Smart campus tools

Adding value to the university campus by measuring space use real-time

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Abstract

Purpose – The objective of corporate real estate management is to optimally attune corporate accommodation to organisational performance. At universities, the dynamic process to match supply and demand is often hindered by difficulties in the allocation and use of space. This is a challenge for the Dutch universities and perhaps also European universities, which own large and ageing real estate portfolio's in need of (re)investment: how can universities invest their resources as effectively as possible and not in space that will be poorly used? The purpose of this paper is to explore the use of smart campus tools to improve space use on campus.

Design/methodology/approach – First, a survey at 13 Dutch universities is conducted, consisting of a questionnaire and semi-structured interviews with Dutch campus managers. Then, semi-structured interviews are held with a number of parties in other industries to explore the use of smart tools in other contexts.

Findings – The universities' demand for smart tools is mainly directed at the automatic and continuous collection of real-time space use data for education spaces and giving students insight into the availability of study places on campus. The tools at the Dutch universities focus largely on effectiveness: helping their users in their search to find a space that supports their activities. In other industry sectors, the results suggest that the use of smart tools is more directed towards efficiency: maximizing the use of existing space or optimising the operations of the organisation.

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 sparse. By providing a framework for smart tools, as well as exploring the work done in theory and in practice, the authors hope to increase discussion and research on the subject from the perspective of corporate real estate.

Keywords Learning environments, Decision-making, Campus management, University campus, Smart tools, Space utilisation

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 organisational performance. The challenge is that real estate is static – with a 50-year life span – and very cost-intensive, whereas demand is dynamic, with yearly budgets and targets and two- to five-year strategies. In addition, the challenge exists on different scales – matching demands from society, organisational objectives and individuals to the portfolio, buildings and places (De Jonge *et al.*, 2009).

The authors would like to thank the directors of the real estate and facilities departments of the 13 Dutch universities for their participation in this research. The authors would also like to thank all the interviewees of both the universities and the companies for their direct or indirect contribution to this paper.

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The current situation at Dutch universities demonstrates this complexity. On the scale level of the portfolio and the organisation, 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). This situation leads to complications on the scale level of places and individuals: individuals have trouble finding a place to work or meet on campus. Research on the European campus suggests that this is not only a Dutch problem but also a European problem (Den Heijer and Tzovlas, 2014).

The authors' hypothesis is that campus management – CREM at universities – can be significantly improved by changing the way space is allocated and used on campus. The campus consists of many different space types – lecture halls, study places, offices, meeting rooms, laboratories, etc. – of which the space use is traditionally very territorial. Spaces are assigned to organisational units such as faculties, departments or individuals and used only by these units. Lecture halls and meeting rooms are often booked, but not actually in use. Study places are often hard to find: students know where to find them in the university library, where all study places are in use, but not where to find them in other buildings. The analogy with the "pool chair" problem at holiday resorts can be made: the phenomenon that people put towels on pool beds to claim their space, even when they are not (yet) there. "Reserved but not used" is also a problem on campus: people tend to claim space more when the availability of the space is uncertain. And – as a result of this behaviour – the universities are under pressure to provide more facilities.

Improving the ineffective and inefficient 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, p. 690). In research on the energy use of buildings, approaches have been developed to reduce the energy use by controlling lighting and/or heating, ventilation and air conditioning systems via occupancy sensors, based on the variability in occupancy (Garg and Bansal, 2000; Martani *et al.*, 2012). However, to the best of the authors' knowledge, there is hardly any research addressing the problems of users not actually using reservations and not being able to find a suitable place to study.

In October 2015, 13 campus managers of the Dutch universities commissioned a research project to explore the use of "smart tools" to improve space use on campus. The main question of this research project was: what is the demand for smart tools of Dutch universities and what smart tools are available? Therefore, a survey at the 13 Dutch universities was conducted. The use of the term "smart tools" and its envisioned benefits to the context of the university campus is similar to the more generic ongoing movement in both cities and buildings. With regard to cities, conceptions are visualised of a "smart city" with "smooth information processes, facilitation of creativity and innovativeness, and smart and sustainable solutions promoted through service platforms" (Anttiroiko et al., 2014, p. 323); with regard to buildings, the emergence of "smart buildings" can be positioned in a continuous effort to improve the longevity, energy and efficiency and comfort and satisfaction of buildings (Buckman *et al.*, 2014). In both the concepts, the increasing automation because of advances in IT systems and sensing technology are key.

Both the terms, smart cities and smart buildings, are terms that are used frequently and ambiguously – this is also the case with smart tools. At the outset of the research, a broad definition of smart tools was used:

> A *smart 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.

This was done to include as many smart tools as possible before analysing and structuring the results. As such, the survey at universities is not only an analysis of the smart tools that are currently applied at universities but also research into the definitions used by the universities and the steps being made in the development of smart tools at the universities. In the discussion, the definitions of smart tools used in practice are revisited. In addition to the survey, interviews were conducted at organisations in other industries, of which the expectation was that they had greater experience with smart tools. These interviews are used to complement the definition of smart tools at universities and to provide direction for the next steps in the development of those smart tools.

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 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 smart tools are currently in use, what the objectives of the smart tools are, etc. In the interviews, these results were elaborated: how were these smart tools selected, which developments are currently going on, what future demand could be expected, etc.

The questionnaire contained the following questions:

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

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

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 smart tool. 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 smart tools at their university, how the information from the smart tools 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 smart tools 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.

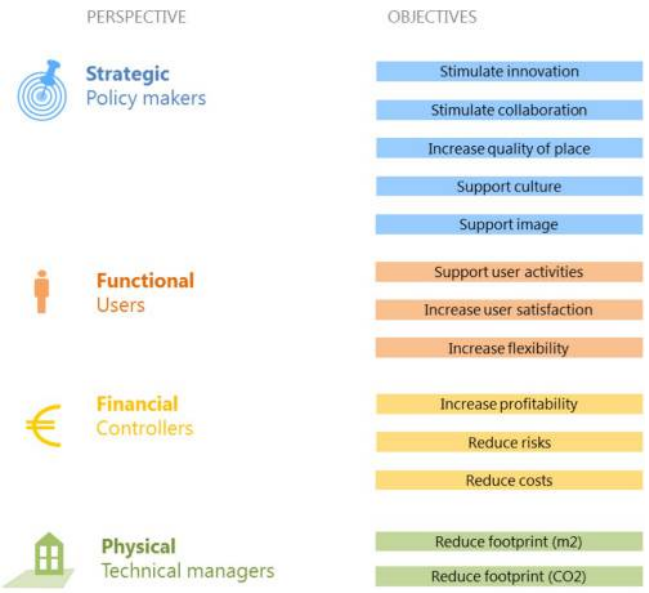
After the survey at the universities, the interview protocol was slightly adjusted for the interviews with other organisations. First, a short introduction of the research was given, after which the results at the universities are discussed. In the interview questions, more emphasis was placed on the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

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 smart tools 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 1 shows an adaptation of the model, which is used to position the reasons to implement a smart tool, 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.



Source: Adapted from Den Heijer 2011

Figure 1. Objectives per stakeholder perspective to add value to the campus

The means to achieve these ends in the case of smart tools 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 *et al.*, 2011; Kasim *et al.*, 2012) commonly refer to NAO (1996) or Space Management Group (2006) for a definition of space utilisation. Space Management Group (2006) 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 [per cent] = frequency rate [per cent] * occupancy rate [per cent].

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:

(1) Frequency: (when) is there at least one person in a zone?
(2) Occupancy: how many people are in the zone?
(3) Identity: who are the people in the zone?
(4) Activity: what are the people doing in the zone?

Space use is measured real-time by using various methods. In an overview of the current positioning technologies, Mautz (2012, p. 107) writes that practically every type of sensor can be used for the purposes of 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 smart tools are central in this study:

(1) The why: what are the drivers for the university to implement the smart tool?
(2) The what: what information does the smart tool collect to achieve the objectives?
(3) The how: what measurement method is used to collect the data?

4. Survey at Dutch universities

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

4.1 Current use of smart tools

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

The results in the table show that the majority of smart tools are implemented in education spaces: either in teaching spaces such as lecture halls and classrooms or in

Table I. Summary of the 26 existing smart tools 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) m2 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) m2 footprint
3	PC classrooms (1x)	Real-time monitoring of space use in PC classrooms	Timetable staff	PC login	Frequency, Occupancy	Optimising (reducing) m2 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) m2 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 CO2 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

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 teaching 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 amount 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 smart tools 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.

The second group of applications is the group that monitors the use of teaching 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. To help campus managers and the people who set the timetable to determine if the portfolio is used effectively and efficiently, some smart tools have been introduced. In addition, almost all universities periodically audit the space use of their teaching spaces via manual counts. Two universities have mentioned these as a smart tool in the survey. In one case, the data from the manual counts are 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 smart tool because the manual counts are done via cameras that are installed in the teaching spaces, which makes the data collection process more efficient.

What is interesting with regard to the smart tools identified in Table I is that the universities do not require the measurement method to be real-time for them to be smart. Almost half of the identified smart tools 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 smart tools were implemented, both in the questionnaire and the interviews. In the survey, the universities were asked through what objectives each smart tool adds value to the campus: the results are shown in Figure 2. Each score in Figure 2 is a sum of the amount of times that a smart tool adds value to that objective – e.g. of the 26 existing smart tools 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 smart tools. The interviews revealed that all smart tools were implemented based on a main objective (Table I): either to better support users, optimise the m^2 footprint or reduce CO_2 emissions. Each time a main objective is stated in Table I, it is also counted in the score in Figure 2. Figure 2 shows that aside from these objectives, smart tools are also found to add value – directly or indirectly – to the campus via other objectives. Especially the strategic objectives can be seen as

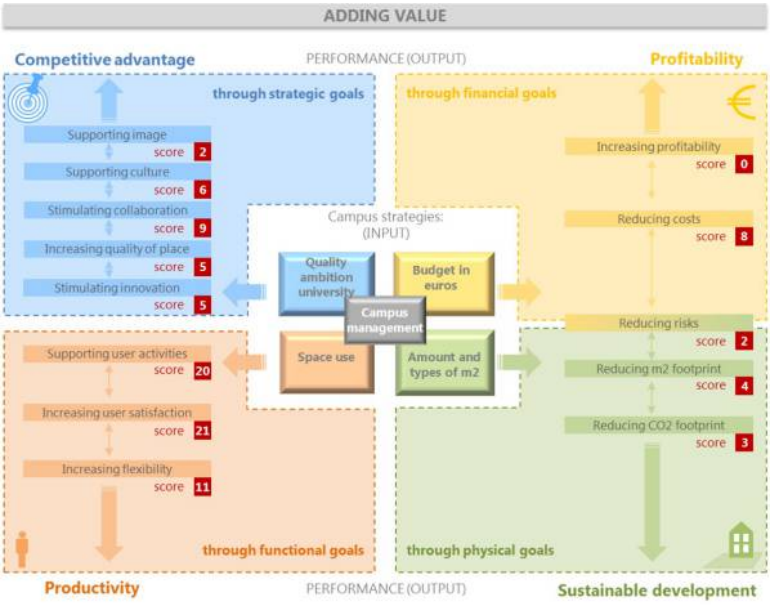


Figure 2.
Objectives through which the current smart tools add value to the campus

Source: Adapted from Den Heijer 2011

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 I and Figure 2 is that the current smart tools 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 smart tools 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 smart tools 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 smart tool need to be measured over a longer term.

4.2 Future demand: development of smart tools

In addition to the existing tools, universities were asked in the interviews about their future demands for smart tools. With regard to the existing tools, the foreseen development is mainly to change or improve the way space use is measured. For the current smart tools that

are used for teaching 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; first, students might use the places equipped with a desktop PC without using the PC, and second, universities are reducing the amount 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 smart tools to increase the effectiveness of space use on campus.

5. Interviews with organisations in other industries

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

The first interviews conducted in this series of interviews were at the UAS. 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 *et al.*, 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 smart tool 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

Table II. Summary of the results identified through the interviews at other organisations, per interviewee

Space type – Organisation	Application	Target group	Measurement 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 m2 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 (building level)	Reducing m2 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.)

further on campus is possible through smart tools, but they should also contain benefits for the users on campus.

The other two applications of smart tools, at the office user and The Netherlands Railways (NS), are both tools, which collect real-time information on the building to inform real estate managers and/or operations. At The Netherlands Railways a number of smart tools based on pedestrian flows are compiled in a programme called Smart Stations (Daamen *et al.*, 2015). These smart tools 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 The 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, The 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 II (van den Heuvel and Hoogenraad, 2014, p. 643). Adjustments are made if necessary – e.g. changing train stopping positions can help to reduce congestion on platforms. The 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 amount 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.

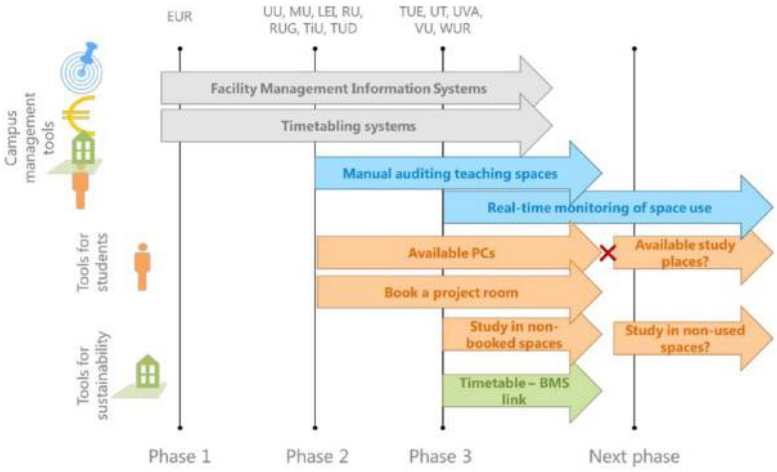
The interviews with end users in other industries show that the implemented smart tools are directed more towards informing management – to improve the efficiency of operations and/or the efficiency of the real estate portfolio – than towards supporting users, which is more common at universities. This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

6. Conclusion and discussion

Both the current smart tools and the future demand the Dutch universities to be focused on using space more effectively through smart tools. The primary function of the existing smart tools is to support users – mostly students – to find available spaces on campus. A few smart tools are also aimed at monitoring the use of teaching 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 smart tools that help users to find available spaces on campus and in monitoring the use of teaching spaces, which is currently still done manually at most universities. Of the solutions found in other industries especially the smart tools of the UAS provide helpful alternatives for this demand.

The development of smart tools at Dutch universities is displayed in Figure 3. Initially, universities monitored their space use via FMIS and timetabling systems. Then most universities started auditing the use of their teaching space because – because of the increase of students – teaching 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 – smart tools 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 teaching spaces real-time.



Note: The acronyms above indicate the current status (2016) of each interviewed university

Figure 3. Development of smart tools at Dutch universities

The future demand is that these developments will continue – real-time information will be used more not only to monitor the use of teaching 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 smart tools 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.

At the outset of this research, the definition for smart tools was:

> A *smart 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 smart tools were found. To explain how these definitions differ, the process of improving space use via smart tools has been outlined in Figure 4.

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 are processed via algorithms – e.g. a conversion factor for devices per user, triangulation to determine location.

Figure 4. Components of improving space use via smart tools

- The results are reported – e.g. x users in y1 teaching space.
- The results are converted to information – e.g. 50 per cent frequency rate during the year in teaching space y1 as opposed to 75 per cent in the timetable.
- An action is taken based on the information to achieve the objective – e.g. the bookings in the teaching space are reviewed critically with the users.

The tools identified as smart tools in this research can be categorised into three types. The first types are smart tools 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 smart tools 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 smart tools 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 to achieve the objective. This definition applied to almost all smart tools found during this research. The third types are smart tools 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 smart tool was found at one of the UAS. The variability in the definitions of smart tools used reflects the ongoing development of the matter at both universities and other institutions.

To summarize, the results suggest that smart tools contribute to university goals and have even more potential to improve CREM at universities. Therefore, the research continues to explore smart tools, 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 not only on the use of smart tools in other countries but also on the development of the existing smart tools at Dutch universities. Special attention needs to be paid to how organisations deal with privacy issues and how users perceive different smart tools with regard to their measurement methods and benefits.

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