frequency and occupancy* (depending on space type) and on *user satisfaction*. Next to the information requirements for IoT, the design process also resulted in further information requirements. For example, in both cases requirements were formulated for the measurement and reporting of *quality*. The use of multiple workshops to test the dashboards, to assess which indicators are useful and if the total dashboard is still a good overview, helps with the selection of information. Prototyping (see section 2.2) was thus found to be a suitable method for the purpose of this research, as suggested by (Bergman et al., 2018; T. Lim et al., 2018; Tuunanen, 2003).

In the process of dashboard prototyping, the number of iterations (workshops) is a factor to consider. Especially when there are many indicators involved and participants feel that one or more of the excluded indicators should be reconsidered, a third workshop is useful. It can also help to test different dashboard alternatives, including different indicators per stakeholder perspective. In the second case, a third workshop could have been used to specify the indicators per space type. However, more iterations may also result in loss of focus or confusion. In case 2, the addition of an indicator after the first workshop was found to result in confusion. Therefore, workshops should generally work towards the use of fewer indicators, the addition of previously removed indicators or specifying existing indicators.

Finally, the results were used to develop design briefs, i.e. implementation designs. These design briefs covered the intended use of the dashboards, detailed definitions for each indicator, including information source, and procedures for addressing the complexity of acquiring the data and translating it to the information in the dashboard. Based on that and the existing situation, costs for acquiring and maintaining the data are estimated, and a step-by-step plan was made for each organisation to realise the dashboard. In both cases, the design briefs were received positively by stakeholders and client.

Through the dashboards seem quite similar, the client statements and departure points of the cases were different, leading to different outcomes. At Radboud University the objective was to help the Campus & Facilities department to manage the portfolio of study places, following the recent transfer of ownership from the faculties to their department. The results showed that even when not much information is available, dashboard design helps to make decisions on structuring information and thus on data collection. The step-by-step plan thus comprised specific steps, e.g. the acquisition of IoT applications, making a policy detailing quality requirements, and the data collection to monitor that policy.

At TU Delft, the objective was to give the CRE department an overview of the portfolio and buildings for use in updating the campus strategy. Compared to the first case an initial design and more information were available. The results showed how dashboard design helps to consolidate information on both a building-level and space-type level in the same screen in a simple, usable way. In particular, this design showed how to organise information on a higher order: to help understand what part of the building or portfolio requires attention, how important that part is, and how comparisons across space types can be made. The step-by-step plan included more generic steps than in the previous case, e.g. decide per space type in which way to measure frequency/occupancy and determine how to measure quality across the portfolio. Within each step, more detailed decisions have to be made.

In summary, the use of dashboard design showed several positive indications for determining IoT information requirements. The designed dashboards could be used by participants to complete the assignments, and led to several indications on how the designs may be further improved. Further research is needed to better understand how choices in the dashboard design affect results. This includes application of the dashboards in tactical and operational decision making.

Library building TU Delft. Photo: TU Delft Image repository.

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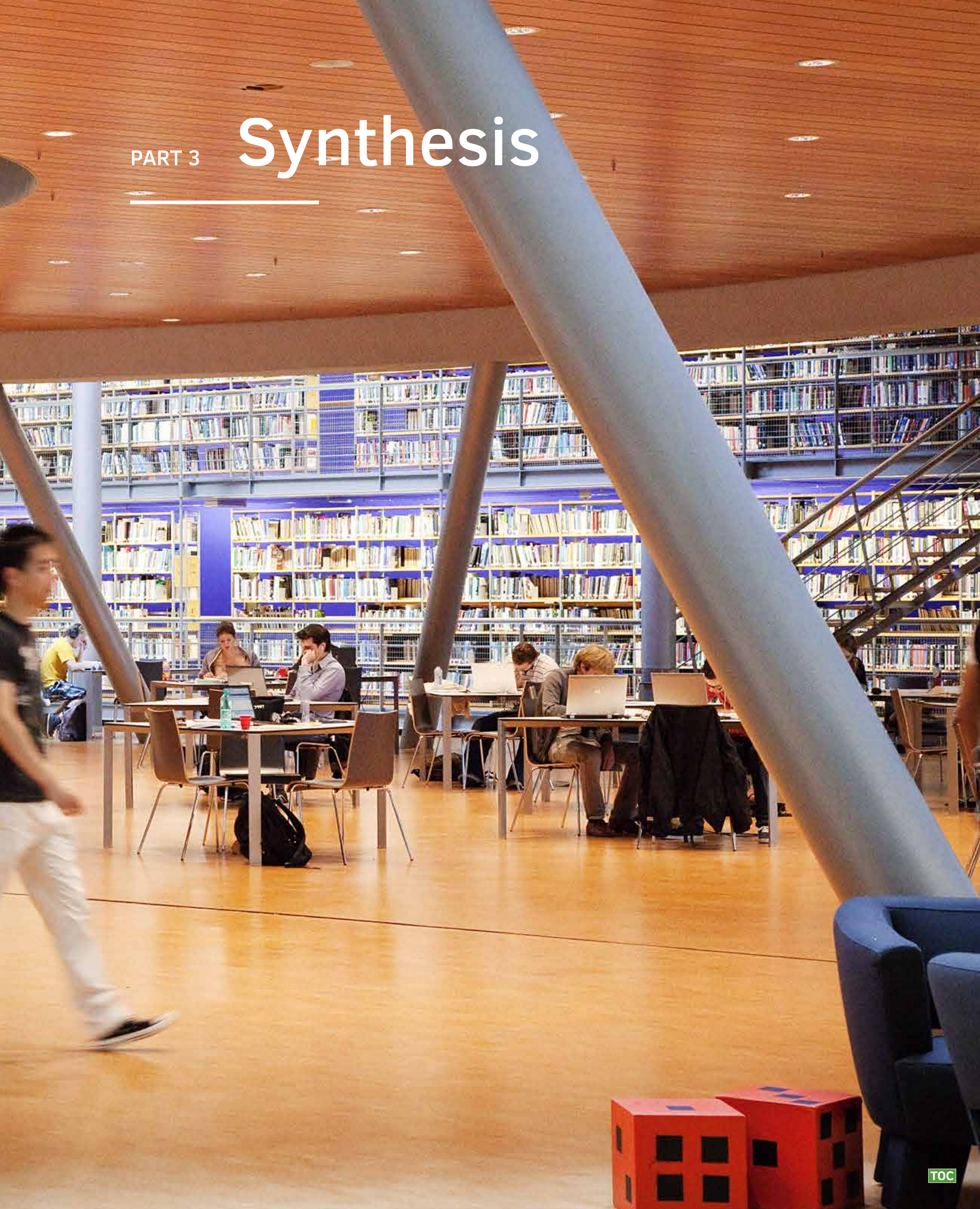
PART 3

Synthesis



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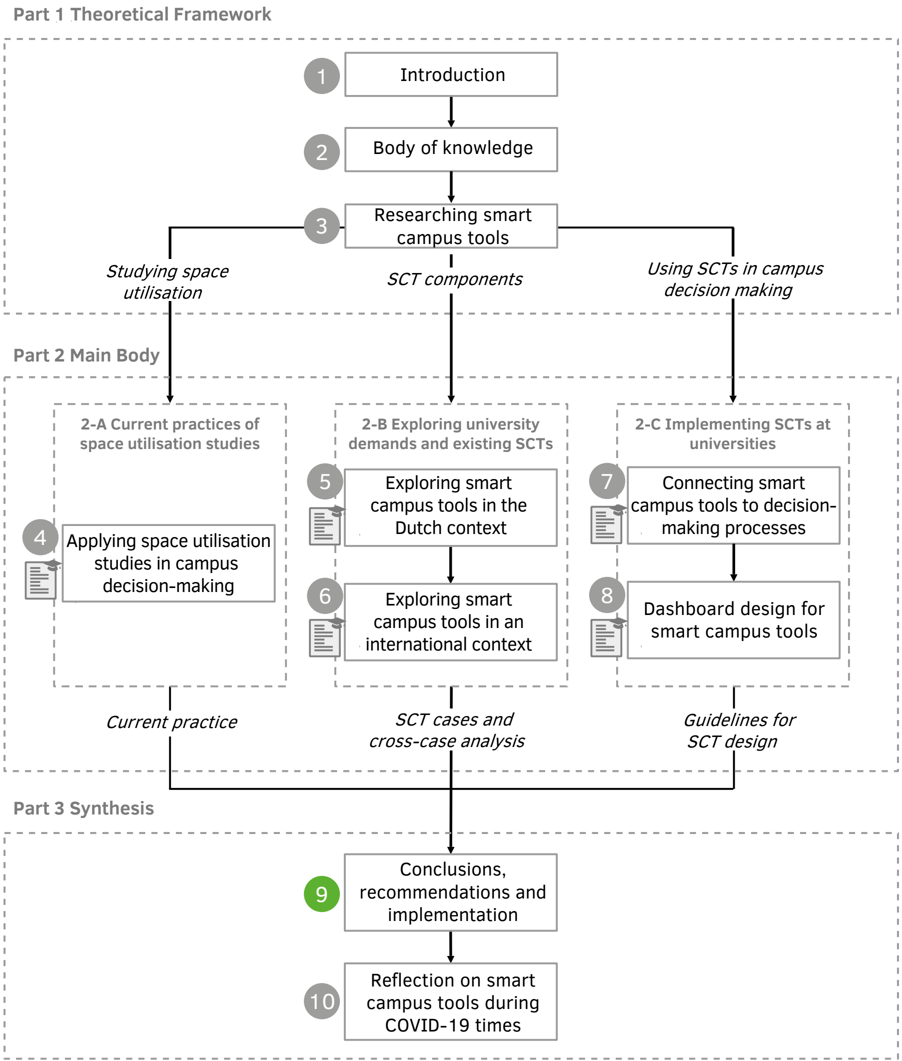


FIG. 9.1 Position of chapter 9 in this PhD dissertation.

9 Conclusions, recommendations and implementation

9.1 Introduction

This chapter brings together the existing knowledge, discussed in part I, and the results of this research, discussed in part II, to conclude this research. This chapter is structured as follows. First section 9.2 provides an answer to the main research question, bringing together the answers to the sub-questions. Then, section 9.3 describes the contributions of this research to the body of knowledge. Following this section, section 9.4 provides a roadmap to implementing SCTs. Finally, section 9.5 will discuss the scientific implications, limitations and recommendations for further research.

9.2 Answering the main research question

In order to answer the main research question, each of the chapters 4 – 8 has answered a specific sub-question. The conclusions of these chapters serve as input to answer the main research question. The main research question of this research was as follows:

"*How can smart campus tools optimally contribute to the match between demand for and supply of space, both on the current campus and on the future campus?*"

This research shows that SCTs can improve the match between the demand for and the supply of space in multiple ways. On many present-day university campuses, students can only find study places by going into a building and walking along each study place until they find an available and suitable study place. At the same time, employees have to submit demands for education spaces and meeting rooms well in advance, leading to an excess in reservations that are not used, or in reservations for groups well below the maximum capacity. Most employees at universities have their own individual workplaces, although many of them do not use their workplaces for large amounts of time due to educational activities, meetings, conferences, etc. As a result of this way of working, either much time is wasted to find available spaces, or many resources –both in terms of finance and sustainability- are wasted to provide spaces that are left unused for long stretches of time.

The cases collected in this research illustrate how SCTs support effective and efficient use of the current campus. Students can easily find study places via applications showing their availability, through PIR sensors underneath desks, cameras or access gates. Students and employees can make use of education spaces for studying or ad-hoc meetings, as applications show their availability through monitoring the Wi-Fi network or PIR sensors at the entrances of the spaces. Meeting rooms are made available for ad-hoc meetings as systems determine through cameras and PIR sensors if meeting reservations are left unused, and removing reservations when this is the case. Finally, sharing of office spaces can be supported effectively in a similar way to study places, as demonstrated in several cases in other organisations.

These findings partially confirm the first assumption:

Smart campus tools add value to the university campus and enable universities to simultaneously support increasing user demands (including health and safety) and increase their resource efficiency.

The collected cases show how SCTs add value to the university campus, enabling universities to cope with the increasing demands of users and with the need for increased resource efficiency. On the short term (on the current campus) this is more evident than on the long term. Because many SCTs collected in this research were still in early stages of development (e.g. in a pilot phase) or not implemented for a longer period of time, it is not known yet if an increased resource efficiency over a longer time period was actually achieved in the many cases where this was the objective. Such evidence was available only occasionally: e.g. 3.400 bookings per month, a 13% increase in frequency and occupancy rates or a 17,8% increase in energy efficiency show that SCTs serve the campus users' demands and they help to reduce the wasting of resources. Still, further research is needed to provide more evidence on the extent to which the intended objectives are achieved over longer time periods.

To improve space use on the future campus, SCTs deliver information to support decision making. In order to understand space use, many campus management departments rely on manual surveys. These surveys are expensive to conduct and result in a limited understanding of space use: (1) they may fail to account for changes just before or after a manual count (e.g. the delayed start of an event), (2) they may fail to show parts of the portfolio where utilisation is high and where it is low, and (3) the space use outside of the observed period may be very different from the space use during other times of the year.

Several case studies show how SCTs report on frequency and occupancy rates, collected through real-time data. For education spaces, reports contain frequency and occupancy rates measured real-time compared to the frequency and occupancy rates in the scheduling system. For study places and workplaces reports contain average workplace occupancy per space, floor or building, depending on which sensors are used and/or which level of detail is desired. For meeting rooms, reports contain frequency rates measured real-time to what is scheduled. By comparing the observed frequency and occupancy rates to objectives for these rates, organisations can understand the relationship between the space use (frequency and occupancy rates) and their space norms (in m^2 per user or users per m^2). For user satisfaction and energy use similar comparisons can be made.

In order to inform strategic decision-making processes -whether to build a new building, which buildings to renovate, if a building can be removed from the portfolio– this information on frequency and occupancy rates, user satisfaction and energy use needs to be connected to these decision-making processes. Four case studies show how process and information analysis are used to design these connections. The case studies also reveal the challenges of decision-making processes: they require a multitude of information and many options to deliver the information, through various systems present within the university and the IoT. To support campus managers in matching demand for and supply of spaces, the dashboards presented in this research brought together information on users per m^2, frequency and occupancy rates, compliance of spaces to design briefs, user satisfaction, costs per m^2, energy use and indoor climate performance in concise overviews. These were used by campus managers to (1) define interventions in the real estate portfolio and (2) determine which information is necessary in the dashboards for them to define those interventions.

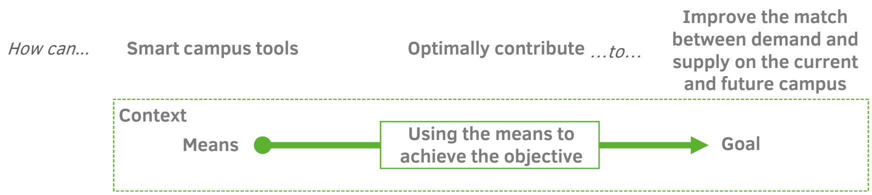
These findings support the second assumption:

A review of the required management information and its use in decision making processes enables SCTs to optimally contribute to the match between demand and supply in real estate.

Using process and information analysis, chapter 7 shows that strategic decision-making processes in campus management require complex overviews of performance, with many different kinds of information from different sources. Then, the results of chapter 8 show how dashboard design can help make decisions about which information to include in these overviews, as well as demonstrating how the dashboards support campus managers in their decision-making processes. The use of these methods thus supports campus managers in (1) determining which information from the IoT is necessary to support their decisions, and in (2) designing the interface including the relevant information for use in their decision-making processes. Still, further research would be needed to conclude if it there are better or more effective methods for this purpose, e.g. by studying organisations using these methods, or by comparing decision making processes using them to those who do not. However, it is expected that as the available information for decision making further increases, so will the need for tools to determine which information is necessary to make those decisions.

9.3 Contributions of this research to the body of knowledge

This section summarises the outcomes of this research related to the body of knowledge. Therefore, the existing knowledge on SCTs as discussed in chapter 2 is used; for this purpose, the findings of chapter 2 were translated into six foundations. Here, these foundations are revisited following the contents of chapter 4-8 and the main conclusion: see Figure 9.2.



	Monitoring building performance (ch. 2.2)	Providing management information (ch. 2.3)	Managing real estate (ch. 2.1)
Theoretical foundations (based on chapter 2) **INPUT** for this research	SCTs are components of smart buildings, which increase performance primarily through increased interaction with building occupants.	SCTs require information management in order to ensure a valuable contribution of its output to campus management.	SCTs add value to the performance of the university through strategic, functional, financial and physical campus perspectives, as an instrument in campus management.
	SCTs (or the broader IoT applications) enable smart buildings, campuses and cities, where the meaning of 'smart' is not narrowly defined and continuously developing.	The implementation of SCTs may lead to changes in both higher and lower-level organisational processes within the university	SCTs support campus management organisations in their CRE alignment in specific building blocks / process steps, resulting in added value.
Theoretical outcomes (based on chapter 4-8) **OUTPUT** of this research	Confirming the position of SCTs within a landscape of systems that is developing towards further integration and interaction.	Confirming the value of information management in designing SCTs for use in campus management.	Confirming the added value of SCTs, and specifying the value added through them.
	Confirming the different perceptions of 'smart' in SCTs and their continuous development.	Confirming the potential of SCTs to support organisational changes.	Confirming the building blocks / process steps in which SCTs support CRE alignment; Identifying the potential of SCTs to increase the frequency and precision of CRE alignment.

FIG. 9.2 Revisiting the theoretical foundations resulting from chapter 2 based on the results of chapters 4-8.

Determining how to add value to the campus through smart campus tools

SCTs add value to the performance of the university through strategic, financial, functional and physical campus perspectives, as an instrument in campus management.

SCTs can be used to add values to the campus in many ways, as demonstrated through the cases documented in this research. Often, they directly contribute to functional goals such as supporting user activities or increasing flexibility, and physical goals such as reducing the CO_2 footprint or enhancing safety. Furthermore, the use of SCTs over a longer period of time supports goals that are achieved over the course of months or years – e.g. reducing the m^2 footprint or reducing costs. More indirectly, the implementation and use of SCTs can contribute to strategic goals such as supporting image or culture, or a need to stimulate collaboration or innovation.

Several adjustments need to be made to the added value model (Den Heijer, 2011) in order to make it more usable for SCTs (Figure 9.3):

- Reducing the footprint needs to be reformulated into ‘Optimising m^2 footprint’ and ‘Reducing CO_2 footprint’. Although optimising the m^2 footprint also reduces the CO_2 footprint (per user), each requires different SCTs to achieve;
- Enhancing safety is added to the model, as SCTs can deliver information to support emergency response situations;
- Optimising the mix of spaces is added to the model, because of the increasing need for resource efficiency. The needs for education spaces, study places, laboratories etc. are competing needs; therefore, they need to be weighed and balanced against each other. This is considered to be an added value in the strategic perspective.

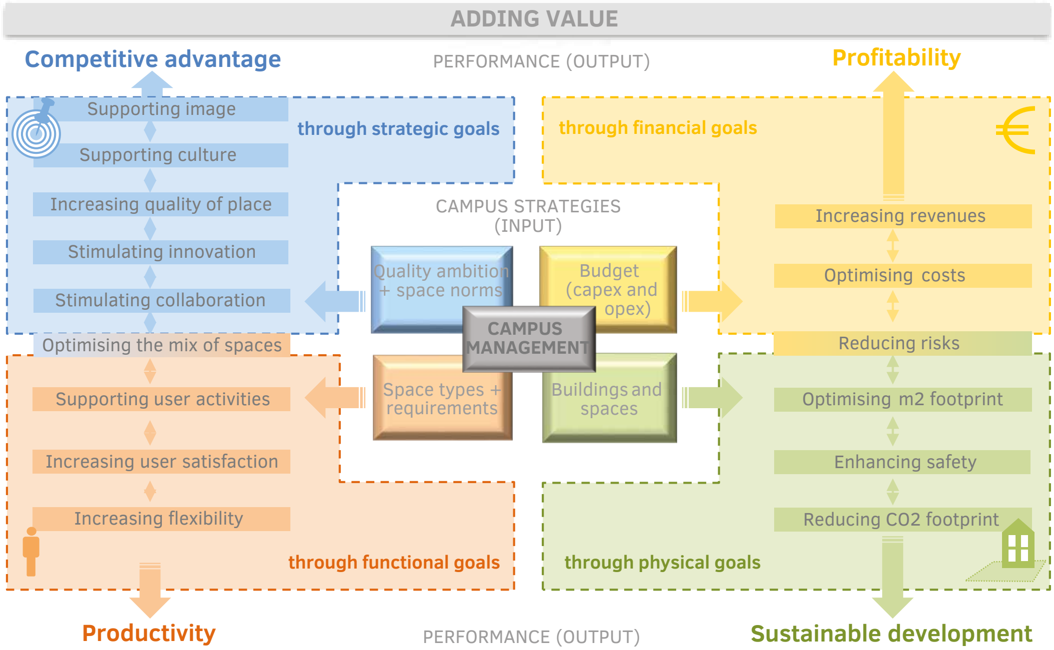


FIG. 9.3 Adding values through SCTs (adapted from Den Heijer (2011).

Understanding how smart campus tools support alignment of the campus to users' demands

SCTs support campus management organisations in their CRE alignment in specific building blocks / process steps, resulting in added value.

SCTs support CRE alignment primarily through matching the existing demand to the existing supply (step 1 of the DAS Frame (De Jonge et al., 2009), and building block 2 – Understanding real estate performance (Heywood & Arkesteijn, 2017)). In doing so, they also support the actions and decisions in further steps of CRE alignment.

In addition, SCTs promise to increase the precision and frequency of alignment of demand to supply. The precision increases due to the availability of much more accurate data. The frequency increases due to different types of decisions that can be supported through this data: see Figure 9.4.

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On a daily basis, users align their demands for space to the available spaces by using them. This is explicit especially in contexts where workplaces (or study places) are shared, as users need to select a workplace. SCTs support this alignment by informing them of available workplaces and their characteristics, and can also connect workplace use to the delivery of building services. Over time, SCTs yield management information on this use of space. This management information can be used to inform decisions on a tactical level, making adjustments to the furnishing, cleaning schedules, settings of building services etc. to align the resources in the building to the actual use. By continuously monitoring the use of the building and making small adjustments to optimise the use of resources and fulfil users' needs, alignment takes place much more frequently and accurately, perhaps reducing the need for large investment.

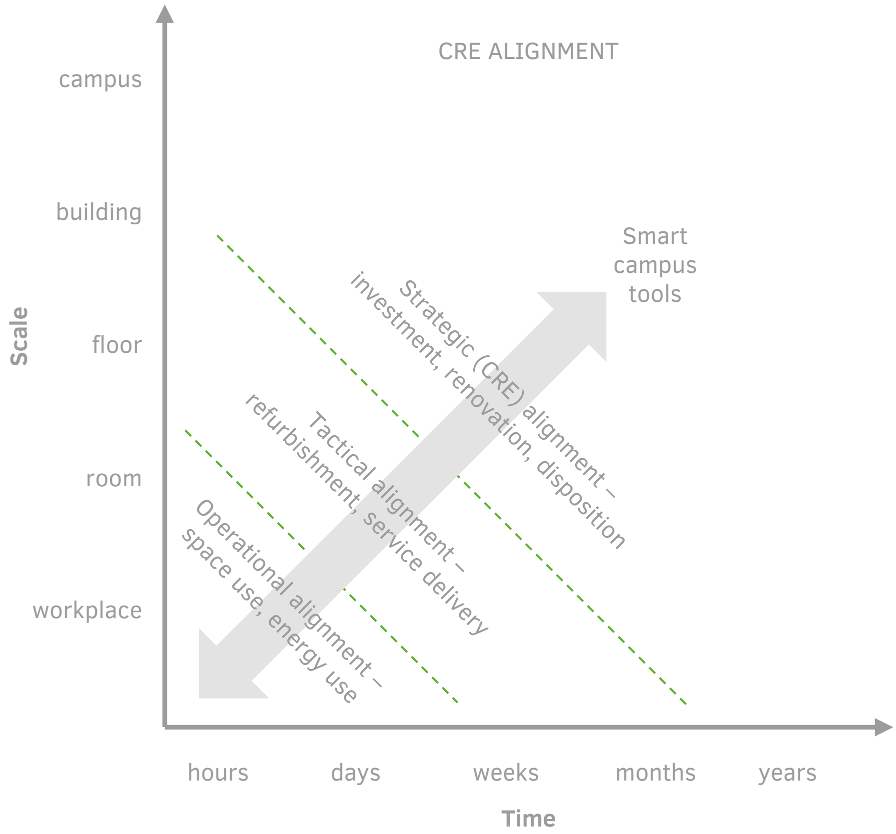

FIG. 9.4 Alignment of CRE to the needs of organisations, on different scales and frequencies.

Considering the further integration and interaction of smart campus tools and other systems

SCTs are components of smart buildings, which increase performance primarily through increased interaction with building occupants.

SCTs (or the broader IoT applications) enable smart buildings, campuses and cities, where the meaning of ‘smart’ is not narrowly defined and continuously developing.

SCTs should be considered as a part of a landscape of systems on campus (including BAS), and the ongoing integration and/or interaction between them. Systems are becoming more comprehensive, making use of multiple sensing methods, and serving multiple objectives (added values). This is made possible by the continuous advancement in sensing and computing technologies. Further advancement of technology is indicated by practitioners as a possible next step (chapter 5), and cases are found at organisations where multiple types of sensors were used (chapter 6). Additionally, researchers are also working in this direction, e.g. through the fusion of data of multiple sensors, and the use of artificial intelligence and machine learning techniques for automation and forecasting.

Therefore, when designing and implementing SCTs one should consider which systems and other SCTs are available on campus, and how the integration and/or interaction of these systems can add further value. Figure 9.5 shows three types of systems, i.e. building automation systems, SCTs to support users, and SCTs to optimise space use. In step 3 of the model these types start to overlap: here, integration and interaction increase functionalities and help to achieve multiple objectives.

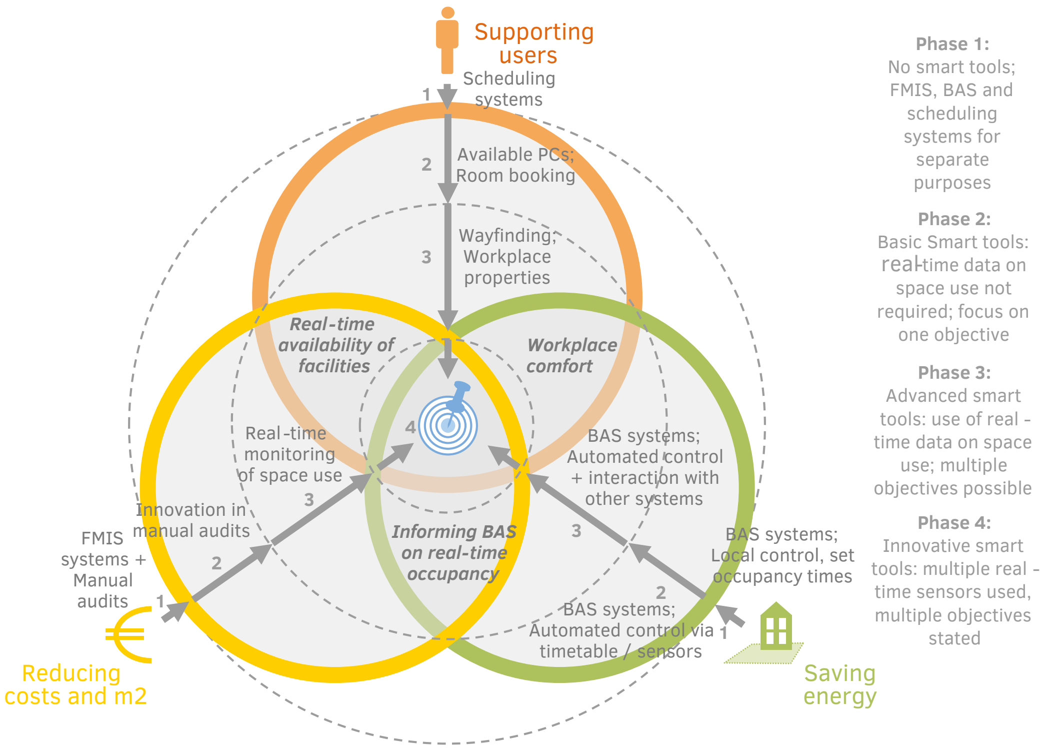

FIG. 9.5 Development of building automation (following Buckman et al. 2014) and SCTs. Every step in the figure (from 1-4) is shortly described, and each step moves towards further integration and interaction.

When it comes to SCTs, smart buildings or smart campuses, there are many different definitions (Buckman et al., 2014; Gil-Garcia et al., 2015). Practitioners have their own perception of what a smart campus tool is: they do not only identify 'SCTs' based on real-time data collection, but also consider SCTs those which use other methods to improve the measurement, or which are innovative in terms of reporting or analysis of data.

These different definitions of what 'smart' is, are implicit in the development stages in Figure 9.5. In the past, the tools in layer 2 were considered 'smart' (see chapter 5). The definition of SCTs used in this research requires tools in layer 3 of the model, i.e. real-time measurement. Furthermore, what is considered to be a SCT now may not be considered to be such in 5, 10 or 20 years. It is conceivable that in the future, academics and practitioners base the level of 'smartness' on the ability to forecast, the quality of the interaction with the users, or the ability to adjust to changes in sensing infrastructure.

Ensuring the valuable contribution of smart campus tools to campus management

SCTs require Information management in order to ensure a valuable contribution of its output to campus management.

Process and information analysis and dashboard design are very useful instruments to properly connect the information from SCTs to decision-making processes. In (strategic) CRE alignment, campus managers require an overview of the performance of current (and future) demand and supply in order to design campus strategies. For this overview, and the entire process, increasing amounts of information are available from various systems, which will only increase due to the Internet of Things. Therefore, it is important to determine which information is required at which moment, and how it is presented.

The tasks to complete in Information Management (Bytheway, 2014) in order to connect SCTs to campus decision-making processes are shown in Figure 9.6. These tasks are reworked in the DAS Frame, as supporting campus management is the main objective of this dissertation, and it is a familiar framework for campus managers. Similar to the use of the DAS Frame for real estate (De Jonge et al., 2009), demand for and supply of information from SCTs can be matched now and in the future, completing four tasks:

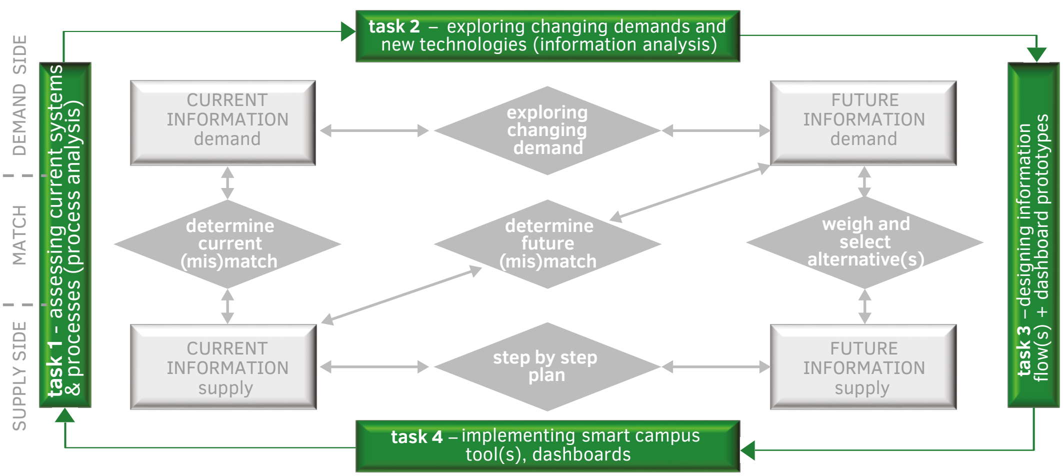

FIG. 9.6 Required steps in information management, positioned in the DAS Framework structure.

- Task 1: Assess the relevant organisational processes to be informed by SCTs (through process analysis), and the currently used systems to determine the current (mis)match;
- Task 2: Explore the changing information demand, as a result of organisational changes and/or the emergence of new technologies, through information analysis;
- Task 3: Refine and determine the information flows for the organisational processes to be informed by SCTs and select the required information through dashboard design;
- Task 4: Implement the SCTs and dashboards that deliver the required information.

When completed, these steps ensure the information delivery to support matching of the current demand for buildings and the current supply of buildings.

Identifying the impact of implementing smart campus tools for the organisation

The implementation of SCTs may lead to changes in both higher and lower-level organisational processes within the university.

The availability of information from SCTs may lead to changes in organisational processes in the university. In chapter 7, the study of processes to design a campus strategy distinguished portfolio-level and building-level matching of demand for and supply of spaces. Of the four cases, the two cases that had portfolio-level processes made use of SCTs, whereas both cases that had building processes did not. Implementing SCTs may thus lead to a change from a building-level to a portfolio-level process. However, in these cases SCTs were most likely not the reason for such a change: it seems to be caused by a more centralised approach to sharing space across the university, which requires matching on a portfolio level.

When considering the scope and depth of change more generally, there is reason to believe that organisational processes may change across the university in the near future. This is not only because of the increasing availability and complexity of technology, but also because the involved actors in SCTs include professionals in campus management, facilities management, IT, library services. The interests and responsibilities of these stakeholders overlap, increasing the demand for SCTs, but also complicating their delivery: see Figure 9.7. SCTs can provide input to each of these stakeholders' respective decision-making processes. For the integrated delivery of these services and continued alignment to user demands, changes in organisational processes or even integration of these departments are options that are and need to be considered in practice.

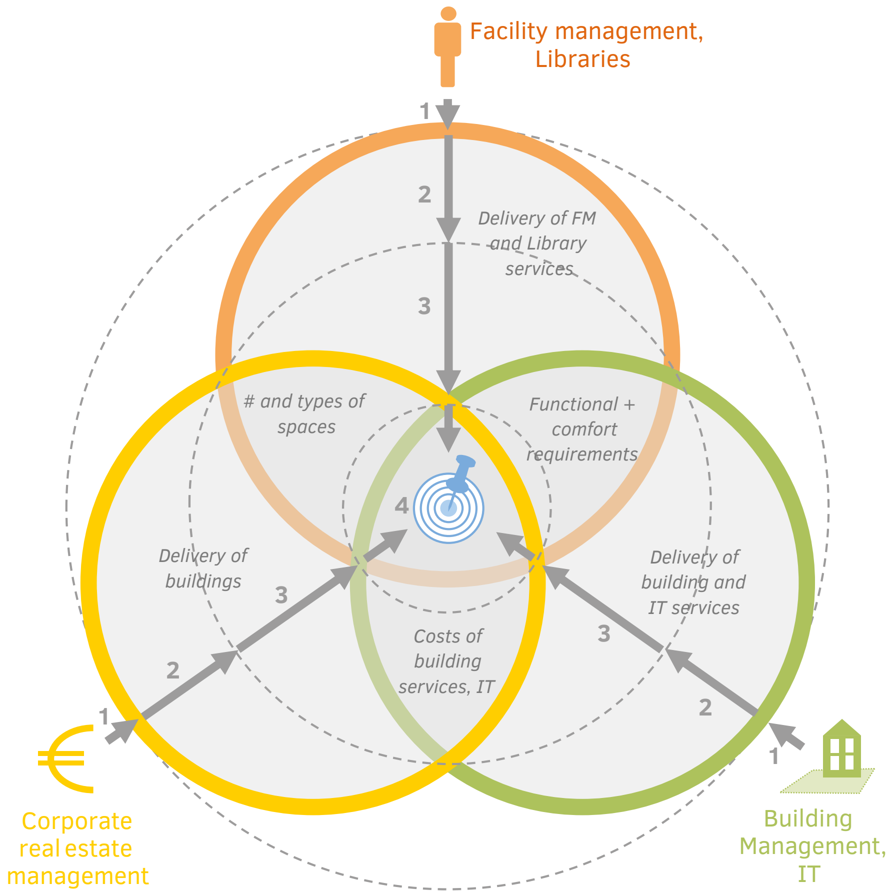

FIG. 9.7 Stakeholders and different types of decisions that can be informed by SCTs, positioned in the development stages of SCTs.

9.4 A roadmap to design and implement smart campus tools

In addition to the previous section, the knowledge from this PhD research has been combined into a roadmap for the design and implementation of SCTs through this section. This roadmap is a generic, high-level structure which universities can walk through to specify their own SCT projects. The various components of this dissertation are each connected to this roadmap.

Smart campus tools to support students, employees and visitors in various activities

The first part of this roadmap discusses how to determine the scope of the SCT project. This is inextricably linked to the campus development: in which direction is the future campus headed and how do SCTs support users on the future campus? In addition, a typical university building exist out of many different kinds of spaces, used for various activities. Therefore, the first part of the roadmap – visualised in Table 9.1 and Table 9.2 – describes the use of spaces across multiple space types and on different kinds of future campuses, using the traditional, network and virtual campus models.

Table 9.1 shows how the use of spaces by activities changes in each type of model. This is also discussed in detail by Den Heijer (2021). Additionally, very rough estimates are given as examples to quantify the estimated amount of space per user. For example, in offices, users work in their own personal workplaces in the traditional model. In the network model, they share workplaces with other employees in their faculty; as a result, the total number of workplaces can be less than in the traditional model. Finally, in the virtual model, employees work partially from home, and partially at their faculty, where they share workplaces with the other faculty employees. In this model, the number of required workplaces is of course even lower than in the network model. Using this table, a university should be able to describe their intended combination of the campus models, and determine which activities they would like to support through SCTs.

Generally speaking, the more a university would like to move towards the network and virtual models, the more important it is to use SCTs. However, in any model, the use of SCTs to optimise the delivery of building services results in substantial energy savings whilst supporting users as well. Table 9.2 shows how SCTs can support users, optimise space use and save energy in every campus model:

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TABLE 9.1 The use of campus spaces by different activities, in each campus model (A, B and C).

Space type	A– Traditional	B – Network	C – Virtual
1 Studio	Project groups work together on campus in studios reserved for them; 1 studio for each group.	Project groups work together on campus in studios reserved by them at need. 1 studio per 1,5 group.	Project groups meet largely off campus or in other spaces next to studios. 1 studio per 4 groups.
2 Office	Staff members work in individually assigned offices; 1 workplace per staff member.	Staff members work anywhere in the faculty; 1 workplace per 1,2 staff member.	Staff members work anywhere in the faculty or at home. 1 workplace per 3 staff members.
3 Lecture halls	Students attend lectures in their own faculty; 1 seat per 1,25 student.	Students attend lectures across campus; 1 seat per 2 students.	Students attend lectures across campus or from home. 1 seat per 4 students.
4 Library	Students study in their own faculty or off campus; 1 study place per 3 students.*	Students study on campus or off campus; 1 study place per 5 students.*	Students study mostly off campus. 1 study place per 10 students.*
5 Other education	Students attend specific education (e.g. practicals) in their own faculty. Students write exams in their own faculty.	Students attend specific education (e.g. practicals) across campus. Students write exams across campus.	Students attend specific education (e.g. practicals) across campus or from home. Students write exams at third party locations or from home.
6 Laboratories	Scientists use laboratories in their own faculty; 1 laboratory per section.	Scientists share similar laboratory facilities (e.g. cleanrooms) across campus. 1 laboratory per section.	Scientists share similar laboratory facilities (e.g. cleanrooms) across organisations. 1 laboratory per section.
7 Conferences	Conferences always use the same dedicated set of spaces on campus (e.g. 2.500 m^2 dedicated for 30 conferences a year).	Conferences partially use a set of spaces that are not in use for education next to the decidated spaces. (e.g. 1.200 m^2 dedicated for 30 conferences a year).	Conferences are organised (partially) online, and use a set of spaces that are not in use for education. (e.g. 0 m^2 dedicated for 20 conferences a year).
8 Restaurants	Each faculty has its own cafeteria with a similar offer.	The campus has a varied offer spread across different restaurant concepts.	The campus has a small offer spread across different concepts, complemented by surrounding locations.
9 Retail, leisure & public	Users are familiar with all public space and functions around their faculty.	Users are not entirely familiar with public spaces and functions across campus.	Users are mostly unfamiliar with public spaces and functions across the city.
10 Storage	Staff members have their own personal storage in their office.	Staff members share a communal storage space with faculty members.	Staff members have a personal storage space at home.

** In each model students are assumed to work partly off campus.*

TABLE 9.2 SCTs to support the different uses of campus spaces per campus model (A, B, and C); Contents in italics denote SCTs not documented in this dissertation.

<table>
<tr><th>Space type</th><th>A– Traditional</th><th>B – Network</th><th>C – Virtual</th></tr>
<tr><td>1
Studio</td><td>Automate indoor climate based on # of occupants.</td><td>Automate indoor climate;
Room booking tools for studios;
Finding available studios on campus (based on occupancy).</td><td>Automate indoor climate;
Room booking tools for studios;
Finding available other spaces on campus (based on occupancy).</td></tr>
<tr><td>2
Office</td><td>Automate indoor climate based on # of occupants or occupant preferences.</td><td>Automate indoor climate;
Finding available workplaces on campus (based on occupancy).</td><td>Automate indoor climate;
Reservation tools for workplaces on campus;
Reservation tools for workplaces at other organisations.</td></tr>
<tr><td>3
Lecture halls</td><td>Automate indoor climate based on # of occupants.</td><td colspan="2">Automate indoor climate;
Monitoring space use to optimise match between activity and space (frequency and occupancy);
Sharing education spaces when not in use for education;
Wayfinding tools for students.</td></tr>
<tr><td>4
Library</td><td>Automate indoor climate based on # of occupants or occupant preferences;
Finding available study places in the faculty (based on occupancy).</td><td>Automate indoor climate;
Finding available study places on campus (based on occupancy).</td><td>Automate indoor climate;
Finding available study places on and off campus (based on occupancy).</td></tr>
<tr><td>5
Other education</td><td>Automate indoor climate based on # of occupants or occupant preferences.</td><td colspan="2">Automate indoor climate;
Wayfinding tools for students.</td></tr>
<tr><td>6
Laboratories</td><td>Automate indoor climate; based on activity of experiments.</td><td colspan="2">Automate indoor climate;
Planning systems to assign laboratory space to users.</td></tr>
<tr><td>7
Conferences</td><td>Automate indoor climate based on # of occupants or occupant preferences.</td><td colspan="2">Automate indoor climate;
Sharing education spaces when not in use for education;
Wayfinding tools for conference users.</td></tr>
<tr><td>8
Restaurants</td><td>Monitoring queues to indicate busy times during the day.</td><td colspan="2">Monitoring queues to indicate busy times during the day;
Wayfinding for campus users.</td></tr>
<tr><td>9
Retail, leisure & public</td><td>Wayfinding for visitors.</td><td colspan="2">Wayfinding for all campus users.</td></tr>
<tr><td>10
Storage</td><td>Asset tracking of storage items on campus for local use.</td><td>Asset tracking of storage items on campus for communal use.</td><td>Asset tracking of storage items on and off campus for communal use.</td></tr>
</table>

First, in the traditional model, SCTs mostly support students and employees by optimising the delivery of building services. There are slight differences between space types here: for example, in offices it also can be considered to give the occupant some control, whereas in laboratories it must be critically assessed for which laboratories it is an option, as some laboratories and experiments require specific environmental conditions.

Then, in the network model, SCTs support students and employees to make use of shared resources by finding available and suitable places to work and study. Because they will be making use of resources across campus, they will also need help in finding their way across the whole campus: hence, under ‘retail, leisure and public’, wayfinding is added for all campus users. In addition, spaces such as lecture halls can be used for other purposes when not in use for education, such as for studying or for conferences.

Finally, in the virtual model, SCTs can support students and employees in coming to the campus, or to find places to work and study off campus. Here, reservation systems can play a role to some extent, as users need some kind of certainty that there is a place to work or study for them. However, this must be part of a SCT based on sensors in order to avoid a large number of no-shows. For example, if employees only have very limited number of reservations, they will only use them when they want to be absolutely sure that there is a workplace available. An alternative to reservation systems may be to offer predictions regarding the expected occupancy based on historical averages, to give users an idea of the likelihood of finding a place to work or study before they travel to the campus.

The benefits of using SCTs as opposed to reservation systems are visualised in Figure 9.8, by connecting the added values to the available space use information. If only booking and scheduling systems are used, the added value with regards to supporting users, optimising space use and saving energy are all limited, because these systems only show the scheduled use of space and not the actual use of space. In an intermediate situation, manual audits can be used (such as in chapter 4), but these only increase the added value somewhat and only with regards to optimising space use. Finally, SCTs can add value to each of the three perspectives by delivering real-time information to support users and inform building services, and they also better support the optimisation of space use by providing a more accurate picture of the space use.

By determining the future mix of campus models and where SCTs should support them, the scope of the project has been determined. The contents of Chapter 5 and 6 and the appendices connected to these chapters can be used to further detail the properties of the desired SCT(s).

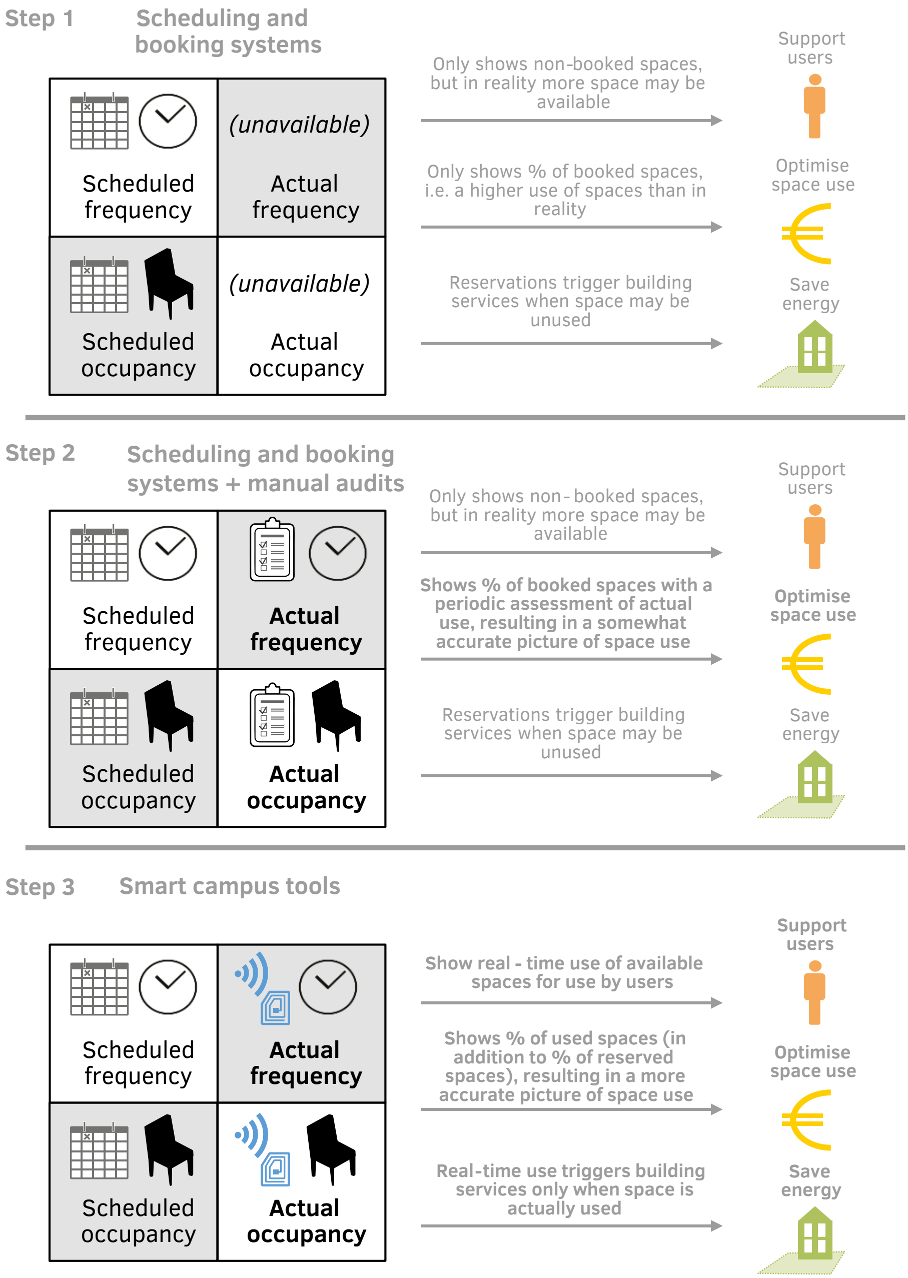

FIG. 9.8 Benefits of SCTs with regards to supporting users, optimising space use and saving energy – as opposed to measurement via scheduling and booking systems (top) and the addition of manual space use measurements (middle). Boldface denotes changes compared to the previous step.

Connecting information from smart campus tools to campus decision-making processes

The second part of this roadmap discusses the process of designing and selecting one or more SCTs after determining the scope. The second part of the roadmap is visualised in Figure 9.9, as a series of steps to complete. For each step, a checklist is shown which can be used to select the relevant items for a particular project.

The steps in the roadmap are organised according to the four tasks to match the demand for information and supply of information (see previous section; Figure 9.6):

- assessing relevant organisational processes and currently used systems;
- exploring changing information demand;
- refining and determining information flows and selecting the required information;
- and implementing the selected SCTs and dashboards.

Prior to these four tasks, a 'task 0' is added to include activities prior to these four tasks.

Task 0: Start-up

The start-up task consists of two steps:

- An organisation needs to be formed to design and implement the SCTs. Depending on the SCT, several actors within the organisation are suggested. In any case, this will involve multiple actors. It is also helpful to define responsibilities here. As the ultimate objective is effective and efficient use of campus resources, real estate management is recommended as the primary owner of the product, IT as the supplier of the solution, and all other stakeholders as secondary owners or users of the solution.

- Objectives need to be set, which specify the intended result of using the SCT. Depending on the SCT, this requires either (a), establishing a policy on requirements for a certain space type, (b) establishing space norms and desired space use, or (c) establishing desired energy performance and indoor environmental quality.

Phase	Step	Content
	Identify desired future mix of campus models + select scope (space type(s))	*Smart campus tool(s) to support students / employees / visitors in campus model Traditional / Network / Virtual*
Start-up	Set up governance (organisation)	❑ Real Estate Management ❑ Faculties ❑ Library ❑ Education & Student Affairs ❑ IT
Start-up	Determine policies and objective(s)	❑ Requirements for spaces (amenities / quality) and user satisfaction ❑ Space norms and desired space use ❑ Energy performance and indoor environmental quality
Assessment	Identify and map relevant processes (to be informed by SCT) **Process analysis**	❑ Inform scheduling process ❑ Inform cleaning schedules ❑ Inform restaurant inventory ❑ Investment in furniture / equipment ❑ Investment in real estate ❑ Energy delivery by building services
Assessment	Identify existing systems + information quality	❑ FMIS systems ❑ Booking, Scheduling systems ❑ Finance systems ❑ etc.
Exploration	Identify changing systems demand: **Information analysis**	❑ FMIS systems ❑ Booking, Scheduling systems ❑ Finance systems ❑ etc.
Exploration	Market consultation	Use items in Smart campus tools as variables (e.g. sensing methods, measurement, added values, costs, benefits, …)
Selection	**Design connection of SCT to processes**	❑ Process + Information analysis per relevant process ❑ Dashboard design per relevant process
Selection	Design connection of SCT to user needs	❑ Customer journey mapping or Interaction design
Implementation	Implement solution	Implement in phases, both in scale and functionalities offered; Implement dashboard
Implementation	Monitor and adjust in campus dashboard	❑ Compliance to design brief versus user satisfaction ❑ Space norms versus frequency and occupancy rates ❑ Energy performance versus indoor environmental quality
Implementation	Achieve objective(s)– added values	❑ Support user activities ❑ Increase user satisfaction ❑ Optimise costs ❑ Optimise m2 footprint ❑ Reduce CO2 footprint

FIG. 9.9 A step-by-step plan to connect SCTs to decision-making processes – to specify for an organisation. Underlined parts denote connections to the contents of chapters 7-8.

Task 1: Assessing current processes and systems

In the assessment task, the focus is on the current situation.

- Relevant processes to be informed by SCTs are identified. This ranges from operational processes such as finding a suitable study place by students to strategic processes such as determining which buildings to renovate. Process analysis (see chapter 7) is used to detail how these processes currently work – which stakeholders are involved, what steps are taken and in which sequence.

- An assessment needs to be made of the existing systems at the university. The result should be an overview of all the information that is contained in these systems, but also what the quality of that information is and which processes exist to keep the data up-to-date. Furthermore, it is helpful to add how the reporting functionality of the systems works, if systems interact and if it is easy to design new connections between systems.

Task 2: Exploring changing demand for information

In the task of exploring changing information demands, the focus shifts towards the future demands of decision-making processes for information.

- Using the outcomes of the process analysis, the roadmap moves towards connecting the knowledge of the available information systems to various processes at the organisation. By using information analysis (see chapter 7), the required information to complete the process can be determined. By comparing this to the current situation, the mismatch between information needs and the available information is determined.

- In this situation, it is also useful to do a market consultation, to explore what is available in the market and if these solutions can deliver the required information. The structure of the SCTs templates (see chapter 6) provide a structure that can be used in the market consultation.

Together, these two activities result in changing demands for existing systems, and information requirements for SCTs.

Task 3: Designing information flows and dashboard prototypes

In the third task, the intended connection of SCTs to processes and the adjustments in other systems is refined. This task moves from exploring the changing demand towards selecting a solution.

- The process and information analysis is refined; based on the market consultation, the intended design of the future process and its use of information from information systems is finalised. During this activity, dashboard design can be used to determine how the information from SCTs comes together with all the other information requirements to inform each process, and can be used to specify information needs (see chapter 8).

- In cases where students and employees are to make use of the information in real-time, methods such as customer journey mapping or interaction design can be used to design their user interfaces. These actions are used as input for the procurement of a SCT.

Task 4: Implementing the smart campus tool(s)

In the final task, the SCT is implemented, together with the campus management dashboard(s) to which the SCT delivers its output. Given the complexity of implementing a SCT, this can be done in stages, increasing the scale step-by-step and/or the functionalities offered to campus users and campus managers.

Over time, the organisation can use the SCT to monitor the effective and efficient use of campus resources. This is used to inform different processes within the university. Each process – on operational, tactical and strategic levels – contributes to the alignment of the use of campus resources to the demands of campus users.

9.5 Discussion

9.5.1 Limitations of this research

There are several limitations of this research.

A From the outset of the research, SCTs were focused on the perspective of improving space use and not on improving user satisfaction or energy savings. If the emphasis had been on improving comfort and/or saving energy from the start of the research (as opposed to improving space use) this may have led to the collection of different kinds of case studies.

B Chapter 4 reports space utilisation studies and their use in decision making at TU Delft. The main limitation of this study is that it does not report on the coefficients underlying the stated space norms. Therefore, in decision making, the current space norm can only be compared to the observed frequency and occupancy rates. With the performance on each coefficient accompanying past and present space norms, a more comprehensive answer can be given to which space norms are desirable and achievable. However, this would also be a very time consuming exercise.

C Chapter 5 and 6 explore SCTs, first in the Dutch context and then by comparing those SCTs to those at international universities and other organisations. The main limitation of these studies is that by choosing the perspective of the end user of the SCTs, the results show what is actually being used rather than what is technologically possible. Innovations developed by researchers or in practice may enable other functionalities not covered in this study. At the same time, focusing on the end user provides a more realistic assessment of what the performance of the SCTs is.

D Another limitation of these studies is that the case study selection at international universities and especially other organisations is biased towards cases that have SCTs. Therefore, it is not possible to say something about the degree in which SCTs are implemented across sectors. Furthermore, it may exclude universities and organisations that have considered SCTs but not implemented them. As a result, the reasons for not implementing SCTs or deciding not to continue after a pilot phase may not have become apparent through this research.

E Chapter 7 studies the process of designing and adjusting a campus strategy in four cases in the Dutch context. However, decision-making processes may differ significantly at other institutions. Furthermore, in many other countries the governance context of universities is different from the Netherlands, affecting which decisions universities can make regarding their own campus and how they make them. Finally, tactical and operational decision-making processes are not considered.

F Chapter 8 studies the use of dashboard design to determine information requirements for SCTs. The main limitation of this study is that the design method is not compared to other approaches for defining information requirements. It is therefore possible that there is a better method available to help campus managers to determine information requirements. Furthermore, the process design is only tested in two cases, leaving several choices in the process design to be made in further research.

9.5.2 Recommendations for further research

The limitations presented in the previous section can also be formulated as recommendations for further research.

A Future research into SCTs should focus on the real-time measurement of space use, indoor environmental climate, and user feedback to equal extent.

B Future space utilisation studies should include data collection on the coefficients underlying the space norms used by organisations. Given the detail required to study the development of the coefficients, a study could emphasise the development between two points in time on the coefficients, supported by the space norms and space utilisation. This can help to further the understanding of what space norms are desirable and achievable, as well as clarify the relationship between space norms and space use. Furthermore, further research in space utilisation studies can improve in their methods for data collection and data analysis – see chapter 4 for more detail.

C Future explorations at SCTs can focus on the most innovative examples found in this research, by comparing the development of the tools to what was reported in those studies. Studying these cases can provide valuable insights into e.g. cost-benefit relationships and the benefits and drawbacks of increasing integration of functions in SCTs. Chapter 6 poses other possible questions for such research.

D A future study into the use of SCTs across the sector can help to understand their uptake, but most importantly the reasons for organisations not to implement SCTs. Such a study will focus more on what the dissatisfiers are, and could provide valuable recommendations for how to minimise or overcome them.

E Future research connecting decision-making processes to Internet of Things applications should study tactical and operational decision-making processes. A study could map all the relevant processes in one organisation to be informed by IoT applications, and connect each of them to these applications. Additionally, similar decision-making processes (e.g. designing a campus strategy) need to be compared across different countries to reveal if these process and information designs can be uniformly applied, or if they are particular to different contexts. Finally, end-user demands are not a focus point of this study, but deserve at least as much attention as campus management demands in terms of determining the scope of the SCT (chapter 7) and its interface design (chapter 8). There are already some studies that show how to design SCTs can be designed through end-user involvement – for example by Priestner et al. (2016) - but still there is much to be shared and learned from respective approaches to developing and implementing SCTs.

F Future research could include an overview of design methods applicable to help campus managers determine information requirements and compare their suitability. On a more general level (e.g. determining information requirements for decision making) such a comparison may already exist. In addition, further research can be conducted using the reported method of dashboard design, in which the researcher evaluates how choices in the process design (e.g. different number of workshops, the use of different dashboard design alternatives in workshops) affect the object design and the implementation design.

9.5.3 Practical and societal implications

The practical and societal implications of this research can be discussed by moving from the scientific contributions of each chapter towards its value for academia and practice, and then to the broader implications of this work.

First, in chapter 4 a study is done that in terms of scale and scope is unmatched in academic publications. Furthermore, it makes a connection between the results of the study and policy developments. As such, this chapter adds significant evidence of space utilisation data to academia, where only few such studies have been reported. In the present, discussions on how to make decisions based on space utilisation data will become maybe more relevant than ever: following the COVID-19 pandemic, many universities, as well as organisations are faced with the challenge of accommodating a hybrid education or office. Sharing practices of how organisations decide which space use on campus is effective and efficient, to what extent people work at home, and how they combine this information to make decisions on the real estate portfolio will add significant value. To such sharing of practices this research provides a very sturdy foundation.

Then, in chapter 5 the topic of SCTs at Dutch universities is explored, providing knowledge to academia on how SCTs are being implemented in practice (in addition to e.g. the academic developments on sensing approaches). In a continuation of chapter 5, chapter 6 systematises and synthesises such explorations into SCTs and delivers insights on where different sectors stand with regards to the development of SCTs. The outcomes of this research have shown what the use of SCTs was at the time, providing a point of reference for future research. Additionally, the data collection format, developed during the research, presents the most important information regarding each case in a succinct way. The data collection format has proven its value as a communication tool in interviews with universities and organisations, and in sharing knowledge amongst themselves. Towards the future, continued research on the subject using these templates can continue to support this sharing of knowledge, as well as highlight the developments that have taken place across time.

In chapter 7, an analysis based on a literature study and four case studies presents how SCTs can be used to support campus decision making. Here, the academic contribution is on a process-level: though many efforts have been made to improve products, only few studies consider the difficulties faced when implementing SCTs into organisational processes. In a continuation of chapter 7, dashboards are designed to support two cases in decision-making processes based on the findings of chapter 8. The chapter shows a method to define IoT requirements based on dashboard design, as well as practical outcomes per case. These outcomes provide an approach to designing IoT solutions. It is expected that as technology continues to develop, it will become more and more difficult to determine which technology to select: not only from the users' perspectives, but also from that of campus management. Given that so many IoT initiatives are discontinued (see Cisco 2017; chapter 7), properly determining IoT requirements may save both suppliers and universities time, resources and frustration and lead to less project failures.

To summarize, each of the implications discussed can provide value to the management practices of universities, but also to those of other organisations. The findings from chapter 4 can also be applied to other real estate portfolios that contain educational spaces, such as those of high schools and universities of applied sciences. With minor to no adjustment, the approach used in chapter 4 can also be applied to other space types that make use of reservation systems, most notably meeting rooms. The SCTs documented in chapter 5 and 6 can be used by any organisation to inform their choice for an SCT, keeping in mind that the characteristics of each SCT are tailored to a specific context. Thus, the performance of the same SCT can be completely different in another context. Finally, the approach used in chapter 7 and 8 can be used by any organisation to design their own IoT solution, and connect it to the relevant decision-making processes. The process and information diagrams and dashboard designs of chapter 8 may inform the solutions developed in other contexts, but should always be adjusted to the specific context of the organisation.

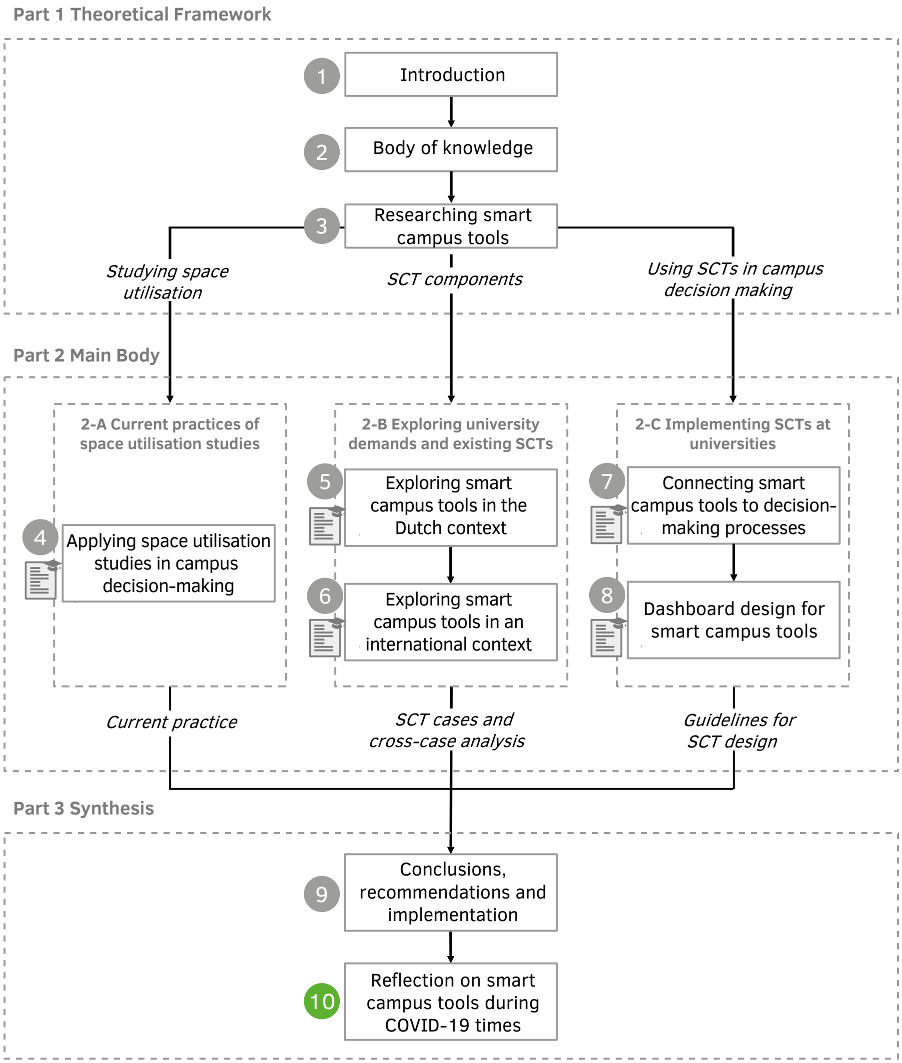

FIG. 10.1 Chapter 10 as an extra reflection on this PhD research, given the COVID-19 pandemic.

TOC

10 Reflecting on smart campus tools in COVID-19 times

10.1 Introduction

When this PhD research was in its concluding phase, the COVID-19 pandemic provided an unusual context for testing SCTs. The findings of this additional research phase are described in this final chapter: see Figure 10.1. In this chapter, the focus is on how SCTs support universities in their response to the COVID-19 pandemic: see Figure 10.2.

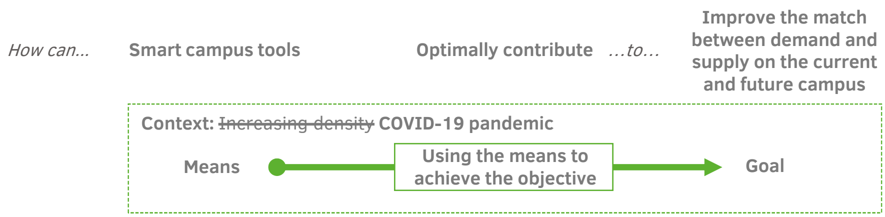

FIG. 10.2 The changing context as reason for additional research (conceptual model).

In this chapter, the developments related to COVID-19 are framed using the traditional, network and virtual models by Den Heijer (2021), which were introduced in chapter 1, to describe the use of spaces by users. Three phases are distinguished in the crisis, together with the past situation:

1. “From bricks to clicks”: the initial phase of the crisis, marked by the fast transition from the physical campus –‘solid’ and ‘liquid’ - to the virtual ‘gas’ campus;

2. “Back to campus”: the intermediate phase of the crisis, in which a restricted use of the physical campus – ‘solid’ and ‘liquid’ is possible (considering social distancing regulations);

3. “Campus of the future”: the phase after the crisis, in which unrestricted use of the campus is again possible.

These three phases and the past situation are visualised in Figure 10.3, and are applied to both the university campus and the broader, societal context.

The developments on campus, as discussed in this chapter, are based on several interviews conducted at universities, both in the Netherlands and abroad. Two universities from the Netherlands (TU Eindhoven and Wageningen University) and two international universities (KU Leuven and Aalto University) were interviewed. These universities were selected because they were all using SCTs prior to the COVID-19 pandemic; thus, it was possible to explore how their use of SCTs might have changed. Following the interviews, a joint meeting brought together practitioners at Dutch universities who are working on SCTs in order to discuss emerging issues and collect further evidence on the changing use of SCTs during the pandemic. Appendix 6 provides detailed reports of the four interviews and the joint meeting. These sources were complemented by personal observations, both working as an academic and a practitioner in the year 2020, as well as by collecting newspaper articles to follow the societal developments.

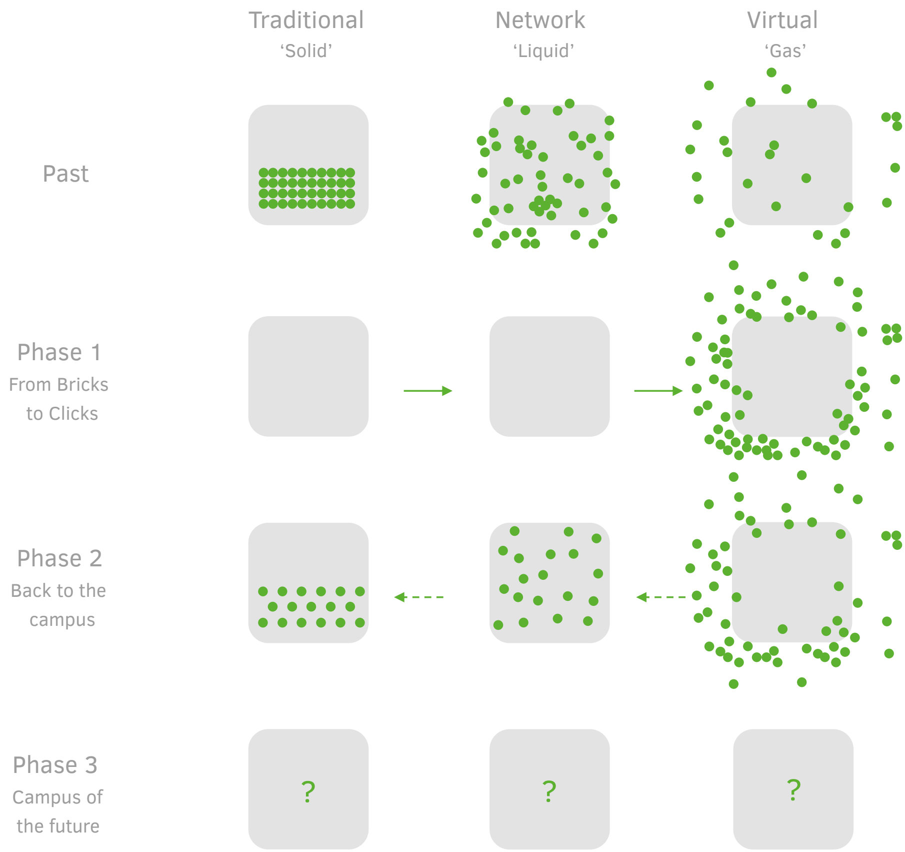

FIG. 10.3 The three phases positioned in the campus states of Den Heijer (2021), as explained in chapter 1.1. The red dots represent the university population, the grey areas represent the physical space on campus (university-owned) per model.

This chapter is structured as follows. First, section 10.2 discusses societal developments relevant to this research as a result of COVID-19. Then, section 10.3 discusses the impact of COVID-19 on universities, and how they have used SCTs to collect data during the pandemic. Section 10.2 and 10.3 both focus on phase 1 and 2 of the pandemic. Then, section 10.4 focuses on the phase following the pandemic, and lessons regarding the use of SCTs for the future. Finally, section 10.5 concludes the chapter.

10.2 COVID-19 and societal changes

Around a year before the writing of this dissertation, on the 11th of March 2020, the spread of the Coronavirus (or COVID-19) was such that the World Health Organisation first declared it a pandemic (WHO, 2020). Around that time, many countries around the world began instating national lockdowns with various measures and intensities. These lockdowns resulted in either the total closure of offices, public buildings, sports facilities, restaurants, etc., or severely restricted access only to those for whom it was necessary. Since then, the world has been moving in and out of lockdown measures, relaxing or tightening measures when deemed possible or necessary by national health experts and governments. The pandemic is of interest to this research, as it has impacted both the demand and use of SCTs: both on campus and in wider society.

The demand for SCTs has temporarily changed because of the access and capacity restrictions of the pandemic. Over the past year, we have experienced what happens when supply dictates demand, and not the other way around – not just on campus, but on a wider societal scale. Prior to the pandemic, it was mostly demand for space that dictated supply. Almost all facilities – restaurants, offices, sport clubs, air travel, highways, etc. were dimensioned based on their peak use. If the peak use was too high, the number of spaces were increased. This system, based on individual needs and their increase over time, is a major cause of the unsustainable use of the planet's resources.

During the pandemic, it is the other way around: the available supply of space dictates the demand. Some facilities are entirely unavailable to the public, such as stadiums or nightclubs. Sports facilities, museums and restaurants only allow very limited numbers of users. Airplanes and (sometimes) public transport are limited to a low maximum capacity. Constrained by health regulations, our use of the facilities and infrastructures around us has temporarily changed.

Additionally relevant to this research is the use of big data by organisations and individuals to support arguments and decisions during the pandemic. On the one hand, the pandemic has generated various examples that show how data from different sources can be combined and presented to inform decision makers and the general public. For example, the Dutch government developed a Corona Dashboard to monitor the status of the pandemic in the country and to inform policy decisions (https://coronadashboard.rijksoverheid.nl/), combining data from the National Institute for Public Health (RIVM), Municipal Public Health Services (GGD), the Central Bureau of Statistics (CBS), and others. Another example is the Dutch Movement Panel (NVP), developed just before the pandemic, which monitors the movements of a representative panel and which transport mode they use (Roekens, 2019). A combination of GPS data with the panel members' background characteristics results in the necessary information. Throughout the pandemic, this mobility dashboard was used to monitor behaviour, e.g. if increasing numbers of people were going to the office again, despite the call to work at home as much as possible (Fietsberaad.nl, 2020).

However, the pandemic also demonstrates that careful consideration must be given to data selection, data quality and proper interpretation and presentation of those data, particularly because of the consequences attached to their use. Consider the following examples:

With regards to data selection and data quality: in the initial stages of vaccinations, the choice was made to adjust the number of vaccinations in the Corona dashboard from the actual number to an expected number, which was higher (NOS, 2021; Volkskrant, 2021). Additionally, some vaccines were counted twice. This resulted in criticism as it was found to be skewing the numbers in favour of the government, as they were lagging behind other countries. In any case, it demonstrates how easily data can be manipulated – consciously or unconsciously – and what the consequences can be. For SCTs, the effect of a few sensors not reporting occupancy data or being omitted from the analysis may be the same.

With regard to data interpretation and presentation, choices such as showing the number of cases per day or cumulatively, or comparing the number of administered vaccines absolutely or per capita, have a great influence on how the data is interpreted. Maglio, Reinholtz, and Spiller (2021) demonstrate how different visualisations of the same data result in different perceptions. In the worst case, the data visualisation is chosen that best aligns with one's opinion or with the preferred policy solution, rather than the visualisation that most accurately depicts the situation. Similarly, for SCTs, benchmarking occupancy rates with universities may be far better aligned to the proposed policy solution than comparing them to space norms.

These examples show that although SCTs and big data are very powerful instruments in decision making, it is also a great responsibility to properly select data, and to collect, process, present, and interpret them.

Although this was a difficult reality that we are not used to (demonstrated by e.g. the unwillingness of some to accept limited freedoms, or the enormous pressure faced by governments from many different user groups to relax measures to serve their interests), the situation during the pandemic has contributed to a more sustainable use of resources: global CO_2 emissions have declined compared to previous years (Earth Overshoot Day, 2021; Le Quéré, Jackson, Jones, & al., 2020).[12] [13]

Because of these capacity restrictions, many facilities such as museums, restaurants, shops, and sports clubs started to use reservation systems in order to safely reopen their businesses. By requiring users to make a reservation for a visit, to play sports, or for a haircut, business owners could regulate the maximum number of people at their facility. This is of course the purpose of reservation systems and their main advantage. Furthermore, it gives users the certainty that they can actually make use of something, and it reduces potential waiting times.

However, reservation systems also have significant disadvantages, which are now more apparent than ever. The largest of these is that the use of reservation systems will always result in a certain degree of no-shows. The less important the activity is –or the smaller the consequences of not using a reservation-, the larger the probability of no-show behaviour. Thus, instead of encountering the 'towel problem' on location, the user leaves a 'digital towel'. For example, instead of occupying a hotel pool bed by leaving belongings behind while not actively using the pool bed, the user reserves the pool bed, but simply does not show up to use it at all. This situation is at least as bad as the 'towel problem', and during the pandemic – when reservations are required – it is much worse, as the entire bed may be left unused because of the no-show.

To further frustrate matters, the users of the facilities are entirely unaware of this situation. In their perception, the reservation system is full of reservations and they cannot make a booking. As a result, there are likely to be frustrated users and complaints about a lack of available facilities, despite suboptimal space use. Also, managers are likely frustrated because of the high number of no-shows. This is exactly the problem, which this PhD dissertation has addressed through SCTs.

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12 Of course, the situation as displayed in this paragraph differs between countries, organisations, and also depends on the stages of lockdowns.

13 It must also be noted that there are negative side effects of the pandemic to the environment, such as increasing car ownership (EY, 2020), and increasing use of plastic (Patricio Silva et al., 2021). There are also concerns that the energy savings resulting from reduced mobility and unused office buildings are largely offset by increasing energy consumption of homes due to mobile working (Hook, Court, Sovacool, & Sorell, 2020).

10.3 Smart campus tools to support back to campus during COVID-19

The situation on the university campus strongly reflects that of the previous section. Like many institutions, universities were and are heavily affected by the pandemic. Monitoring by UNESCO shows a significant percentage of learners affected by total lockdowns on all levels of education, ranging from 84% of all learners in March 2020 to around 13% in January 2021 (UNESCO, 2021). If partial lockdowns are also included, this number was even higher. Following the closure at universities in March 2020, students and employees have rapidly adjusted to online lectures, exams, meetings, and research.

Just as happened in society, phase 1 and 2 of the pandemic are characterized by supply dictating demand, rather than the other way around. The problem statement of this research has thus (temporarily) changed due to COVID-19, for at least as long as capacity restrictions persist. Previously, universities experienced an increasing frustration of reserved spaces that were not in use, resulting from strategies to increase the users per m^2. Because spaces were sometimes used to the maximum capacity – at least on paper, according to reservations –users demanded more space. During the pandemic, universities are faced with a maximum capacity, and have to determine how to offer access to the limited number of spaces that is available, given the very large group of users who want to access it, without everyone coming to the campus to find their own spaces.

Shift towards reservation systems

In response to the revised problem statement, universities have adjusted their existing SCTs or invested in new ones. In the joint session, universities also acknowledged that there was an increased sense of urgency to invest in SCTs as a result of the changing context. The interviews at four universities and the joint meeting revealed that there is a high demand among universities for reservation systems. Universities added reservation functionalities to existing systems using sensors, or invested in new reservation systems while temporarily deactivating SCTs based on sensors. Reservation systems are a suitable solution following the problem statement:

- They can be used to offer access to a limited number of spaces;
- In order to divide resources according to needs, some users may be given privileges;
- Reservations are made prior to coming to the campus (either by the user or by an administrator who allocates users to timeslots), which prevents an excess of the maximum capacity.

Contrary to reservation systems, the existing SCTs using sensors proved to be of less value. In cases where they are used to monitor the space use of education spaces, there was no added value as the education spaces were not used at all, or used at a fraction of the maximum capacity. By adjusting the capacities to the maximum allowed capacity (due to COVID-19), building management could still use the systems to monitor if the allowed capacity was exceeded. However, the use of these tools has become much less: it was already known that the occupancy of individual spaces would be very low.

In cases where SCTs were used to monitor the availability of study places, the information provision to students needed to be shut down in order to prevent students from all coming to the campus to study. However, in some cases the sensing technology could still be used to measure student check-in and check-out times, and thus also possible no-shows. Furthermore, in some cases the SCT also included a reservation module for small meeting rooms. In these cases, the reservation module was extended so students could reserve the available study places. SCTs in office buildings will have likely followed a similar pattern to these applications.

Pros and cons of reservation systems: minimising no shows

The shift from sensors to reservation systems is not surprising, but rather interesting, as it strongly contrasts the previous trend of using sensors as the basis for determining space use in SCTs rather than a reservation system. When implementing the aforementioned reservation systems to enable the back to the campus phase, campus managers are faced with many different questions:

- How many times is each user allowed to reserve a study place?
- How far in advance is a user allowed to reserve?
- What is the duration of a reservation?
- Do certain users have more privileges in the reservation system than others? If so, what are the privileges and criteria to get them?
- What happens if a user does not make use of his/her reservation?

Each of these questions influenced the way that the systems were used, as well as the full utilization of the available capacity. First, availability was considered: the number of times a user is able to reserve and the duration of the reservation are important parameters related to the availability. To avoid excessive claim behaviour, the number of reservations per user was limited, as a higher number of reservations per user also increases the chance of no-shows. The allowed duration of a reservation was different across universities, ranging from 2 hours to 4 hours. This was not only linked to making the study places available for more students, but also to cleaning schedules required to facilitate proper hygiene on the study places in between shifts.

Secondly, the no-show percentage was considered in order to make sure the capacity was used to its maximum extent. In the joint meeting organised with universities, they reported no-show percentages of 25 – 50% (% of used reservations). Some campus managers indicated that the no-show percentage was reduced by reducing the time a student was able to reserve in advance, and by sending reminders per e-mail prior to reservations. This can also be explained from a student’s perspective. The longer a student is able to reserve in advance, the more uncertain they will be about if they actually need a study place at that time, and the greater the risk of having to self-quarantine in the meantime.

Even with reservations only possible shortly in advance, no-shows remain a persistent problem. Therefore, the use of reservation systems seems to be a more temporary solution at this time to help as many people as possible, rather than a permanent way to make more effective and efficient use of space. Until the pandemic is over, the main question is: how to maximise space use within restrictions while minimising no-shows? This is a balancing act between making spaces easy to use despite the presence of the reservation system, and introducing measures to avoid unwanted behaviour. In addition to the parameters stated above, one can think of ways to stimulate correct behaviour – for example by allowing increased privileges in case of correct use, or by temporarily restricting access in case of repeated no-shows.

This brings us to the final point, i.e. privacy regulations. Is it even allowed to monitor the behaviour of individual users and grant them privileges, or restrict them access, based on their behaviour? In chapter 6, several approaches have been distinguished within the existing SCTs: direct anonymization of personal data, use of personal data via the opt-in principle, and personal data ownership. However, these do not apply here: the reservation system requires personal data, so anonymization is not possible, and users can hardly opt out as they need the reservation system to make use of campus facilities. More research is needed on suitable privacy approaches for reservation systems, and how these systems can balance the need to minimize no-shows with privacy regulations.

Increase of Access control systems

Next to the increasing use of reservation systems, access control systems are becoming more common. These are used to regulate the number of users in the building at any time, offering monitoring across space types and user groups on the level of a whole building. Because the maximum capacity is determined on a building level, these systems deliver important information to support the back to the campus phase.

Additionally, access control systems offer important information to compare with reservations. As is stated before, no-shows are a persistent problem with reservation systems (whether digital or manual). Access control systems may enable universities to check if someone who has reserved a space actually comes to the campus to use it. Actively steering on no-shows will support the movement back to campus of as much people as possible by the regulations.

10.4 The use of smart campus tools following COVID-19

In addition to facilitating the current situation (in phase 1 and 2) as much as possible, everyone is already imagining scenarios of what the future of working and learning might look like after the pandemic. Will we continue to keep working and learning at home for one or two days per week? Some suggest that we might: for example a growing trend of people relocating to the countryside (NOS, 2020) or employers offering the possibility to work at home indefinitely (Brownlee, 2020). Also, there are some indications that we will not, as the campus offers many an opportunity to separate their work and private lives again, to meet their peers and friends, and to reduce the amount of time spent behind a device during their workday.

Especially on the short term after the pandemic, when measures are relaxed, some expect a great demand by students and employees to be on campus, perhaps even more than before. Especially meeting together and attending large scale events, such as lectures, defences, and conferences may be more in demand than ever as people will want to do things that they have not been able to do during the pandemic. This is echoed on a societal level: some expect an overcompensation in consumer spending behaviour, e.g. on travel, shopping and restaurants, leading to temporary shortages and price increases (Deloitte, 2021; Light, 2021). Long-term changes in the way that we make use of buildings, spaces and services may thus have to go through an initial phase of overcompensation.

For the longer-term, it may be tempting to think that the virtual campus is here to stay, and that the spaces on campus can be used even more efficiently. Because the investment costs per m^2 of real estate have increased continuously over the past years (see section 1.1), making optimal use of the existing spaces on campus will remain important. In particular, universities may start to rethink the academic workplace, which was already identified as a strategic choice for the campus of the future prior to COVID-19 (Curvelo Magdaniel, Arkesteijn, & Den Heijer, 2019; TU Delft, 2016). There is much that can be learned from corporations in this regard, where minimising the cost (and size) of office real estate has been a priority for many years, and methods to share workplaces already emerged in the 1990s (Cooper, Maraslis, Tryfonas, & Oikomonou, 2017).

At the same time, one should consider the drawbacks of more efficient accommodation. The pandemic has also shown that the more efficient organisations were able to accommodate themselves before the crisis, the less opportunity they had to welcome employees back safely to their offices. In cases of rare, unexpected events such as a pandemic, an efficiently used real estate portfolio thus performed less than an inefficient real estate portfolio. Robust optimization (Ben-Tal & Nemirovski, 2002) is a method that takes this into account when determine the optimal amount of education spaces, study places and offices on campus. This method takes into account all the regular variables, i.e. strategic, functional, financial and physical, whilst also accounting for a certain degree of uncertainty. The use of robust optimisation to determine the size of the future campus also supports discussions to larger, societal questions (Bertsimas & Sim, 2004), such as: at which cost do we want education and research at universities to continue? Which degree of uncertainty are we willing to accept? In the Netherlands, such questions would need to be answered on a national level, as increasing the size of the accommodation without financial means from the government will come at the expense of resources spent on education and research.

Connecting smart campus tools demands to future campus models

After the pandemic, some kind of shift is foreseen from the physical (traditional + network) campus to the virtual campus. How large this shift will be, remains to be seen. As the previous sections have shown, this causes a change in the demand for SCTs. Therefore, the future demand for SCTs may be positioned within the three campus models (see also Figure 10.4):

- In a largely networked campus, where many spaces are shared between users, the need for SCTs is the largest. Here, many users come to campus each day, but mostly do not know in advance where they will learn, study, meet and work. Thus, SCTs can help users to find available spaces by measuring space use via sensors;

- In a largely traditional campus, where spaces are mostly assigned to students and employees, the demand for SCTs to find available spaces is much smaller. Because the spaces are assigned, users don’t need information on the availability of spaces. However, SCTs can still support users in optimising the comfort of their own workplace;

- In a largely virtual campus, where many users study and work off-campus, there is a need for SCTs to support users in determining when to come to campus. Here, users will want some kind of certainty that they have a suitable place to work or study

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when they decide to come to the campus. This can be supported by reservation systems, or by giving users a forecast of the expected space use based on past data.

It is very unlikely that the use of spaces on the future campus will be organised in just one of these models; most likely, it will be a combination of all three. The combination of all three types will definitely exist across activities and space types (for example, studying occurs in spaces shared on a campus level, research in traditionally used laboratories, and office work largely takes place virtually), but also within a combination of activity and space type. Therefore, it is useful to consider the different demands for SCTs that exist per space type (see chapter 9).

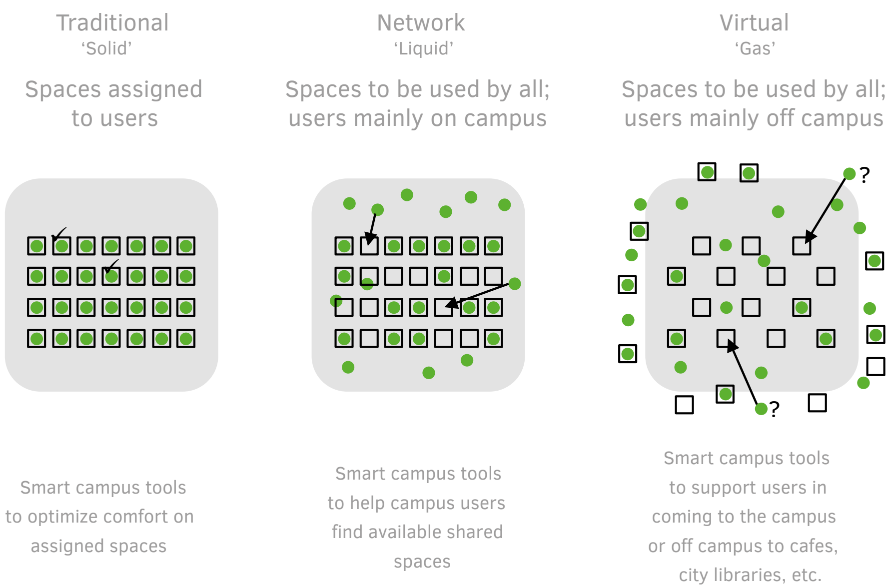

FIG. 10.4 Main demands for SCTs in different models for the campus of the future. Red circles show users, squares show spaces.

The Dutch universities support the idea that the campus is a combination of the traditional, network and virtual campus. With regards to education spaces, the participants thought the demand for large education spaces would decrease somewhat, and that the demand for spaces for working in groups would increase. For study places, they foresaw an increase in both individual study places and meeting places. For office work, they foresaw an increase in both place for silent work and meeting on campus, as well as well-equipped workplaces at home. In each of the space types, these findings point to some combination of campus models – and SCTs.

The phase following the pandemic will thus be very interesting and challenging from a SCTs perspective. First, as many universities have made use of reservation systems to make study places available to students during the pandemic, there may be a greater demand from them to provide information on available study places once the campus reopens. Second, the increasing use of the virtual campus means that SCTs have to support two information demands: (a) for users on campus, they need to show real-time availability; and (b) for users off-campus, they need to give some form of assurance regarding the availability in the near future. A combination of reservation systems and sensors can be used so unused reservations are immediately removed, or forecasts can be given to users through past space use data to support them. With regards to reservation systems, the pandemic has shown which considerations to take into account.

Increasing use of smart campus tools to balance demand and supply

In addition to the changing demand for SCTs during the pandemic, their use also increased, as many reservation systems were implemented on campus and in wider society. As mentioned in section 10.3, there has been an increased sense of urgency to use SCTs during the pandemic. Hopefully, following the pandemic this sense of urgency can be maintained by positioning SCTs more prominently in a more sustainable use of resources.

In the future, the use of SCTs can help to improve the matching between demand and supply, instead of letting demand dictate supply. By increasing facility sharing between departments, faculties and even with other organisations, they make use of each other's spaces during peak use, rather than having their own facilities scaled to meet peak demands. This will result in a reduction of costs and energy consumption, which provides an opportunity to invest in quality where necessary. SCTs help users, tenants and owner-occupiers to become more flexible in using spaces by making sharing easy, accessible, and cost-efficient.

The transition towards a more balanced match of demand and supply on campus is visualised in Figure 10.5-10.7, in an example, moving from past to present to future. Prior to the pandemic (Figure 10.5; phase 0), this university had too much seats per user, while space use was considerably lower than the objective. Because there were no SCTs available, (1) users could not find available spaces and (2) the university could not monitor it in its own dashboard. As a result of this situation, the total operating costs were too high. Additionally, the university had old buildings and furnishing, resulting in a high energy use per m^2 and a low compliance to the design brief.

However, because of peak use at specific times and/or specific locations, users would even demand more spaces. This would result in this imbalance staying the same, or worsening.

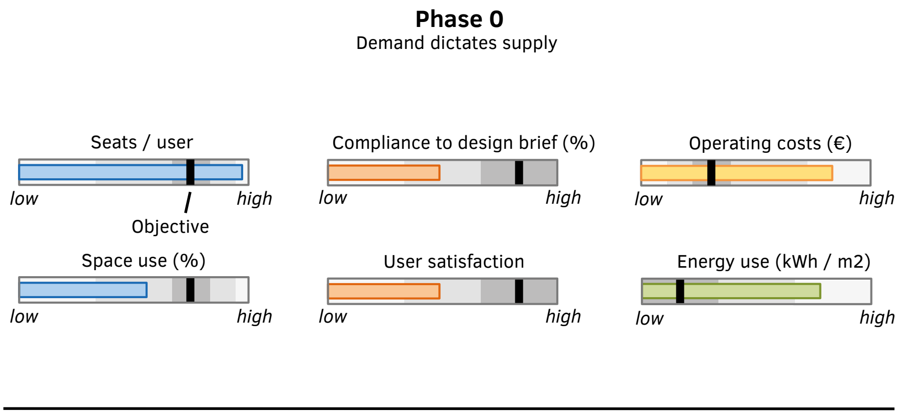

FIG. 10.5 Visualising the shifts in the use of campus resources during the pandemic and after the pandemic (based on the campus dashboards designed in chapter 8). Use of campus resources in Phase 0.

In phase 1-2 (Figure 10.6), the situation was totally reversed. Because of capacity restrictions, the seats/user were only a percentage of the potentially available space. That small number of available spaces was made available via reservation systems. According to these systems, the space use was very high, however, because of a high number of no-shows the actual use of even these limited spaces is considerably lower, even lower than it was prior to the pandemic. Because of the restricted capacity, the university has spent less on operating costs and the energy use per m^2 has been reduced. Outside of the university, this is at least to some extent offset against the increase of costs and energy use of the campus users, who are all working and studying at home.

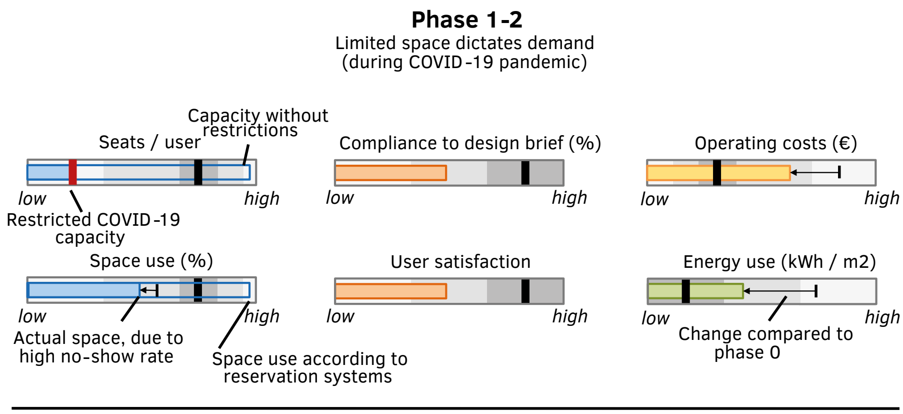

FIG. 10.6 Use of campus resources in Phase 1-2.

Following the pandemic (Figure 10.7, phase 3), the university wants to move towards a better balance between demand and supply. Therefore, it implements a SCT. Because of the SCT, users can find available spaces better, leading to a higher space use and less complaints. At the same time, the university can monitor the space use and optimise the required capacity, trying to balance the seats/user against the frequency and occupancy rates. Additionally, SCTs can be used to optimise the delivery of building services. As a result, the seats / user are reduced, resulting in cost and energy savings. These resources can then be spent on investment in the ageing buildings, making the campus more energy efficient and compliant to the design brief, thus optimising the campus portfolio on all stakeholder perspectives. This approach requires the use of sensors, as the use of reservation systems will (a) show the reserved and not actual use of space and (b) thus result in less energy savings.

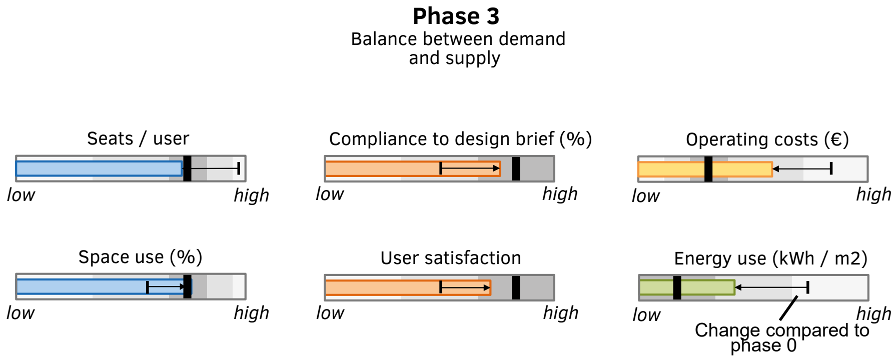

FIG. 10.7 Use of campus resources in Phase 3, following the pandemic.

Smart campus tools to encourage sustainable user behaviour

This principle, illustrated in Figure 10.7 for the university campus, can also be extended to the university organisation as a whole. As buildings are one of the major sources of energy emissions, the data from SCTs would be an important component of such a dashboard. The 'Academic Air Miles' app (see Figure 10.8) was imagined as such, already before the pandemic in 2019. The concept is that each campus user gets a budget of a maximum footprint, which can be spent on different organisational resources. According to preference, a user can trade their office space for more resources to travel to conferences, or gain more reservation privileges by commuting more sustainably. As such, it can be considered to be a space charging approach on an individual level (see subsection 2.1.4). These kinds of approaches stimulate a discussion about what the match between demand and supply should be, rather than just assuming more resources are needed when demands cannot be met.

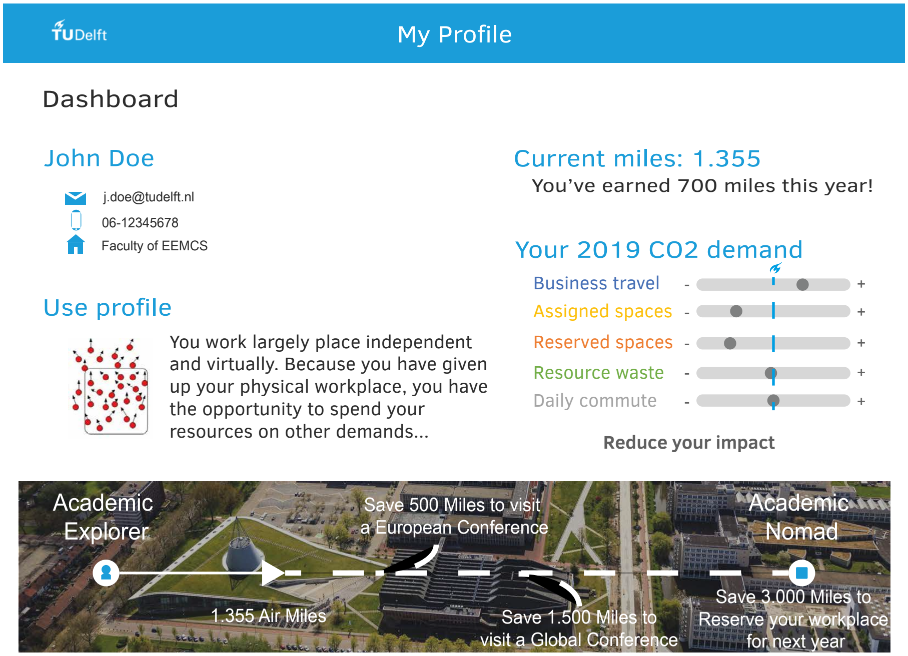

FIG. 10.8 'Academic Air Miles' – conceptual app for employees to select use of organisational resources.

Technology can thus also be used to make users aware of the effects of their demands and to support discussions on how organisations can become more sustainable. This idea is connected to the pool chair problem outlined at the start of this dissertation (Figure 10.9): in order to encourage more sustainable user behaviour, SCTs should not just display scheduled versus actual use, but also its effect on financial and energy performance.

FIG. 10.9 Making inefficient use of spaces and places visible not just by displaying scheduled vs. actual use, but also by showing the effects on financial and energy performance. (Illustration: Mark van Huystee)

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10.5 Reflecting on smart campus tools research with insights from COVID-19

This chapter has explored the impact of the Coronavirus pandemic on SCTs, the topic of this dissertation. The various sections discussed the insights on the added value of SCTs during the pandemic and afterwards, on campus and within wider society.

Both on a societal level and at universities, the pandemic has shown a reality in which supply dictates demand, rather than demand dictating supply: instead of making use of buildings and spaces at will, their access was restricted, with many activities now taking place virtually. Suddenly, the objective of SCTs was no longer to make sure that the increasing demand fits as well as possible into the existing supply – it was to make sure that the limited supply was distributed maximally, fairly and evenly. Because of the limited supply, there has been an enormous increase in the use of reservation systems. However, reservation systems have several limitations and various parameters that influence the extent of these limitations.

After the pandemic, it is expected that there will be a continued demand for SCTs, in a combination of traditional, network and virtual models. This combination results in two demands that need to be combined. On-campus users will want information showing the real-time availability of places to study and work, while users off-campus will need some form of assurance that there will be places available for them once they arrive on campus. The lessons learned with regards to reservation systems during the pandemic can support decisions on this matter. This finding can be summarised as a proposition, to be tested in future research:

Smart campus tools will require both real-time information on the availability of places to study and work for users on campus, and some way to provide assurance to off-campus users that there will be places available for them once they come to campus.

Additionally, the increasing use of reservation systems may be a first step towards a more sustainable use of resources. SCTs support a transition towards a campus where spaces are shared between more users, resulting in a lower m^2 per user, a higher space use, and a reduction of costs and energy consumption. These SCTs may be combined with reservation systems, but require sensors as reservation systems will result in suboptimal use of spaces and energy. In addition, SCTs can inform the university on an organisational level, helping users to understand their use of university resources and stimulating them to move towards a more sustainable use of resources. This finding can also be summarised as a proposition for future research:

Smart campus tools should not just display scheduled versus actual use, but also its effect on financial and energy performance in order to encourage more sustainable user behaviour.

Finally, the COVID-19 crisis has emphasized the importance of smart campus tools for health & safety reasons, next to the functional, environmental and organisational goals that SCTs can contribute to. At the end of this research process, Dutch universities have indicated that smart campus tools are more relevant than ever.

Maria Montessori building Radboud University. Photo: Radboud University / Dick van Aalst.

PART 4

Appendices

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APPENDIX 1

Space utilisation measurements

Space use at Dutch universities

This appendix contains data related to space utilisation measurements. The data were collected in 2015-16 as evidence supporting the problem statement of this PhD research. In addition to the survey of the smart campus tools, additional data was collected with regards to space utilisation measurements. Dutch universities were also asked to provide the frequency and occupancy rates of their education spaces and offices, together with details of the properties of these space utilisation measurements such as the number of measurement periods, number of observations per day, etc. The results were collected via different methods: some universities filled in the survey, others sent reports from which the data was extracted, and others referred to the benchmark of Dutch universities. Because there was only a substantial amount of data available for the education spaces, other space types are not reported here.

The results of this survey are summarised in Table APP. 1.1, Figure APP. 1.1 and Figure APP. 1.2. First, Table APP. 1.1 shows the characteristics of the space utilisation studies and their setup. It shows differences in the variables measured by universities, i.e. scheduled frequency, actual frequency, scheduled occupancy and actual occupancy. It also shows differences in the amount of periods included in the space utilisation studies (one or two periods), the duration of the studies (ranging from one week to one year). Sometimes, information on these characteristics was not known.

TABLE APP.1.1 Properties of the reported space utilisation studies across Dutch universities, using the data from SMG (2006b) as benchmark.

	Scheduled Freq.	Actual Freq.	Scheduled Occ.	Actual Occ.	Measure-ment period(s)	Measure-ment duration	Observa-tions per day	Maximum availability
EUR	Yes	No	No	No	One	One year	n.a.	40 hours
LEI	Yes	Yes	Yes	Yes	One	Two weeks	Unknown	Unknown
MU	-	-	-	-	-	-	-	-
RUG	-	-	-	-	-	-	-	-
RU	Yes	Yes	No	Yes	Two	One week	8	40 hours
TiU	No	Yes	No	Yes	One	10 days	7	40 hours
TUD	Yes	Yes	No	Yes	One	7 weeks	8	40 hours
TUE	Yes	Yes	No	Yes	Unknown	Unknown	Unknown	Unknown
UT	Yes	No	No	No	One	One year	8	40 hours
UU	-	-	-	-	-	-	-	-
UvA	Yes	No	No	Yes	Unknown	Unknown	Unknown	Unknown
VU	No	No	No	Yes	Unknown	Unknown	Unknown	Unknown
WU	Yes	No	No	No	One	8 weeks	n.a.	40 hours
UK (avg.)	Yes	Yes	Yes	Yes				

Second, Figure APP. 1.1 and Figure APP. 1.2 visualise the outcomes of the survey in terms of frequency and occupancy rates. These figures show that, when compared to a target rate of 75% frequency and occupancy, no universities meet the scheduled frequency target and only one meets the scheduled occupancy target. With regards to observed frequency and occupancy, improvements from 4% (Tilburg) to 16% (TU Eindhoven) are possible in terms of observed frequency and improvements from 5% (University of Amsterdam) to 26% (Radboud University) in observed occupancy.

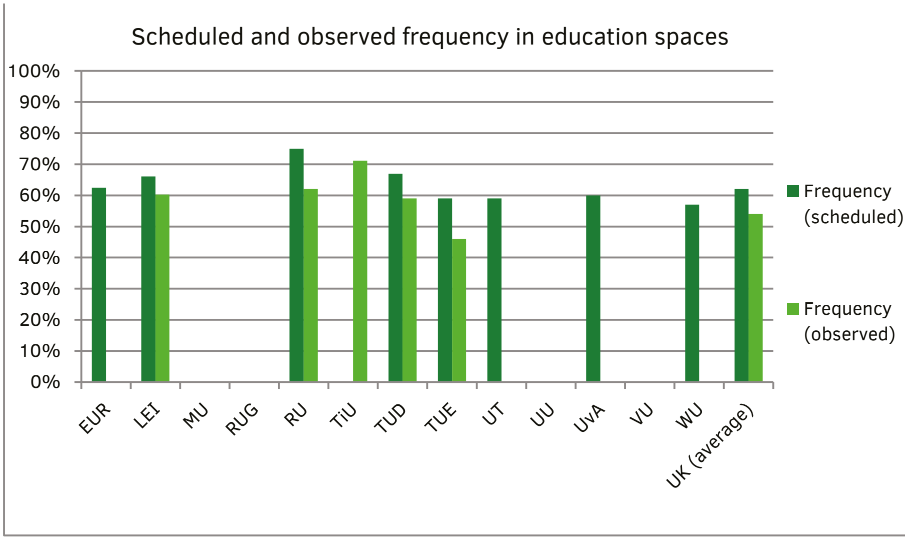

FIG. APP. 1.1 Scheduled frequency and observed frequency per university.

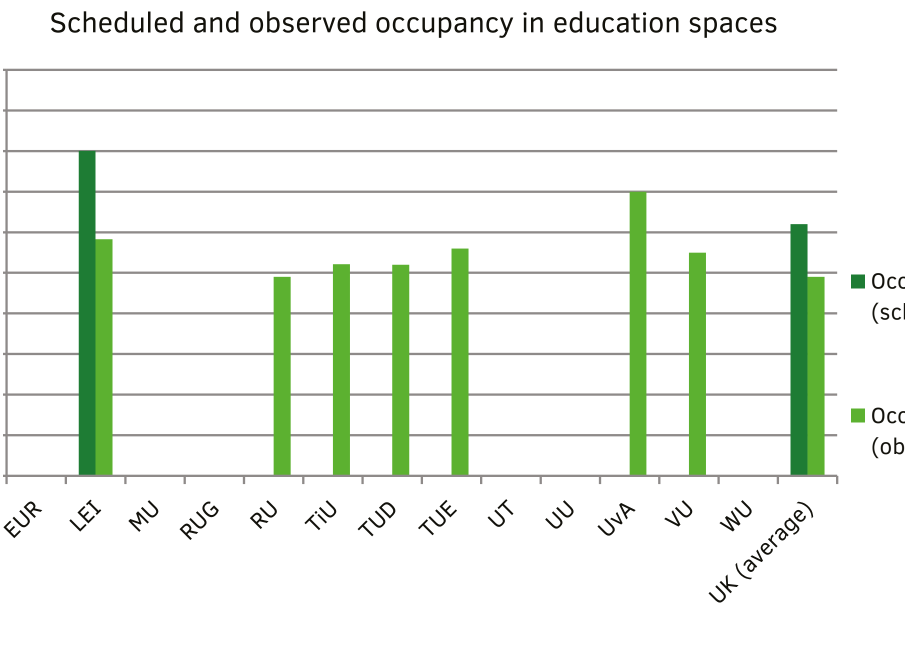

FIG. APP. 1.2 Scheduled occupancy and observed occupancy per university.

The results in Figure APP. 1.1 and A1.2 can be compared to those reported in chapter 4 at TU Delft, during the academic years 2015-16 to 2019-20. The frequency and occupancy rates reported by Dutch universities suggest that the space use of the education spaces at TU Delft is comparable to that of the other Dutch universities. In addition, Table APP. 1.1 demonstrates the variability present in the set-up of space utilisation studies across institutions. This is a limitation in the comparison of these studies. Following this survey of space utilisation at Dutch universities, a review was done of academic literature regarding (1) the reported space utilisation and (2) the set-up of the space utilisation studies. This review was the starting point for the research reported in chapter 4.

Space use at TU Delft: Supplementary data

Additionally, this appendix contains supplementary data to what is reported in Chapter 4. Section 4.5.1 reports the results of the space utilisation studies for education spaces at TU Delft. The three tables in this section display the results in those weeks of the academic year that are included in each of the studies (between 2015-16 and 2019-20). The first table shows the scheduled frequency, the second table shows the actual frequency, and the third table shows the actual occupancy.

The tables in this appendix show the results reported in these tables (in week 1.3 and 1.4) next to the results reported by TU Delft in each of the space utilisation reports. The results reported are averages of all weeks included in each study.

TABLE APP.1.2 Scheduled frequency – for all education spaces and per space type.

Reported average (week 1.1-1.8; 2.1-2.2)					
Type	2015-16	2016-17	2017-18	2018-19	2019-20
Lecture halls	78%	85%	83%	79%	86%
Classrooms	62%	73%	68%	62%	72%
PC halls	65%	70%	59%	52%	67%
Exams	57%	64%	63%	66%	55%
Total	67%	74%	70%	65%	74%
Average - week 1.3-1.4					
Type	2015-16	2016-17	2017-18	2018-19	2019-20
Lecture halls	79%	87%	82%	80%	90%
Classrooms	63%	81%	67%	64%	75%
PC halls	68%	72%	65%	53%	72%
Exams	59%	62%	66%	67%	56%
Total	68%	81%	70%	66%	77%

TABLE APP.1.3 Actual frequency and no-shows – for all education spaces and per space type.

	Reported average (week 1.1-1.8; 2.1-2.2)					Reported average (no-shows)				
Type	2015-16	2016-17	2017-18	2018-19	2019-20	2015-16	2016-17	2017-18	2018-19	2019-20
Lecture halls	73%	75%	77%	74%	82%	6%	11%	6%	6%	3%
Classrooms	52%	66%	62%	56%	67%	9%	6%	5%	6%	5%
PC halls	58%	62%	56%	51%	63%	8%	4%	2%	2%	4%
Exams	50%	51%	60%	62%	54%	6%	6%	3%	4%	1%
Total	59%	68%	65%	59%	70%	8%	6%	5%	6%	4%
	Average - week 1.3-1.4					Average - week 1.3-1.4 (no-shows)				
Type	2015-16	2016-17	2017-18	2018-19	2019-20	2015-16	2016-17	2017-18	2018-19	2019-20
Lecture halls	74%	82%	77%	75%	87%	5%	5%	5%	5%	3%
Classrooms	52%	74%	63%	58%	72%	12%	7%	4%	6%	4%
PC halls	59%	69%	62%	52%	69%	9%	3%	2%	1%	3%
Exams	53%	57%	63%	64%	56%	6%	5%	3%	3%	1%
Total	59%	75%	66%	61%	74%	9%	6%	4%	5%	3%

TABLE APP.1.4 Actual occupancy – for all education spaces and per space type.

Reported average (week 1.1-1.8; 2.1-2.2)					
Type	2015-16	2016-17	2017-18	2018-19	2019-20
Lecture halls	51%	44%	45%	50%	54%
Classrooms	54%	49%	44%	54%	56%
PC halls	57%	51%	46%	50%	49%
Exams	35%	40%	33%	49%	45%
Total	52%	47%	44%	51%	54%
Average - week 1.3-1.4					
Type	2015-16	2016-17	2017-18	2018-19	2019-20
Lecture halls	48%	49%	49%	45%	50%
Classrooms	54%	55%	47%	51%	53%
PC halls	53%	50%	50%	52%	49%
Exams	24%	49%	31%	55%	45%
Total	49%	52%	48%	48%	52%

APPENDIX 2

Smart campus tools: Case studies

This appendix provides more detail on the interviews that were conducted at all Dutch universities in the first study on Smart campus tools, in 2016. These interviews and their results were first published in a book (Valks et al. 2016) and formed the basis for the results reported in chapter 5.

This appendix first provides the questionnaire and interview schedules. Then, translated excerpts of chapter 3 and 4 of the book are given, which describe in more detail the contents of the chapter.

Questionnaire and Interview schedules

Online questionnaire		
1	Question	Are smart tools currently being used at your university?
	Answer	Yes / No
2	Question	Which smart tools are in use at your university?
	Answer	Open question – max. 5 answers
Question 2a – 2e is repeated for every smart tool that is recorded in question 2		
2a	Question	What type of smart tool is [smart tool]
	Answer	– Smart tool to improve the space use at the university – Smart tool to improve the scheduling process at the university – Smart tool(s) to improve the services of the university (e.g. ventilation, heating, etc.) – Other type of smart tool, i.e. …
2b	Question	What are the objectives for the smart tool?
	Answer	– Supporting image – Supporting culture – Stimulating collaboration – Stimulating innovation – Improving quality of place – Supporting user activities – Increasing user satisfaction – Increasing flexibility – Increasing revenues – Reducing (financial) risks – Reducing costs – Reducing CO_2-footprint – Reducing m^2 footprint
2c	Question	Which measurement methods are used by the smart tool? (multiple answers possible)
	Answer	– Wi-Fi network – RFID: for example access gates, card readers at doors – Ultra-wideband (UWB) – Bluetooth or other radio frequencies – Movement sensors, underneath desks or on walls – Cameras – Building services (lighting sensors, CO_2 sensors, …) – Other, i.e. …
2d	Question	For which space types is the smart tool used (multiple answers possible)
	Answer	– Education spaces – Study places – Office spaces – Meeting rooms – Laboratories
2e	Question	In which phase of implementation is the smart tool?
	Answer	– Development phase – Pilot phase – Implementation phase

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Online questionnaire		
3	Question	For which space types does your university have space use measurements? (multiple answers possible)
	Answer	– Education spaces – Study places – Office spaces – Meeting rooms – Laboratories
3a	Question	Which of these data are measured at your university for [space type]
	Answer	– Frequency rate (predicted use) – Frequency rate (actual use) – Occupancy rate (predicted use) – Occupancy rate (actual use) – Utilisation rate (predicted use) – Utilisation rate (actual use)
3b	Question	Which definitions are used at your university for [space type]
	Answer	– Frequency rate (predicted use) – Frequency rate (actual use) – Occupancy rate (predicted use) – Occupancy rate (actual use) – Utilisation rate (predicted use) – Utilisation rate (actual use)
3c	Question	Could you provide the following data for the space use measurement of [space type]
	Answer	– The time when the data was collected (e.g. 2015, Q1) – The number of hours that is taken as a baseline for 100% (e.g. 40 hours a week) – Other relevant information
3d	Question	Which values are measured for [space type]
	Answer	– Frequency rate (predicted use) : x% – Frequency rate (actual use) : x% – Occupancy rate (predicted use) : x% – Occupancy rate (actual use) : x% – Utilisation rate (predicted use) : x% – Utilisation rate (actual use) : x%
3e	Question	Does your university have targets for [space type]
	Answer	– Frequency rate (predicted use) : x% – Frequency rate (actual use) : x% – Occupancy rate (predicted use) : x% – Occupancy rate (actual use) : x% – Utilisation rate (predicted use) : x% – Utilisation rate (actual use) : x%
4	Question	What are the responsibilities of the Facility Services department of your university (multiple answers possible
	Answer	– Facility management – Real estate development – Building maintenance – Scheduling – Project management

Interview schedule – Interview with policy officer		
	Main questions	Supplementary questions
1	– In the questionnaire you indicated that your university uses the smart tool (…). Could you position this smart campus tool in the following framework? – [For the framework: see chapter 3, figure 3.7: From manual counts to SCTs (own illustration)]	– Can I see the application of the smart tool / the management report? – How does the smart tool / management report work? What functionalities does it have? – Which results have been achieved with it? – Does the app satisfy the users' demands? – Which measurement methods are used? What are the experiences with those? – What are the estimated costs of the smart tool? – Are the reports / smart tools linked to the FMIS system or a reporting system? – How was the development of the smart tool initiated? How would you do it a next time?
2	– Are you satisfied with the use of this smart tool?	– How satisfied are the various stakeholders with the smart tool / the results of the measurements?
3	– Are you currently developing new smart tools / space use measurements?	– How was the development initiated? – Which measurement methods are being considered? Are there already measurement methods present at the university? – Is this development related to your answer on the previous question (1), or is this a next step? – What are the estimated costs?
4	– Could you position the situation that is expected / desired by you in the near future in the framework (see question 1)?	– The same questions as those related to question 1.

Interview schedule – Interview with director		
	Main questions	Supplementary questions
	(A summary of interview 1 is given)	
1	– Based on the results of the questionnaire and the first interview, your university uses the following tools to achieve the following objectives. – Would you like to add something to this?	– Do you recognise this positioning? – Are you familiar with the smart tools that are mentioned here? – Is there information that is missing?
	(Introduction campus models: traditional, shared and online)	
2	– Do you recognise that your university is a mix of these three models, and which accents there are (within these models)?	
	(Explanation of the framework used in interview 1; from manual counts to SCTs)	
3	– In the first interview we have assessed the position of the current smart tools as follows. In the future we have assessed that the university wants to move towards this point in the framework. – Would you like to add something to this?	– Do you recognise this positioning? – Are you familiar with the smart tools that are mentioned here? – Is there information that is missing?
4	– How is the information from the smart tool currently used in the decision making about your real estate portfolio? Have you, for example, made adjustments to your strategy, or to buildings or spaces based on the information from the smart tool?	– Which kinds of decisions have you taken? – For which space types? – Could you name an example of such a decision (document)
5	– Are you interested in the possibility to use smart tools more in the future in your decision making?	– For what kind of decisions is this applicable? – For which space types?

Overview Smart campus tools

In the interviews 26 (smart) tools have been identified that are currently implemented, or are in a pilot / rollout phase after a tendering process. These are described shortly below and organised per space type.

Education spaces – space utilisation studies

In education spaces, space utilisation studies and related tools are used to report periodically on the space use of these resources. Differences can be found in the frequency which measurements are carried out and what exactly is measured. Leiden University enters the results from their space utilisation study behind every reservation in their system, and has made its own reporting tool which is used to make every report that is needed for analysis. TU Eindhoven has camera's that are placed in every space, and measures the frequency and occupancy by counting it from a back office location.

Wageningen University recently started with a rollout of Lone Rooftop for the education buildings of the university. In Lone Rooftop, the Wi-Fi network is used to determine the use of an entire building. It can be used to show the frequency and occupancy of every education space real-time. By comparing that information with the scheduled hours of a course and the expected number of students, insight is given into which courses continuously have no-shows and a low occupancy. Additionally Wageningen University has a tool that monitors the use of desktop PCs in PC halls, which helps schedulers to match the demand for and supply of PC halls optimally.

Summary:

All: Manual counts for measuring frequency and occupancy rates.

A study based on manual counts which measures for each space what the frequency (in hours) and/or the occupancy (in seats) is, always compared to the schedule.

1 **LEI: ZRS-Cube**

A reporting tool in which all the information of reservations for education spaces is included, complemented with data from manual counts per reservation.

2 **TUE: Manual counts through cameras**

A study based on manual counts in which the counts are observed via cameras that are positioned in each education space. These are used to determine the frequency and occupancy rates.

3 **WU: Lone Rooftop / PIE**

A website on which campus managers and technical managers can see where in the building it is crowded (heat maps) and which give insight in the use of (large) education spaces, based on Wi-Fi measurements.

4 **WU: Available PCs in PC halls**

A tool with which schedulers can see how many desktop PCs are in use during education in PC halls.

Study places – finding available spaces, booking meeting rooms, studying in other spaces

The smart tools are used mostly for study spaces, often to support the users with finding available study places and booking spaces to meet. These tools are almost exclusively used for the entire campus. In addition, some universities have recently started using small education spaces for studying. Through different tools they communicate to students when these spaces are available.

Availability of study places with a desktop PC

5 LEI: Free PCs

A website on which students can see in which university buildings there are study places, where in the buildings those study places are and which study places with desktop PCs are available at that moment.

6 RU: Student workplaces

A website which shows real-time per space how many PCs are used by students.

7 RUG: Availability for students

A website that gives insight into the use of the university library, so students can estimate if there are study places available. The business is determined based on camera images.

8 RUG: Available PCs in UB

A website that shows students which desktop PCs are available for self-study in the university library.

9 TiU: PC Availability

A website that shows students in which university buildings desktop PCs are available for self-study.

10 TUD: Workplace availability service (WAS)

A website that shows real-time per space how many desktop PCs are used by students.

11 UU Studyspot

A website on which students can see in which university buildings there are study places, where in the building those study places are and which study places with desktop PCs are available.

12 WU Available PC App

An app on which students can see which desktop PCs are available for self-study on the level of workplaces, spaces and buildings.

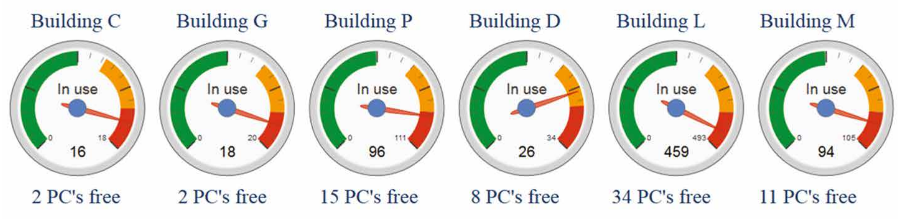


FIG. APP. 2.1 Dashboard of PC Availability, Tilburg University.

Booking systems for project rooms

13 **RU: Planon**

An app/website, complemented with kiosk screens at the entrances of buildings. Students can book project rooms via these media, and see which spaces are available.

14 **TiU, RU Web Room Booking**

A website which allows students to book project rooms (small meeting spaces) to work together on a project. Requests via Web Room Booking are processed by Facility Services.

15 **UM, HvA, WU, UT Web Room Booking**

A website which allows students to book project rooms (small meeting spaces) to work together on a project.

16 **TUD Mapiq**

An app/website which allows students to book small project rooms in the Library, and in which they can see where in the building various services are located.

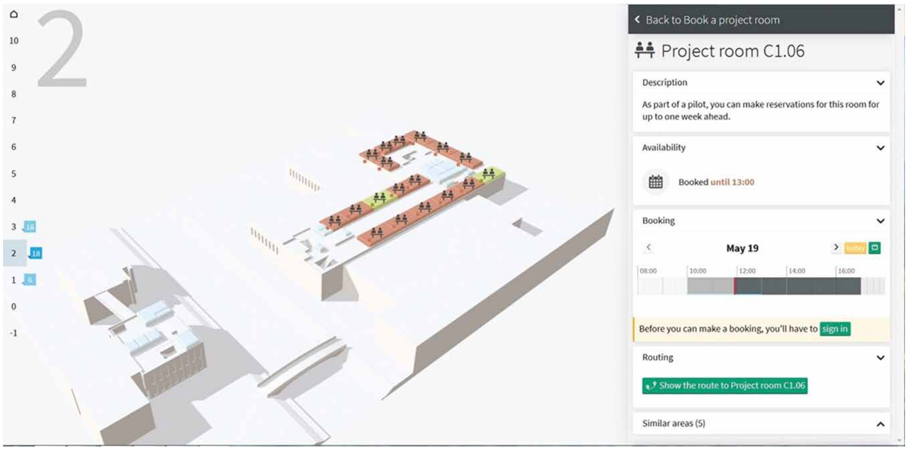


FIG. APP. 2.2 User interface of Mapiq, University of Amsterdam.

Tools in which (among others) small education spaces are made available for studying

17 **UvA Mapiq**
An app/website on which students can book project rooms and available education spaces, and in which they can see which amenities there are in the buildings.

18 **VU Studyspot**
A website on which students can see which education spaces are available for studying, based on the timetable. (This is another Study Spot than is used in Utrecht)

19 **TUE Book my space – Planon**
An app/website, complemented by kiosk screens at the entrances of buildings. Students and employees can reserve small education spaces, project rooms and meeting rooms, and at the moment also individual study places.

Office spaces – reserving meeting rooms and/or office workplaces

In the office spaces several experiments with different tools are ongoing. They give primarily insights into the availability of meeting spaces and booking those spaces, and in one case a similar functionality for office workplaces. All three of these tools are only applied in one building or even part of a building. At University of Utrecht the tool has been applied because the faculty that uses the building, has less space than it needs according to the university's space norms. Therefore, the tool needs to help support the users. In the case of Twente University, the tool is used to gain experience in using the tool, for possible implementation in a new build project.

20 **TUE Evoko**
A software programme which allows employees to reserve meeting rooms. It is complemented by screens at the entrances of meeting rooms and linked to Microsoft Outlook.

21 **UU Mapiq**
An app/website which allows employees to see which office workplaces and meeting rooms are free, and where they can reserve these resources.

22 **UT Smart signs**
A software programme that allows employees to reserve meeting rooms; complemented by screens at the entrances of meeting rooms and linked to Microsoft Outlook.

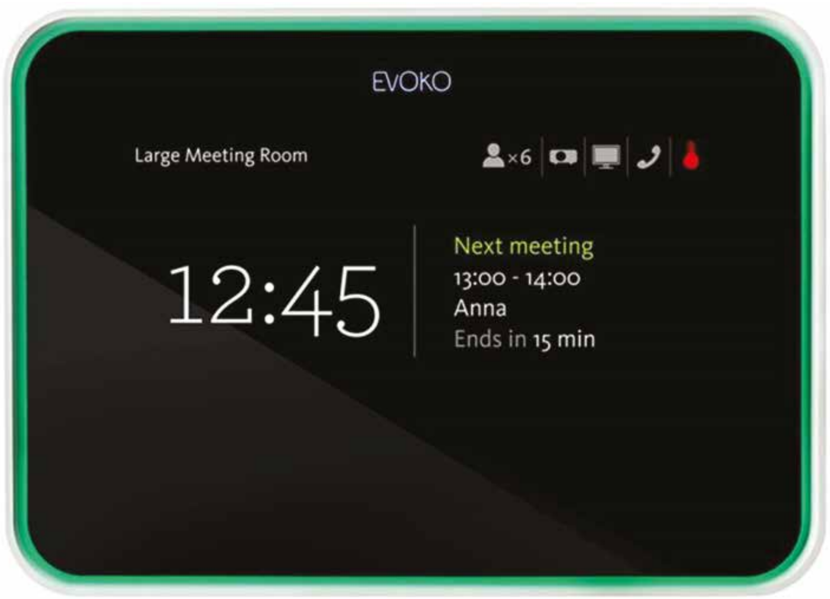


FIG. APP. 2.3 Impression of the screens at meeting rooms; Evoko (at TU Eindhoven).

Miscellaneous tools

Finally, several other existing tools have been identified in the interviews. Two of these tools link building automation systems to other systems to realise energy savings in education spaces. The third tool is the addition of the own floor plans in Google Maps to assist users with the navigation on campus. The fourth tool is a system which gives insight into the availability of parking spaces by measuring the occupancy of each parking space. This system has been applied to several parking lots on the campus.

23 **RUG Link Building Automation System – Syllabus – Traka**

A software programme that links the scheduling system of the university and the key access system to the building automation system. That way before and after a scheduled activity for which the education space is used, the lighting, heating and ventilation are adjusted.

24 **UT Facility Scheduler**

A software programme which links the scheduling programme of the university to the building automation system. That way before and after a scheduled activity the lighting, heating and ventilation are adjusted.

25 **UT Google Indoor Maps**

An addition to Google Maps (website) which makes the functions of spaces in each building visible to the user.

26 **UT Nedap – Parking system**

A system that uses sensors to determine how many parking spaces are in use. This information is displayed at the entrance of the parking lot.

Tools om gebruikers te ondersteunen	Universiteit	Dienst (a)	Functionaliteit	Input (b)	Ruimtetype (c)	Schaalgrootte	Fase
Mapiq	**UvA**	FB	Reserveren van onderwijszalen locatie van studieplekken	Boekingen rooster Boekingen studenten	OZ SP	Drie gebouwen	Pilot (richting implementatie)
Book my Space - Planon	**TU/e**	FB	Reserveren van ruimten, inzicht in beschikbaarheid o.b.v boekingen	Boekingen rooster Boekingen studenten	OZ PR SP VZ	Drie gebouwen	Pilot (richting implementatie)
Mapiq (2)	**TUD**	UB	Reserveren van kleine overlegzalen; locatie van studieplekken	Boekingen studenten	SP PR	Library	Implementatie
Web Room Booking	**UT, HvA, WUR, MU**	FB	Reserveren van kleine overlegzalen	Boekingen studenten	PR	Campusbreed	Implementatie
Web Room Booking	**TiU, RU**	FB	Reserveren van kleine overlegzalen (behandeling door FB)	Boekingen studenten, medewerkers	PR	Campusbreed	Implementatie
Studyspot (a)	**UU**	FB	Locatie van studieplekken en beschikbare PC plekken	Ingelogde PC's	SP	Campusbreed	Implementatie
Study Spot (b)	**VU**	FB	Beschikbaarheid van onderwijszalen voor zelfstudie	Boekingen rooster	OZ	Campusbreed	Implementatie
Beschikbaarheid voor studenten	**RUG**	FB	Beschikbaarheid van universiteitsbibliotheek voor zelfstudie	Camerabeelden	SP	Library	Implementatie
Available PC in UB	**RUG**	ICT	Inzicht in beschikbare PC plekken	Ingelogde PC's	SP	Library	Implementatie
PC Availability	**TiU**	ICT	Inzicht in beschikbare PC plekken	Ingelogde PC's	SP	Campusbreed	Implementatie
Studentwerkplekken	**RU**	ICT	Inzicht in beschikbare PC plekken	Ingelogde PC's	SP	Campusbreed	Implementatie
Workplace Availability Service	**TUD**	ICT	Inzicht in beschikbare PC plekken	Ingelogde PC's	SP	Campusbreed	Implementatie
Available PC App	**WUR**	FB	Inzicht in beschikbare PC plekken	Ingelogde PC's	SP	Campusbreed	Implementatie
Vrije PC's	**LEI**	UB	Inzicht in beschikbare PC plekken	Ingelogde PC's	SP	Campusbreed	Implementatie
Indoor Maps - Google	**UT**	FB	Navigatie	-	Alle	Campusbreed	Implementatie
P-systeem - Nedap	**UT**	FB	Beschikbaarheid	Sensordata	P	Enkele velden	Implementatie

Tools voor verbetering van services / duurzaamheid	Universiteit	Dienst (a)	Functionaliteit	Input (b)	Ruimtetype (c)	Schaal	Fase
Facility Scheduler	**UT**	FB	Koppeling rooster en GBS (onderwijszalen)	Boekingen rooster	OZ	Aantal zalen	Implementatie
GBS - Syllabus - Traka	**RUG**	FB	Koppeling rooster, sleuteluitgiftesysteem en GBS (onderwijszalen)	Boekingen rooster Uitgifte sleutel	OZ	Aantal zalen	Implementatie
Creston Fusion	**UT**	FB	Monitoren levensduur, storingen van beamers	Informatie van beamers in onderwijszalen	Alle	Campusbreed	Implementatie

Tools voor het verzamelen van managementinformatie voor besluitvorming	Universiteit	Dienst (a)	Functionaliteit	Input (b)	Ruimtetype (c)	Schaal	Fase
Pie - Lone Rooftop	**WUR**	FB	Vergelijking boekingen en werkelijk gebruik (bezetting)	Boekingen rooster Wi-Fi data	OZ	Drie gebouwen	Pilot (richting implementatie)
Beschikbare PC's in zalen	**WUR**	FB	Vergelijking ingeroosterde groepen en gebruikte PC's	Boekingen rooster Ingelogde PC's	OZ	Campusbreed	Implementatie
Cube	**LEI**	FB	Vergelijking boekingen en werkelijk gebruik: bezetting en benutting	Bestaand	OZ	Campusbreed	Ontwikkelfase
Bezettingsmeting o.b.v. camera's	***TU/e***	*FB*	*Meting bezetting en benutting in onderwijszalen*	*Boekingen rooster Telling bezetting en benutting via camera's*	*OZ*	*Campusbreed*	*Implementatie*

Opmerkingen

a - FB = facilitair bedrijf ; UB = universiteitsbibliotheek

b - gegevens die verzameld en verwerkt worden in de tool

c - OZ = onderwijszaal ; SP = studieplek ; PR = projectruimte ; VZ = vergaderzaal ; P = parkeerveld; SV = sportveld

FIG. APP. 2.4 Overview of the current Smart tools at Dutch universities.

Ongoing developments

In addition to the existing tools several ongoing developments for the smart tools were discussed in the interviews; these are reported below. With these developments, the universities (partially) respond to the changing demand for smart tools. The developments are summarized below.

Tools for campus management

Some universities are already experimenting with sensors to get real-time insight into frequency and/or occupancy of spaces. Some only want insight into the time that a space is in use (frequency); some also want to know the number of people in a space (occupancy). At Twente University researchers are involved in finding a suitable method to do this. At TU Delft, a project is started to try different kinds of sensors.

Tools for students

In the current implementation of Planon TU Eindhoven has tested a reservation system for individual study places. This test has revealed that the reservation system does not work well for study places: students make use of the study places without reservation, and with the reservation system the 'towel problem' becomes a more frequent issue. Therefore, the university is researching which method is most suitable to give insight into the availability of study places.

The use of education spaces for study places is also increasing. Erasmus University is developing a tool with the same functionality as Study Spot at the VU Amsterdam. Furthermore, the University of Amsterdam is researching if they can give insight into the availability of seats in education spaces. The University of Amsterdam, VU Amsterdam and TU Eindhoven have all indicated to look at ways in which their current tools can be developed further. The desire is to complement the availability, which is now based on reservations, with information on the actual use of the space.

Tools to make the campus more sustainable

A development that is relevant for all space types, as it is on a building level, is the tendency to link systems and thus further automate buildings. In the framework of the 'Internet of Things', more parts of buildings are equipped with sensors, which increases the data about (parts of) the building portfolio and the possibilities to make connections between the data.

Twente University is currently looking for a system that can monitor the maintenance of its buildings, by monitoring the status of different elements. A system has just been implemented for this purpose: Creston Fusion, by Creston. Twente University is continuously looking for a system that can connect as many data sources as possible together. Furthermore, it is installing a Low Bandwidth ('LoRa') network on the campus, to which sensors can be connected and which simplifies the connection to sensors. The University of Amsterdam and Wageningen University are also working on this issue, together with Johnson Controls and Lone Rooftop respectively.

Tools om gebruikers te ondersteunen

	Universiteit	Dienst (a)	Functionaliteit	Input (b)	Ruimtetype (c)	Schaalgrootte	Fase
Eigen ontwikkeling	**EUR**	FB	Inzicht in beschikbare uren van onderwijszalen	Boekingen rooster	OZ	Campusbreed	Ontwikkelfase
Mapiq	**UvA**	FB	Bestaand + Localiseren van gebruikers	Bestaand + CO2 concentratie (GBS) Sensordata (n.t.b.)	OZ PR SP	N.n.b.	Ontwikkelfase
Book my Space - Planon	**TU/e**	FB	Bestaand + Werkelijke beschikbaarheid	Bestaand + Sensordata (n.t.b.)	SP	Drie gebouwen	Ontwikkelfase

Tools voor verbetering van services / duurzaamheid

	Universiteit	Dienst (a)	Functionaliteit	Input (b)	Ruimtetype (c)	Schaal	Fase
Facility Scheduler	**UT**	FB	Bestaand + Koppeling rooster en GBS (sportzalen)	Bestaand + Boekingen Planon	SV	Sportzalen	Pilot
N.n.b. (Nu: Creston Fusion)	**UT**	FB	Monitoren klimaat, storingsmeldingen, etc. van ruimten	Informatie uit gebouwgebonden systemen	Alle	Campusbreed	Ontwikkelfase
Pie - Lone Rooftop	**WUR**	FB	Heatmap: waar zijn gebruikers in gebouw. Gebruik in beheer	Bestaand (Wi-Fi data)	Alle	N.n.b.	Ontwikkelfase
Pie - Lone Rooftop (2)	**HvA**	FB	Monitoren klimaat, storingsmeldingen, etc. van ruimten	Informatie uit gebouwgebonden systemen	Alle	?	Pilot
Johnson Controls	**UvA**	FB	Koppeling rooster en GBS (onderwijszalen)	Boekingen rooster	OZ	Aantal zalen	Pilot

Tools voor het verzamelen van managementinformatie voor besluitvorming

	Universiteit	Dienst (a)	Functionaliteit	Input (b)	Ruimtetype (c)	Schaal	Fase
Pie - Lone Rooftop	**WUR**	FB	Vergelijking boekingen en werkelijk gebruik (bezetting) + benutting	Bestaand (Wi-Fi data) + mogelijk sensordata (n.t.b.)	OZ	N.n.b.	Ontwikkelfase
Bezettingsmeting	**UT**	FB	Vergelijking boekingen en werkelijk gebruik: bezetting	Bestaand + sensordata (niet Wi-Fi)	OZ	Campusbreed	Ontwikkelfase
Tool voor bezettingsmeting (n.n.b.)	**TUD**	FB, ICT	Vergelijking boekingen en werkelijk gebruik: bezetting en benutting	Boekingen rooster Wi-Fi of sensordata (n.t.b.)	OZ SWP PR	Aantal gebouwen	Ontwikkelfase (een of meerdere pilots)

Opmerkingen

a - FB = facilitair bedrijf ; UB = universiteitsbibliotheek
b - gegevens die verzameld en verwerkt worden in de tool
c - OZ = onderwijszaal ; SP = studieplek ; PR = projectruimte ; VZ = vergaderzaal ; P = parkeerveld

FIG. APP. 2.5 Overview of the current developments in Smart tools at Dutch universities.

Considerations in selecting future smart campus tools

In the interviews, the universities indicated several factors that are relevant in selecting a smart campus tool. It is noteworthy that between universities there are large differences in these factors.

The supplier of the smart tool

Is this a large organisation, a start-up or does the university choose to develop the tool itself? Some universities indicate that they have chosen for a large organisation, so as to guarantee a good level of support when the tool has been implemented. Other universities prefer start-ups or small organisations, because of their technological innovation or their adaptability to the demands of the university. The development of tools internally is an option or even a preference for some universities: Utrecht University and the University of Groningen indicate this, as it saves costs and results in having the knowledge in-house. It seems that the preference for the internal development of tools is mainly linked to the expertise and strategy of the university's IT department.

Selecting sensors

Many universities choose a type of sensor based on proven technologies. There is also a stated preference for the use of existing infrastructure, although there are no examples available that make use of e.g. the sensors in lighting systems. Currently most smart tools that are in use at the universities are based on reservations. The universities appear reluctant to install new infrastructure, involving additional investment and operating cost. The most promising existing infrastructure at the universities seems to be the Wi-Fi network, although opinions diverge: Twente University indicates that the precision of this method is too low, and the VU Amsterdam, University of Amsterdam, and Wageningen University are currently going to collect frequency and occupancy data with Cisco or Lone Rooftop.

Privacy aspects

In selecting a smart tool, both users and campus managers have concerns with regards to the information sensitivity of different solutions. Preferably sensors or other data sources are used that guarantee anonymity. These concerns apply especially with regards to the use of Wi-Fi data.

Precision of the information

The previous point is connected to the desired accuracy of the information. For example, Twente University and Maastricht University indicate they want to know the frequency (in hours) of the education spaces and other spaces. The occupancy (in seats) is not found to be necessary by all universities – although it differs per solution. The desired accuracy has a large effect on the chosen solution.

Costs and benefits

Ultimately it is the costs of any solution and the (presumed) benefits that determine if it is desirable to move from the current solutions towards other smart tools. Estimating costs and benefits, however, is complicated. On the one hand, the costs are difficult to compare between tools because of the difference in scale of implementation (from one building to the whole campus) and because costs of internally developed tools are often not available. On the other hand, the benefits per tool are different in nature: from reducing energy costs to not having to invest in building new buildings over a period of time.

APPENDIX 3

Smart campus tools 2.0: Case studies

This appendix contains the outcomes of all the cases included in the Smart campus tools 2.0 part of the research (chapter 6). In the paper the cross-case analysis is reported. In this appendix the details of each individual case can be found.

First, this appendix provides the interview schedule that is used. Then, the appendix includes the following cases, in order:

- A generic mock-up template that describes which contents are discussed in the templates.

Cases at organisations

- ABN AMRO
- Agnelli Foundation
- Erasmus MC
- Ericsson
- Google
- Microsoft (case 1)
- Microsoft (case 2)
- OVG (now EDGE)
- Dutch government

Cases at international universities

- Aarhus
- Cambridge University
- Carnegie Mellon University (case 1)
- Carnegie Mellon University (case 2)
- DTU
- KU Leuven
- Oxford University

- Oxford Said Business School
- Sheffield Hallam University

Cases at Dutch universities

- TU Delft (case 1)
- TU Delft (case 2)
- TU Eindhoven
- Twente University
- University of Utrecht
- University of Amsterdam
- University of Tilburg
- VU Amsterdam
- Wageningen University

Note: In some templates, generic pictures are shown in place of figures when images of user information and/or management information are unavailable. These pictures are made by Saulo Mohana on Unsplash (user information) and Carlos Muza on Unsplash (management information).

Interview schedule

Generic questions

#	Topic	Question / subject
1	Context	Organisational development, CRE portfolio development
2	Smart tools	Which smart tools / examples of use of real-time data are currently applied at [university]
3	Decision-making	How is the data from smart tools used at [university] in decision-making processes? Has it led to the redesign of offices, adjustments to the CRE strategy, etc.?
4	Privacy	How does [university] deal with privacy in the use of sensitive information?
5	Interest in smart campus tools research	How can we keep [university] updated during the research and with which results?

Questions related to each separate smart campus tool (see templates)

Interview	Fields in template
	Organisation-#
	Fill in the abbreviated name of the organisation and a number to distinguish multiple smart tools at the same university.
input	
	Project description
question	Could you indicate how the initiative for this smart tool was taken (problem) and why this smart tool has been chosen (solution)
answer	
	Phase
question	In which phase of implementation is the smart tool?
options	
	Options?
	Research – if the smart tool is part of a scientific project
	Product development – if the smart tool is being developed towards a market-ready product
	Pilot – if the smart tool is market-ready and being tested with the objective of assessing if it can be applied on a large scale
	Expansion – If the smart tool is currently being implemented on a large part of the portfolio
	Implementatie – If the smart tool has been implemented and is now part of the regular operation
answer	
	Scale
question	Could you indicate how large the application area of the smart tool is, in m^2 Gross Floor Area and amount of buildings?
answer	
	Duration
question	Since when is the tool in use at your organisation?
answer	
	Functions
question	Which functions does the smart tool have?
options	
	Wayfinding, room booking, find a workplace, monitoring space use, linking systems, optimising workplace comfort. Other options can apply
answer	
	Space types
question	For which space types is the smart tool used?
options	
	Education spaces, study places, project rooms, laboratories, offices, meeting rooms, whole building
answer	

>>>

Interview	Fields in template
	Foreseen developments
question	Are there foreseen developments in the near future - amendments or improvements to the existing tool, replacement, etc.?
answer	
	Investment costs (per m^2 GFA)
question	Could you indicate what the investment costs of the smart tool are, in € per m^2 gross floor area?
explanation	
answer	
	Operating costs (per m^2 GFA)
question	Could you indicate what the operating costs of the smart tool are, in € per m^2 gross floor area?
explanation	
answer	
	Benefits
question	What objectives are defined to be achieved with the tool, and what is the progress on these objectives since implementing the tool?
explanation	
	For example: the tool must lead to 10% energy savings / a user satisfaction of 9 out of 10 / an occupancy rate of 75%. Since the implementation of the tool we have achieved ...
	User information
question	Could you indicate what information is available to the user and how the tool works?
explanation	
answer	
	Management information
question	Could you indicate what information is available to the campus manager and how the tool works?
explanation	
answer	
	Why: Objectives
question	Could you indicate to which goals the smart tool contributes?
options	
	Multiple options are possible:
	Strategic-> Stimulating innovation, stimulating collaboration, supporting image, supporting culture, improving quality of place
	Functional -> Supporting users, increasing user satisfaction, increasing flexibility
	Financial -> Increasing profits, reducing costs, reducing risks
	Physical -> Optimising m^2, reducing CO2 emissions, Enhancing safety
answer	
	Why: Objectives
question	Which goals have priority? How are they achieved?
answer	

>>>

Interview	Fields in template
	What: Measurement
question	How is space use measured with the smart tool?
options	
	Multiple options are possible:
	Frequency - is a space in use, yes/no
	Occupancy - x amount of users in a space
	Identity - who are the people in the space
	Activity - what are the people in the space doing / how do they move
answer	
	What: Measurement
question	What exactly is measured? How is privacy addressed?
answer	
	How: measurement method
question	Which measurement method(s) is/are used?
options	
	Manual - manual counts are used
	Booking - booking systems or scheduling data is used
	Sensors - sensor data is used
	Indicate which sensors are used: e.g. Wi-Fi, infrared, CO2, Bluetooth, …
answer	
	How: measurement method
question	How does the measurement method work?
explanation	
	E.g. Wi-Fi registers the amount of connected users to the network, or: an iBeacon is placed in each room and users in that room make a connection with the iBeacon via Bluetooth.
answer	
	Actuality of the information
question	How up-to-date is the information reported in the smart tool?
explanation	
	This can be different for different functions in the smart tool. Options are: near real time, in minutes, and hourly or more
answer	
	Actuality of the information
question	Could you further specify how up-to-date the information in the smart tool is? Are there differences between functions?
answer	
	Access levels
question	Who has access to the smart tool?
options	
	managers, support, users, open access.

>>>

Interview	Fields in template
answer	
	Access levels
question	Who has access to which function of the smart tool?
answer	
	Side notes
question	Could you share some of the experiences with the smart tool, or other information which you think could be of interest for campus managers?
options	
answer	
	Images
question	Could you send a number of images of the smart tool?
	1 general image, 2 user information, 3 management information
answer	

SCT Templates

SCT # Case Smart campus tool

phase
Phase of implementation
(limited options)

scale
Area (in m2 GFA)
# of buildings

duration
Duration of the project

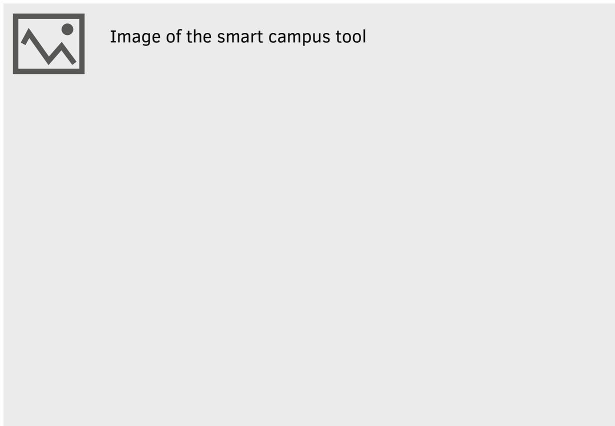
Location of case

Project description

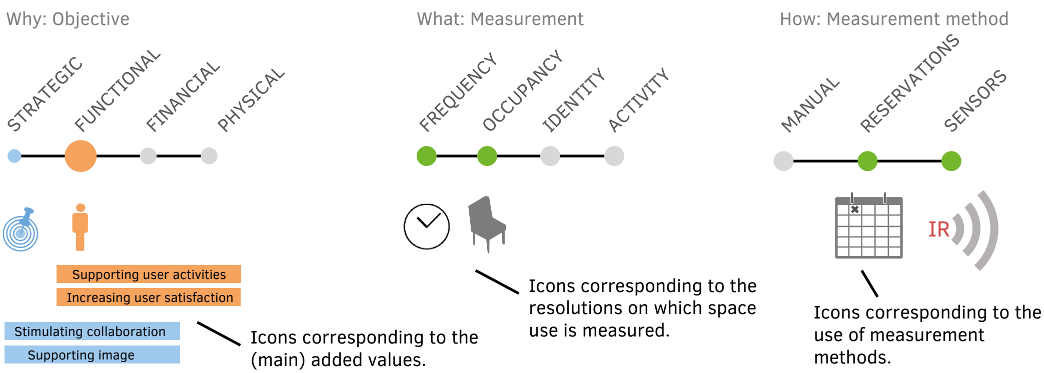
Description of the project. Explains why it was initiated and/or what is its purpose.

Foreseen developments

Description of intended future additions to the Smart campus tool project.



Profile



Description of the (main) added values by the interviewee.

Description of the resolution on which space use is measured. If space use is measured on the identity or activity resolution, additional information regarding privacy is provided.

Description of how the stated methods measure the use of space.

SCT # Case Smart campus tool

functionalities
Functionalities of the Smart campus tool
(limited options)

space types
Space types the SCT is used for
(limited options)

Location of case

User information

Description of the information available to the user (student / employee) in the user interface of the smart campus tool.

Image of the user interface of the smart campus tool

Image of the reporting interface of the
the
smart campus tool

Management information

Description of the information available to the campus manager in the reporting interface of the smart campus tool.

Actuality of the information

>= DAYS HOURS REAL-TIME

Access levels

MANAGERS SUPPORT USERS OPEN ACCESS

Icons corresponding to the use of interfaces.

Description of the actuality of the information in the user interface.

Description of the information that can be retrieved in the reporting interface.

Icons corresponding to the stakeholders.

Description of the stakeholder(s) that have access to the user interface.

Description of stakeholder(s) who have access to the reporting interface.

Benefits

Description of the intended benefits of the smart campus tool project and the extent to which they have been achieved.

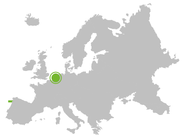
Side notes

Discussion of additional information related to the project that is not discussed elsewhere.

TOC

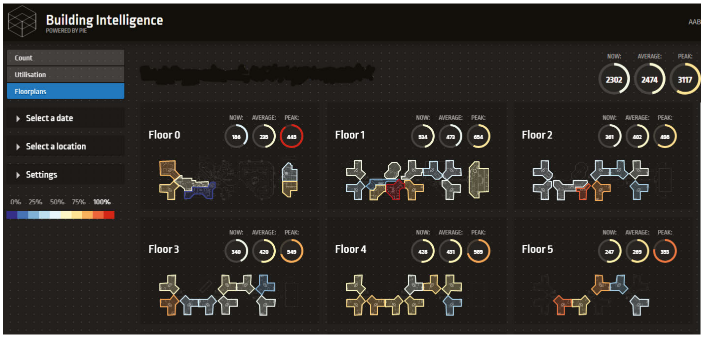
ABN | ABN AMRO | Intelligent Building - Lone Rooftop

phase: Implementation
scale: 232.000 m2, 11 buildings
duration: dec. 2016 - present



Project description

The project was initiated because we wanted to manage our scarce resources better. We wanted insight into hidden vacancy in the different buildings in order to discuss the space use with our different business lines and to optimise our services as FM. In addition we wanted to show our employees the availability of workplaces. We then started to look at options to use existing infrastructure and initiated a pilot with Lone Rooftop. The project includes three different services: the building dashboard, the SPOT app and Wally.

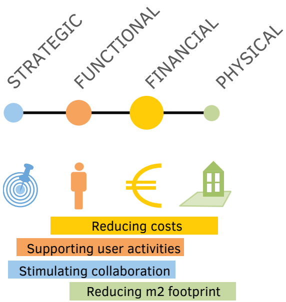


Foreseen developments

We want to get insight into the frequency (no-show) and occupancy (amount of persons) of meeting rooms with other sensors.

Profile

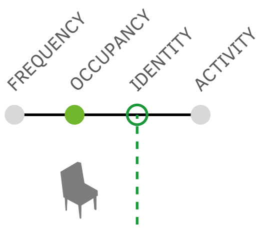
Why: Objectives



Also mentioned: increasing user satisfaction, increasing flexibility, stimulating innovation, supporting culture, improving quality of place

Cost reduction has the highest priority, followed by supporting our users. Cost reduction is achieved by discussing space use with our business lines, which will result in not having to build new buildings or disposing of existing buildings.

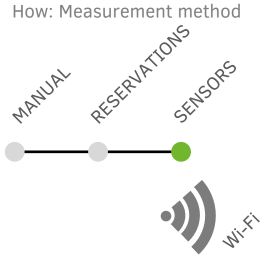
What: Measurement



With Wi-Fi personal data is collected. Lone Rooftop deals with this issue by anonymising its data differently every day and by anonymising it directly after data collection

An indication of the occupancy is given for a predetermined zone. The size of this zone is aligned to the accuracy of the measurement.

How: Measurement method



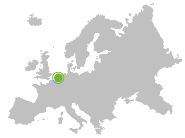
The amount of people is measured. First, the devices are counted, both actively via connections and passively via connection attempts, on a certain time in a certain place. This measurement is processed by an algorithm that pairs devices that belong to one person.

TOC

ABN | ABN AMRO | Intelligent Building - Lone Rooftop

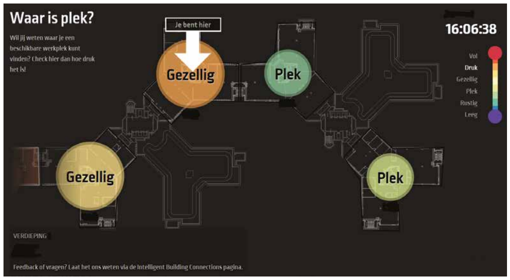
functionalities
Monitoring space use,
find a workplace

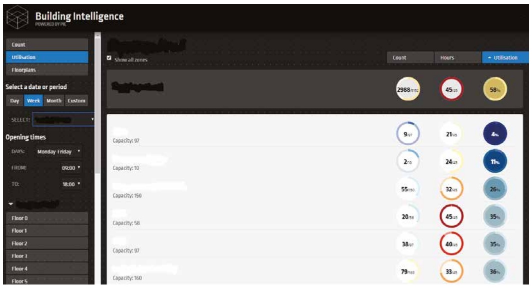
space types
Offices,
(whole building)



User information (employees)

The user - in this case employees - can see the occupancy of different zones in the buildings on TV screens installed on each floor and via the SPOT app. Per floor a number of zones have been defined, consisting of multiple workplaces, of which an indication of the occupancy is given in labels: “full”, “busy”, “calm”, etc.

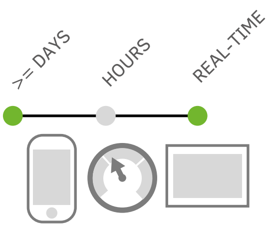




Management information

In the dashboard it is possible to view both real-time and historical data. The user of the dashboard can display the information in diagrams and on blueprints of the building. Recently the dashboard has been updated, which makes it possible to aggregate the data on different levels.

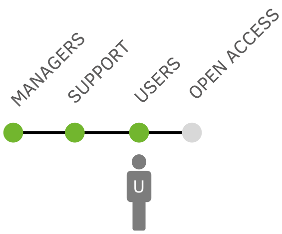
Actuality of the information



The information displayed in the dashboard for employees, in floorplans and reports is real-time.

The data used in reporting goes from real-time to as far back as possible.

Access levels



The Avex screens display information on real-time availability of workplaces that can be accessed by all employees

The dashboard and reporting functions are available to the BI department and account managers.

Benefits

- determining an accommodation strategy with the collected data
- reducing costs due to less investment in extra accommodation
- advising the building user on the efficient use of space

Side notes

The use of Wi-Fi for this purpose within a bank is a challenge, because the network has a very strong security. In the pilot we tested how to transfer the data from in the organisation to outside (Lone Rooftop, MSE application of Verizon) and then again to inside the organisation.

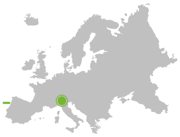
During the pilot we discovered that this required a lot of effort and we ran into a number of unforeseen complications. Further complicating the matter was the communication of different systems: Lone Rooftop, our network provider Verizon and Avex, the party who provided the TV screens and narrowcasting solution.

AGF — Agnelli Foundation, Carlo Ratti Associati — Office 3.0

phase: Implementation

scale: 6.500 m2, 1 building

duration: June 2017-present



Project description

There are two problems addressed by Carlo Ratti Associati: the first is energy wasted by heating and cooling empty buildings and the second is how to design a space that maximally enables users. The building enables users to check in, interact with coworkers, book meeting rooms, and regulate environmental settings in order to achieve energy savings and realise the vision for the office of the future.

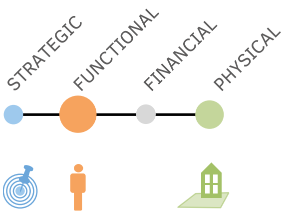
image by Carlo Ratti Associati

Foreseen developments

The building will serve as a testbed for research into the relation between office design and productivity, by analysing building use statistics.

Profile

Why: Objectives



Supporting user activities

Increasing user satisfaction

Reducing CO2 footprint

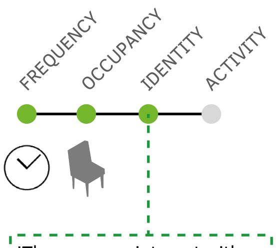
Stimulating innovation

Stimulating collaboration

Also mentioned: increasing flexibility, supporting image, supporting culture, improving quality of place

Functional goals seem to have priority, by maximally enabling the building's occupants through the use of IoT technology.

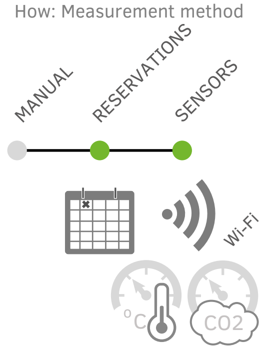
What: Measurement



'The user can interact with the BMS, by downloading an App on his/her smartphone (this enables geolocation). Users have to give their consent to share this data.

The desk or meeting room booked by a building occupant, the occupant's location within the building is determined to adjust the indoor climate to his/her preferences.

How: Measurement method



Temperature and CO2 sensors are matched with occupant preferences in order to adjust ventilation and heating settings. Wi-Fi is used for localisation.

Frequency and occupancy data are generated through workplace and meeting room bookings.

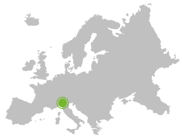
AGF

Agnelli Foundation, Carlo Ratti Associati

Office 3.0

functionalities
Optimising workplace comfort, room booking, find a workplace

space types
Offices, Meeting rooms



User information (employees)

A building occupant can set his preferred temperature and illumination settings in the app. He/she can also book meeting rooms and co-working spaces and share his/her location within the building.

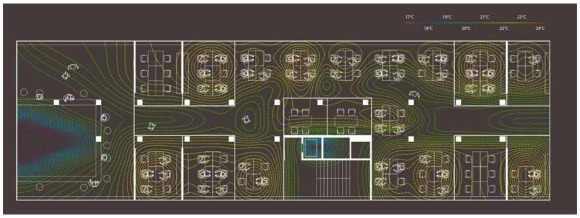
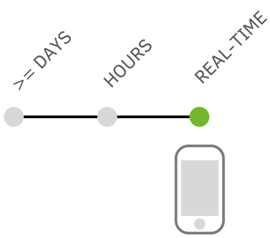


image by Carlo Ratti Associati

Management information

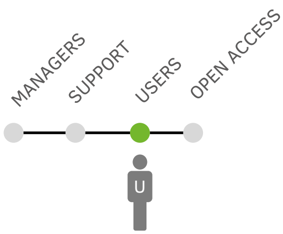
We are not involved on this regard. Siemens and Talent Garden are still discussing on this regard.

Actuality of the information



The information reported in the user app is real-time.

Access levels



Users have access to a smartphone app.

Benefits

The tool is used for synchronizing energy usage and human occupancy within the building – potentially slashing energy consumption by up to 40%. It is too early to say what the progress is, considering that the building was opened only four months ago.

Side notes

-

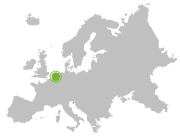
EMC

Erasmus MC programme of requirements

phase
Design brief

scale
13.000 m2
1 building

duration
foreseen
Q1 2018



Project description

EMC is about to change their office workplace concept to be able to accommodate more employees in the building. About 20% more people will use this building in the future due to the demolition of their current offices. Implementing the new workplace concept is met with resistance of the end users. I

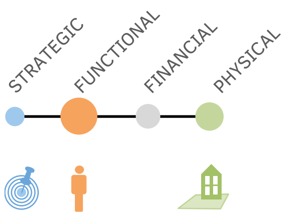
In order to address this problem EMC is thinking of a solution that gives users insight into the occupancy of workplaces, helping them to find workplaces, as well as to monitor the occupancy of the office in order to determine if extra space is needed or not. Functionalities might be added to further support users.

Foreseen developments

-

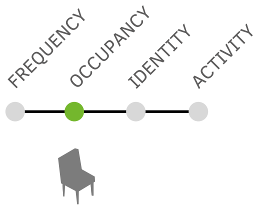
Profile

Why: Objectives



Supporting users has priority.

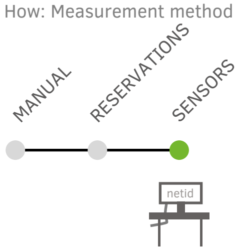
What: Measurement



(intended)

The use of a desktop PC is measured per workplace.

How: Measurement method



Desktop PCs
(intended)

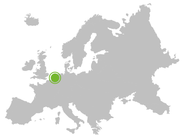
The ICT department has a system in which all desktop PCs are monitored - this system usually contains a registration of the amount of PCs, their location and their current activity. This activity (login by users) can be monitored to derive the occupancy of offices.

EMC

Erasmus MC programme of requirements

functionalities
Find a workplace,
monitoring space use

space types
Offices,
Meeting rooms



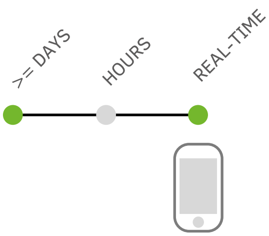
User information (employees)

The user receives access to a dashboard that displays the workplaces in the building and whether the workplaces are available.

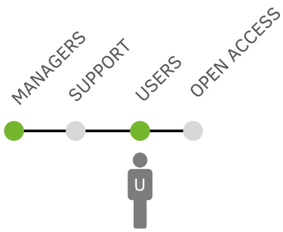
Management information

The real estate department needs access to data on the space use of the office environment and meeting rooms during the day for offices, floors and the whole building in order to make appropriate decisions.

Actuality of the information



Access levels



Users have access to user interface.

The user interface needs to display near real-time data in order to provide actionable information.

The reporting tool must include both real-time and historical data.

Reporting tool accessible by real estate management.

Benefits

EMC has set an occupancy of 60-75 percent of each workplace as objective. If the occupancy is lower, a department can be accommodated more efficiently. If the occupancy is higher, a department needs more workplaces.

Side notes

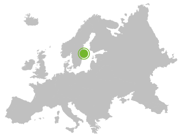
PM - no experience yet.

ERI — Ericsson — Flowscape

phase: Expansion

scale: 250.000 m2, 5 buildings

duration: ?



Project description

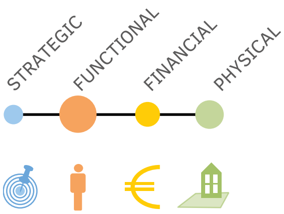
Flowscape started out as an intitiative to provide Ericsson Real Estate more insights on how our premises was used. We later changed the approach to focus on marketing it as a tool to provide the end user a better service to find space when needed. We have looked at different options, both from what sensors to use and also using different system solutions... We finally decided to start with something and as Ericsson is working in the field of IOT we decided to use an application owned and sold by Ericsson as a basis. From sensor perspective we have not limited ourselves to a certain tech.

Foreseen developments

As we get the infrastructure in place our plan is to find more used cases and to improve service delivieries. What to improve specifically has not yet been decided.

Profile

Why: Objectives



Supporting user activities

Reducing costs

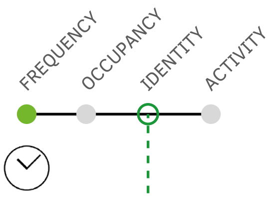
Reducing m2 footprint

Stimulating collaboration

also mentioned: Increasing user satisfaction, increasing flexibility, reducing risks, increasing revenues, reducing CO2 footprint, stimulating innovation, supporting image, supporting culture, improving quality of place

Hopefully all of the mentioned objectives are achieved. Functional objectives have priority.

What: Measurement



Indoor positioning is optional. You can choose if you want to use the service or not. If you use it you need to share your info

Currently we know if a room is occupied or not. You are able to use sensors that can detect how many but have not yet used that sensor.

How: Measurement method

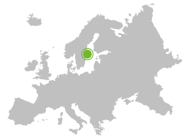
Infrared sensors are used to determine the frequency. Wi-Fi data and beacons are used for indoor positioning.

TOC

ERI　　Ericsson　　Flowscape

functionalities
Wayfinding, room booking,
find a workplace, monitoring space use

space types
Meeting rooms



User information (employees)

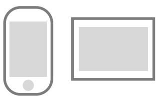
There are different realtime channels, such as an billboard application, a web application and a smartphone application. On these channels the user can view floor plans of the building that display the availability of spaces and book them.

Management information

A lot of realtime data is collected, which can then be transferred for analysis. We are aggregating data into trend analysis. Some reports has been produced but as this is an ongoing work. The development of the analysis will be a continuous work.

Actuality of the information

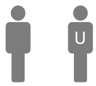
>= DAYS　HOURS　REAL-TIME



The information displayed in the dashboard for employees, in floorplans and reports is (near) real-time.

Access levels

MANAGERS　SUPPORT　USERS　OPEN ACCESS



User have access to user interface. Admin tool can be accessed by operators.

Reporting tool by Real estate and report developer

Benefits

PM

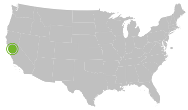
Side notes

PM

TOC

GGL Google 'Meeting room Nanny'

phase Implementation — scale >70 buildings — duration 2013-present



Project description

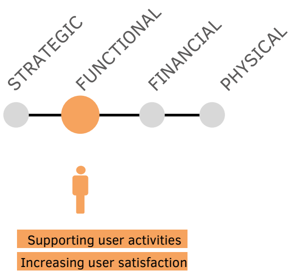
In the 10.000+ meeting rooms in its portfolio Google had a specific problem: that these were being claimed too often for long periods of time. A smart tool was developed to solve this problem. This smart tool is a component of Google's analysis tool, which contains all real estate related data.

Foreseen developments

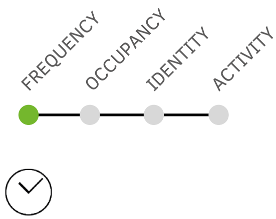
-

Profile

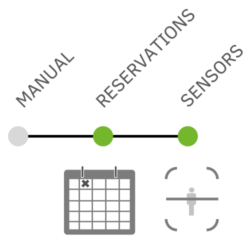
Why: Objectives



What: Measurement



How: Measurement method



video conferencing

The objective of the solution is to support user activities – finding out which spaces are needed and making sure that there are meeting spaces available rather than claimed for meetings that will not take place.

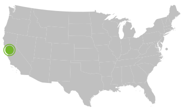
Is a meeting room actually used when it is booked.

The videoconferencing software senses if there are people using the room or not.

GGL Google 'Meeting room Nanny'

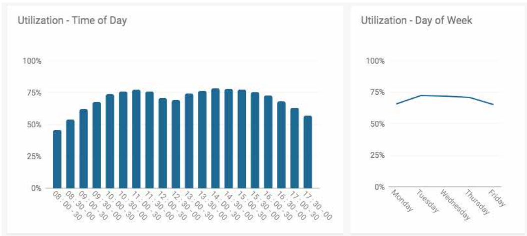
functionalities
Monitoring space use

space types
Meeting rooms



User information (employees)

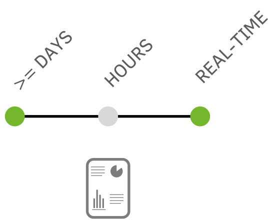
There is no specific user information in the tool - rather the outcomes are periodically shared with employees to show what the impact of claiming space is on the availability of meeting rooms.



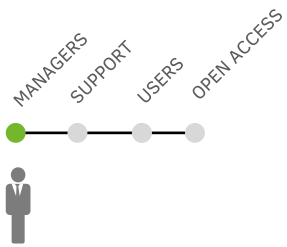
Management information

In the tool the campus manager can browse through the portfolio and see which types of meeting rooms are used most frequently (the utilisation rate). Also reports are given on the amount of meetings removed from the calendars of meeting rooms.

Actuality of the information



Access levels



Benefits

Based on the collected data Google has concluded that it typically builds too many large meeting rooms (8+ people) and that it needs more rooms for 3-8 people.

Also the measurement of actual use is used to remove recurring meetings from calendars: if a recurring meeting has not taken place more than two times it is removed automatically from the calendar.

Side notes

The data used in reporting goes from real-time to as far back as possible.

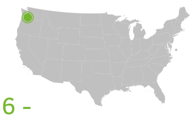
Reporting tool accessible by real estate management.

MIC-1 Microsoft Smart building app

phase
Pilot

scale
80.000 m2
4 buildings

duration
jan. 2016 - present

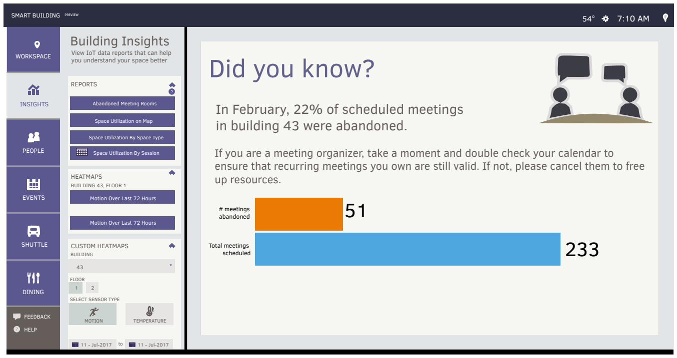


Project description

The initiative was taken more from a hypothesis if it was possible to create an application with the stated functionalities based on our expertise at Microsoft. Initially we looked at more traditional ways of measuring space use, such as PIR sensors underneath desks, but we concluded that the return on investment was not high enough. Therefore we used data from existing infrastructures.

Foreseen developments

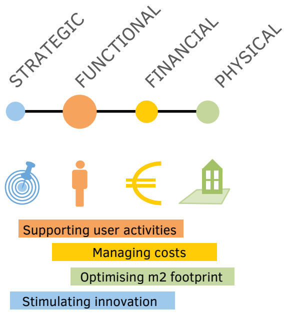
If we can get the right return on investment, we would like to develop an app that displays the data, making the tool more user-friendly



Impression - Smarter buildings dashboard on digital signage at Microsoft

Profile

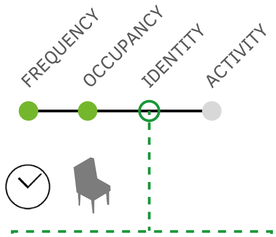
Why: Objectives



also mentioned: increasing user satisfaction, increasing flexibility, supporting culture, improving quality of place

First priority is supporting our employees, then the efficient management of assets. The third priority is to showcase our technology as Microsoft.

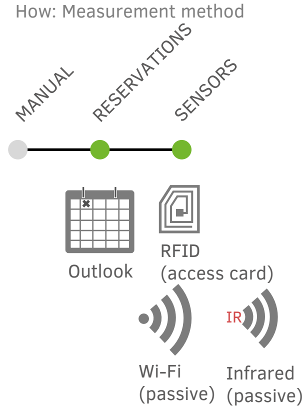
What: Measurement



Microsoft has a very strict privacy policy, so we make sure that anonymisation happens correctly. Anonymisation happens directly after registration of a device.

We measure the peak average utilisation, which is a metric that shows the average utilisation during a predefined peak period of the week (Tuesday- Thursday, 9AM-5PM). For meeting rooms, scheduled use and # of people are compared with actual use.

How: Measurement method

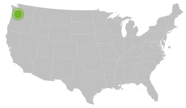


Access card data shows the amount of people in the building; Wi-Fi data shows the location of devices; PIR sensors measure if a meeting room is in use. Outlook data is used for meeting rooms

MIC-1 Microsoft Smart building app

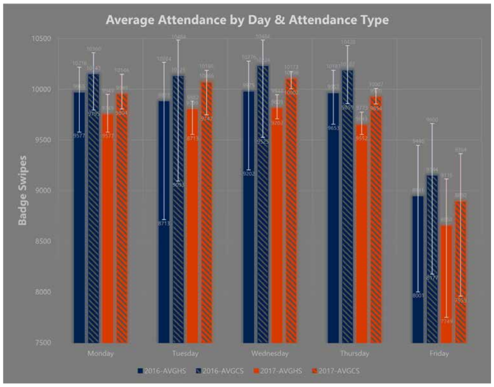
functionalities
Find a workplace,
Room booking

space types
Offices,
meeting rooms



User information (employees)

The user can see a floor plan in which the availability of desks (in zones) and meeting rooms are indicated in green and red. When zooming in, information about the temperature and noise levels are also given to help the user select a workplace that fits his/her needs



Management information

The dashboard shows numerous forms of data for buildings over a period of time. Per building information is shown of the people assigned to that building over time, which is compared to the use of each building. Microsoft uses its own platform - PowerBI - in which the data from the different sources is collected and where it can be combined and aggregated in any way possible.

The image shows an example of a report of the average attendance based on badge swipes.

Actuality of the information

>= DAYS HOURS REAL-TIME

The information displayed in the dashboard on the displays is real-time.

The data used in reporting goes from real-time to as far back as possible.

Access levels

MANAGERS SUPPORT USERS OPEN ACCESS

The employees can access the user dashboard.

The dashboard and reporting functions are available to the RE&FM team.

Benefits

In the offices we measure a peak utilisation rate of 85 percent. Keep in mind that not always this is the best measure of the value of a space. Our games room for instance only has an occupancy rate of 30 percent during the day, but according to employees the effectiveness when it is used is very high.

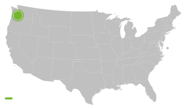
Side notes

Some experiments have been done with Raspberry Pi computers with occupancy, temperature and noise sensors attached to them.

TOC

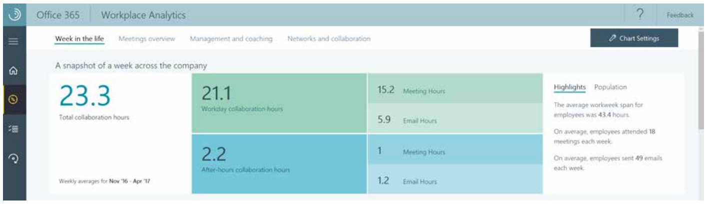
MIC-2 Microsoft Delve / Workplace analytics

phase Implementation — scale Unknown — duration dec. 2015 - present



Project description

The project was started in order to understand better how networks of people within the organisation work together. Workplace analytics is one of the possible products Microsoft provides in its Office365 suite, which we also apply in our own work environment.



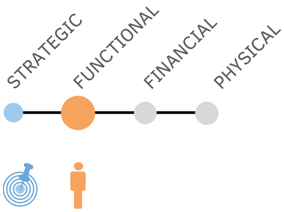
Impression - Workplace analytics dashboard

Foreseen developments

-

Profile

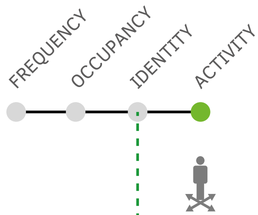
Why: Objectives



- Supporting user activities
- Increasing user satisfaction
- Stimulating innovation
- Stimulating collaboration
- Supporting culture
- Improving quality of place

First priority is supporting our employees.

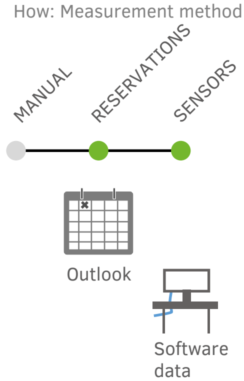
What: Measurement



Customers own their Office 365 data and decide how to apply insights generated by Workplace Analytics to solve tough business challenges. Workplace Analytics only leverages metadata that is aggregated and de-identified.

In the tool space use data is not measured, it can be added to the analysis though. What is measured is activity

How: Measurement method

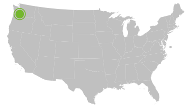


Data from Outlook and Microsoft exchange, showing how people collaborate, how much meetings they schedule, when they are in the office, if they work during their meetings, …

MIC-2 — Microsoft — Delve / Workplace Analytics

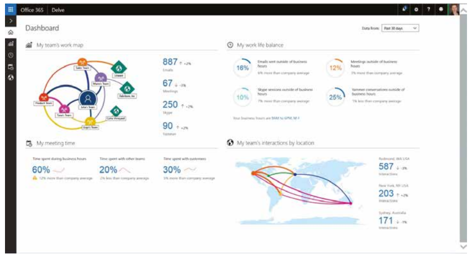
functionalities
Improving employee productivity

space types
Offices, meeting rooms



User information (employees)

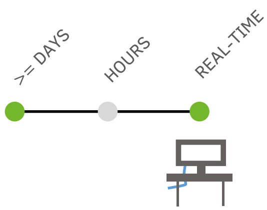
Delve, MyAnalytics / MyAnalytics for teams. Provides insights into data on an individual and team basis in order to maximise productivity
(Mailbox data) Insights into your individual productivity/work habits, in order to help you plan your efficiency.
(Incremental data) Insights into the projects your colleagues are working on, as well as projects that are trending. - anonymous



Management information

Workplace analytics - an organisational view of the aggregated, anonymous data of productivity and how it can be improved. Just like with PowerBI the user has the possibility to generate queries and research relationships between the data.

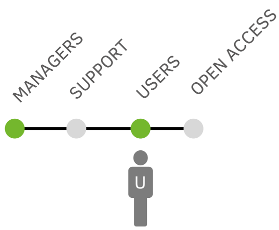
Actuality of the information



The information displayed in the dashboard on the webpage is real-time.

The data used in reporting is on a weekly basis

Access levels



Employees have access to MyAnalytics and MyAnalytics for teams.

Managers have access to Workplace analytics.

Benefits

Based on the data we did a rework of our seating arrangement - we put people who work together frequently closer together in the office. Afterwards we found that the amount of collaborations between people increased, but that the amount of time spent per collaboration decreased.

Side notes

The link with the workplace can be made for example by matching the work environment to the amount of hours spent on meetings and e-mail, the meeting spaces can be matched by adjusting the size of the room to the size associated with the highest meeting productivity, etc.

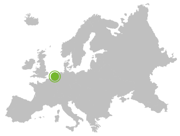
TOC

OVG OVG the Edge - Mapiq & Philips

phase
Implementation

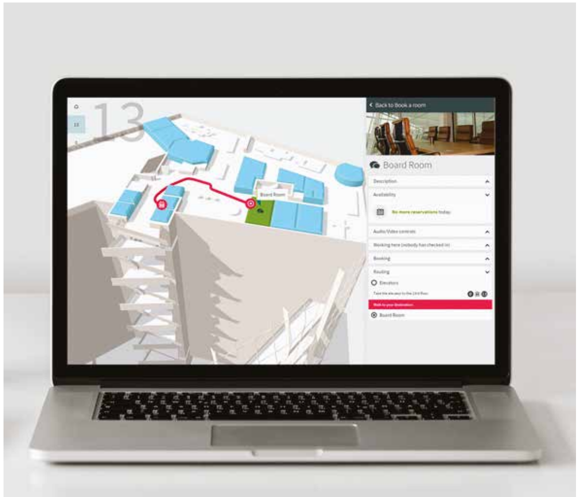
scale
40.000 m2
1 building

duration
2014-
present



Project description

The initiative for this development originated from Deloitte's desire to attract talent. The firm saw that it was moving from accountancy into consulting and that in the future it would need to attract highly educated talent. Therefore The Edge was developed as the 'office of the future'. The vision was a building in which everything is connected to the internet (IoT).



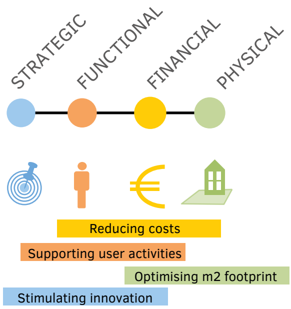
Foreseen developments

We continuously look at ways to optimise the building. For instance at the moment we are looking at the operation of our elevators with ThyssenKrupp. Lift movements are very inefficient. It turns out that if you put a sensor in and use it to control the elevator, that it is possible to reduce the energy consumption up to 30 percent and reduce the wear and tear of the elevator.

Another development is the Edge 2.0: we are currently installing iBeacons together with a new, native version of our app to improve localisation in the building.

Profile

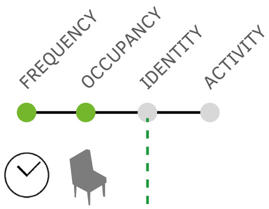
Why: Objectives



also mentioned: Reducing risks, increasing revenues, increasing user satisfaction, increasing flexibility, reducing CO2 footprint, stimulating collaboration, supporting image, supporting culture, improving quality of place

Reducing costs has priority. The way in which this is realised is via sharing workplaces.

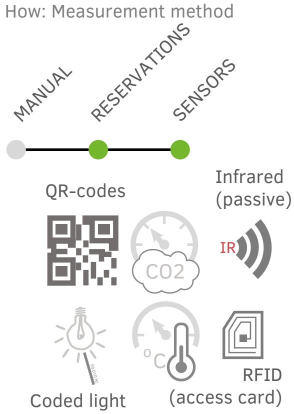
What: Measurement



Privacy is addressed by giving everyone a privacy profile page in which they can manage how their data is used for specific functions. For about 90 percent of our systems we do not register information that can be retraced to individuals.

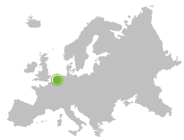
Frequency is measured in the meeting rooms. In the workplaces occupancy per zone is measured via workplace checkin via QR and coded light.

How: Measurement method



PIR sensors register activity in a space to determine presence. Coded light works by setting every LED panel to emit light in a slightly different frequency, which enables your smartphone to identify under which LED panel you are located. The building also has access card data from access gates at the entrance.

OVG OVG the Edge - Mapiq & Philips

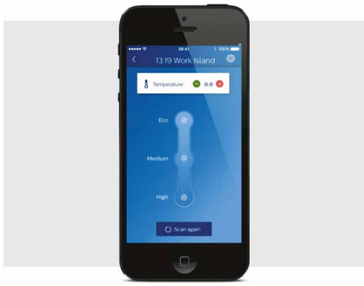


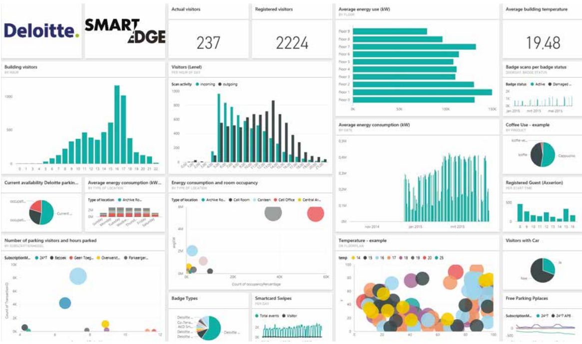
functionalities
Optimising workplace comfort, find a workplace, room booking, wayfinding, monitoring space use

space types
Offices, meeting rooms (whole building)

User information (employees)

The user can use an app to check in at a workplace via QR codes or coded light. The user can use controls for rooms and workplaces to change temperature and light. Also they can see floorplans on which he/she can navigate to a workplace or meeting room.



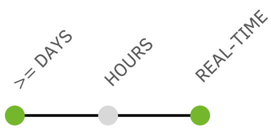


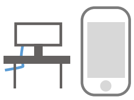
Management information

The manager can access a PowerBI dashboard in which he/she can design elements based on the available data. The dashboard on the left is available to everyone working in the Edge and shows information about the amount of visitors, the use of parking facilities, energy consumption and temperature in the building.

Also there are specific dashboards and reports for building management data and space use of each organisation in the building.

Actuality of the information

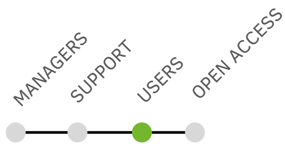




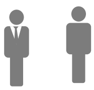
The information in the dashboard (webpage) and user app is displayed real-time

The data used in reporting goes from real-time to as far back as possible.

Access levels



Employees have access to the user app and a dashboard showing building information



Specific individuals (5-6) have access to specific dashboards and reports for building management.

Benefits

There were no objectives defined prior to the project. We do measure some metrics though. For instance Deloitte knows that since the delivery of the building the amount of job applications has increased significantly. Also, 65% of those applicants state in their applications that they want to work in the Edge! Also, further proof that suggest that smart buildings work is that at the start Deloitte had 1800 employees using 1000 desks, and now they have around 3400 people working in the Edge - and only 100 desks have been added.

Side notes

Localisation for the colleague finder turned out to be very difficult technically. QR codes do not work well enough, because people do not always use them: you can occupy a workplace without scanning the QR code. iBeacons with a user app is the best solution.

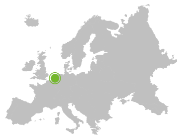
TOC

NLG-1 | Dutch government | Plekchecker

phase: Implementation

scale: 80.000 m2, 1 building

duration: July 2017-present

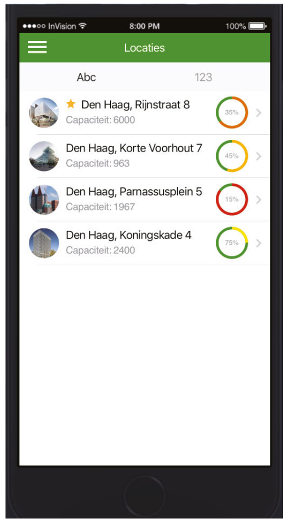


Project description

The initiative was started because of the implementation of the I-strategy of the government, the governmental accommodation system and the furbishing of the office at the Rijnstraat. In that building the norm will be 0,7 workplace per 1 employee. The development of the smart tool was started to help users find a workplace. First this was done within the organisation, but later an external party was added. The Plekchecker is foremost developed by the government and partly by an external party.

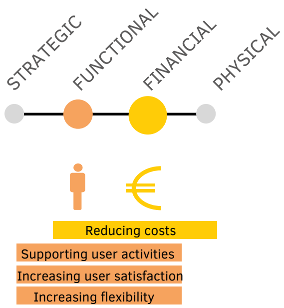
Foreseen developments

The foreseen developments are (1) complying with all our requirements; (2) expanding to more buildings; (3) determining if investment is needed in current and future wishes with regard to the smart tool.



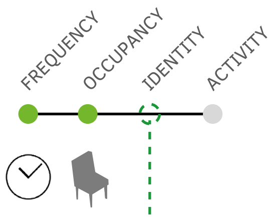
Profile

Why: Objectives



Financial objectives have priority, they are achieved by reducing the amount of offices and using the existing space more effectively.

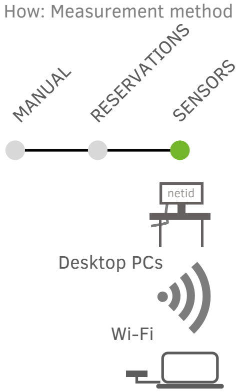
What: Measurement



No personal data is used or saved. Only once is the e-mail address used to validate if the user is a civil servant.

Via the Wi-Fi network an indication is given of the occupancy on floor-level. On zone level the data of port replicators and desktop PCs is used.

How: Measurement method



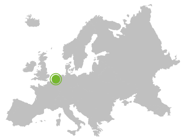
Wi-Fi measures the amount of devices inside a building that tries to connect with the network. Via desktop PCs and port replicators/-docking stations the use of these devices can be detected, and thereby the frequency.

TOC

NLG-1 Dutch government Plekchecker

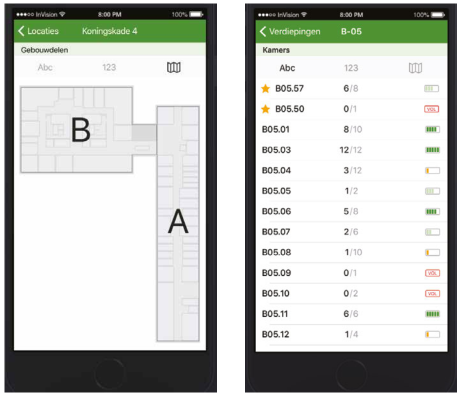
functionalities
Find a workplace, monitoring space use

space types
Whole building



User information (employees)

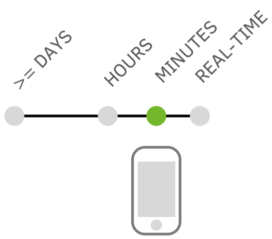
The user sees a list with buildings, in which it it possible to click further to lists of floors and defined zones per floor. Per floor an indication of the occupancy is visible. There are also floor plans available, but they are still separated from the real-time data.



Management information

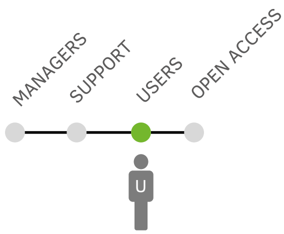
The occupancy reports based on the collected Plekchecker data has not been developed yet. At the moment there are talks with facility services providers about the form of these reports. This functionality will then be developed in a separate development process.

Actuality of the information



The information is updated every few minutes (ca. 3 minutes) in the Plekchecker.

Access levels



Employees that are serviced by the government's ICT shared service centre.

At the moment we are exploring how to shape different roles in the tool.

Benefits

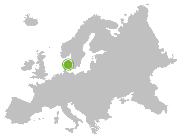
In the business case a calculation has been made of the time that a civil servant spends on finding a workplace to indicate the potential savings. It is not possible to report on that yet - in the future the savings will be in the adjustment of spaces with low utilisation or in adjusting the way we work (e.g. spreading meetings over the week).

Side notes

Wi-Fi makes it possible to show the occupancy within 5-10 meters. With algorithms this information is displayed in zones, with a reliability of 90 percent. That determines the size of the zone, which in some cases can become too large to offer the users the level of detail they desire.

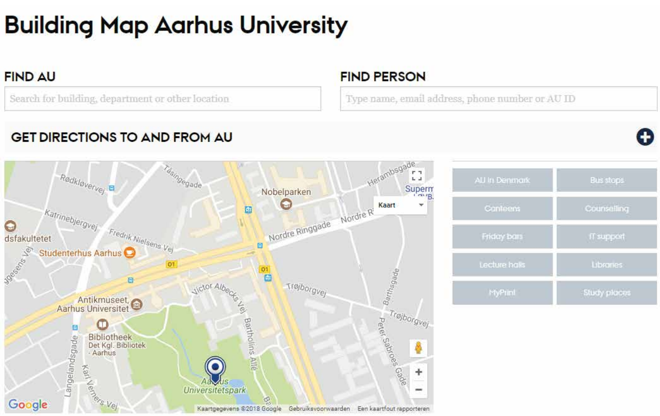
AU — Aarhus University — design brief

phase: Design brief — scale: 16 buildings, 40.000 m2 — duration: t.b.d.



Project description

The project was started to make it easier for visitors to navigate on campus. In the conceptual stages it was also identified that monitoring study places could be interesting: we believe that there is a great potential in giving the students a real time overview of available study spaces on campus in order to reduce the wasted time looking for places to study. Using iBeacons looks like the best solution, because the study places at AU are scattered across the campus in many different buildings. Currently the project is only aimed at AU's Business and Social Sciences School (AU BSS).

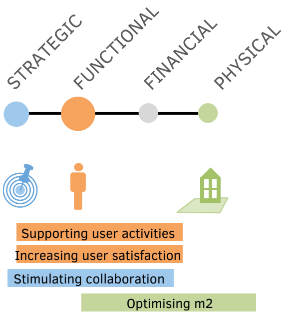


Foreseen developments

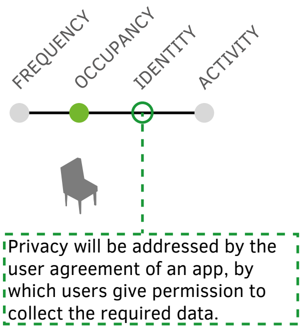
In further stages of the project the use of Location-based services (LBS) are foreseen. In a '2.0' version push services for activities on campus could be included, and in a '3.0 or 4.0' version push services based on the needs of the users

Profile

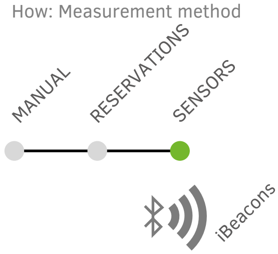
Why: Objectives



What: Measurement



How: Measurement method



Functional goals have priority.

The amount of devices connected via Bluetooth to an iBeacon.

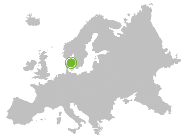
iBeacons measure the amount of occupants by letting devices connect to the iBeacon via Bluetooth. Bluetooth is switched on via an app

AU

Aarhus University design brief

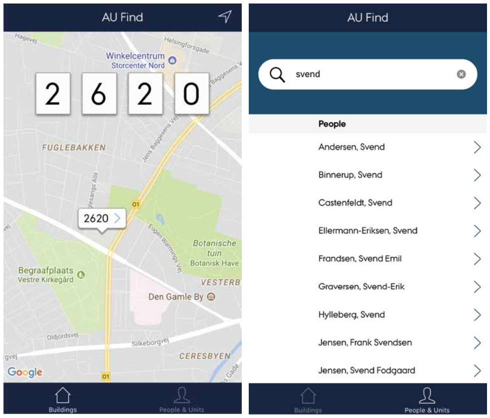
functionalities
Wayfinding,
(Find a study place)

space types
Whole buildings
(study places)



User information

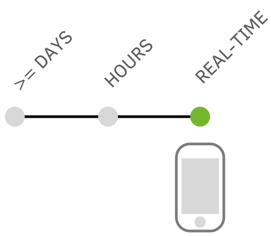
The user will be able to review his/her own location and his/her new location to find their way on the campus. Real-time availability will be given on a room level or floor level to search for available spaces.



Management information

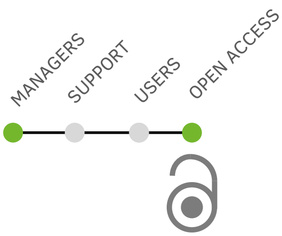
Aside from the information on users, managers will be able to retrieve information over a longer period on a specific building or space type. This gives the opportunity to provide the preferred spaces in the future by knowing what needs to be enlarged or what is not used. It helps to make space use more effective.

Actuality of the information



The information on available study places will be updated in near real time.

Access levels



Everyone can access the wayfinding application via a smartphone app.

Campus management has access to the reporting tool.

Benefits

The main objective is user satisfaction. So far this has not been translated into any metrics. By measuring the usage, different spaces can be assigned to the users that need it. This will result in more effective space use.

Side notes

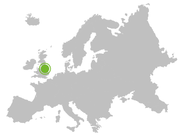
The images on this template show the current version of the smart tool. The web-based version offers additional information on the position of different facilities on campus.

CAM — Cambridge University — Spacefinder

phase: Implementation

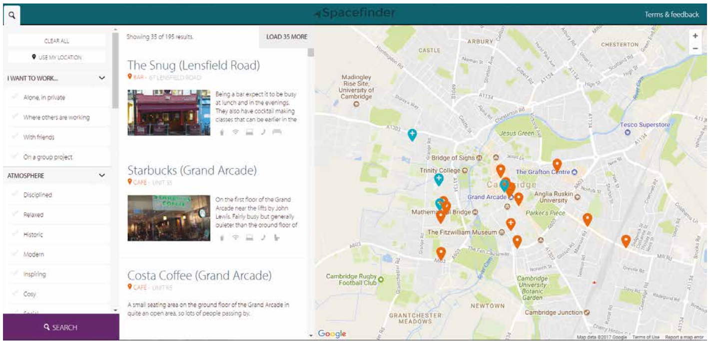
scale: 206 spaces

duration: 2015 - present



Project description

The problem at Cambridge University is that the University has an abundance of libraries across the city of Cambridge, that each have their own study facilities. There are a lot of facilities and a lot of different ones, and the problem for students is to find the facilities that suit their needs. In previous research the University Library identified that there were different needs among students. Spacefinder was developed as a solution to match these differing needs and differing facilities.



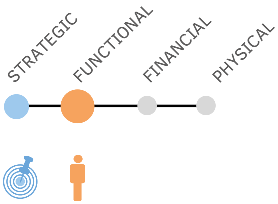
User interface via https://spacefinder.lib.cam.ac.uk/

Foreseen developments

Spacefinder was adapted in June 2016 where a number of features were added in collaboration with the Student Union, such as gender-neutral toilets, disability access etc. The most important thing for a next step would be to be able to filter on opening hours (e.g. open on Sundays and during evenings).

Profile

Why: Objectives



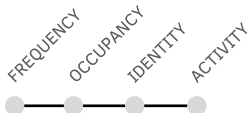
Supporting user activities

Increasing user satisfaction

Increasing flexibility

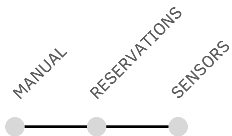
Stimulating collaboration

What: Measurement



Not applicable - no space use measurement.

How: Measurement method



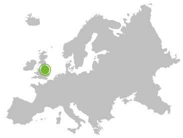
Not applicable - no space use measurement.

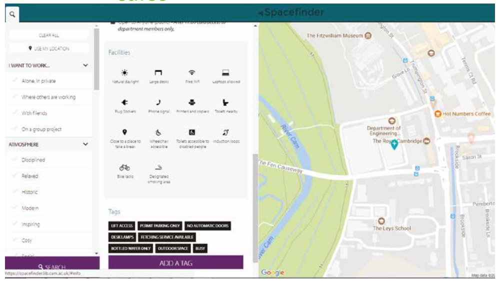
The tool is often used when people begin their studies at Cambridge and are looking for a suitable workspace. It also experiences high levels of traffic during other peak periods such as exam time when students are looking for a change of scenery, or a new place to study. Repeat visits are relatively low as students and other users seem to use the service to find their ideal space, rather than revisiting to vary their workspace.

CAM — Cambridge University — Spacefinder

functionalities
Find a workplace

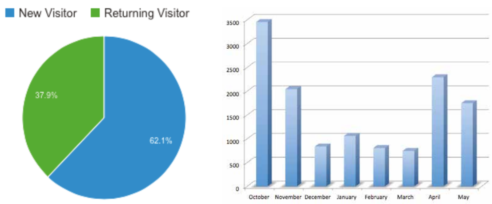
space types
Study places, project rooms, cafes





User information

The user accesses an interace that shows a map of Cambridge with all the possible study locations on it, as well as a column with search options on it. As the user applies different preferences such as type of lighting, atmosphere etc. the amount of locations lighting up on the map are adjusted to indicate which study spaces comply, thereby helping the student to find a suitable study place. For each study space a description, photo, list of facilities and tags are given.



Examples of usage statistics, obtained via Spacefinder report

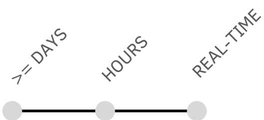
Management information

The types of information available from the back end are shown in the report as well, which include data on the amount of visits per month, unique visitors vs. recurring visitors and the device used to access Spacefinder.

Benefits

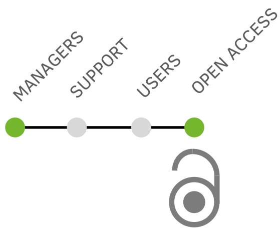
The objective of the project was to cater to students' needs in the best way possible. Evaluating whether this was the case was done mainly through qualitative data (ethnographic) - being conversations with students, and through the continuous involvement of users throughout the design and development process.

Actuality of the information



Not applicable - no space use measurement

Access levels



Everyone can access the webpage.

The back-end of Spacefinder is accessible to the programme manager, which can be used to generate various reports

Side notes

Through the analytics it was discovered that most users were using Spacefinder via a desktop or laptop rather than a mobile device (smartphone or tablet) and that there were more unique visitors than recurring visitors. This suggested that people usually use Spacefinder to deliberately plan where to study and that once they find a place that suits their needs, they don't often need to return to Spacefinder again. This was corroborated by qualitative data gathered during interviews with students.

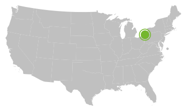
Cambridge used a human centred design process. This process involves designing a prototype version of a product, testing it on users, and then iterating on the prototype based on user behaviours and approaches, as well as feedback received. This process continues until a product is arrived at which fulfils the majority, but crucially not all, of people's needs. The goal is a 'minimum viable product' (MVP for short): a product that has enough features gathered via research to ensure its deployment and use, ahead of continued development and updates.

CMU-1 — Carnegie Mellon University — Sentinel

phase: Research

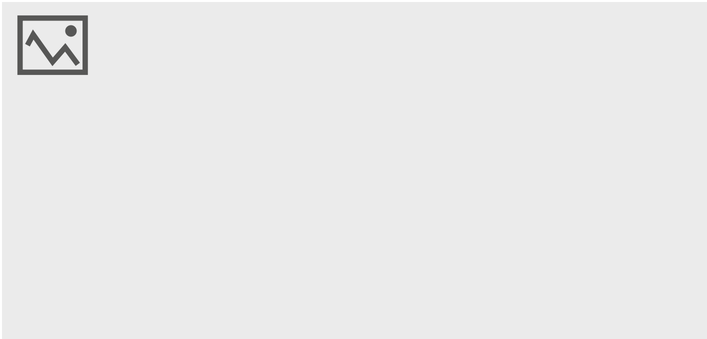
scale: 13.470 m2, 1 building

duration: 2013



Project description

In general, commercial buildings are a large contributor to primary energy consumption (19%), of which HVAC systems contribute 39,6%. HVAC systems commonly use static schedules to condition modern buildings, which leads to considerable waste of energy. Sentinel was started to research the use of Wi-Fi to collect occupancy information, because (1) existing methods require new infrastructure and thus high investment costs and (2) existing solutions with Wi-Fi encounter limitations.

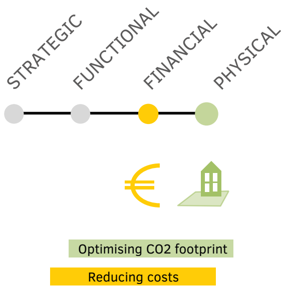


Foreseen developments

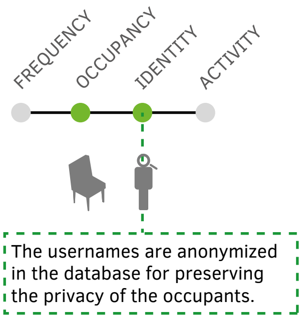
To explore the use of occupancy-based HVAC control in shared spaces, to further explore infrastructure based localisation techniques

Profile

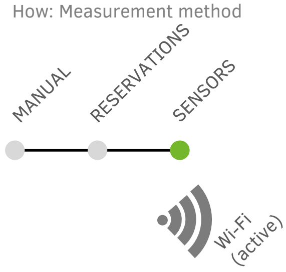
Why: Objectives



What: Measurement



How: Measurement method



Reducing CO2 emissions is the main objective. Reducing costs is a secondary objective and a reason to research the use of Wi-Fi instead of other methods.

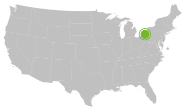
For individual offices Sentinel measures if the user of the office is present in the office. Therefore Sentinel requires data on which office belongs to whom, therefore it also requires user data (identity)

Wi-Fi is used to map a specific user to a specific location. Each access point covers a number of zones. If a user is in the same zone as his/her office, he occupies his office according to Sentinel. Access, Authentication and Accounting logs are used.

CMU-1 Carnegie Mellon University Sentinel

functionalities
Linking systems

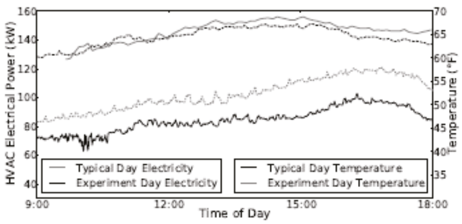
space types
Individual offices



User information (system)

Not applicable - the users do not receive any information in this case.

The system receives information about the use of the offices in the building by their occupants. If the office's user is in the neighbourhood of his/her office the system classifies the room as 'occupied' and the HVAC system conditions the space.



Management information (research output)

Data is provided on the occupancy levels of the offices in the building and the power consumption levels of the HVAC system, enabling the comparison of the two. Furthermore the amount of energy savings can be calculated by comparing days with the same temperature and their energy consumption with Sentinel and without Sentinel.

The diagram to the left shows the typical day temperature and electricity use versus the experiment day with Sentinel.

Actuality of the information

>= DAYS HOURS REAL-TIME

The information used by the system is real-time.

Access levels

MANAGERS SUPPORT USERS OPEN ACCESS

not applicable.

Benefits

Energy savings; the achieved energy savings during the project were 17,8%.

The data used in the analysis goes from real-time to as far back as possible.

Side notes

The researchers find that it is possible to infer occupancy of individual offices based on coarse-grained Wi-Fi data (active over passive)

A drawback of using Wi-Fi data in this system is that it assumes that a device is continuously connected to the network. This is not always the case because some smartphones disconnect from networks in sleep mode. In order to address this issue the researchers have asked users to automatically refresh their e-mail every 15 minutes in order to avoid disconnecting.

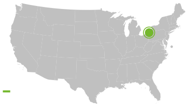
The measured energy savings of 17,8% could be higher if the Wi-Fi data is more fine-grained, or if the HVAC system can control smaller zones

CMU-2 Carnegie Mellon University GENIE

phase
Research

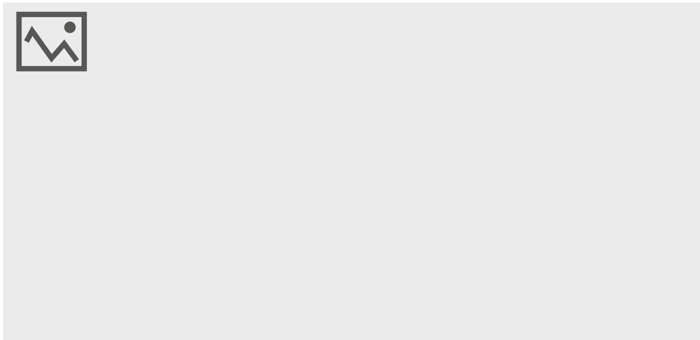
scale
1 building
14.000 m2

duration
Oct. 2013-
Jun. 2015



Project description

The initiative for this tool was taken to provide users with more information about room temperature to enlarge their wellbeing. To bring this information, software thermostats were user rather than modern thermostats, as software thermostats cost only a fraction of the price of modern thermostats and there was not much research about the effectiveness of these software thermostats in real settings.



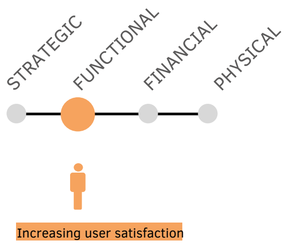
images not yet available

Foreseen developments

More research is needed to verify the findings across different thermostat types, cultures and climate zones

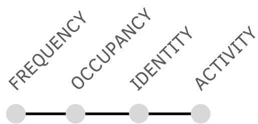
Profile

Why: Objectives



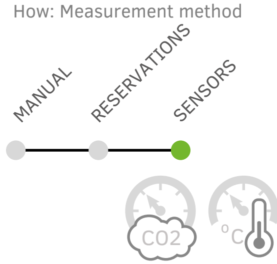
Our goal is to provide transparent access to HVAC information to avoid user misconceptions. Occupants should be able to control the temperature as needed and send feedback about their comfort.

What: Measurement



Not applicable; no occupancy measurement used.

How: Measurement method

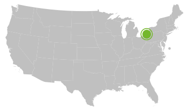


The thermostat measures CO2 and temperature per zone (a meeting room or a few small offices). This data is collected via the BMS and displayed in an app.

CMU-2 — Carnegie Mellon University — GENIE

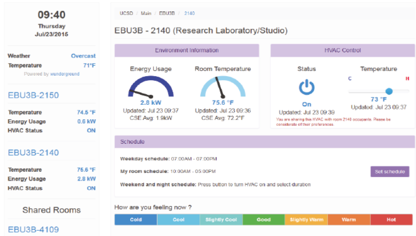
functionalities
Optimising workplace comfort

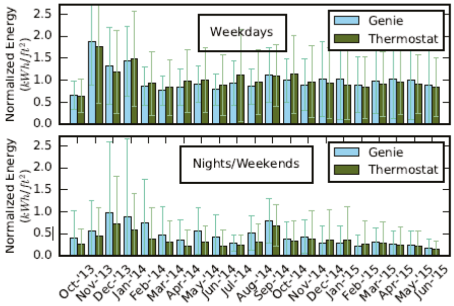
space types
Small offices



User information

The tool gives personalized energy feedback to its users and a possibility to give feedback on the comfort of the room by scoring on a 7 point scale and report in free tekst.



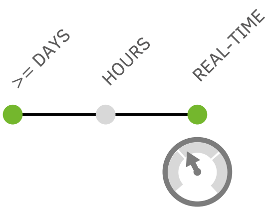


Comparison of energy consumption: GENIE vs. regular thermostats.

Management information

The campus manager is able to compare the adaptions made by users on both the genie tool and the traditional thermostat. The user satisfaction is measured and textual feedback is send to the campus manager. Besides that, also insights are given into energy usage.

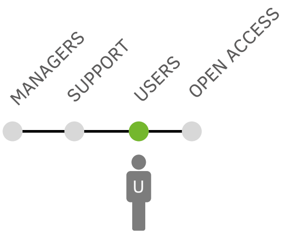
Actuality of the information



The tool shows measurements like room temperature and energy usage. Depending on the moment it refreshes, it shows the actual temperature and energy usage.

The data used in reporting goes from real-time to as far back as possible.

Access levels



When someone has specific access to a room they can request the data for this room. These requests are processed manually.

Benefits

Improved occupant experience and energy savings; the results report an improved occupant experience and no significant impact on HVAC energy savings

Side notes

Giving users the ability to adapt the temperature enlarges their comfort and lowers complaints. Lowering complaints results in less work for the Facility services. The FM department would like to deploy Genie in all university buildings. It is not indicated if a follow-up to the project is foreseen.

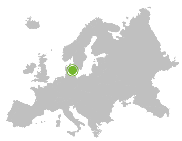
TOC

DTU — Technical University of Denmark — Smart Library

phase: Living Lab

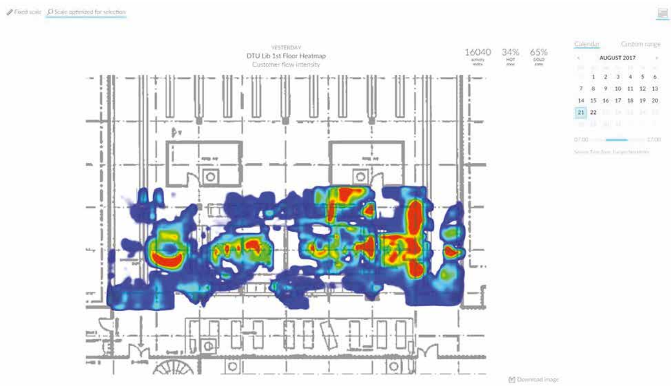
scale: 35.000 m2, 1 building

duration: Expected Oct. 2017



Project description

The initiative was started because of the ageing Library building. The building was built 50 years ago for books and not for people. Now it has almost 2500 visitors per day and is open 24/7. Because of this there are issues with the indoor climate and lighting. We also wanted to improve our services for students. Therefore we chose a solution that helps students to find a place that fits their needs and in which they are able to adjust the lighting. The building is now being renovated and the Smart Library is part of the renovation project.



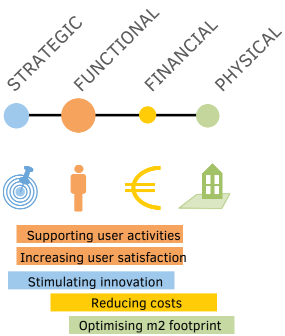
Heatmap of the Library, based on Wi-Fi measurements

Foreseen developments

Smart Library is a pilot for the Smart Campus. We want to experiment here in order to find out what works and apply that to the whole DTU campus. We hope that in the future research projects will take place in our Living Lab and that these projects add more sensors and data to the Smart Library.

Profile

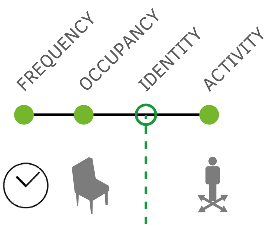
Why: Objectives



Also mentioned: stimulating collaboration, supporting image, supporting culture, improving quality of place, increasing flexibility, reducing CO2 footprint.

The comfort of our users has the highest priority for the Library. Comfort has a huge impact on the ability to learn something, so personal comfort is the main goal. Besides that it is working with data, making data open.

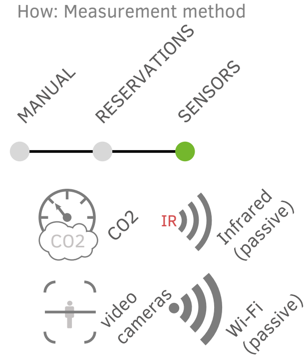
What: Measurement



First we want to make sure all the other aspects are in place and that we comply to privacy laws. Later on we want to offer users to share their identity for additional services such as finding their friends.

Frequency and occupancy are measured by counting the amount of people in a zone. Movement is measured by registering how the people move between zones.

How: Measurement method



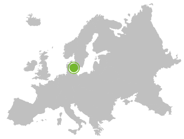
The Sensortags are placed underneath each chair and they measure movement, temperature, humidity etc.

The cameras in place create a panorama as they each measure the amount of users in a predefined square and communicate with each other to see movements across squares.

DTU

Technical University of Denmark

Smart Library



functionalities

Find a workplace,
Optimising workplace comfort,
Monitoring space use

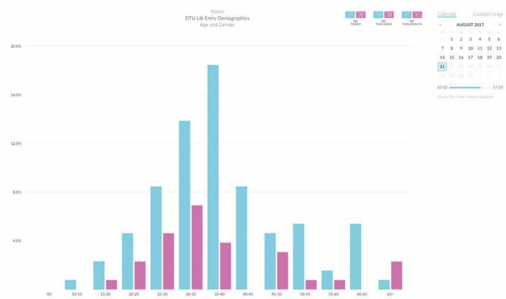
space types

Study places,
project rooms

User information (employees)

The users will be able to access a webpage that gives them information about the available seats in the Library, as well as the temperature, humidity and lighting in different zones. They will also be able to modify the lighting settings (LED lights)

In a next phase the Library will release an app which will also include features such as wayfinding and room booking.

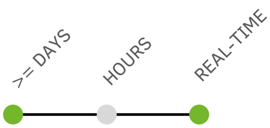


Management information

We will be able to see what kind of chairs to our users like, what services they use, what the preferred temperature and lighting settings are. Also, what are the frequency and occupancy rates of the library. In the future we hope via iBeacons to see how much people attend events and to get feedback from them via the iBeacons.

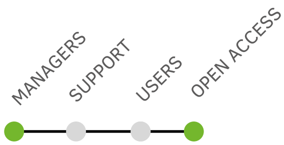
The visual on the left is an example, showing the age and gender of the visitors of the Library.

Actuality of the information



The information displayed on the webpage is real-time.

Access levels



Everyone can access the webpage and the open data.

Benefits

Unknown

The data used in reporting goes from real-time to as far back as possible.

The reporting will be internal in the initial stages.

Side notes

There are plenty of things that we are trying out in the near future. Because we are not done yet we're not sure what is going to work. We're trying out different types of cameras.

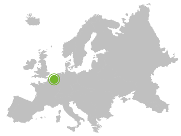
The Sensetag seems to be a very good solution to make something on your own very quickly.

KL — University of Leuven — Blokken in Leuven

phase: Implementation

scale: 28.785 m2, 10 buildings

duration: 2013 - present

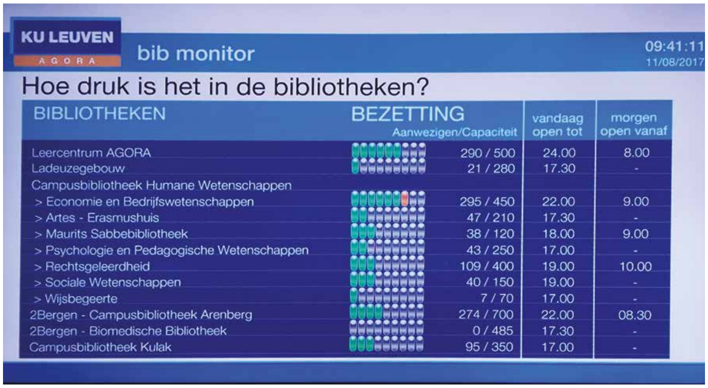


Project description

The initiative of this smart tool was taken as one of the measures to enable the increasing demand for social learning on campus. Blokken in Leuven was introduced to give students insight into the distribution of students across campus. The data and infrastructure was already in place; access control systems had been in the Library for quite a while and the data was already being used to determine the # of study places and opening hours of Library locations.

Foreseen developments

It is a wish to make a distinction between the occupancy of study places and project rooms, but that is still in an exploratory phase. Also the data of the access control is being used to do (anonymised) research on the relation between the time that a student studies in the library and his/her study results - Learning Analytics.



KU LEUVEN AGORA bib monitor 09:41:11 11/08/2017

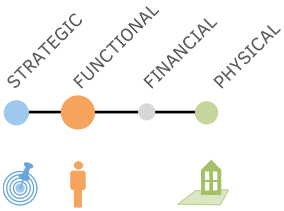
Hoe druk is het in de bibliotheken?

BIBLIOTHEKEN	BEZETTING Aanwezigen/Capaciteit	vandaag open tot	morgen open vanaf
Leercentrum AGORA	290 / 500	24.00	8.00
Ladeuzegebouw	21 / 280	17.30	-
Campusbibliotheek Humane Wetenschappen			
> Economie en Bedrijfswetenschappen	295 / 450	22.00	9.00
> Artes - Erasmushuis	47 / 210	17.30	-
> Maurits Sabbebibliotheek	38 / 120	18.00	9.00
> Psychologie en Pedagogische Wetenschappen	43 / 250	17.00	-
> Rechtsgeleerdheid	109 / 400	19.00	10.00
> Sociale Wetenschappen	40 / 150	19.00	-
> Wijsbegeerte	7 / 70	17.00	-
2Bergen - Campusbibliotheek Arenberg	274 / 700	22.00	08.30
2Bergen - Biomedische Bibliotheek	0 / 485	17.30	-
Campusbibliotheek Kulak	95 / 350	17.00	-

User interface on digital signage in the Library

Profile

Why: Objectives

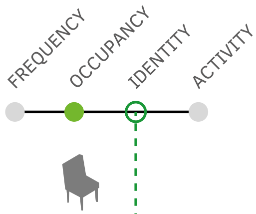


Supporting user activities
Increasing user satisfaction
Stimulating collaboration
Supporting image
Optimising m2 footprint

Also mentioned: increasing flexibility, supporting culture, improving quality of place

Supporting users has the highest priority; this is achieved by providing a supply that fits the needs of our users

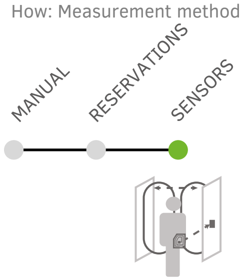
What: Measurement



The data is anonymised, but perhaps the method which is currently used needs to be revised to comply with new EU regulations

The amount of registered users present at a location is measured, resulting in an occupancy number per library.

How: Measurement method



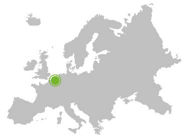
Access control (campus card)

Access to each Library is granted via access control systems. These systems allow users entry based on the privileges on their campus card. Each user is counted individually, therefore the users in the building at a given time can be monitored.

KL — University of Leuven — Blokken in Leuven

functionalities
Find a workplace,
Monitor space use

space types
Study places,
project rooms



User information (open access)

The user can see an overview of the Library locations on campus and the occupancy of each of these locations (building level). The interface also shows the opening hours and provides links to the website of each library, the location in Google Maps and the Facebook page. The information is also displayed on other media, such as the student app Quivr.

Home › Toegang en gebruik › Studeren in de bibliotheek › Blokken in Leuven

BLOKKEN IN LEUVEN

Locatie	Openingstijden	Bezetting
2Bergen - Biomedische Bibliotheek	8.30 - 17.30	30 / 450
2Bergen - Campusbibliotheek Arenberg	08.30 - 22.00	197 / 700
Alma 2	gesloten	0 / 300
Leercentrum AGORA	8.00 - 24.00	152 / 500
Leercentrum FEB Leuven	9.00 - 22.00	138 / 450

De volgende studieplaatsen worden aangeboden in bibliotheken, waar collectiegebruikers voorrang hebben op blokkende studenten. De beschikbaarheid die in deze bezettingsgraadmeter wordt aangegeven is met andere woorden niet gegarandeerd.

Bezetting van de bibliotheek

Maand	All
Week	All
Bibliotheek	AGORA

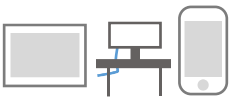
Sum of Bezet	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2/01/2017	23	291	316	339	300	179	322	372	355	360	293	167	259	283	216	106	-3
3/01/2017	29	378	409	428	342	176	370	436	424	420	310	183	297	340	232	108	-13
4/01/2017	0	371	387	410	329	204	371	421	426	420	295	223	322	362	269	122	0
5/01/2017	26	376	397	422	351	208	365	437	431	424	312	207	334	342	267	126	-8

Management informatio

A report of the informatics department. Analytics: amount of unique visitors per year/month, amount of visitors per year/month, occupancy per hour.

Actuality of the information

>= DAYS — HOURS — MINUTES — REAL-TIME



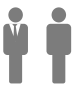
The information displayed on digital signage, the app and the webpage has a refresh rate of a few minutes.

The data used in reporting is aggregated data over a monthly or yearly period.

Access levels

MANAGERS — SUPPORT — USERS — OPEN ACCESS

Everyone can access the webpage.



Reports are accessible to the persons responsible for each Library desk and to the coordinator. Libraries can specify the reports to their own locations.

Benefits

Prior to the implementation the objective was to spread the business of the inner city locations to the Heverlee campus (Arenberg and Gasthuisberg). The occupancy rates per location are compared - to each other and to the previous periods - to see if this achieved.

Side notes

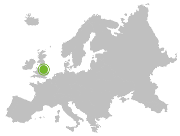
The interface of Blokken in Leuven is not a goal in itself, but providing the data that is displayed there is. What is important is that the data can be communicated to different systems and applications that have a use for the data.

OSBS — Oxford Said Business School — design brief

phase
Future implementation

scale
1 building
840 m2

duration
expected
2017



Project description

The development of the solution was initiated because the university wants to support the users of the coworking space to find people based on their field of interest. The idea of the Foundry is that users across the whole university can apply and start using the building, but there has to be some way for them to connect to each other. This solution (self-developed) will help them to do that.

Foreseen developments

It would be interesting to see if the data can be correlated to data from the success of start-ups, i.e. if amount of visits and stay duration influence success. This is not foreseen, though.

Profile

Why: Objectives

STRATEGIC — FUNCTIONAL — FINANCIAL — PHYSICAL

Supporting user activities
Stimulating collaboration
Stimulating innovation

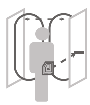
What: Measurement

FREQUENCY — OCCUPANCY — IDENTITY — ACTIVITY

Privacy will be addressed by allowing people to enable and disable the service.

How: Measurement method

MANUAL — RESERVATIONS — SENSORS



Supporting users has the highest priority, this tool helps them by supporting them to find meaningful collaborations

The people that are in the building at any given time.

When a user uses the access gate, the gate collects data of the user that has entered the building (who is it, from which faculty and with which field of interest.). The access gates also record departure.

OSBS

Oxford Said Business School

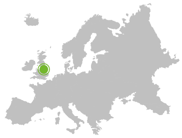
design brief

functionalities

People finding

space types

Whole buildings (offices, informal places)



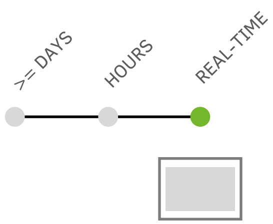
User information

There will be a display in the building on which users can see profiles of who is currently present in the building and what their field of interest is.

Management information

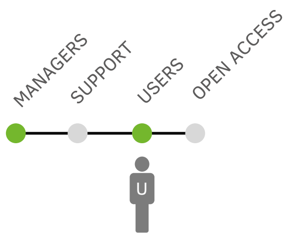
Management will get information on the amount of visits and stay duration of individuals.

Actuality of the information



User information is real-time, management information unknown

Access levels



The user information can only be accessed on site, locally.

The reporting functions can be accessed by the department director only.

Benefits

The project is being financed by donations so there is not much pressure on monitoring the use. Probably we will report on the amount of start-ups that translate into businesses through the Oxford foundry as a metric for success.

Side notes

We're still working out if we want the user information loaded into the access card data - which would make the link to the display easy - or if the access card data is linked to a database which would interface with the display. We know that the first option is feasible, the access card system supplier can provide enough fields in the system to satisfy our current demands.

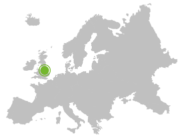
TOC

OXF Oxford University design brief

phase
Design brief

scale
1 building
? m2

duration
t.b.d.



Project description

The problem of the university faces is that the amount of development locations in Oxford is finite and so the university needs to decide (1) if demands for new buildings are necessary and (2) if they are necessary, what the amount of realised space should be.

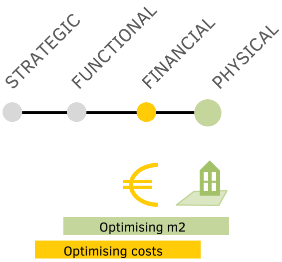
Currently Oxford is looking at a solution that can be easily installed and moved in order to record space utilisation for a finite period at a location in order to make these decisions. In addition, the size of the estate has being growing steadily and is one of the largest financial impacts to the University, there is an increased emphasis on using utilisation methods to combat unnecessary growth.

Foreseen developments

We are still developing a briefing note on new sensor technology, which will need to be signed off by the University before we can start using it.

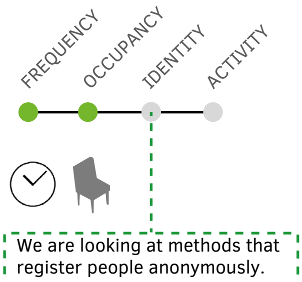
Profile

Why: Objectives



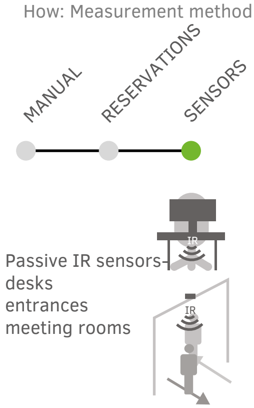
The primary objective is to optimise the use of space on campus as this is becoming more and more a scarce commodity.

What: Measurement



In teaching space the amount of in- and outgoing people are measured. In offices the usage of each desk is measured. In meeting rooms the use (yes/no) of the room is measured.

How: Measurement method



In teaching space the infrared beam registers when a user passes through it. For desks and meeting rooms similar concepts apply

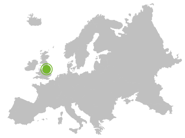
OXF

Oxford University

design brief

functionalities
Monitoring space use

space types
Education spaces, offices, meeting rooms, (potentially research space)



User information

Not known if users receive information.

Management information

The management information is space utilisation rates for the teaching spaces in the building, the individual office spaces and meeting rooms.

Actuality of the information

>= DAYS · HOURS · REAL-TIME

Reporting based on real-time information is done over an entire period (probably two weeks or a month)

Access levels

MANAGERS · SUPPORT · USERS · OPEN ACCESS

Managers will have access to the utilisation reports that are used to determine what intervention is appropriate.

Benefits

Unknown.

Side notes

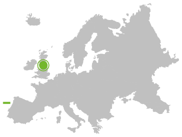
The energy department has a different interest in selecting sensors. We want a solution that is flexible and movable, they want to use another type of sensor (not known which) to link to energy systems in order to reduce energy use.

SHU-1 Sheffield Hallam University Clocks (Lone Rooftop)

phase
pilot

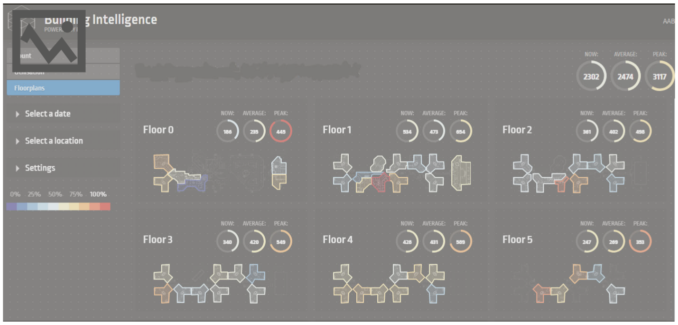
scale
? m2
5 buildings

duration
nov. 2017 - present



Project description

The initiative was taken because of two reasons. The primary reason is that the academics at the university tend to overbook space. The university shares space across departments and has a high scheduled frequency rate: 70%, which means that there is pressure to use the scarce amount of space efficiently. We are looking at ways to penalise when bookings are not used. The second reason is the Estates masterplan, to inform their development projects as they progress. Lone Rooftop was selected to deliver concrete data to support this.



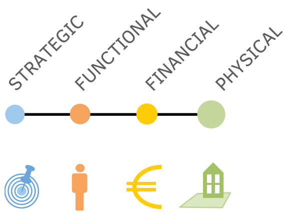
Images not yet available; image from another case with Lone Rooftop (ABN AMRO)

Foreseen developments

To expand the use of Lone Rooftop to our whole portfolio (58 buildings) and possibly to look at other modules such as PIE.

Profile

Why: Objectives



Reducing m2 footprint

Reducing costs

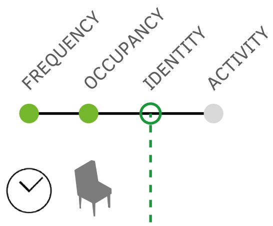
Increasing flexibility

Stimulating innovation

Also mentioned: reducing risks, increasing revenues, supporting users, increasing user satisfaction, supporting culture, supporting image, improving quality of place, stimulating collaboration

Definitely optimising m2. This is achieved by confirming no-shows and sharing the data with faculties, and planning with them how to improve next year's timetable.

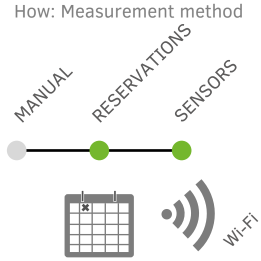
What: Measurement



Privacy is addressed by working together with a compliance officer - at the moment looking at the GDPR.

An indication of the occupancy is given for a predetermined zone. The size of this zone is aligned to the accuracy of the measurement.

How: Measurement method

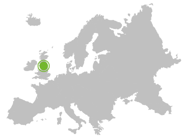


The amount of people is measured. First, the devices are counted, both actively via connections and passively via connection attempts, on a certain time in a certain place. This measurement is processed by an algorithm that pairs devices that belong to one person.

SHU-1 | Sheffield Hallam University | Clocks (Lone Rooftop)

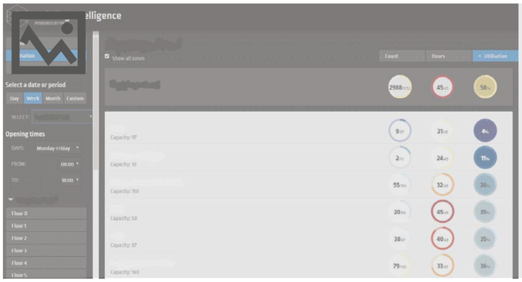
functionalities
Monitoring space use

space types
Education spaces



User information

Users do not receive any information from the dashboard. Based on the results reported in Clocks, workshops are scheduled with departments in order to improve next year's schedule.



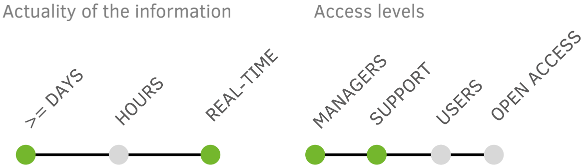
Images not yet available; image from another case with Lone Rooftop (ABN AMRO)

Management information

The management information is the Clocks module, which compares the scheduled use and actual use for each course. Per module a figure is shown for the amount of no-shows, amount of empty hours and amount of empty seats.

Actuality of the information

Access levels

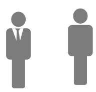


Benefits

to be filled in...

The information displayed in Clocks is near-real time.

The data used in reporting goes from real-time to as far back as possible.



The dashboard and reporting functions are available to the space resource manager and the management information officer.

Side notes

When piloting/implementing Wi-Fi, a lot of attention needs to be given to details - for example the location of the access points, linking Syllabus to Lone Rooftop. Also the start of the pilot was delayed because Cisco's MSE went down, which was something that we didn't anticipate.

The reporting function in Clocks surprised us - I would prefer having a view per classroom instead of per module.

TUD-1 TU Delft Mapiq - Blinq Systems

phase
Implementation

scale
26.000 m2
2 buildings

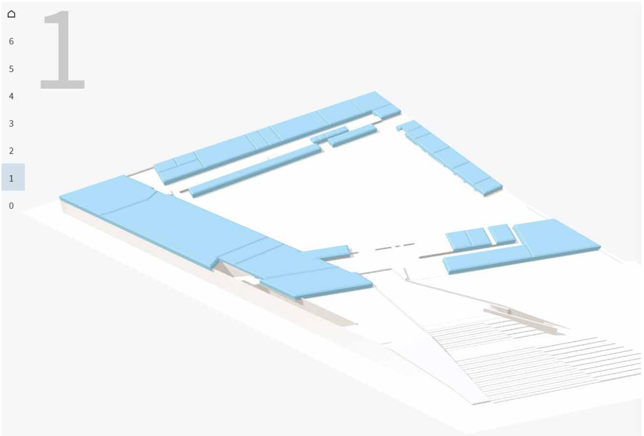
duration
2014-present

Project description

Mapiq is a product that has been developed by two TU Delft alumni. The Library has decided to implement it because of their service concept and the services they want to offer to students. In the development of Mapiq the faculty of Industrial Engineering was done as a pilot, after which Mapiq has been kept running. Recently a number of sensors have been added in the Library to indicate actual use.

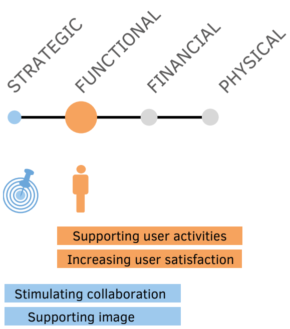
Foreseen developments

The future developments depend on how the users experience the partial availability of information from sensors in the building. We are looking at options to increase the amount of information offered to students based on already available sensors.

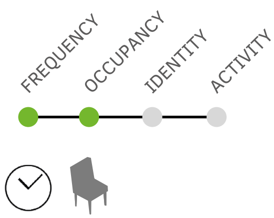


Profile

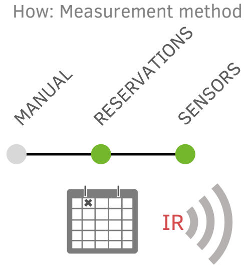
Why: Objective



What: Measurement



How: Measurement method



Mapiq supports user activities by offering information with regard to the amenities in the Library and by enabling reservation of project rooms. That indirectly stimulates collaboration.

The frequency of meeting rooms is determined: both via reservations (booked) and via sensors (in use). The occupancy of 100 workplaces is shown real-time.

The data source used is reservations, from the reserva-tion system of Mapiq. Infrared sensors have been added on 100 workplaces; they measure activity on that workplace. 10 infrared sensors have been added to meeting rooms; they measure activity in the room.

TUD-1 TU Delft Mapiq - Blinq Systems

functionalities
Wayfinding, find a study place, book a project room

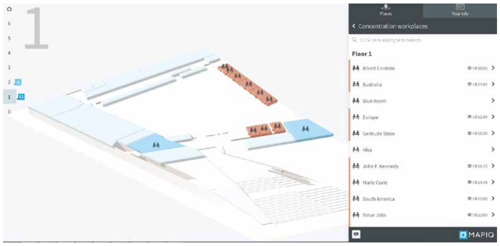
space types
study places, project rooms

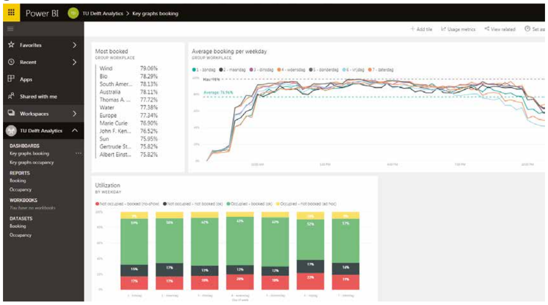
User information

The user can search for a space by space type in the interface, e.g. workplace with a computer or workplace for group. Then the user can see the availabilityof these spaces.

For project rooms the user can make a reservation via a reservation system. The availability of the room is displayed, based on already made reservations.

For each space a route from the entrance to the space can be given.

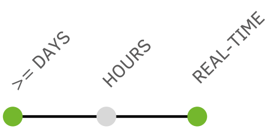




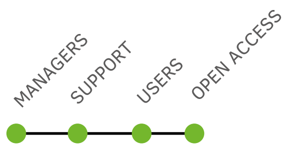
Management information

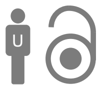
The campus manager can design reports and dashboards in PowerBI. Dashboards show real-time information; Reports show information over the whole measurement period.

Actuality of the information



Access levels

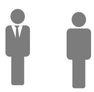




De displayed information on the webpage and in the PowerBI dashboard is (near) real-time.

The reporting function in PowerBI shows real-time data until as far back as possible.

De blueprints, location of each space and availability is visible for everybody; reservations can only be made by students and employees.



Support staff can access a backend to the booking tool. PowerBI functions can be accessed by specific individuals.

Benefits

The objective was to improve the service towards students; students are satisfied with the service and the Library has a reduced workload because of the self-reservation system.

Side notes

The implementation of Mapiq has been received very positively by students. The Student Council regularly has meetings with the Library, which are also about Mapiq. They would like to see more information on the availability of study places given the business in the Library during exam weeks. Information on where study places are and which amenities they have, is seen by them as an important first step.

TUD-2 | TU Delft | Pilot education spaces

phase: Pilot

scale: 1 building, 2.500 m2

duration: Q3 2016 - present

Project description

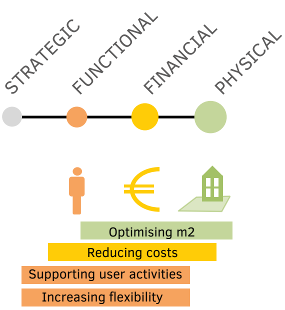
The initiative has been taken because TU Delft wants to get better insight into the use of facilities on campus. The university has been growing in terms of student population for years and that results in pressure on the education spaces. Four years ago we had 1 seat in an education space per student; now we have about 0,85 seat per student. In order to monitor what the effect of this change is on the use of space and to be able to schedule more efficiently in the future, the university decided to start measuring the frequency and occupancy rates real-time for education spaces. Wi-Fi has been selected as preferred method.

Foreseen developments

The next step in this project is to measure frequency and occupancy in education spaces on a campus level.

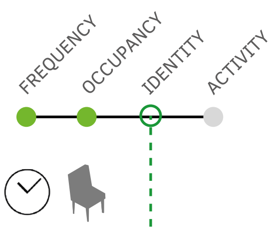
Profile

Why: Objectives



Optimising m2 has priority. On the long term this is achieved because schedulers receive information about the actual use of spaces by users. With that information it is possible to evaluate the space use and search for better solutions together with teachers.

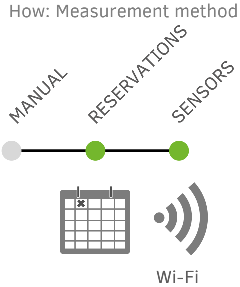
What: Measurement



Wi-Fi data is anonymised on-site before it goes to the cloud. In addition a different encryption is used so users can never be tracked for longer than one day if anyone is able to deanonymise the data.

The amount of devices in the building at a certain moment. That is converted via algorithms to an amount of people.

How: Measurement method



Wi-Fi registers both the amount of connected devices and connec-tion attempts. Based on the signal strength between device and access point the location of a device in the building can be pinpointed.

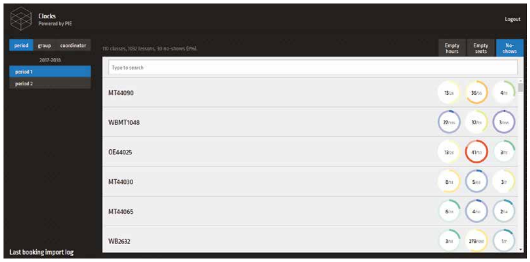
TUD-2 TU Delft Pilot education spaces

functionalities
Monitoring space use

space types
Education spaces

User information

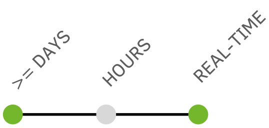
The user (scheduler) receives a report with in it per course the amount of bookings, the amount of no-shows, empty hours (partly used bookings) and the average occupancy. This makes the performance in relation to the schedule visible.



Management information

The manager can see the same reports as the scheduler and also the PIE dashboard in which the whole building is visible. PIE is not linked to the scheduling data, but shows real-time what the use of spaces in the building is in relation to their capacity.

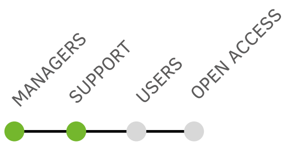
Actuality of the information



PIE displays real-time data.

The information in Clocks is visible real-time; for lectures currently underway a tentative frequency and occupancy is shown. The report shows data per period.

Access levels



The scheduling team has access to Clocks.

A few project team members and two people from the management of a faculty have access to Clocks and PIE.

Benefits

Implementing a system with which the schedulers can evaluate the space use of lecture halls has been identified as one of the measures that enable the university to move to a more efficient space use. The university intends to move from a policy of 0,9 education spaces/student to 0,81 education spaces/student. The pilot is not aimed at assessing what efficiency can be achieved, rather to get experience with the method and testing the results with Wi-Fi in a second building.

Side notes

The reason that this pilot is undertaken is because of the results in the proof of concept in the faculty of Industrial Design Engineering were not as positive as expected. The lecture halls showed promising results, but the other spaces in the building did not. Multiple causes were identified: an open central hall with multiple floors adjacent to it, the pedestrian flows in the hall and around the building, the layout of access points and the way in which the network allocates users to access points. The pilot in 3mE is a test to see if the results in another building are comparable.

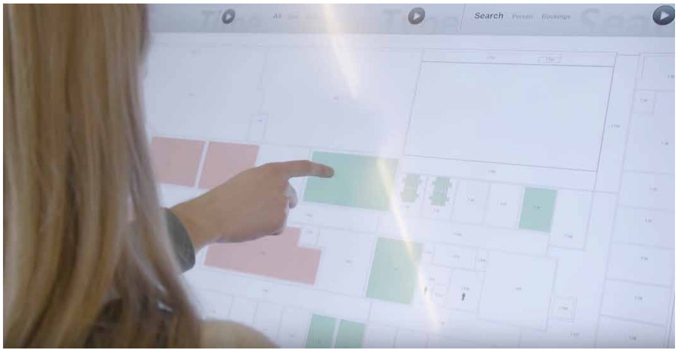
TUE | TU Eindhoven | Book my space - Planon

phase: Implementation — scale: 213.000 m2 — duration: Q1 2016 - present

Project description

The project was initiated because of the strong increase in students studying at TU Eindhoven. The university could not invest in buildings, so the amount of users per m2 needed to increase. A functional programme of requirements was written to six parties. Planon was chosen because they best met the requirements and because it was already used at TU Eindhoven.

The basis is in an implementation phase; the sensoring and linking Syllabus to Planon is in the development phase.



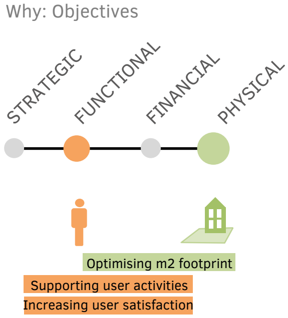
Foreseen developments

Linking Syllabus to Planon, upgrading the release of 2017 (Planon webclient), workplace sensoring, Lora network.

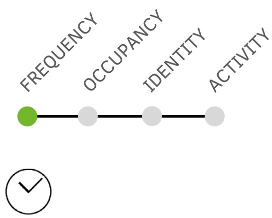
Another objective is to bring the data from Planon and the data from the manual occupancy measurements together in one report.

Profile

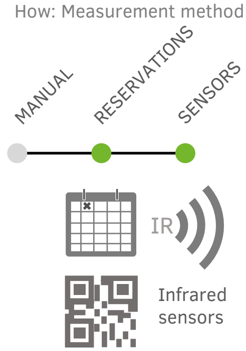
Why: Objectives



What: Measurement



How: Measurement method



A higher amount of users per m2 has priority, and is achieved by a uniform way of making reservations and findability of available spaces.

The duration of the reservation is compared to the maximum amount of available hours in order to determine frequency. There is a pilot in one building with sensors, which register the actual frequency and can thus determine no-show and early leave.

Reservations are made via Planon. Infrared sensors that are connected to the lighting, detect presence in meeting rooms which indicates if a reservation is used. In addition manual counts are done (separately) in the education spaces.

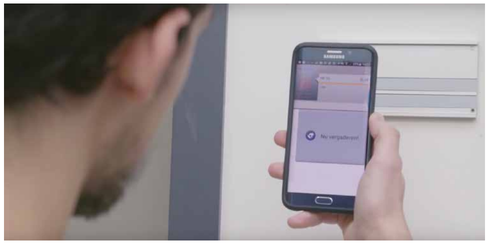
TUE TU Eindhoven Book my space - Planon

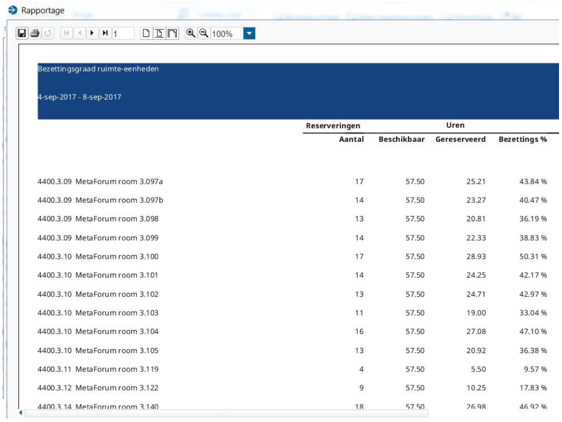
functionalities
Find a workplace, room booking, monitoring space use

space types
Education space, flexible workplaces, meeting rooms

User information

Users can see where the study places, meeting rooms or work places are on campus and if they are available with their smartphones, a website or one of the kiosks. Then they can reserve a workplace or a group room.





Rapportage

Bezettingsgraad ruimte-eenheden

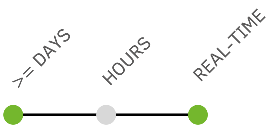
4-sep-2017 - 8-sep-2017

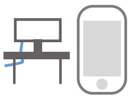
	Reserveringen	Uren		
	Aantal	Beschikbaar	Gereserveerd	Bezettings %
4400.3.09 MetaForum room 3.097a	17	57.50	25.21	43.84 %
4400.3.09 MetaForum room 3.097b	14	57.50	23.27	40.47 %
4400.3.09 MetaForum room 3.098	13	57.50	20.81	36.19 %
4400.3.09 MetaForum room 3.099	14	57.50	22.33	38.83 %
4400.3.10 MetaForum room 3.100	17	57.50	28.93	50.31 %
4400.3.10 MetaForum room 3.101	14	57.50	24.25	42.17 %
4400.3.10 MetaForum room 3.102	13	57.50	24.71	42.97 %
4400.3.10 MetaForum room 3.103	11	57.50	19.00	33.04 %
4400.3.10 MetaForum room 3.104	16	57.50	27.08	47.10 %
4400.3.10 MetaForum room 3.105	13	57.50	20.92	36.38 %
4400.3.11 MetaForum room 3.119	4	57.50	5.50	9.57 %
4400.3.12 MetaForum room 3.122	9	57.50	10.25	17.83 %
4400.3.14 MetaForum room 3.140	18	57.50	26.98	46.92 %

Management information

Occupancy percentages of all reservable spaces: education spaces, study places and flexible workplaces.

Actuality of the information

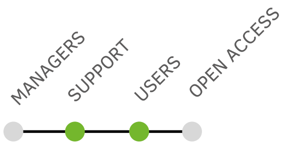




Information on the selfservice, app, and the kiosks is real-time.

Reports are available on demand. Dashboards need to be used more in the future.

Access levels



Students and employees have access via Selfservice, an App, Outlook and the Kiosks in the buildings

Secretaries have access to reservations via Planon Procenter.

Benefits

The objective was to increase the frequency rate of meeting rooms and the occupancy rate of workplaces by 10% within four years. After one year the increase is already 13%.

Side notes

Managers get more insight into space use and can make decisions more conciously. Students have a tool to reserve space and have access to more spaces (also in other buildings) than previously.

UT — Twente University — Research on adaptive scheduling

phase: Research

scale: 5.360 m2 NFA, 5 buildings

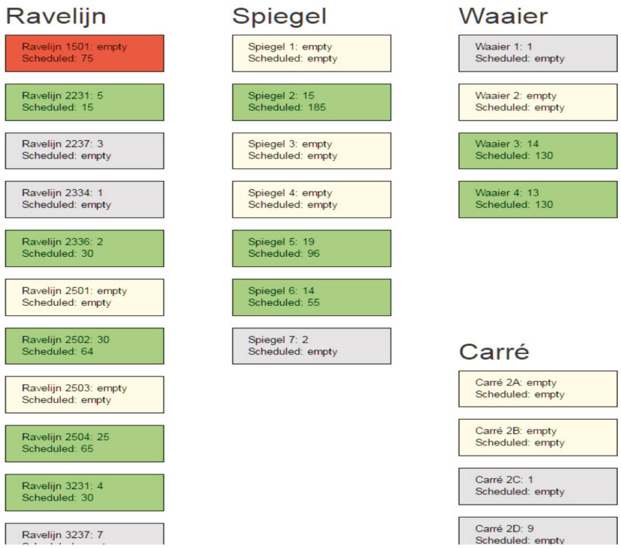
duration: Jan. 2017 - present

Project description

The research on adaptive scheduling is aimed at a concept of education logistics that supports interactive, project-driven learning. Based on the demand of students, a lecturer can choose an available appropriate space when needed - rather than planning a set of lectures in advance. In order to facilitate this, real-time insight into space use is needed.

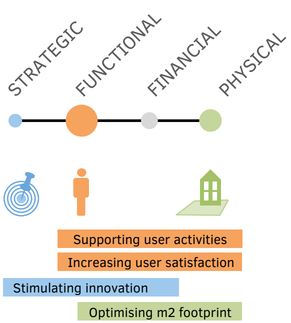
Foreseen developments

The researchers are also working on a method to assess a university timetable (or set of bookings) on suitability for the primary process to balance the current assessment method on efficiency.

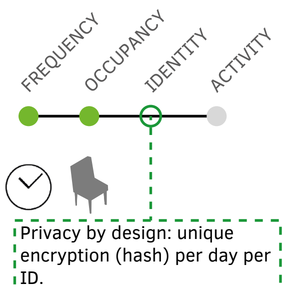


Profile

Why: Objective



What: Measurement



How: Measurement method

The objectives are achieved by changing the way in which scheduling takes place

Wi-Fi measures the amount of connected devices located in various parts of the building. This is converted to a number of users by using the data from Eduroam. This number is used to capture frequency and occupancy.

Wi-Fi registers the number of registered and unregistered MAC addresses. Question to be answered is what method to use; access points or passive Wi-Fi sniffers.

UT Twente University **Research on adaptive scheduling**

functionalities
Monitoring space use

space types
Education spaces

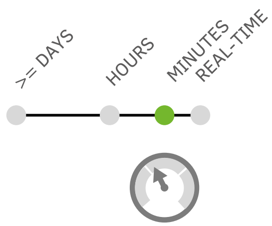
User information

The users (researchers and technicians) see a dashboard with an overview of the occupancy per space and information on if the space is scheduled or not.

Management information

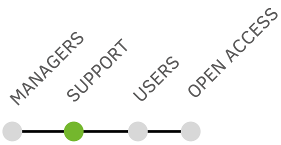
Same as above.

Actuality of the information



The displayed information updates every six minutes

Access levels



Researchers and technicians have access to the data.

Benefits

The benefit of the project is an solution to the problem of underutilised space and a way to facilitate the foreseen shift of education towards a more demand-based (learner demand) education programme.

Side notes

Different measurement methods are being piloted. At the moment ground-truth measurements are being conducted. We are getting an average of 80-97% accuracy, depending on the measurement method and the algorithm to interpret the data.

https://www.surf.nl/kennisbank/2017/optimaal-roosteren-op-basis-van-realtime-data.html

UU

Universiteit Utrecht - Proof of concept Lone Rooftop

phase
Pilot

scale
2 buildings

duration
start Q4 2017

Project description

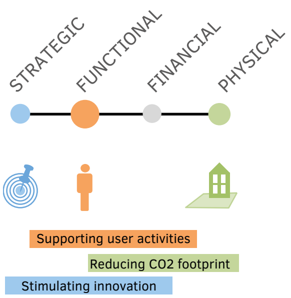
There is insufficient insight into the actual frequency and occupancy rates of the education spaces. Improvement in the education process requires actual insight into the space use of education spaces.

Foreseen developments

Using this kind of technology on a large scale at UU. Selecting a product, based on the experiences of this proof of concept.

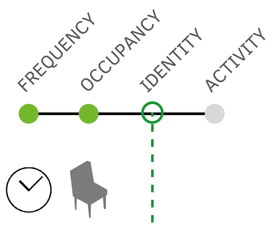
Profile

Why: Objectives



First the objective is to give insight into space use to improve the scheduling process. Then the idea is to apply this technology to improve the comfort of our users, save energy and strengthen the innovative character of UU.

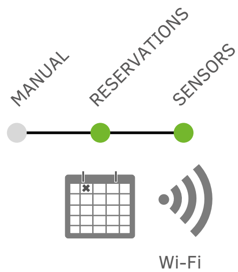
What: Measurement



A PIA has been made by an external bureau. Measures have been identified. A modification agreement has been made with the supplier. Communication with users.

The amount of devices on a certain location in the building. That is converted into an amount of people by an algorithm.

How: Measurement method



Wi-Fi registers both the amount of connected devices and attempts to connect to the network. Based on the signal strength between the device and the access points the location of a device can be pinpointed.

UU

Universiteit Utrecht - Proof of concept Lone Rooftop

functionalities
Monitoring space use

space types
Education spaces

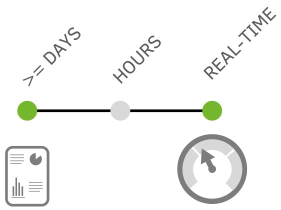
User information

Collecting frequency and occupancy data based on Wi-Fi signals and translating that to overviews displaying the amount of people per education space.

Management information

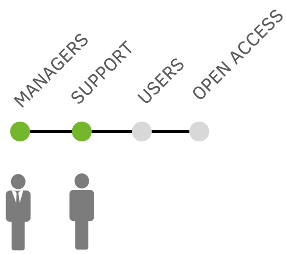
The report gives insight into no-shows, in frequency and occupancy of individual spaces. Information about space use through the day, percentage booked vs. in use, insight into the occupancy (efficient scheduling), information during a whole education period.

Actuality of the information



Dashboards displaying the current situation and reports showing the use over a period are required.

Access levels



Project team members

Benefits

-

Side notes

TOC

UvA — Universiteit van Amsterdam - Mapiq

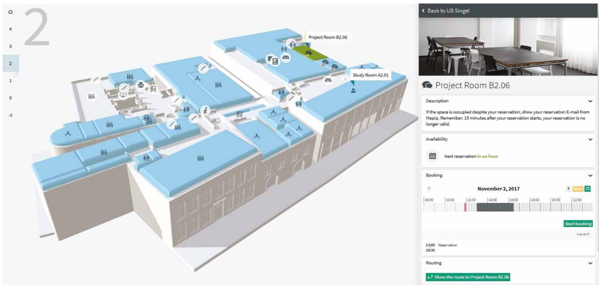
phase: Expansion

scale: 6 buildings, 105.184 m2

duration: 2015-present

Project description

From the student council of the university and faculties there was a desire to get more access to the classrooms, which used to be restricted for students. Furthermore their demand was to make study places visible. Therefore we started with the implementation of Mapiq: to give students access to classrooms and display study places and project rooms.



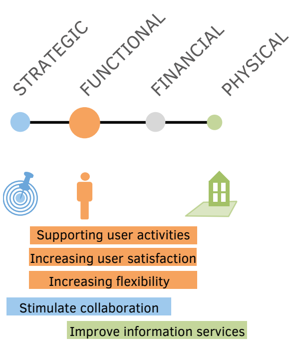
Other demands:
Offices: a demand to reserve meeting rooms, find empty flex spaces and increase the findability of colleagues (opt-in).
Offices: frequency and occupancy information, wayfinding and security/emergence response applications.
Accessibility information for students and employees with a handicap.

Foreseen developments

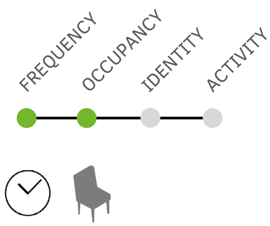
Part of the implementation project is realising a link to the scheduling system, in order to use available space in the schedule for self study by students. Also a link to the Wi-Fi network is made in order to display business in the building and in spaces. Aside from the functionalities for students we are working towards the application on the office spaces for employees.

Profile

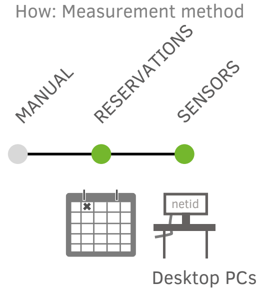
Why: Objectives



What: Measurement



How: Measurement method



Our objective with Mapiq is to enable users to use the available space better. The next step is to use the information for improved decision-making.

Different per space: frequency is measured for education spaces and project rooms. Occupancy is measured for PC spaces.

Booking data is used from Mapiq and from Syllabus to show availability. Desktop PC usage is logged in order to show occupancy per workplace.

UvA

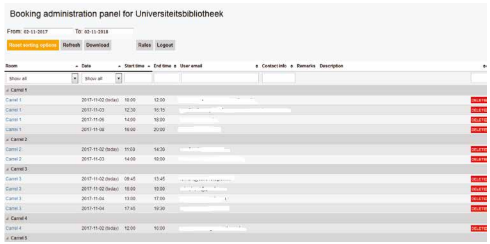
Universiteit van Amsterdam - Mapiq

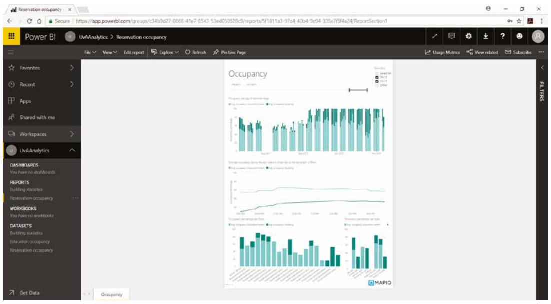
functionalities
Wayfinding, room booking monitoring space use

space types
Whole building

User information

The user can search for a space in the interface per type (e.g. PC workplace or group workplace) and see if these spaces are available. Project rooms can be booked via a booking system. For education spaces it is indicated if it is available for self study. For PC places the availability is displayed. The actual availability based on reservations is displayed. For each space a route to the space can be displayed.

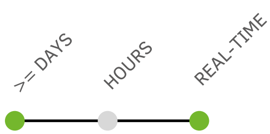


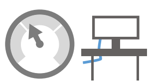


Management information

Via Power BI reports are realised. PowerBI can be used to make dashboards, which is also able to add other information from other sources. This part is still in development.

Actuality of the information

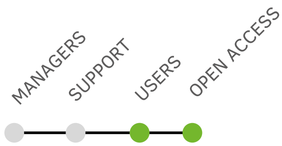




The displayed information on the webpage and in the PowerBI dashboard is real-time.

The reporting function shows real-time data until as far back as possible.

Access levels



The floor plan and location of spaces is visible to everyone.

Room bookings can only be made by students and employees (via UvA netID).

Benefits

Enabling users to use the existing space better is not monitored per se. However, the amount of reservations in Mapiq has increased from 1.600 in 2 buildings to 3.400 in 4 buildings, and is still increasing. Also, implementing Mapiq will help the university to substantiate their policy and real estate decisions with data.

Side notes

Based on the results of the pilot in two buildings in which students could reserve project rooms and student PCs it was decided to move forward with further implementation. In 2016-17 four buildings were added and in 2017-18 a minimum of three buildings will be added. At the end of 2017 we will do two pilots: one with visualising business with Wi-Fi data and one with linking the scheduling system for

UvT   Tilburg University   design brief

phase: Design brief

scale: 2 buildings, 5.000 m2 (fase 1)

duration: expected

Project description

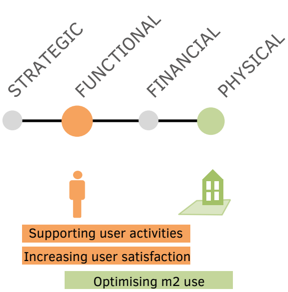
Students have no user-friendly tool to book meeting rooms. We want to increase the frequency rate in meeting rooms and increase the findability of free self-study places.

Foreseen developments

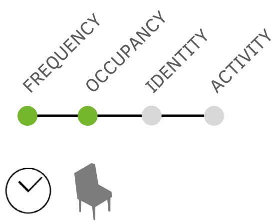
The proposition is to replace Web Room Booking and PC availability with this tool in time. The phasing proposal is to implement 5.000 m2 GFA in 2 buildings first, then to add +13.000 m2 GFA in a new building and finally to add +10.000 m2 GFA with the Library. That is four buildings with possibility for further expansion.

Profile

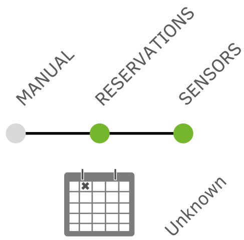
Why: Objectives



What: Measurement



How: Measurement method



The priority per divisional unit of the university is different. A project initiation document is being drafted at the moment.

Unknown, but frequency and occupancy are expected.

The design brief will state real-time measurement of space use, but it is unknown what sensor it will be.

UvT

Tilburg University

design brief

functionalities

Find a study place, room booking, monitoring space use

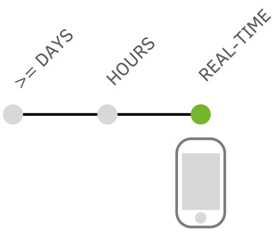
space types

Study places, meeting rooms, project rooms

User information
(unknown)

Management information
(unknown)

Actuality of the information



Access levels

Benefits
(unknown)

Side notes

(unknown)

The design brief will state real-time.

Unknown.

VU   Vrije Universiteit   Study Spot

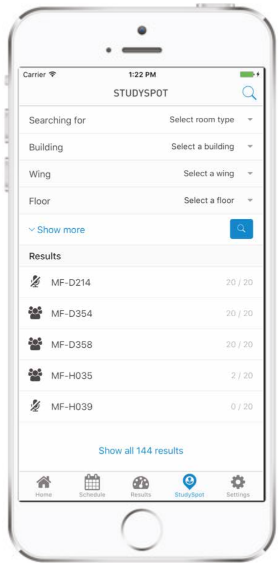
phase Implementation

scale 7 buildings 276.484 m2

duration 2016-present

Project description

In the campus renewal of the VU optimisation of the space use is an important motive next to facilitating the primary process of the university. Study Spot is a service that has been initiated by FCO, but in a work group with students, employees, researchers and IT. We facilitated the work group in order to achieve a solution that has everyone's support. A PID (project plan) has been made that states what kind of application it is, what the system must be able to do and how the system has been chosen.

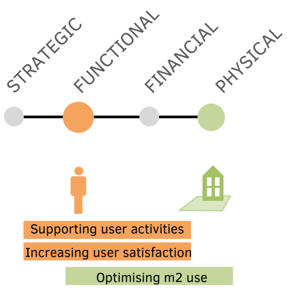


Foreseen developments

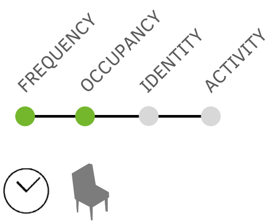
In the ideal situation real-time information available to everyone is desired. Maybe a student can receive a push-message at the start of the day in which it says when his/her first lecture is and at what location (LBS). There are different ways to reach that point. If everything is possible, then it is easier to set restrictions from there and only offer parts of the service to different user groups, or to make information unavailable.

Profile

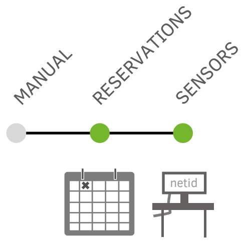
Why: Objectives



What: Measurement



How: Measurement method



Desktop PCs

Supporting the user has the first priority.

For education spaces and project rooms frequency is shown. For PC halls occupancy.

The booking data from Study Spot and Syllabus are used to show if education spaces and project rooms are in use. PC login data is used to show occupancy data of PC halls.

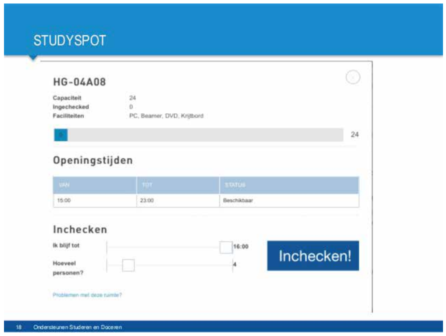
VU Vrije Universiteit Study Spot

functionalities
Wayfinding, room booking find a study place

space types
Education spaces, study places, project rooms

User information

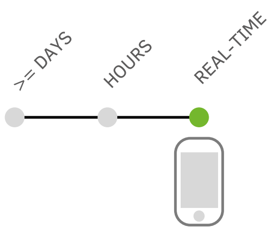
Study Spot displays the availability of education spaces to students based on information of room bookings from Syllabus. Also it displays the occupancy of PC halls. The student is not able to reserve classrooms.



Management information

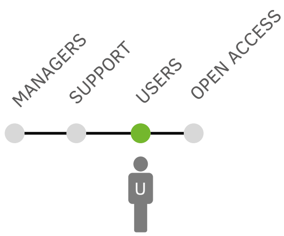
PM

Actuality of the information



The information displayed in the app is real-time.

Access levels



Access to StudySpot is restricted via VUlogin.

Benefits

In order to evaluate Study Spot the data on amount of users is monitored to see how often it is used; also short surveys are done to determine the satisfaction of students.

Side notes

Because of Study Spot the space is used more frequently, which indeed means that the services must be aligned to the increased frequency. The tasks of the wardens has been expanded. for example. When a space is used often by students, it is important that the space is left behind properly for the next lecture.

WU — Wageningen University — PIE, Clocks (Lone Rooftop)

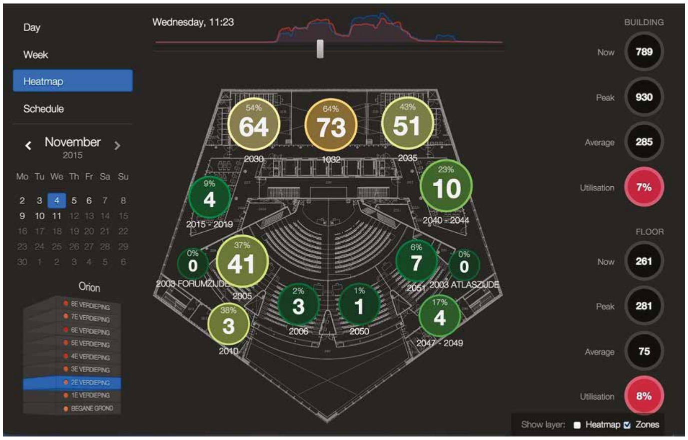
phase: implementation

scale: 21.000 m2 NFA, 6 buildings

duration: 2015 - present

Project description

At the WUR we had a demand for the use of big data and sensors relating to our operations, but it was difficult to formulate a specific application. We didn't know exactly what we wanted to know. In this project we could make it very specific: we measure in specific buildings, we measure students, with a specific method to understand the use of education spaces in relation to the schedule. That makes it easy to steer on the project. At the time the WUR had just built a number of new education buildings, and building more was not an option. Therefore the question was: how well are these buildings actually used? Lone Rooftop came at the right moment, after which we started in 2015.

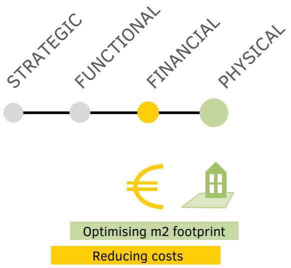


Foreseen developments

A pilot is being initiated to use the data of building occupancy in building management systems. More accurate measurements on building level and in small spaces will take place in the next few months

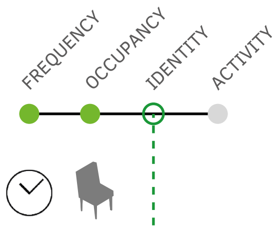
Profile

Why: Objectives



Optimising m2 is done by gaining insight into no-show behaviour. From the facility management perspective the delivery of this information was one of the measures taken to use the existing space more efficiently.

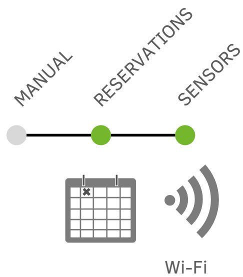
What: Measurement



The IP addresses are anonymised differently each day. Also, this is done before the data leaves the university's network.

An indication of the occupancy is given for a predetermined zone. The size of this zone is aligned to the accuracy of the measurement.

How: Measurement method



Wi-Fi determines where devices are within the building (active and passive). Via an algorithm devices are paired if the algorithm determines they belong to one user. That is how the amount of users in a zone is determined.

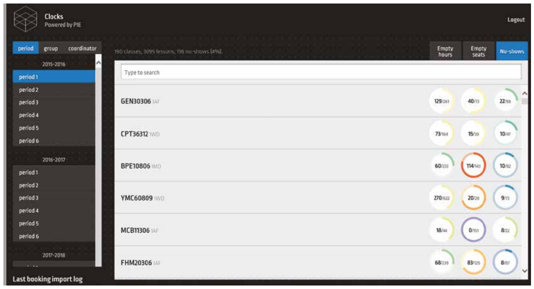
WU — Wageningen University — PIE, Clocks (Lone Rooftop)

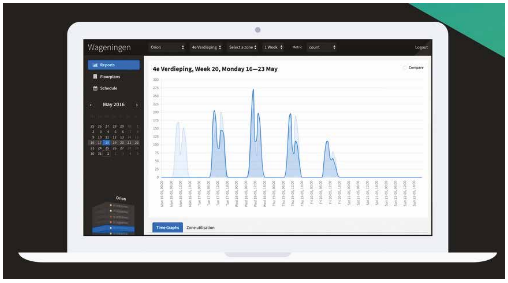
functionalities
Monitoring space use

space types
Education spaces, whole building

User information (scheduler)

The user (scheduler) receives a report in which the occupancy data for lecture halls is linked to scheduling data. The amount of no-shows and occupancy per activity is displayed. The system is also used by location management to get insight into where people are in the building and how many people there are during the day, and during the evening hours.





Management information

The manager can see how many devices there are in different zones of the building, although the system is working less with devices and more with users. For the education spaces the data can be linked to the schedule. We are looking specifically at no-shows. The focus is on the use of education spaces and scheduling.

Actuality of the information

>= DAYS — HOURS — REAL-TIME

The information displayed in PIE is near-real time.

Access levels

MANAGERS — SUPPORT — USERS — OPEN ACCESS

PIE is available to location managers; Clocks is available to schedulers.

Benefits

The first experiences with the system are that it leads to an improvement of 5-10 procent in space efficiency. In 2018 a new schedule will be implemented that includes more hours per day and shorter hours, which enables us to accommodate growth in the near future.

Side notes

The data used in reporting goes from real-time to as far back as possible.

PIE and Clocks are available to specific people from Facility Services.

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APPENDIX 4

Connecting campus decision making to IoT applications

This appendix contains supplementary information to chapter 7. First, the interview schedule for the first series of interviews is provided. These interviews result into the initial product (a customer journey map), which is translated into process and information diagrams and verified with the interviewees. Then, some supplementary material to the results is provided: Table APP. 4.1 connects the analysis of the literature study in section 7.3.1. to each of the papers studied. Then, the activity diagrams of two cases are shown.

Interview schedule

Start	
Which steps has your organisation taken in the strategy process?	What was the reason to start the strategy process? Which decisions have been taken during the process?

Per step of the strategy	
Which steps did you take to gain insight into the current match (between demand and supply) of the real estate portfolio?	What was the starting point and what was the finishing point? Was the process very straightforward, or very complicated and unpredictable, and why? Who was involved in the process?
Which information was taken into account in this step?	How is the quality, functionality, costs, physical state assessed? How is the perspective of the users, the faculties, the Executive Board taken into account? Which information was not available?
Could you show how the available information is presented?	In which way is the information presented? How is the information used in the process?
What were the limitations of the information?	Was the information precise, current? Was the information sensitive? Was the information on an aggregation level that was comparable to other information?
What were the consequences of these limitations for the process?	Did these limitations lead to discussion? Acceleration or delay? Strategic behaviour? Did the limitations influence the end result?
What was your own experience regarding this process step?	What were your thoughts during the process? What were your feelings during the process?
Which information would you have liked to have had available, that was not available at the time?	How is the quality, functionality, costs, physical state assessed? How is the perspective of the users, the faculties, the Executive Board taken into account? Which information was not available?
How would the process go if this information was available?	Would the process be different? Would there be more or different information? Would other stakeholders be involved?

Currently present smart campus tools	
What is the result of the implementation of the current smart campus tools?	Did it lead to a better use of buildings? Did it lead to a higher user satisfaction? Did it lead to energy savings?
How is this result determined?	Are there reports where this result is monitored?

Personal experience and knowledge	
What were your expectations before the start of the process?	Which information did you expect to be available within the university? Which expectation did you have related to colleagues (in same / other departments) and common ground? Which possibilities or constraints did you see? Which feeling did you have regarding the process?
How did you prepare yourself?	Did you look up old files? Did you contact (ex) colleagues? Did you have conversations within and outside of the organisation? Did you follow a seminar or education programme?

Supplementary results

TABLE APP.4.1 Extension of Table 7.2, showing the literature categorised per application type

No. of IoT applications	Type of IoT application	Literature
18	Location-based user applications	(Castro, Chiu, Kremenek, & Muntz, 2001; Chapre et al., 2013; Y. Chen, Lymberopoulos, Liu, & Priyantha, 2013; D'Souza, Wark, Karunanithi, & Ros, 2013; Dave et al., 2018; Deak et al., 2010; Furey, Curran, & McKevitt, 2012; Jiang et al., 2012; Kosba, Saeed, & Youssef, 2012; Lim, Ng, & Da, 2008; Liu, Makino, Kobayashi, & Maeda, 2008; Maraslis, Cooper, Tryfonas, & Oikomonou, 2016; Romero Herrera et al., 2018; Shrestha, Talvitie, & Lohan, 2013; Sutjarittham et al., 2018; Talvitie, Renfors, & Lohan, 2015; Toh & Lau, 2016; Vu, Nahrstedt, Retika, & Gupta, 2010)
13	Optimising building services	(J. Chen, Chen, & Luo, 2019; Christensen et al., 2014; Chuah et al., 2013; Dave et al., 2018; Dodier, Henze, Tiller, & Guo, 2006; Ekwevugbe et al., 2017; Garg & Bansal, 2000; Ioannidis et al., 2017; Labeodan, Aduda, Zeiler, & Hoving, 2016; Pesic et al., 2019; Romero Herrera et al., 2018; Saralegui et al., 2019; Schwee et al., 2019)
13	Monitoring user flows	(Abedi et al., 2013, 2014; Daamen et al., 2015; Liebig et al., 2014; Lopez-Novoa et al., 2017; Prentow, Ruiz-Ruiz, Blunck, Stisen, & Kjærgaard, 2015; Ruiz-Ruiz et al., 2014; Schauer et al., 2014; Stange et al., 2011; Stisen et al., 2017; Utsch & Liebig, 2012; van den Heuvel & Hoogenraad, 2014; Versichele et al., 2012)
5	Monitoring space use	(Mohottige & Moors, 2018; Sutjarittham et al., 2018; Sutjarittham, Gharakheili, Kanhere, & Sivaraman, 2019; Y. Wang & Shao, 2017; Zhang et al., 2010)
5	Building energy simulation	(J. Chen & Ahn, 2014; Chung & Burnett, 2001; Martani, Lee, Robinson, Britter, & Ratti, 2012; Tekler, Low, Gunay, Andersen, & Blessing, 2020; W. Wang, Chen, Huang, & Lu, 2017)
4	Telecare	(Orozco-Ochoa, Vila-Sobrino, Rodríguez-Damián, & Rodríguez-Liñares, 2011; Rodríguez-Martín, Pérez-López, Samà, Cabestany, & Català, 2013; Vathsangam, Tulsyan, & Sukhatme, 2011; Villarrubia et al., 2014)
2	User detection	(Chang et al., 2010; Kilic, Wymeersch, Meijerink, Bentum, & Scanlon, 2014)
2	Social sensing applications	(Kjaergaard, Wirz, Roggen, & Troster, 2012; Rachuri, Efstratiou, Leontiadis, Mascolo, & Rentfrow, 2014)
1	Emergency response	(Nyarko & Wright-Brown, 2013)

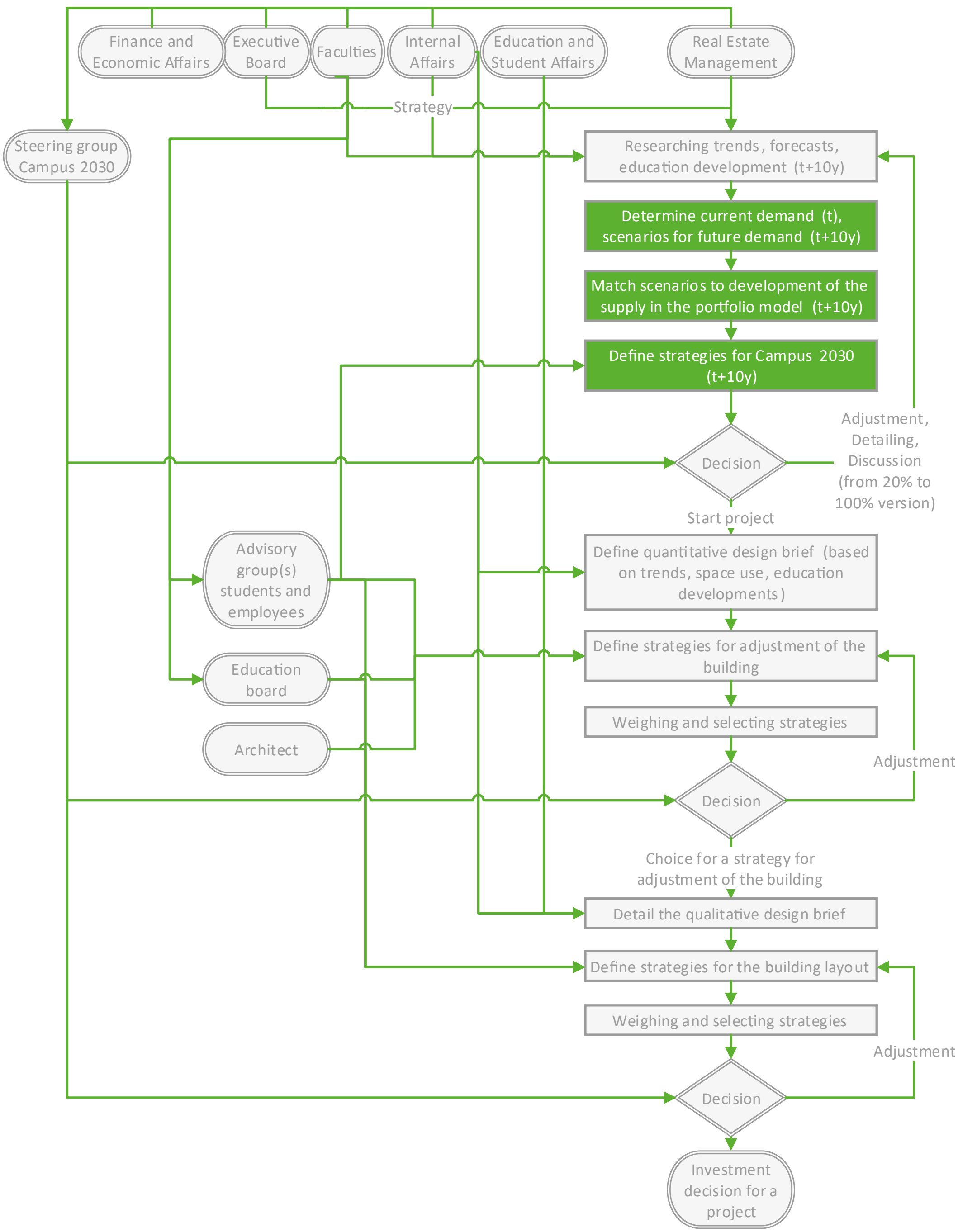


FIG. APP. 4.1 Activity diagram TU Eindhoven. The matching of supply and demand on a portfolio level and the subsequent definition of strategies are emphasized.

TOC

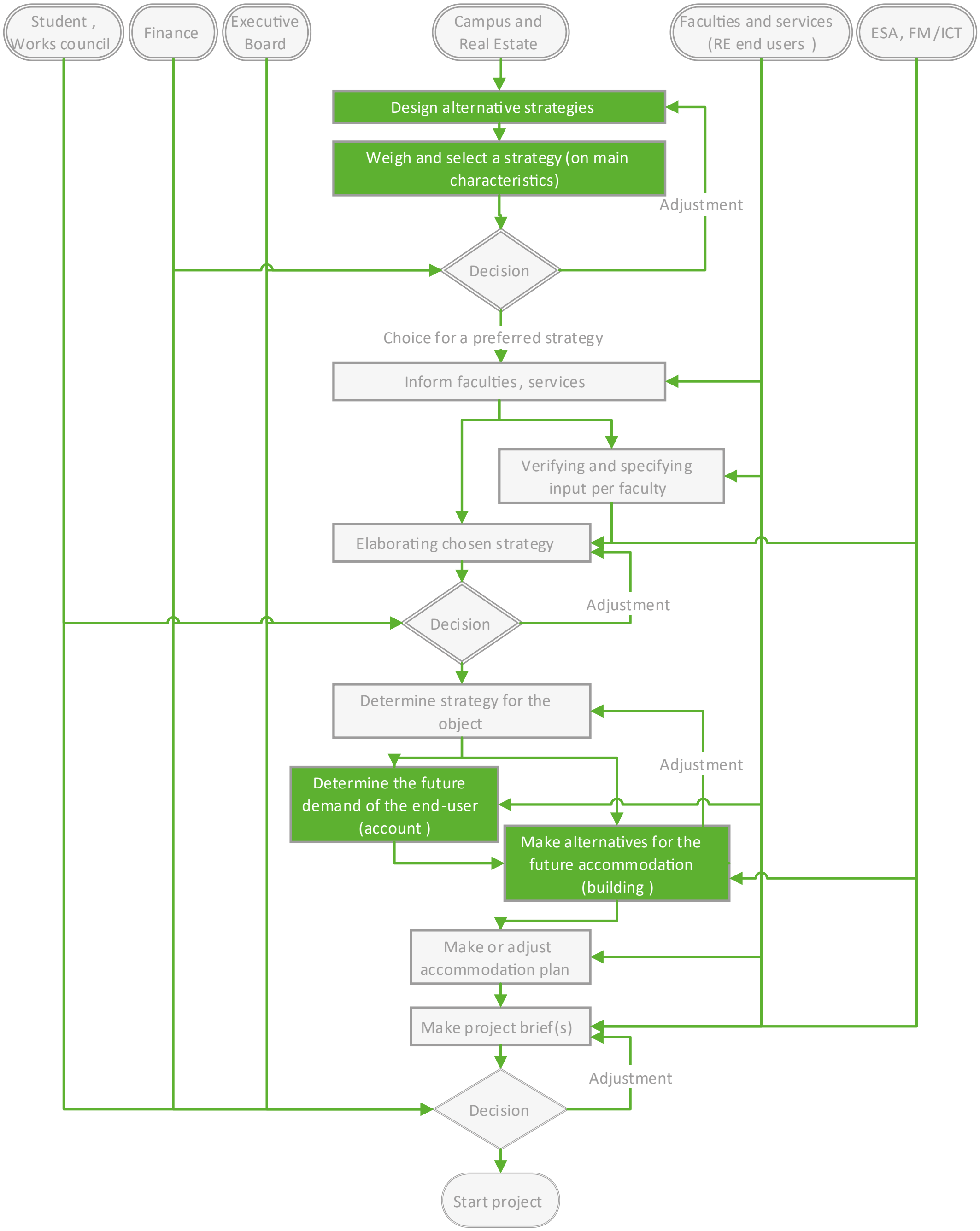
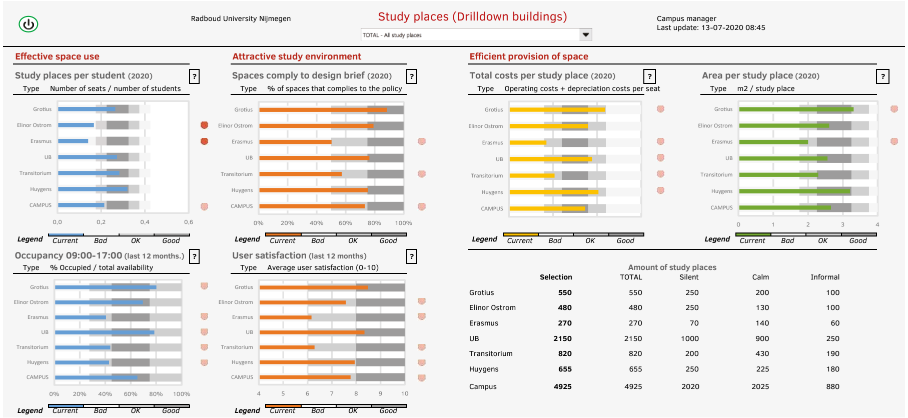


FIG. APP. 4.2 Activity diagram TU Delft. The definition of strategies and the subsequent matching of demand and supply on a building level are emphasized.

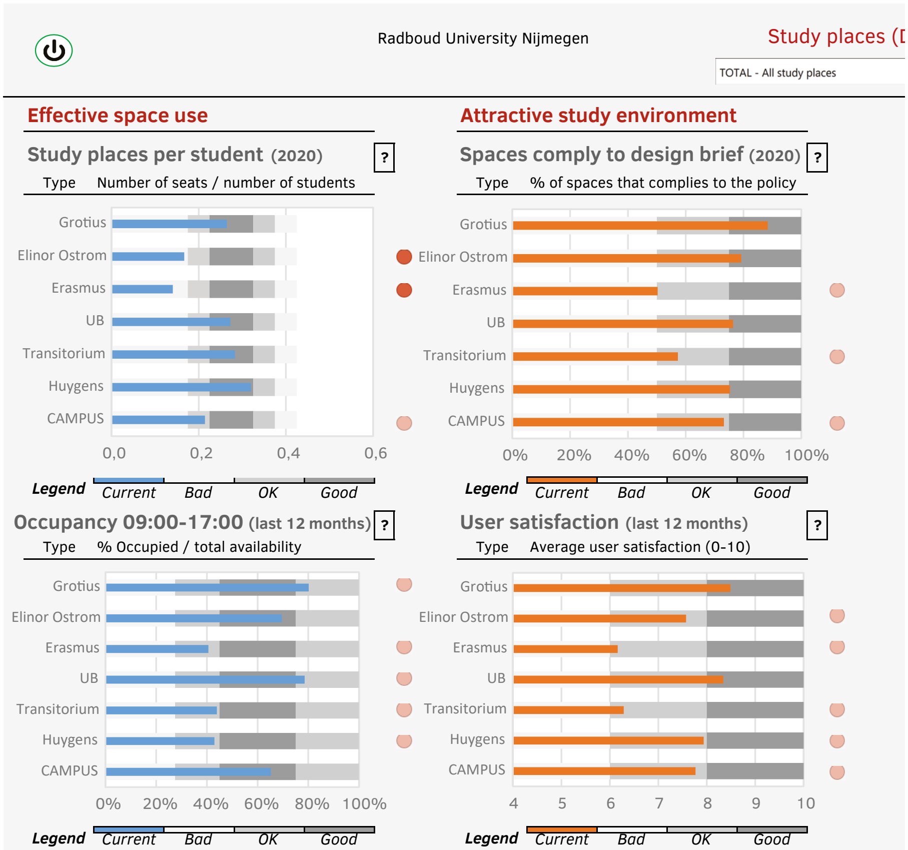
APPENDIX 5

Designing dashboards for campus decision making

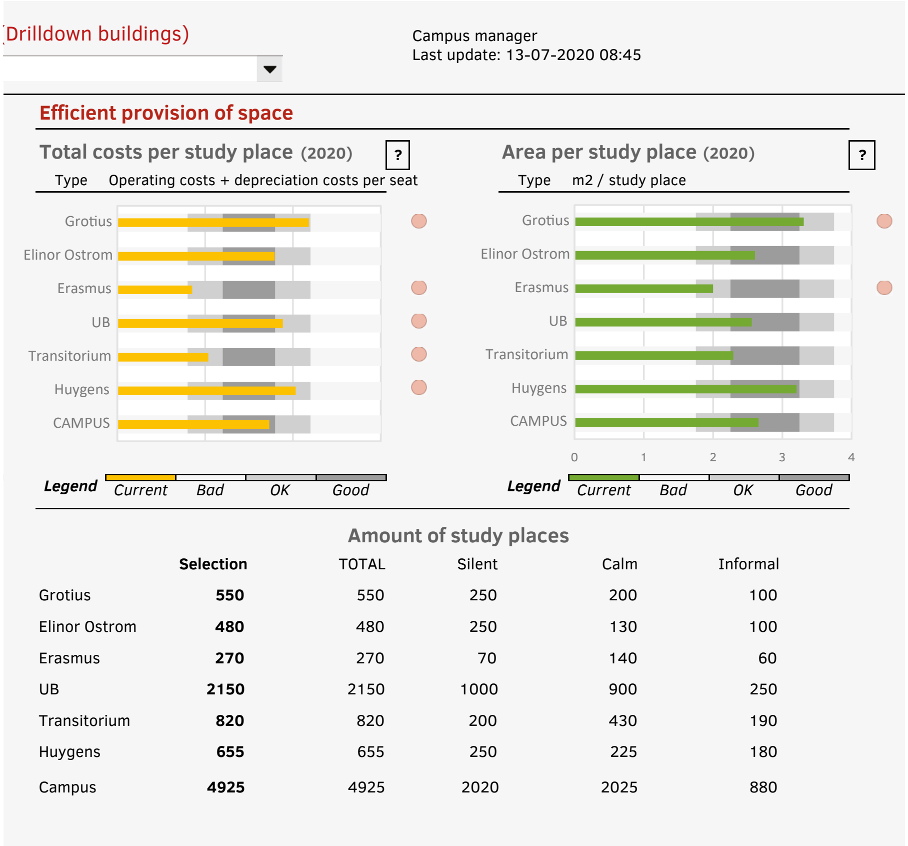
This appendix contains supplementary information to chapter 8. First, several additional dashboard prototypes not included in the chapter are displayed. In order of appearance these are:



	Selection	TOTAL	Silent	Calm	Informal
Grotius	**550**	550	250	200	100
Elinor Ostrom	**480**	480	250	130	100
Erasmus	**270**	270	70	140	60
UB	**2150**	2150	1000	900	250
Transitorium	**820**	820	200	430	190
Huygens	**655**	655	250	225	180
Campus	**4925**	4925	2020	2025	880

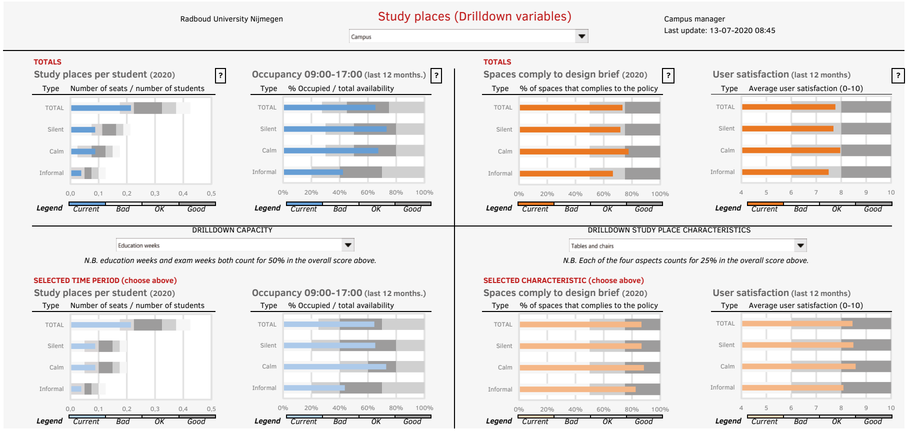


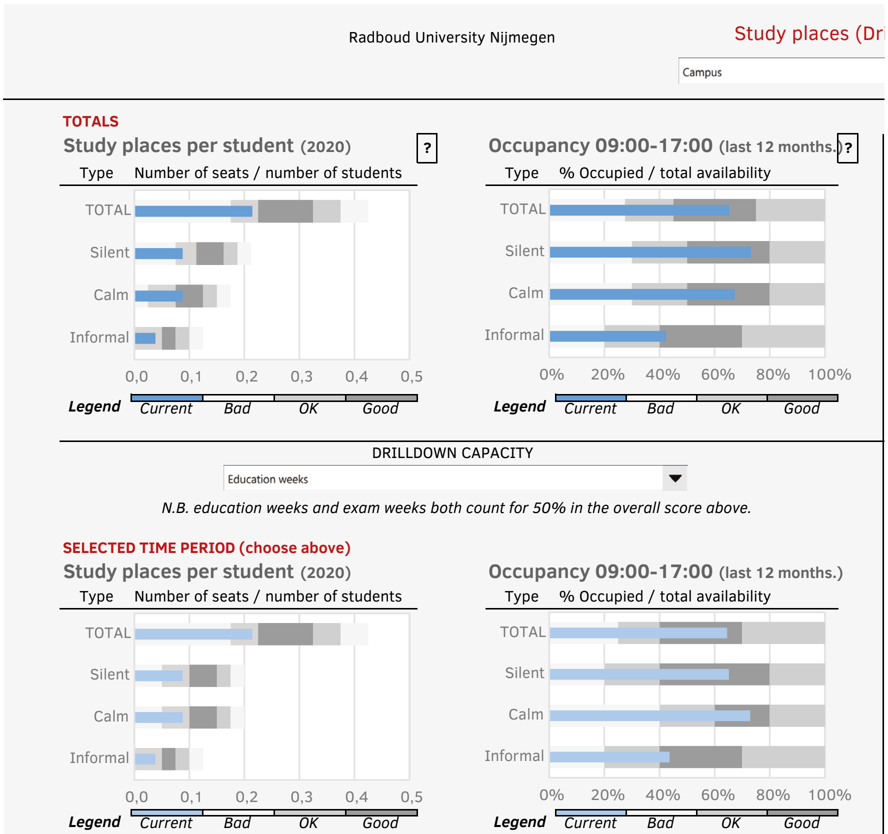
TOC



	Selection	TOTAL	Silent	Calm	Informal
Grotius	**550**	550	250	200	100
Elinor Ostrom	**480**	480	250	130	100
Erasmus	**270**	270	70	140	60
UB	**2150**	2150	1000	900	250
Transitorium	**820**	820	200	430	190
Huygens	**655**	655	250	225	180
Campus	**4925**	4925	2020	2025	880

FIG. APP. 5.1 Buildings dashboard ‘Study places Radboud University’ (tested in workshop 2).


Radboud University Nijmegen
Study places (Drilldown variables)
Campus
Campus manager
Last update: 13-07-2020 08:45
TOTALS
Study places per student (2020)
Type Number of seats / number of students
Occupancy 09:00-17:00 (last 12 months.)
Type % Occupied / total availability
Spaces comply to design brief (2020)
Type % of spaces that complies to the policy
User satisfaction (last 12 months)
Type Average user satisfaction (0-10)
TOTAL
Silent
Calm
Informal
Legend Current Bad OK Good
DRILLDOWN CAPACITY
Education weeks
N.B. education weeks and exam weeks both count for 50% in the overall score above.
DRILLDOWN STUDY PLACE CHARACTERISTICS
Tables and chairs
N.B. Each of the four aspects counts for 25% in the overall score above.
SELECTED TIME PERIOD (choose above)
SELECTED CHARACTERISTIC (choose above)


Radboud University Nijmegen
Study places (Dri
Campus
TOTALS
Study places per student (2020)
Type Number of seats / number of students
TOTAL
Silent
Calm
Informal
0,0 0,1 0,2 0,3 0,4 0,5
Legend Current Bad OK Good
Occupancy 09:00-17:00 (last 12 months.)
Type % Occupied / total availability
0% 20% 40% 60% 80% 100%
DRILLDOWN CAPACITY
Education weeks
N.B. education weeks and exam weeks both count for 50% in the overall score above.
SELECTED TIME PERIOD (choose above)
Study places per student (2020)
Type Number of seats / number of students
Occupancy 09:00-17:00 (last 12 months.)
Type % Occupied / total availability

TOC

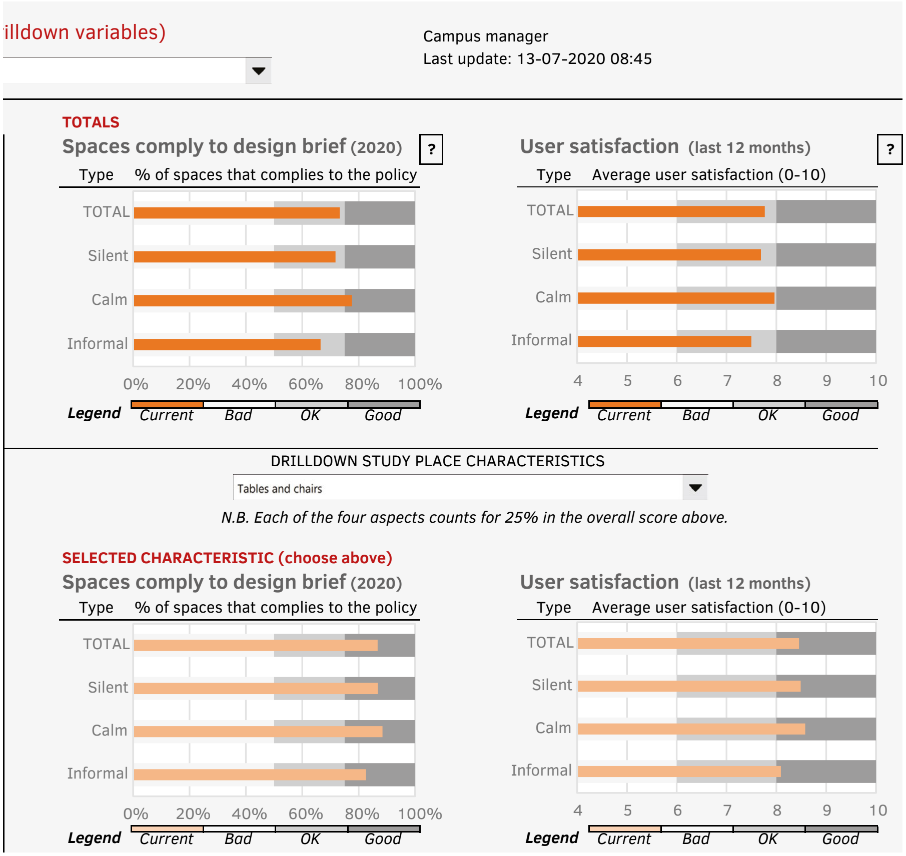
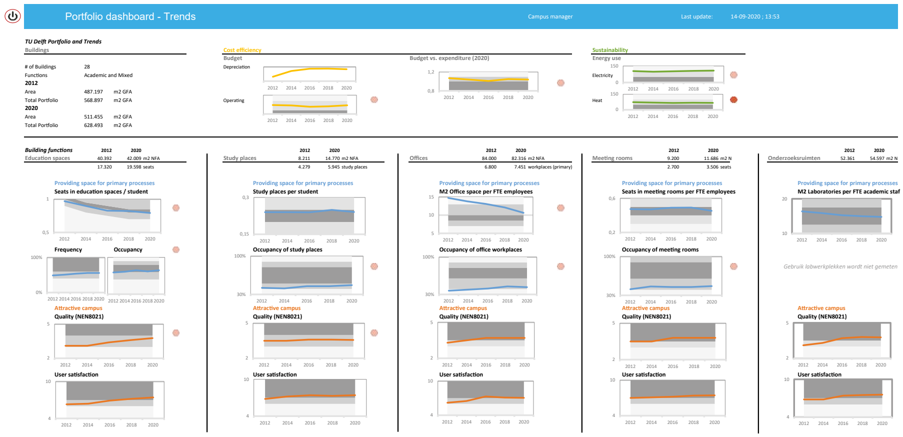


FIG. APP. 5.2 Drilldown dashboard 'Study places Radboud University' (tested in workshop 2).


Portfolio dashboard - Trends
Campus manager
Last update: 14-09-2020 ; 13:53
TU Delft Portfolio and Trends
Cost efficiency
Sustainability
Building functions
Education spaces
Study places
Offices
Meeting rooms
Onderzoeksruimten


Portfolio dashboard - Trends
TU Delft Portfolio and Trends
Buildings
# of Buildings 28
Functions Academic and Mixed
2012
Area 487.197 m2 GFA
Total Portfolio 568.897 m2 GFA
2020
Area 511.455 m2 GFA
Total Portfolio 628.493 m2 GFA
Cost efficiency
Budget
Depreciation
Operating
Budget vs. expe
Building functions 2012 2020
Education spaces 40.392 42.009 m2 NFA
17.320 19.598 seats
Study places 8.211 14.770 m2 NFA
4.279 5.945 study places
Offices
Providing space for primary processes
Seats in education spaces / student
Study places per student
Frequency
Occupancy
Occupancy of study places
Attractive campus
Quality (NEN8021)
User satisfaction
2012 2014 2016 2018 2020

FIG. APP. 5.3 Trends dashboard TU Delft (workshop 2).

FIG. APP. 5.4 Overview of buildings TU Delft (workshop 2). The dashboard shows the five buildings that require the most attention and to which aspects attention should be directed.

Next, the positive and negative interactions of the participants are elaborated in four tables. Each table contains the results of a workshop or series of workshops for a case. In the chapter, these four tables are summarised in table 8.7.

TABLE APP.5.1 Positive and negative interactions of users with the dashboard in workshop 1 (Radboud).

Workshop 1	Positive (Confirmation)			Negative (Disproval)		
Indicators	Reaction to alerts, trends	Relation between indicators	Connection to reality	Ignoring alerts	Confusion (Definitions etc.)	Dead ends
Study places per student	21	7	5	1	2	1
Stay duration	8	2	3	2	7	0
Total costs	14	4,5	1	0	0	0
Occupancy	18	8	4	2	5	0
Compliance to brief	18	8,5	3	1	1	0
User satisfaction	15	10	5	1	1	0
M2 / place	12	6	1	2	1	0
Energy use	13	3	0	4	0	0
Confirmation / Disproval	190			31		

TABLE APP.5.2 Positive and negative interactions of users with the dashboard in workshop 2 (Radboud).

Workshop 2	Positive (Confirmation)			Negative (Disproval)		
Indicators	Reaction to alerts, trends	Relation between indicators	Connection to reality	Ignoring alerts	Confusion (Definitions etc.)	Dead ends
Study places per student	13	7	11	2	3	0
Stay duration						
Total costs	4	5,5	2	4	1	0
Occupancy	14	6	2	1	2	0
Compliance to brief	15	3,5	7	1	2	0
User satisfaction	14	3,5	6	3	1	0
M2 / place	8	7,5	6	3	2	0
Energy use						
Confirmation / Disproval	135			25		

TABLE APP.5.3 Positive and negative interactions of users with the dashboard in workshop 1 (TU Delft).

Workshop 1	Positive (Confirmation)			Negative (Disproval)		
Indicators	Reaction to alerts, trends	Relation between indicators	Connection to reality	Ignoring alerts	Confusion (Defini-tions etc.)	Dead ends
Costs	8	3	2	0	1	0
Building efficiency	3	0,5	4	0	0	0
Sustainability	6	0,5	2	1	0	0
m2 per user	31	17,5	27	0	5	0
Frequency and occupancy	15	8	15	2	0	0
Quality	18	5,5	18	6	13	0
User satisfaction	12	8,5	8	2	5	0
M2 per seat	13	6,5	7	2	2	0
Score indoor climate	16	0	6	8	3	0
Confirmation / Disproval	261			50		

TABLE APP.5.4 Positive and negative interactions of users with the dashboard in workshop 2 (TU Delft).

Workshop 2	Positive (Confirmation)				Negative (Disproval)	
Indicators	Reaction to alerts, trends	Relation between indicators	Connection to reality	Ignoring alerts	Confusion (Defini-tions etc.)	Dead ends
Costs	4	2,5	3	1	6	0
Building efficiency	2	0,5	0	0	0	0
Sustainability	11	1,5	10	0	0	0
m2 per user	27	11,5	29	0	2	0
Frequency and occupancy	19	8,5	29	0	5	0
Quality	18	8	9	2	2	0
User satisfaction	18	6	9	3	5	0
M2 per seat	0	0	0	0	0	0
Score indoor climate	0	0	0	0	0	0
Confirmation / Disproval	226,5			26		

APPENDIX 6

Smart campus tools in a changing context

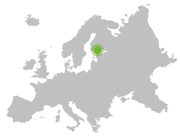
This appendix contains the results of four interviews conducted in the summer of 2020, and a joint session organised for the Dutch universities in November 2020. This data was collected as input for the contents of chapter 10. For each interview, the resulting update of the case study templates is shown. In one case (Aalto University) this is an update of data collection in the master's thesis of Rahkonen (2017). Next, a summary is given of the propositions surveyed during the joint session.

Aalto University Aalto Spaces

phase: Implemented

scale: 104 000 m2, 4 buildings; 2020: 200 000 m2, 18 buildings

duration: 2016-present



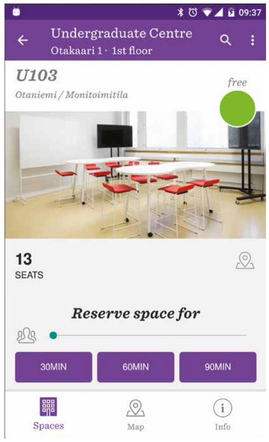
Project description

Aalto University wanted to develop a user-friendly space information system, which enables to utilize space reservation information with mobile devices. The mobile app enables to spot vacant spaces, reserve them, and find a route by using self-phone's location data.

Foreseen developments

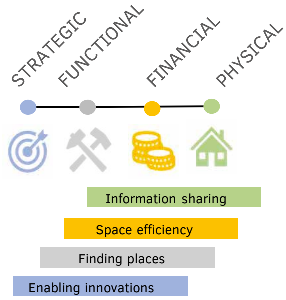
The objective is to extend Aalto Spaces to eventually cover all buildings on campus. Including identification to the service is also being considered.
2020: We are currently looking at using sensors to measure no-shows and occupancy. This would be helpful to further improve the efficient use of spaces on campus.

Investment costs (per m2 GFA): € 1,15. 2020: € 0,75
Operating costs (per m2 GFA): € 0,12. 2020: € 0,05



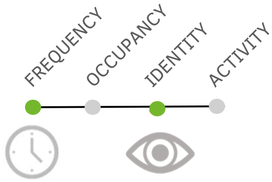
Profile

Why: Objectives



Main objective is to provide easy access to information regarding what kind of spaces are available, and in that way increase space usage rates.

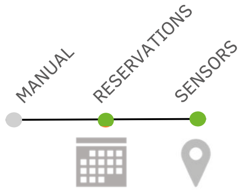
What: Measurement



Application has rights to identify users by phone number. Identification is used to minimize misuse cases.

Reservation data is used to determine the frequency (usage) rate of the spaces that can be reserved in Aalto Spaces.

How: Measurement method



Aalto Spaces offers a functionality to reserve spaces via the app. Spaces can also be reserved via MS Exchange and via a webpage. In the reservation system, all bookings are put together and one can see from which interface the booking is made.

Location data of the users is provided via Bluetooth (by Steerpath). This enables the user to navigate through the building from their current position.

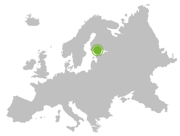
TOC

Aalto University

Aalto Spaces

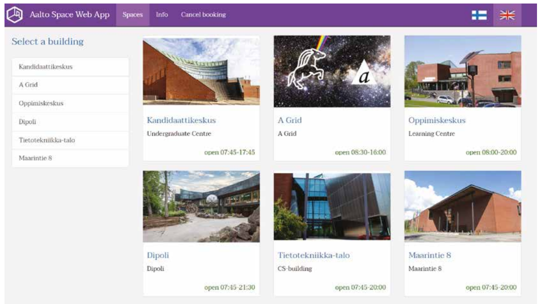
functionality: Finding space, guiding route

Space types: Class rooms, learning spaces, meeting rooms



User information

Easy to view which spaces are vacant in real time in any location with your own self-phone. Some of the spaces can be booked via the app. The app also guides user to the selected destination (room). The service is also available in web browser version.

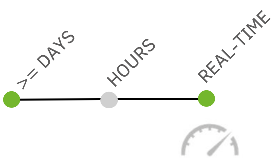


Management information

Management can use the system to deliver emergency messages. Managementmay monitor the number of bookings made by individual users. The system collects anonymous raw data which can be used in statistics, analyses, andresearch carried out by Aalto university and its partners.

2020: The analyses mostly are done with booking system data, which serves Aalto Space app. Feedback of the app itself & the spaces may be also given in the app. App usage provides data for the usage of various reservation channels.

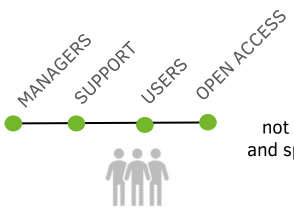
Actuality of the information



Real-time information about space reservations is available in mobile app.

2020: Management information is available from real-time until a year back in the reservation system.

Access levels



Data collection is enabled for management, space bookings are available for students and staff, and guidance to selected places is provided as open access.

Benefits

2020: The navigation functionality reduces the time needed to find a suitable space to 3-5 minutes. The space reservation functionality has dramatically increased the space usage (frequency); exact number not available. During COVID-19, the reservations and space tracking enable safe use of the campus.

Side notes

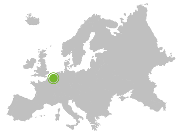
Aalto Space has been designed together with the users of the spaces and with the entire Aalto community. The aim of the Aalto Space campus app is to support the University's digital strategy. We want to offer a seamless mobile user experience and platform that serves the whole Aalto community. Aalto Space is user-oriented, and its agile development process brings together the different actors at the campus.

KL — University of Leuven — Blokken in Leuven

phase
Implementation

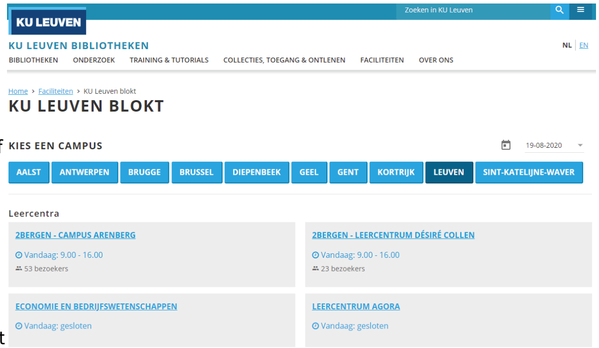
scale
30.151 m2 (+2.276 m2)
12 buildings (+2)

duration
2013 -
present



Project description

The initiative of this smart tool was taken as one of the measures to enable the increasing demand for social learning on campus. Blokken in Leuven was introduced to give students insight into the distribution of students across campus. The data and infrastructure was already in place; access control systems had been in the Library for quite a while and the data was already being used to determine the # of study places and opening hours of Library locations.
2020: The initiative to make adjustments was taken in reaction to the Coronacrisis and the need to facilitate use of the campus given the restrictions to using indoor spaces.



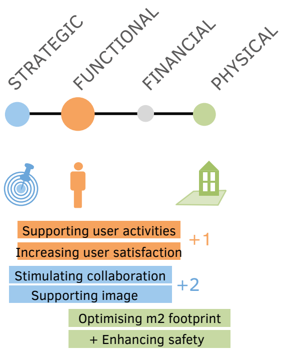
User interface on webpage (2020)

Foreseen developments

It is a wish to make a distinction between the occupancy of study places and project rooms, but that is still in an exploratory phase. Also the data of the access control is being used to do (anonimised) research on the relation between the time that a student studies in the library and his/her study results - Learning Analytics.
2020: Reducing synchronisation time to enable action on no-shows and early check-outs. Learning Analytics is still an idea, perhaps for a student research project.

Profile

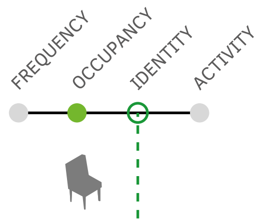
Why: Objectives



Supporting users has the highest priority; this is achieved by providing a supply that fits the needs of the users.

2020: Enhancing safety is added: the tool supports a safe return to campus

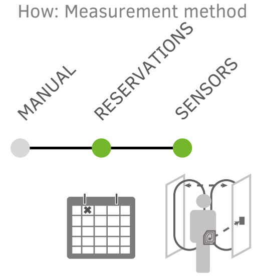
What: Measurement



The data is anonymised in reporting. 2020: The system uses sensitive information as it can identify if a student has a reservation. The student agrees to the use of his/her personal data for the purposes of access control when he/she accesses the location.

The amount of registered users present at a location is measured, resulting in an occupancy number per library.

How: Measurement method



Reservations (booking system) — Access control (campus card)

Access to each Library is granted via access control systems. These systems allow users entry based on the privileges on their campus card. Each user is counted individually, therefore the users in the building at a given time can be monitored.

2020: During the Corona crisis students can reserve a workplace and gain access to buildings via their reservations.

TOC

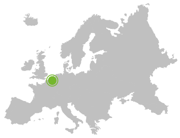
KL

University of Leuven

Blokken in Leuven

functionalities
Find a workplace, Monitor space use, Room booking

space types
Study places, project rooms



User information (open access)

The user can see an overview of the Library locations on campus and the occupancy of each of these locations (building level). The interface also shows the opening hours and provides links to the website of each library, the location in Google Maps and the Facebook page. The information is also displayed on other media, such as the student app Quivr.

2020: The user sees an overview of the Library locations on campus and opening hours. The occupancy of the locations is now hidden during Corona to avoid confusion. The user can click on each location to show further information, among which a link to the reservation portal (KURT) to make a reservation for a study place.

Home > Faciliteiten > Blokken in Leuven

BLOKKEN IN LEUVEN

Leercentra

2BERGEN - CAMPUS ARENBERG
614 / 700
Vandaag: 08.00 - 24.00

2BERGEN - LEERCENTRUM DÉSIRÉ COLLEN
280 / 400
Vandaag: 8.30 - 21.00

ECONOMIE EN BEDRIJFSWETENSCHAPPEN
500 / 500
Vandaag: 8.00 - 24.00

LEERCENTRUM AGORA
455 / 500
Vandaag: 8.00 - 24.00

Bibliotheken

ARTES – ERASMUSHUIS
186 / 186
Vandaag: 9.00 - 20.00

ARTES – UNIVERSITEITSBIBLIOTHEEK
167 / 280
Vandaag: 9.00 - 20.00

CAMPUS KULAK
201 / 350
Vandaag: 8.30 - 22.00

HOGER INSTITUUT VOOR WIJSBEGEERTE
64 / 70
Vandaag: 9.00 - 22.00

Bezetting van de bibliotheek

Maand	All
Week	All
Bibliotheek	AGORA

Sum of Bezet	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2/01/2017	23	291	316	339	300	179	322	372	355	360	293	167	259	283	216	106	-3
3/01/2017	29	378	409	428	342	176	370	436	424	420	310	183	297	340	232	108	-13
4/01/2017	0	371	387	410	329	204	371	421	426	420	295	223	322	362	269	122	0
5/01/2017	26	376	397	422	351	208	365	437	431	424	312	207	334	342	267	126	-8

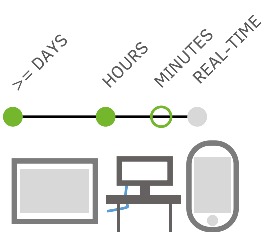
Management information

A report of the informatics department. Analytics: amount of unique visitors per year/month, amount of visitors per year/month, occupancy per hour.

In the picture, the library occupancy per hour is shown. The shades of red show intensity; light red shows low occupancy, dark red high occupancy.

2020: There are now also reports available regarding the reservations. Reporting is done in Excel, but there are plans to do reporting via PowerBI.

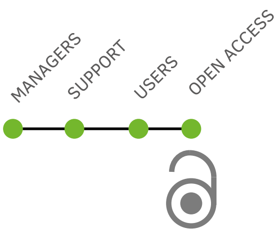
Actuality of the information



2020: The information that is displayed has a delay of +/- an hour due to synchronisation issues between applications. (Previously the delay was a few minutes)

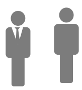
The data used in reporting is aggregated data over a monthly or yearly period.

Access levels



Everyone can access the webpage.

2020: Reservations are restricted to users.



Reports are accessible to the persons responsible for each Library desk and to the coordinator. Libraries can specify the reports to their own locations.

Benefits

Prior to the implementation the objective was to spread the business of the inner city locations to the Heverlee campus (Arenberg and Gasthuisberg). The occupancy rates per location are compared - to each other and to the previous periods - to see if this achieved.

2020: We were worried that the demand for study places would be too big in returning to campus. The Smart campus tool has resulted in the acceptance of the reduced capacity.

Side notes

The interface of Blokken in Leuven is not a goal in itself; providing the data to the user is. Therefore it is important that the data is communicated to different systems and applications that have a use for the data.

2020: The balance between types of places in the libraries and learning centres is something that we will have to figure out in this new situation. What kind of study places do students want when they come to study on campus?

TOC

TUE | TU Eindhoven | Book my space - Planon

phase: Implementation

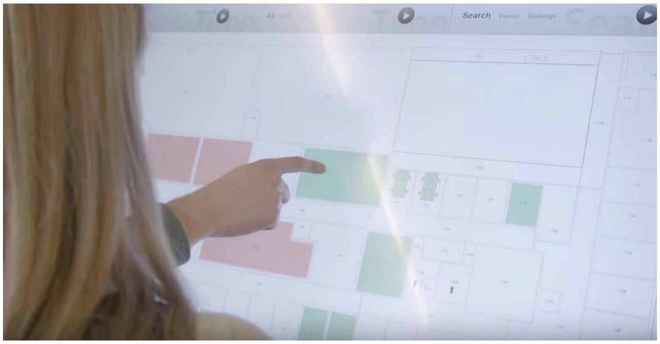
scale: 243.905 m2 (+30.905)

duration: Q1 2016 - present

Project description

The project was initiated because of the strong increase in students studying at TU Eindhoven. The university could not invest in buildings, so the amount of users per m2 needed to increase. A functional programme of requirements was written to six parties. Planon was chosen because they best met the requirements and because it was already used at TU Eindhoven.

The basis is in an implementation phase; the sensoring and linking Syllabus to Planon is in the development phase.



Foreseen developments

Linking Syllabus to Planon, upgrading the release of 2017 (Planon webclient), workplace sensoring, Lora network.

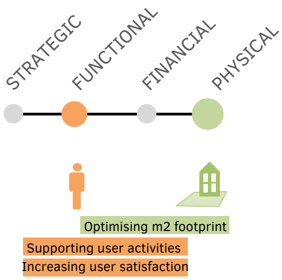
Another objective is to bring the data from Planon and the data from the manual occupancy measurements together in one report.

2020: Planon has organised a webinar with ideas to help in times of Corona, e.g. by entrance control. This has not yet been implemented.

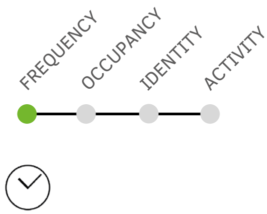
There is now a link between Planon and Syllabus, but it is a one-way link (from Syllabus to Planon). We will wait with developing a two-way link until we have a new scheduling system (TimeEdit). Also, we are in the process of procuring our FMIS system (Planon). In the new Planon-app, it is possible to verify a reservation (via QR) - without verification it is cancelled after 15 minutes, in order to reduce the waste of space due to no-shows.

Profile

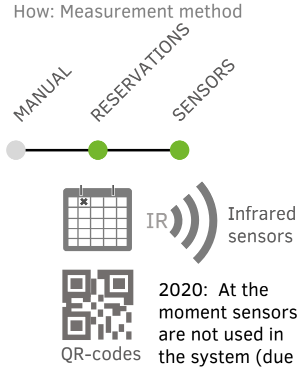
Why: Objectives



What: Measurement



How: Measurement method



2020: At the moment sensors are not used in the system (due to COVID-19)

A higher amount of users per m2 has priority, and is achieved by a uniform way of making reservations and findability of available spaces.

The duration of the reservation is compared to the maximum amount of available hours in order to determine frequency. There is a pilot in one building with sensors, which register the actual frequency and can thus determine no-show and early leave.

Reservations are made via Planon. Infrared sensors that are connected to the lighting, detect presence in meeting rooms which indicates if a reservation is used. In addition manual counts are done (separately) in the education spaces.

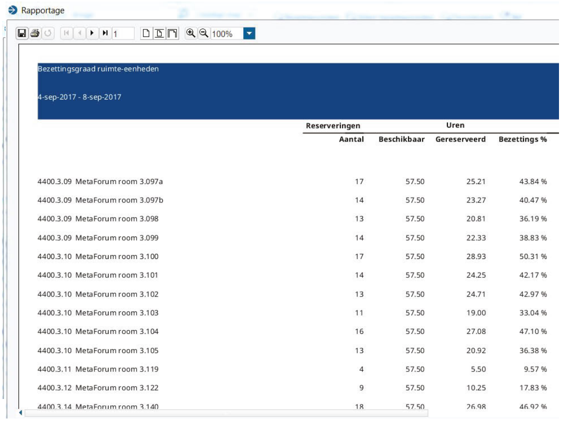
TUE TU Eindhoven Book my space - Planon

functionalities
Find a workplace, room booking, monitoring space use
2020: reserving study places + workplaces

space types
Education space, flexible workplaces, meeting rooms

User information

Users can see where the study places, meeting rooms or work places are on campus and if they are available with their smartphones, a website or one of the kiosks. Then they can reserve a workplace or a group room.

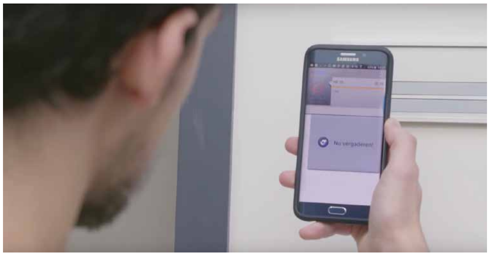


Rapportage

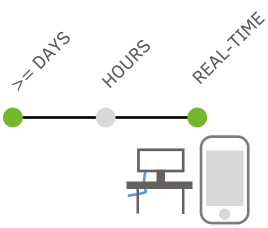
Bezettingsgraad ruimte-eenheden

4-sep-2017 - 8-sep-2017

	Reserveringen	Uren		
	Aantal	Beschikbaar	Gereserveerd	Bezettings %
4400.3.09 MetaForum room 3.097a	17	57.50	25.21	43.84 %
4400.3.09 MetaForum room 3.097b	14	57.50	23.27	40.47 %
4400.3.09 MetaForum room 3.098	13	57.50	20.81	36.19 %
4400.3.09 MetaForum room 3.099	14	57.50	22.33	38.83 %
4400.3.10 MetaForum room 3.100	17	57.50	28.93	50.31 %
4400.3.10 MetaForum room 3.101	14	57.50	24.25	42.17 %
4400.3.10 MetaForum room 3.102	13	57.50	24.71	42.97 %
4400.3.10 MetaForum room 3.103	11	57.50	19.00	33.04 %
4400.3.10 MetaForum room 3.104	16	57.50	27.08	47.10 %
4400.3.10 MetaForum room 3.105	13	57.50	20.92	36.38 %
4400.3.11 MetaForum room 3.119	4	57.50	5.50	9.57 %
4400.3.12 MetaForum room 3.122	9	57.50	10.25	17.83 %
4400.3.14 MetaForum room 3.140	18	57.50	26.98	46.92 %



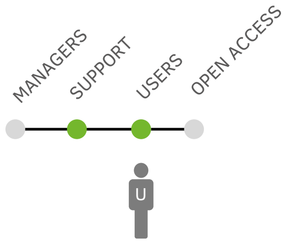
Actuality of the information



Information on the selfservice, app, and the kiosks is real-time.

Reports are available on demand. Dashboards need to be used more in the future.

Access levels



Students and employees have access via Selfservice, an App, Outlook and the Kiosks in the buildings

Secretaries have access to reservations via Planon Procenter.

Management information

Occupancy percentages of all reservable spaces: education spaces, study places and flexible workplaces.

Benefits

The objective was to increase the frequency rate of meeting rooms and the occupancy rate of workplaces by 10% within four years. After one year the increase is already 13%.

2020: With a reservation system for study places it is easier to keep sight of where students are on the campus, and if there may be capacity issues. With regard to the previous benefit: there is no accurate picture at the moment, because not all study places can be reserved.

Side notes

Managers get more insight into space use and can make decisions more conciously. Students have a tool to reserve space and have access to more spaces (also in other buildings) than previously.

2020: In order to check whether rooms are not used with a larger capacity than possible, employees will check on-site if spaces are used correctly.
It was a huge operation to realise more bookable spaces: drawings with bookable workplaces, implement al these workplaces and make them bookable or not-bookable, rearrange the furniture in the rooms, communicate with posters, banners and stickers .

WU — Wageningen University — PIE, Clocks (Lone Rooftop)

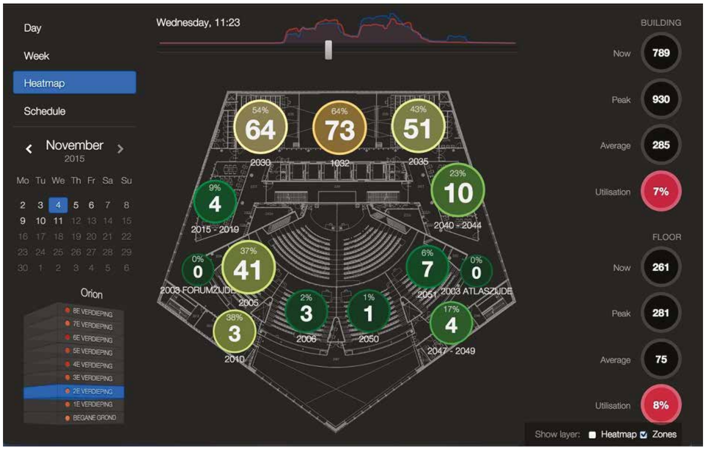
phase: implementation

scale: 21.000 m2 NFA, 6 buildings

duration: 2015 - present

Project description

At the WUR we had a demand for the use of big data and sensors relating to our operations, but it was difficult to formulate a specific application. We didn't know exactly what we wanted to know. In this project we could make it very specific: we measure in specific buildings, we measure students, with a specific method to understand the use of education spaces in relation to the schedule. That makes it easy to steer on the project. At the time the WUR had just built a number of new education buildings, and building more was not an option. Therefore the question was: how well are these buildings actually used? Lone Rooftop came at the right moment, after which we started in 2015.



PIE dashboard

Foreseen developments

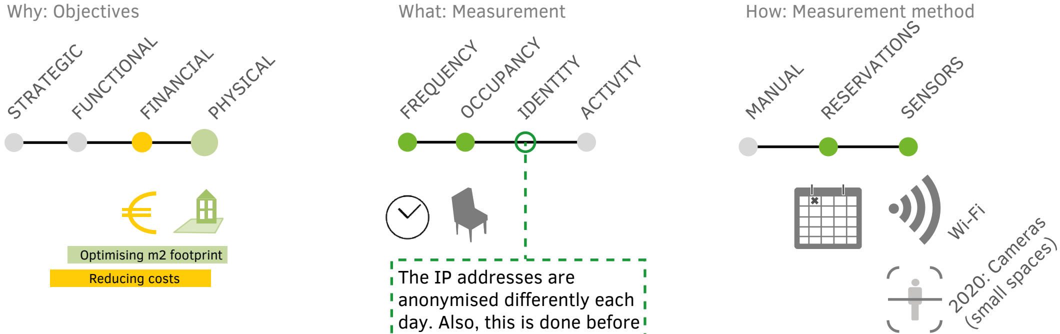
2020: The measurements in small spaces have led to the use of cameras to determine occupancy. The size of the implementation will increase once the new education building is delivered.

Profile

Why: Objectives

What: Measurement

How: Measurement method



The IP addresses are anonymised differently each day. Also, this is done before the data leaves the university's network.

Optimising m2 is done by gaining insight into no-show behaviour. From the facility management perspective the delivery of this information was one of the measures taken to use the existing space more efficiently.

An indication of the occupancy is given for a predetermined zone. The size of this zone is aligned to the accuracy of the measure-ment.

Wi-Fi determines where devices are within the building (active and passive). Via an algorithm devices are paired if the algorithm determines they belong to one user. That is how the amount of users in a zone is determined.

TOC

WU Wageningen University PIE, Clocks (Lone Rooftop)

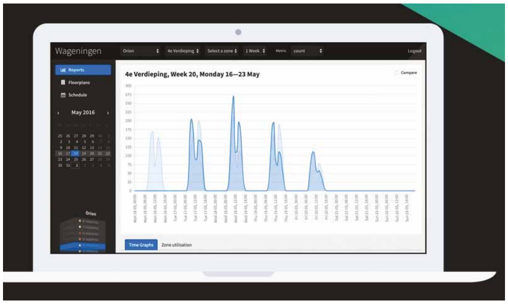
functionalities
Monitoring space use

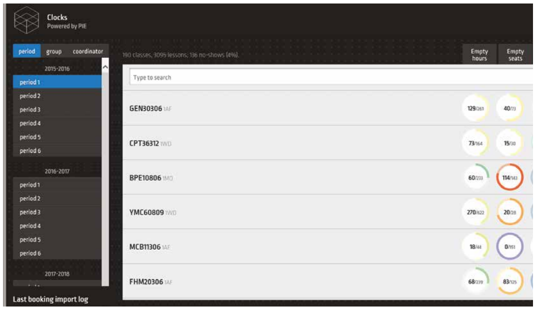
space types
Education spaces,
Whole building
2020: + Common areas

›r information (scheduler)

›user (scheduler) receives a report in which the ›ıpancy data for lecture halls is linked to scheduling ›ı. The amount of no-shows and occupancy per activity ›splayed.

›system is also used by location management to get ›ght into where people are in the building and how ›y people there are during the day, and during the ›ing hours.





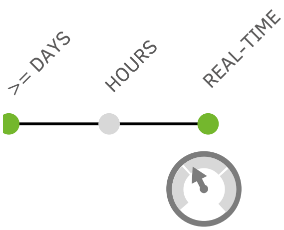
Management inform›

The building manager can see how many users there a› different zones of the building (see PIE dashbo›

For the education spaces the data can be linked to› schedule. We are looking specifically at no-shows.› focus is on the use of education spaces and schedul›

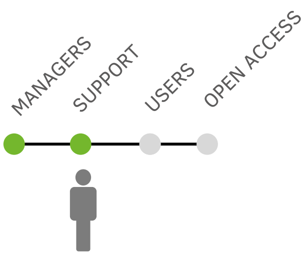
2020: The schedulers now look at empty hours to optir› the schedule, in addition to no-sh›

›tuality of the information



The information displayed in PIE is near-real time.

Access levels



PIE is available to location managers. Clocks is available to schedulers.

Ben›

The first experiences with the system are th› leads to an improvement of 5-10 procent in s› efficiency. In 2018 a new schedule wi› implemented that includes more hours per day› shorter hours, which enables us to accommo› growth in the near fu›

Side n›

2020: Additional sensors have been adde› monitor the use of small spaces - Wi-Fi is› accurate enough for these spa›

›data used in ›orting goes from ›-time to as far back ›ossible.

PIE and Clocks are available to specific people from Facility Services.

TABLE APP.6.1 Results on the first three propositions in the joint meeting, discussing the current use of smart campus tools in the changing context.

Proposition	Respondents	Response	#
Smart campus tools have not been used during the lockdown	15	Disagree	1
		Partly agree	9
		Agree	6
Since the lockdown my university…	14	Purchased new smart tools (or in progress)	6
		Expanded the functionality of existing tools	7
		Nothing – existing tools fulfil current needs	1
		Nothing – no smart tools in use	0
The willingness to adopt Smart tools at my university…	12	Increased	7
		Decreased	0
		Stayed the same	5

TABLE APP.6.2 Results on the remaining propositions of the joint meeting, discussing the future demand for smart campus tools related to the future demand for spaces on campus.

Proposition	Respondents	Response	Score*
What is the future demand for education spaces	12	Lecture halls and large classrooms	3.4 (-1.6)
		Spaces for group work	7.9 (+2,9)
What is the future demand for smart campus tools in education spaces	12	Steering based on scheduled frequency and occupancy	6.9 (+1.9)
		Steering based on real-time frequency and occupancy	6.2 (+1.2)
		Using education spaces as study places when not in use	7.8 (+2.8)
What is the future demand for study places	10	Silent study places	7.8 (+2.8)
		Spaces to meet	8.8 (+3.8)
		Study hubs outside of the campus	4.7 (-0.3)
What is the future demand for smart campus tools in education spaces	11	Steering based on reservation data (+ incentives)	5.3 (+0.3)
		Steering based on sensing (real-time occupancy)	7.3 (+1.3)
What is the future demand for offices	10	Silent places + meeting on campus	7.4 (+2.4)
		Hubs outside the campus	4.5 (-0.5)
		Well-equipped workplaces at home	7.9 (+2.9)
What is the future demand for smart campus tools in the offices	11	Steering on reservation data	6.4 (+1.4)
		Steering on incentive model	4.2 (-0.8)
		Steering based on sensing (real-time occupancy)	6.5 (+1.5)

** 0-10; 5 = current demand*

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Publication list

Journal papers

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Curriculum Vitae

Bart Valks (1990) is a specialist in the intersection between real estate management, management information and sensing technology. He has a background in Architecture (BSc. 2008-11) and Real estate management (MSc. 2011-13). During his minor at TU Vienna (2010), he started to focus on researching the built environment, through three different theses. For his Master's thesis -aimed at the design of a real estate portfolio of lecture halls of TU Delft based on stakeholder preferences- he received an honourable mention from the university, and a second place in the 2013 CoreNet Student Award for best MSc thesis. The resulting journal paper was awarded the 'Outstanding paper award' from the Journal of Corporate Real Estate in 2016.

After his graduation in 2013, Bart worked as a policy officer at the department of Campus and Real Estate, TU Delft. As a policy officer, his objective was to support campus decisions through analysis and policy making. He was part of the team that developed TU Delft's policies for education spaces and study places, implemented them on campus, and monitored the progress over time. The results include an increase in the quality of the spaces, uniformity in the use of all spaces across campus, and a decrease in the required amount of spaces per user. Furthermore, the buildings Pulse and Echo were planned and realised during this period. Next to the policies on education spaces, he has contributed to the university's portfolio management, in particular through the development, monitoring and adjustment of the university's campus strategy in various roles.

Since the start of 2016, Bart has combined his position as a policy officer with his research on Smart campus tools. In this position, he has conducted research in assignment of the directors of Facility Management departments of the 14 Dutch universities. During his research, he built an international network of real estate managers, facility managers, IT professionals and librarians who are working on Smart campus tools both at universities and other organisations. He involved them in the research as interviewees, but also shared the results with them via interactive sessions and two book publications for practitioners, which have sold over 150 copies. Furthermore, he also supervised more than 10 students in their Master's thesis projects related to Smart campus tools – both in formal and informal roles. His research has been published in various scientific journals and cited by academics in different fields. Also, he has given many presentations to national and international audiences, students, academics and practitioners – both on his research and on his work in practice.

21#18

Smart Campus Tools

Technologies to support campus users and campus managers

Bart Valks

In recent years, the density on the Dutch university campus has increased substantially due to a continued growth of student populations. Campus managers face the challenge of accommodating the university's students and employees mainly in the existing buildings, which are used ineffectively and inefficiently. In order to improve the space use on campus, campus managers need better information about space use. Therefore, this PhD dissertation proposes the use of Smart campus tools: a service or product with which information on space use is collected real-time to improve utilization of the current campus on the one hand, and to improve decision-making about the future campus on the other hand. The main research question is: How can smart campus tools optimally contribute to the match between demand for and supply of space, both on the current campus and on the future campus?

To answer the research question, this PhD dissertation explores the use of Smart campus tools in Dutch and international contexts, at universities and other organisations. Then, it researches how information from Smart campus tools can be properly connected to campus decision-making processes. The results from this research are used to inform existing theories and draw lessons for practice.

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