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Smart campus tools 2.0 exploring the use of real-time space use measurement at universities and organizations

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Abstract

Purpose – The purpose of this study is to generate knowledge about the use of smart campus tools to improve the effective and efficient use of campuses. Many universities are facing a challenge in attuning their accommodation to organisational demand. How can universities invest their resources as effectively as possible and not in space that will be poorly utilized? The hypothesis of this paper is that by using smart campus tools, this problem can be solved.

Design/methodology/approach – To answer the research question, previous survey at 13 Dutch universities was updated and compared with a survey of various universities and other organizations. The survey consisted of interviews with structured and semi-structured questions, which resulted in a unified output for 27 cases.

Findings – Based on the output of the cases, the development of smart campus tools at Dutch universities was compared to that of international universities and other organizations. Furthermore, the data collection led to insights regarding the reasons for initiating smart campus tools, user and management information, costs and benefits and foreseen developments.

Originality/value – Although the use of smart tools in practice has gained significant momentum in the past few years, research on the subject is still very technology-oriented and not well-connected to facility management and real estate management. This paper provides an overview of the ways in which universities and organizations are currently supporting their users, improving the use of their buildings and reducing their energy footprint through the use of smart tools.

Keywords Public sector, Facilities management services, Smart buildings, Space planning, Space utilization, Strategic facilities management

Paper type Research paper

1. Introduction

In the field of corporate real estate management (CREM), the objective is to optimally attune the corporate accommodation to organizational performance. The challenge is that real estate is static –with a 50-year life span – and very cost-intensive, whereas demand is

The authors would like to thank the directors of the real estate and facilities departments of the fourteen Dutch universities for their request for and participation in this research. They would also like to thank all the interviewees of both the universities and the companies for their direct or indirect contribution to this paper.

dynamic, with yearly budgets and targets and 2-5 year strategies. In addition, the challenge exists on different scales – matching demands from society, organizational objectives and individuals to the portfolio, buildings and places (De Jonge *et al.*, 2009). This alignment of corporate real estate and corporate strategies for organizational value is a long-standing issue in the field (Heywood and Arkesteijn, 2017).

The current situation at Dutch universities demonstrates this complexity. On the scale level of the portfolio and the organization, the universities are dealing with large, ageing real estate portfolios, which are increasingly unfit for purpose and require renewal. At the same time, they are faced with an increase in student numbers, a decrease in public funding per student and a high-quality ambition for education spaces and laboratories. This means that the universities have to do more – provide more workplaces with higher quality – with relatively fewer resources (Den Heijer, 2011; TU Delft, 2016). Research on the European campus suggests that this is not only a Dutch problem – it is also a European problem (Den Heijer and Tzovlas, 2014). This change in context was the cause for the directors of facilities management of the Dutch universities to fund a research project on how to improve the effective and efficient use of space. The hypothesis of the research is that by measuring space use real-time, this problem can be solved: information on real-time space use can help users to make better use of spaces on today's campus and support campus managers with management information to make better decisions on the future campus. In this research, systems or services that measure space use real-time and deliver this information to users or campus managers are termed "smart campus tools".

There are many examples of research from various fields where space use is measured real-time. The earliest examples can be found in the fields of electrical engineering and computer science, where sensors were used to automate lighting, heating and/or ventilation based on the presence of people or the number of occupants. The purpose of the research is to achieve energy savings. Earlier research uses infrared sensors to determine presence (Chung and Burnett, 2001; Garg and Bansal, 2000), whereas more recently existing infrastructure is used such as Wi-Fi networks or monitoring PC activity (Balaji *et al.*, 2013; Christensen *et al.*, 2014; Martani *et al.*, 2012).

Another application area in indoor environments is the development of indoor localisation systems based on FM radio signals or Wi-Fi (Castro *et al.*, 2001; Chen *et al.*, 2012; Jiang *et al.*, 2012). Localization systems focus on the benefits for the end-user, mentioning the potential that it has to help people search and navigate within buildings (Chen *et al.*, 2012), but also on the insight that it can deliver into issues such as employee productivity or building security (Jiang *et al.*, 2012). The papers in this area focus on system development or improvement and report on system accuracy and other performance criteria. In healthcare research, Bluetooth, wearable sensors and Wi-Fi are used to monitor people in assisted living situations (Orozco-Ochoa *et al.*, 2011; Rodríguez-Martín *et al.*, 2013; Villarrubia *et al.*, 2014). The studies in this area report on technical aspects such as accuracy or system design.

Finally, in (semi-)outdoor environments, larger scale studies have been done that measure user flows using Wi-Fi and Bluetooth at large events such as Formula 1 races, football matches or outdoor festivals to improve safety, improve wayfinding or to review the performance of investments (Liebig *et al.*, 2014; Stange *et al.*, 2011; Versichele *et al.*, 2012). These studies usually report on the number of visitors, their stay duration and movement patterns. A few studies exist where similar methods are applied in indoor environments: station areas (Van den Heuvel *et al.*, 2012; van den Heuvel and Hoogenraad, 2014), hospitals (Ruiz-Ruiz *et al.*, 2014) and airports (Schauer *et al.*, 2014).

However, what is common among the smart campus tools reported in scientific publications is that the papers present the development of new or improved systems. Therefore, most papers report on performance criteria such as accuracy and apply the systems on a relatively small scale – for example, a room or floor. Similarly, studies in semi-outdoor environments report experiments done during an event of a few days. Mathisen *et al.* (2016) argue that this is an issue from a technical perspective: the lack of extensive evaluations of systems in large-scale real-world environments leads to issues when transferring system performance results (i.e. accuracy and related metrics) from a small controlled setting to a large environment. However, with regard to the hypothesis of the smart campus tools research, there is another issue: systems are still primarily evaluated from a technical perspective and not yet from a functional perspective. To know if and how smart campus tools actually support users, save energy or help make better decisions on the future campus, data need to be collected on real-life implementations. This study has collected data of 27 real-life cases, studying how smart campus tools are implemented in practice and what organizational demands are, thereby providing valuable knowledge to researchers developing new systems. Simultaneously, it helps to develop knowledge on the subject from a FM/CREM perspective, where the use of these technologies is still a sparsely researched area.

In 2016, a first research project on "smart campus tools" was initiated, exploring the use of smart campus tools at the Dutch universities. In this research, a conceptual model was constructed to understand the concept of smart campus tools. Because the focus of the research was product-oriented (i.e. what is the demand and what is available), the focus of the conceptual model was also on understanding what smart campus tools were and what its components were. Based on the findings of this research, a second project was started – Smart campus tools 2.0 – which aimed to explore the use of smart campus tools at international universities and other CRE organizations. The research question of this project is:

RQ1. What smart tools are being used by international universities and organizations and how do they compare to the use of smart tools in the Netherlands?

In this research project, the development of the conceptual model is expanded, not only viewing the studied cases of smart tools in isolation but also looking at the surrounding context.

The remainder of this paper is structured as follows: first, the research methodology is discussed, followed by the conceptual model of smart campus tools, which reflects how the researchers view the phenomenon. Then, the results of the data collection are discussed, followed by a discussion on additional findings of the research and a conclusion in which the research question is answered.

2. Research methodology

The smart campus tools research can be framed within a naturalistic system of inquiry. The researchers recognize that there is an inherent dynamic between the researchers, the practitioners and the object of study (Groat and Wang, 2002, p. 33); this is reflected in the explorative nature of the study and the objectives. Smart campus tools 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.

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 and Wang, 2002, p. 176). Smart campus tools are part of a very complex system in which organizational, technological and behavioral factors together determine if real estate is used more effectively and efficiently. To understand if smart campus tools add value to the university campus, they must be understood within this complex system. In addition, because smart campus tools are relatively new, collecting quantitative data on their added value would be premature. Table I shows how the qualitative research strategy is applied in this research.

The research consists of three major components:

(1) a survey of international universities;

(2) a survey of other organizations (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 standardized "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 smart campus tools 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 organizations, the interviews are administered in one or two sessions, either physically or by telephone. An organization can fill in multiple templates if they have multiple smart campus tools implemented. For the survey of Dutch universities, the interview schedule is filled in with the data from the previous research (Valks *et al.*, 2018) 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 smart tools for study places. For other organizations, news alerts were used to discover cases in which smart tools 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

Characteristics of qualitative research	Smart campus tools 2.0 research
Studying things in their natural settings	By studying smart campus tools from the perspective of campus managers, the data collection focuses on smart campus tools 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 smart campus tools 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

Table I. Smart campus tools 2.0 research and characteristics of qualitative research selection process; all universities were requested to fill in the survey and update the data recorded in the previous research.

3. Constructing the conceptual model

The development of a conceptual model has been an ongoing process from the outset of the smart campus tools 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, we refer to Valks *et al.* (2018):

- *The why*: why would a university implement a smart tool? Just as with real estate, the basic assumption with smart campus tools is if they would not add value to the university campus, then no university would invest in it. To understand how smart campus tools 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 smart tool collect to achieve the objectives? To understand what data are collected, traditional space use frameworks of NAO (1996) or Space Management Group (2006) 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 Valks *et al.* (2018), 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 smart campus tools is 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 smart campus tools. Practitioners wanted to know if and how the EU's General Data Protection Regulation (GDPR) would affect smart campus tools, what the costs and benefits of different types of smart campus tools were, what the interfaces of different smart campus tools look like and what management information is generated. Smart tools – and whether they are "smart" or "not smart" – can be viewed from many different perspectives, which is visualized in Figure 1. The aspects in the inner circle will be elaborated further in the results section of this paper.

4. Results

This chapter 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 smart campus tools. Finally, the results of the semi-structured data collection are reported, and the focus will shift to understanding smart tools in their respective contexts. The data collection yielded much information that is not discussed in this paper – for a more detailed analysis, we refer to the book publication (Valks *et al.*, 2018).

4.1 Case studies

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

To illustrate the results of the case studies, we provide an example in Figures 2 and 3. The case shown here is the development and implementation of a Smart campus tool called “Plekchecker” by the Dutch government. It was initiated after the government had implemented a new policy for the governmental workplace. 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.

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 Figures 2 and 3. Analysis of the structured output mainly reveals how far along each case is in the development of smart campus tools: how many objectives are achieved, is the smart tool already implemented, how many m2 are covered by the smart tool, 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 smart campus tools phenomenon can be put into context. In the book publication, the

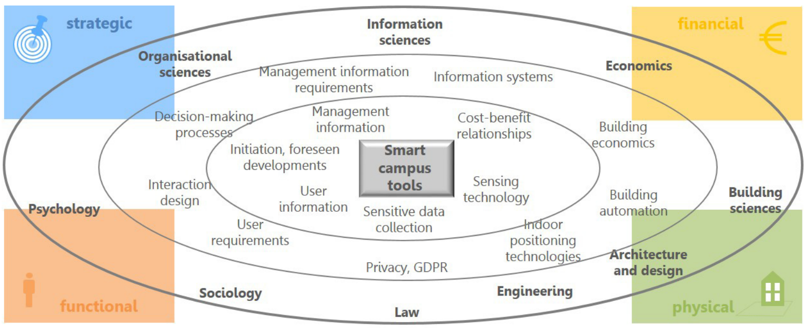

Figure 1.
Smart campus tools and related fields of (applied) research (based on an adaption of Den Heijer (2011)), reflecting the multidisciplinary nature of the research topic

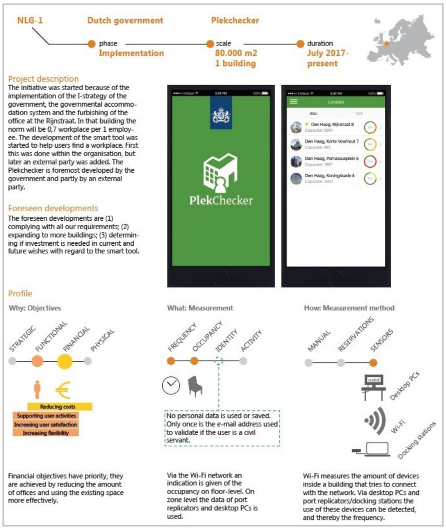

Figure 2. Overview of the results for one of the cases in the research; Page 1

Figure 3. Overview of the results for one of the cases in the research; Page 2

cross-case analysis is done across cases; here, the cases are grouped in international universities, other organizations and Dutch universities.

4.2 Results of the structured data collection

In Table II, the aggregated results on the most relevant aspects of the structured data collection are displayed. When studying the functions of the smart tools in the cases, the following observations can be made. With regard to functions, the smart tools at international universities are highly diverse; furthermore, each case tends to focus on one

Table II. 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, CO2 (2) * Coded light (1) ****	
Wayfinding			Not applicable ***

(*continued*)

	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 m2 footprint	2	2	4
Reducing CO2 footprint	1	2	
Optimising costs		1	
Not specified			2

Notes: *One case also measures these values but has not yet linked them to a specific function; **temperature and CO_2 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

Table II.

specific function. Other organizations have a more unified approach to smart tools, in the sense that find a workplace and monitoring space use are present in most cases. However, organizations tend to combine multiple functions in their smart tools. 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 smart tool project finds itself, the Dutch universities and other organizations are often further when compared to international universities. Also, at universities in both The Netherlands and abroad, research initiatives related to smart campus tools are included as cases.

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, optimizing 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 organizations and to a lesser extent, Dutch universities, this is more complicated: there are more cases of smart tools 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 smart tools. Table III 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 organizations, which they combine in the same smart tool) 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; and
- 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 organizations mention supporting user activities as the main objective. At Dutch universities, reducing the m2 footprint has the highest priority. However, when compared to the functions provided in the smart tools, it seems that there is a slight misbalance; at other organizations, one would expect a more equal priority for supporting user activities and reducing the m2 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 organizations, strategic and functional objectives are dominant, while physical and financial objectives are often mentioned.

4.3 Results of the semi-structured data collection

The aggregated results of the semi-structured data collection are shown in Table III. In the project description, the interviewees indicated the reasons for initiating the smart

Table III. Cross-case analysis showing the aggregated results per survey

	International universities	Other organizations	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 optimize space use and in some cases also to save energy. However the interviewees have stated different reasons for initiating their smart tools, 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 smart tool	2	3	5
Development of a user app		3	
Other	2 (Analyzing space use data in relation to study success)	2 (use of data for further optimization of the building)	3 (Linking the smart tool to other information systems)
Costs	Anonymized comparison; nine cases indicate investment costs/m2, ranging between €0.7-18/m2. Five cases indicate operating costs per m2, ranging from €0-1.9/m2.		
Benefits	6/9	7/9	7/9
Optimizing 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 amount of reservations in the system (3400 per month) 1; evaluated through short surveys with students 1; smart tool enables a transition to a different way of scheduling 1; evaluated through anecdotal evidence

(*continued*)

	International universities	Other organizations	Dutch universities
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		
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

Table III.

campus tool 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 organizations, the solutions are more alike and similar in what they measure and their objectives, although the reasons for initiating the smart campus tools vary slightly. A possible explanation for this is that organizations commonly have the office as their primary type of space, for which more standardized 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 Smart campus tools 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 smart campus tool if applicable. The fact that many cases indicate some form of development shows how topical smart campus tools is and how fast-paced the development is going. With regard to foreseen developments, the components mentioned amongst the different surveys are very similar.

Gathering data on the costs of smart campus tools was quite complex. Some interviewees preferred to not share data on costs at all, while 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 smart campus tool – more sensors means a more expensive solution – and the scale on which they are applied – generally more m2 means a slight decrease in costs per m2. This is reflected in the large bandwidth that is found in the collected data on costs.

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

(1) What is the main objective that is stated?
(2) In what way is the objective evaluated?
(3) Is there concrete evidence of an improvement with regard to the stated objective?

The results in Table III 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 smart tools have only been implemented for a very short time, if they have been implemented at all – Table II showed that only 11 of the 27 cases are implementations.

With regard to the way privacy is addressed in the smart tools, 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 anonymized before it leaves the network of the university of organization. Furthermore, the opt-in principle is used in multiple cases. Here, users can give or revoke permission to share their data to make use of the service. Finally, personal data ownership is applied at two other organizations. In these cases, employees have access to a personal page in which they can determine how their personal data are used in the smart tool.

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 smart campus tools. When analyzing the data after the data collection, the responses could be roughly grouped into four categories:

(1) 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.

(2) 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 smart tool. Campus managers can see automated reports, but not adjust them.

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

(4) None; no information is provided.

Table III shows the amount 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 categorize 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 it was generated by an analyst. 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 are collected show 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.

5. Discussion

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 among students, employees, policy-makers and campus managers for the topic. As discussed in the paragraph on the conceptual model, the data collection approached smart campus tools 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 smart campus tools within their context.

5.1 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 Valks *et al.* (2018). The first framework displayed the development of smart campus tools at Dutch universities where each phase stands for a phase in which the Dutch universities are working on smart campus tools (Figure 4). During the previous year, the results of the interviews were continuously positioned in this framework which led to the realization that in terms of objectives smart campus tools were becoming increasingly integrated. The figure was then reworked to its current form in Figure 5, containing the following phases:

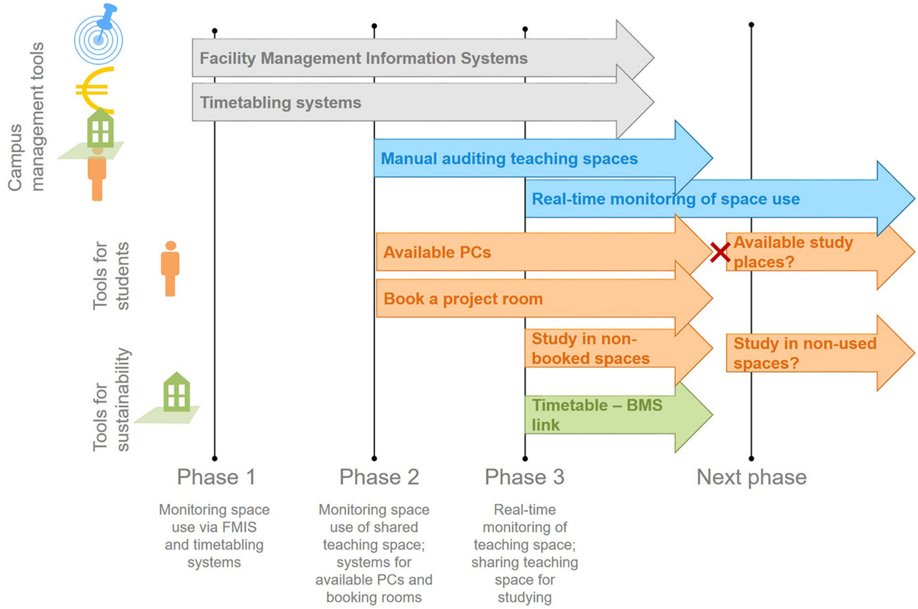

Figure 4. Overview of the available smart campus tools at Dutch universities in 2016, positioned in time to indicate the development of smart campus tools

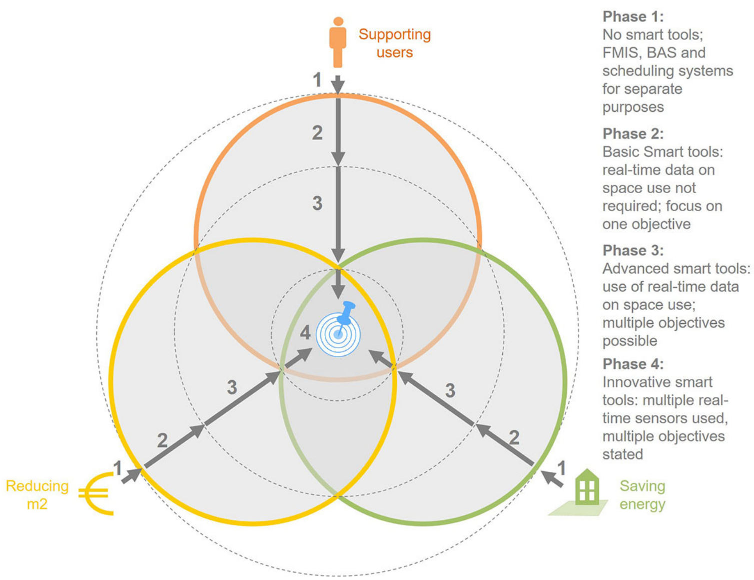

Figure 5. Adjusted overview of available smart campus tools based on the findings of this research

- *Phase 1* – no smart tools, 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 smart tools, which are aimed at individual objectives: usually supporting users and to a lesser extent saving energy and reducing m2; real-time measurement of space use is optional;
- *Phase 3* – advanced smart tools, which collect real-time data of space use; it is possible, but not necessary that multiple objectives are achieved in this phase; and
- *Phase 4* – development of innovative smart tools, 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).

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 organization. Most of the cases discussed in this paper 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 smart tools: Do the benefits of such a smart tool 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 organizations deal with privacy issues in these implementations?

5.2 Directions for further research based on the data collection

The data collection on smart tools gives many directions for further research on smart campus tools. As shown in Figure 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 smart campus tools are available. The following opportunities for further research have been identified by practitioners:

- A detailed study of two or three cases that focuses on the total costs of ownership of their smart tools and their stated and achieved benefits can help academics and practitioners to better understand the business case for smart campus tools. However, especially when a reduction of m2 is desired, it is necessary to wait until a smart tool 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 smart campus tool 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 smart campus tools in relation to other variables of the workplace.

Case studies that study the relationship between the intended benefits of a smart campus tool and the internal processes of an organization. For example, to optimize the use of teaching space, not only a smart tool is necessary, but also identifying what needs to be changed in the organization 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 smart campus tools at organizations.

6. Conclusion

The main research question at the outset of the project was: what smart tools are being used by international universities and organizations and how do they compare to the use of smart tools in The Netherlands? To answer the research question, a total of 27 cases have been recorded, expanding and complimenting the findings reported in Valks *et al.* (2018). The results of the structured data (Chapter 4B) can be used to answer the main research question.

At international universities two implemented smart tools are found to help students find study places and one pilot project to optimize 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 tools are being considered, researched, developed and tested to support students and employees, optimize space use and save energy.

At other organizations, most cases reveal that organizations are working on smart 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 to building use. Most smart tools are in the implementation phase. Organizations are generally further along than universities with their implementations. Multiple cases are found that use multiple types of sensors in their smart tools.

At Dutch universities, smart tools are aimed at either real-time monitoring of teaching space or on smart tools that support students, in which multiple functions are brought together. Previous research concluded that by looking at all available smart tools – which includes more room booking apps and available PC apps – the focus of smart 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.

Aside from answering the main research question, one of the main objectives of the paper was to increase the understanding of smart campus tools through development of the conceptual model. To achieve this, a number of additional elements were added to the data collection; these have been discussed in Chapter 4C of this paper. 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 smart campus tools and the solutions chosen are found to be diverse, especially among international universities;
- that many universities and other organizations will move forward with their smart campus tools by expanding in size, adding sensors and functionalities or using the data for new types of analysis;
- that cost data are hard to collect and very variable, depending primarily on the use of sensors;
- that most organizations 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 smart campus tools;
- that most universities and organizations deal with privacy in similar ways, that is, via direct anonymization, the opt-in principle and to a lesser extent personal data ownership; and
- 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 smart campus tools suggest that in the future, smart campus tools 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 smart campus tools to the decision-making process of campus management, to optimally support the university's primary processes.

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