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The Added Value of Smart Stadiums: A Case Study at the Johan Cruijff ArenA

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Abstract
Purpose – The objective of stadium owners is to attract visitors to their stadiums and by this optimally utilise their business potential. Stadiums face increasing competition from home-viewing options, with which especially ageing stadiums have trouble competing. This paper studies the concept of smart stadiums as a solution to this problem, adding the corona age as an additional challenge
Design/methodology/approach – First, (smart) stadium literature and theories are reviewed. Then, a case study is conducted, consisting of document review, observations, and semi-structured interviews with specialists. The case that is studied is the Johan Cruijff ArenA in Amsterdam - the stadium has the ambition to be the most innovative stadium in 2020.
Findings – Nine different smart tools were identified in the case study which support the optimisation of various processes in the stadium, such as ticketing and crowd control. The findings from this case study showed the potential of the smart stadium concept and how it can add value for the stadium's stakeholders. The use of smart tools can improve effectiveness and efficiency of stadium operations, and it can be used to improve the visitors' experience. However, concrete numbers of progress were difficult to obtain, because the smart tools were only recently implemented.
Originality/value – As seen in the past few years, more and more stadiums are branding themselves as a smart stadium. However, research on this subject is still scarce: existing research focused on other types of real estate. By exploring the work done in theory and practice, the authors hope to increase research on the subject of smart stadiums.
Keywords – Smart tools, Smart stadium, Innovation, Internet of Things, Smart buildings, Corporate Real Estate Management
Paper type – Research paper

1. Introduction

At the moment of writing this paper, the corona crisis and its societal restrictions force us –at least temporarily- to reconsider our use of physical environments for work, transport and leisure. As environments that accommodate large masses of people, this is especially the case for stadiums. Almost from one moment to another, stadiums have seen a cancellation of all scheduled events for the foreseeable future with few indications if and when normal activity can be resumed. This paper presents research conducted prior to the outbreak of the virus, and showcases how stadiums are considering ways to improve their operations and experience. In the conclusion, results are reflected and critically assessed, also with regards to these latest corona developments.

Over the past years, stadiums face increasing competition from home-viewing options (Giorgio, Deweese, Reicheld, & Ebb, 2018), with which they have to compete in order to avoid empty stadiums. In recent years, the so-called "At-Home Experience" has been improved, as a result of developments such as the availability of high quality streaming services, high definition video and audio, accessibility to live statistics via laptops, the availability of replays from different angles and other technological improvements (Melander, 2016). Furthermore, it is expected that through virtual reality, fans will be able to watch a football match from the side of the pitch or from the goalkeeper's perspective, or experience what it is like to walk on the pitch (Butler, 2017). In stadiums technology is also changing the way spectators experience live events. By increasing the attractiveness of their facilities and services, stadiums can remain competitive: The physical environment of the stadium has a significant effect on the extent to which spectators will desire to stay and return to the stadium (Wakefield, Blodgett, & Sloan, 1996).

As a response to this development, the concept of a 'smart stadium' is gaining ground. Stadiums are typically characterised by the gathering of a lot of people in a short period of time on a limited space, which creates challenges relating to logistics and safety. Recent advancements in technology have enabled the real-time measurement of how the stadium is being used: Today's smartphone owner carries a device with processing power that would have required a computer the size of a stadium fifty years ago (Giorgio & Campbell, 2016). Providing (real-time) information to users of the stadium can lead to improvements along many different objectives of stadiums, such as safety and security, the satisfaction and experience of the fan, sustainability, energy reduction, efficiency, and longevity (Buckman, Mayfield, & Beck, 2014; O'Brolcháin, de Colle, & Gordijn, 2019; Panchanathan et al., 2017). In addition to this, the information required from the smart tools can be used for the long term, by using the information to develop long-term plans and real estate strategies, and thereby supporting decision-making processes (Valks, Arkesteijn, Den Heijer, & Vande Putte, 2016). The principle of integrating these tools in stadiums in order to improve certain processes in stadiums can be defined as the concept of a smart stadium. O'Brolcháin, Colle and Gordijn give a definition for smart stadiums: *"the way sports stadiums are designed and managed by using smart technologies in order to enhance the experience of attending a live match through innovative and improved services for the audience, as well as for the players, vendors and other stadium stakeholders"* (O'Brolcháin et al., 2019).

The use of the term 'smart stadium' is similar to the ongoing movement in both buildings and cities. Concerning buildings, the emergence of "smart buildings" can be characterized by the ability to acquire knowledge or data from their environment (Cook & Das, 2007). Buckman, Mayfield and Beck (2014) are using a more holistic definition, that Smart Buildings consists of for intelligence, enterprise, control, and materials and construction as an entire building system, with adaptability, not reactivity, at its core, in order to meet the drivers for building progression (Buckman et al., 2014). Both definitions emphasize the role of enterprise / data systems in buildings. Valks, Arkesteijn, Den Heijer, and Vande Putte (2018) explored the various 'smart tools' present in building portfolios of universities and organisations. They defined a smart tool as: *"a service or product which collects real-time information on space use to improve the space use on the current campus on the one hand, whilst supporting decision making on the future space use on the other hand"* (Valks et al., 2018). With regard to the smart city environment, it uses the information and communications technologies to make the critical infrastructure components and services of a city's administration - education, healthcare, public safety, real estate, transportation and utilities - more aware, interactive and efficient (Bélissent, 2010). In both smart buildings (Buckman et al., 2014; Wong, Li, & Wang, 2005) and smart cities (Gil-Garcia, Pardo, & Nam, 2015), there are varying definitions of what is 'smart'. Rather than focusing on a unified definition, it is more useful to understand smart stadiums as a concept that is still developing, and which aims to increase the

performance of the stadium. The distinction of smart stadiums from smart buildings and smart cities is useful, as a stadium has its own unique challenges because of the way it is used. However, the use of a smart stadium is also thought to be a perfect living laboratory to more easily deploy and evaluate technologies of the smart city concept (Panchanathan et al., 2017). In practice, a lot of research into smart stadiums is used as a living laboratory for smart city concepts, for example in Dublin (Ireland), Barcelona (Spain), and Amsterdam (The Netherlands).

The research field of 'smart stadiums' is in its infancy and quite limited. Understanding the role of innovations and technologies on the fan experience and the potential privacy issues has been the main drives for most of the research initiatives (Levallet et al., 2019; Melander, 2016; O'Brolcháin et al., 2019; Panchanathan et al., 2017). However, to the best of the authors' knowledge, there is hardly any research that focuses on how measuring space-use (real-time) in stadiums can lead to advances for the various stakeholders. So, it can be said that there is a lack of knowledge in science and practice about: (1) which specific smart tools can be integrated to solve challenges related to stadiums, and (2) what the effects are of integrating smart tools within stadiums which can lead to 'smart stadiums'.

The research question that this paper addresses is which smart tools can be identified in stadiums, and how the use of these smart tools can be optimized. In this research the term 'smart tool' is largely in accordance with the definition of Valks et al. (2018) in the sense that it is a service or product meant to improve current stadium operation on the one hand and improve decision-making about the future stadium on the other hand. However, the information used in these smart tools does not have to measure space use – for the effective and efficient operation of stadiums the performance of other information may be relevant. As such, the smart tools in this research have a broader scope which fits within the definition of O'Brolcháin et al. (2019).

The remainder of this paper is organized as follows. First, the research method will be presented. After this, the analytical framework will be discussed, which is based on Corporate Real Estate Management (CREM) and stadium management literature. Then, the results of a case study at the Johan Cruijff ArenA in Amsterdam will be discussed. The paper closes off with practical and theoretical implications and concluding remarks.

2. Research methods

In February 2019, this research took place to explore the 'smart stadium' concept and the use of smart tools to improve the use of stadiums. The main question that is addressed in this research: which smart tools can be identified in stadiums, and how can the use of these smart tools be optimized? Due to this nascent character of the research topic, a qualitative research method is conducted. A qualitative research method is more suitable for subjects that are more in a nascent phase (Edmondson & McManus, 2007). The research contains two parts, a literature study and an exploratory case study.

In the first part, a literature review was conducted to understand the principles of stadiums, (smart) real estate management theories, and the characteristics and specifications of (smart) stadiums. Relevant literature was selected based on the quality of the source, the relevance of the topic, and the number of citations. The whole literature review into smart stadiums was structured following the four perspectives on added value in real estate as described by Den Heijer (2011): physical, strategic, functional, and financial. In addition to this, a fifth perspective (economic) is added to account for added economical value on an urban or regional level. This literature review approach specifies the phenomenon of smart stadiums while combining the limited smart stadium literature with more mature theories about CREM and (smart) tooling.

The second part of the research consisted of an exploratory case study. The case study is used to assess the different smart tools in the stadium and to identify the effects of the smart tools. To suit the research objectives, the stadium that would be used for the case study should be branded as a ‘smart stadium’. That is why the Johan Cruijff ArenA was selected, which is a stadium located in Amsterdam, which would also fit in the scope of the research. The goal of the stadium management is that by 2020 the Johan Cruijff ArenA must be the most innovative stadium in the world (Johan Cruijff ArenA, 2017), and by this create a 'smart stadium’. The integration of smart tools and other innovations in the Johan Cruijff ArenA are among the frontrunners, which is the main selection argument for selecting this case. The used sources of evidence in the case study are semi-structured interviews and documentation review.

A semi-structured interview approach was chosen to balance between the current available findings of smart tools, whilst also allowing room for further exploration. The objectives of the interviews were based on four aspects:

(1) Assess the smart tools that are implemented in the stadium.
(2) Identify the objectives for the stadium to implement the smart tool.
(3) Investigate the effects since implementing the smart tool
(4) Find out how the current use of smart tools can be improved to achieve the objectives

The interview protocol was based on the structure used in previous smart tool research of Valks, Arkesteijn, and Den Heijer (2019). The semi-structured interviews started always with an assessment of the smart tools: Which smart tools are currently in use in the Johan Cruijff ArenA?

Based on the expertise and knowledge of the interviewees, they were asked to provide specifics of each tool. Firstly, the interviewees were asked to describe how the smart tool works, in which phase the smart tool is, and the duration of the smart tool, in order to create understanding by the interviewer. After this, interviewees were asked to explain the objectives for implementing the tool, describe the measurement method, the partners involved with the smart tool, and the access level. Then the interviewees were asked how the user information of the smart tool is used in decision-making processes, the progress since implementing the smart tool, and what could be improved in order to create the desired situation regarding the use of the smart tool in the future. In total seven different interviews were held with specialists who were involved in the Johan Cruijff ArenA project.

3. Analytical Framework

Today, a multitude of technological developments around our daily lives are implemented and changing the way people live and the way they use real estate. This digital change is also described as the Fourth Industrial Revolution, or Industry 4.0 (Lasi, Fettke, Kemper, Feld, & Hoffman, 2014), which can be seen as a new step based on the past three industrial revolutions from the last two decades. The concept of the Industry 4.0 principle is based on the use and exchange of data in real time (Ślusarczyk, 2018). This is in line with the novel paradigm of the Internet of Things (IoT) that is rapidly gaining ground and attention. IoT can be described at the fundamental level as a means of connecting physical objects to cloud services as a ubiquitous network that enables objects to collect and exchange information (Trappey, Trappey, Govindarajan, Chuang, & Sun, 2017). This creates a lot of opportunities for a variety of objects or things to interact and cooperate with each other. In the research of Porter and Heppelmann (2014), this is called the connectivity component of a smart, connected product.

The Internet of Things has the potential to add value to different types of real estate. For each type of real estate, meaningful IoT applications can be designed based on user demands and building characteristics. When compared to the use of IoT on university campuses, as researched by Valks et al. (2018), it is expected that different applications are found as stadium users have different demands than those of campus users. . However, events are a common denominator amongst stadium users and campus users – on campus events such as PhD defences, inaugural speeches and conferences would benefit from smart campus tools that provide information on where to park, wayfinding on campus, etc. Furthermore, there are likely to be similarities in the demands of building management. The applications in both contexts are based on the premise that the application of IoT will result in actionable information for end-users or building managers, thus adding value through real estate. This is the basis of a smart environment and by this the basis of the smart stadium.

The impact of technology is also shown in the development of stadiums. Generally speaking, four generations of 'specialized' modern football stadia can be identified since the late nineteenth century. As the commercial opportunities of stadia have expanded, more technological innovations have been incorporated in the design and management of stadiums, and the comfort, safety, hospitality and accessibility have improved as a result (Paramio, Buraimo, & Campos, 2008). Especially in the last years, stadiums and their networks are keen to find new business models around connectivity and IoT. This change subverts the traditional way of thinking about the stadium experience, resulting in stadiums that are more connected than ever before. Some scholars are speaking about stadiums as a platform (Giorgio & Campbell, 2016), resulting in a new generation of postmodern stadiums: the 'smart stadium'.

The shift from stadiums to smart stadiums is similar to the development that can be observed in (corporate) real estate. The basis of Corporate Real Estate Management (CREM) is that buildings add value to individuals, organisations and society, otherwise they would not invest in it (Den Heijer, 2011). Over the years, the development of installations in buildings has moved through various phases: from automated to intelligent to smart buildings, each of these with the objective of increased building performance (added value) for the users. The process of attuning the buildings (supply) to the users' demands (demand) is a continuous challenge in CREM termed 'alignment', covered by many authors (Appel-Meulenbroek, Gordon Brown, & Ramakers, 2010; De Jonge et al., 2009; Heywood & Arkesteijn, 2017, 2018; Nourse & Roulac, 1993). These authors understand the 'smartness' in buildings to be the provision of real-time information to users, which helps them to better use the existing space, and to managers in order to improve the decision-making about the future development of buildings. As such, smart tools, smart buildings, and also smart stadiums have the potential to align the existing real estate more frequently and on a higher level of detail to the demands of its users, thereby adding value.

As described in the second paragraph of this paper, five perspectives were used in this research to understand which value is added by smart stadiums. A literature review is conducted that focused on the five perspectives and to find out how the smart stadium concept can add value to each of the concepts. The results of this review can be found in table 1.

Table 1. Five perspectives of the potential of a smart stadium based on the literature review with references

Economic perspective	Stadium developments can have an economic impact on the (local) area, however, this is on a lower scale than policy makers often claim. It is used as justification for investing with public money. Stadium development can be used as a driver for new area developments. The smart tool can contribute to improve the image of a stadium for policymakers and to utilize the potential for 'smart-city concepts'.	(Ahlfeldt & Maennig, 2010; Chapin, 2004; Coates & Humphreys, 2003; Johnson & Whitehead, 2000; Panchanathan et al., 2017; Siegfried & Zimbalist, 2000)

Physical perspective	Stadiums contain more and more different functions (office space, leisure), which can affect the type of tools needed. Stadiums are located in or around city centers, in urban areas, which means that events have a high impact on the infrastructural network and stakeholders. This can affect the need for smart tools: a lot of visitors and employees during a short period of time means an intensive space use (both inside and outside the stadium).	(Bess, 1996; Newsome & Comer, 2000; Sartori A.; Nienhoff, 2013)
Strategic perspective	Stadiums are typically a combination of a partnership with sports clubs, municipalities, and other investors. their interests are reflected in the stadium policy. The need for smart tools is strongly connected to the objectives of these partners. These need to be considered in smart tool investments and ambitions.	(Baade, 1996; Delaney & Eckstein, 2007; O'Brolcháin et al., 2019)
Functional perspective	Various stakeholders are involved in stadiums. An important user of the stadium is the visitor: visiting a stadium is all about offering visitors the best experience. Visiting a stadium require extensive preparation: from buying a ticket to the return home, which is the customer journey of the visitor. During this customer journey, various incidents can take place, which can harm the visitors' experience. Smart tools could add value throughout the customer journey. Besides the visitor, the operational stakeholders play a key role, and the integration of smart tools can add value for them by improving the effective use of stadium resources.	(Giorgio & Campbell, 2016; Giulianotti, 2002; O'Brolcháin et al., 2019)
Financial perspective	Integrating tools seems to affect the income and expenditure of a stadium, which shows that it has the potential to optimize a stadium's business case. The most important income for the stadium organization is leasing the stadium for events. Integrating smart tools can lead to a reduction in costs, or the creation of extra services, which can impact the business potential and financial situation of stadiums.	(Paramio et al., 2008; Sartori A.; Nienhoff, 2013)

In order to obtain the right (real-time) information to the users of smart stadium tools, different steps have to be taken. In general, this process can be explained by three different steps, which take place in the technology infrastructure of the stadium. Firstly, (real-time) data is obtained from sensors or other data sources. Secondly, the (real-time) data will be translated to (real-time) information, which is often done in an integrated (open cloud) platform or data lake. Lastly, the information is made visible for the user of the real estate in dashboards, which can decide to adapt the decision making based on real-time information. This principle is visualized in figure 1.

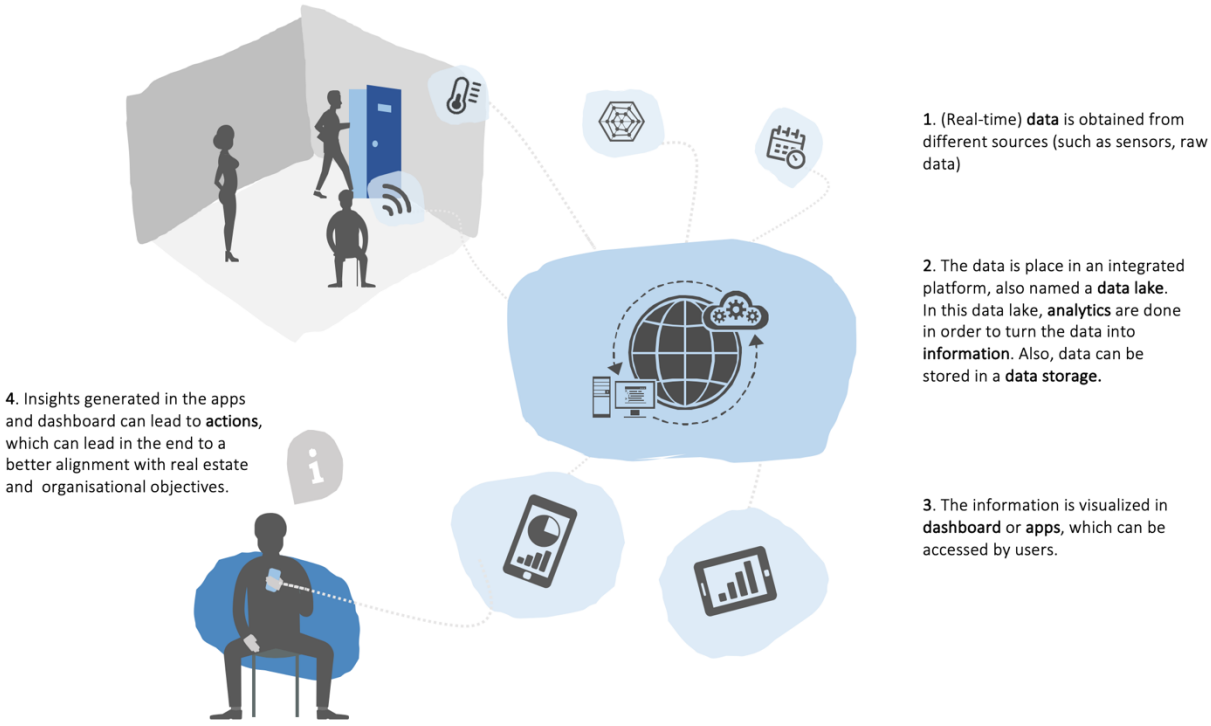


Figure 1. The principle of a smart tool: insight in real-time information to improve the use of real estate (own illustration)

4. Case Study: The Johan Cruijff ArenA, Amsterdam

In this section, the results of the case study are summarized. Firstly, the results of assessing the smart tools in the interviews are discussed with their characteristics and their objectives for integrating. After this, the effects of the smart tools and how they could be improved are discussed.

In total, nine smart tools were distinguished in the Johan Cruijff ArenA based on the semi-structured interviews, which are in alphabetical order: cash registers, cleaning, crowd control, energy consumption and battery, mobility portal, smart turf monitoring system, staffing, technical maintenance, and ticketing check-in. The results of the smart tool assessment are summarized in table 2.

Objectives are primarily functional and financial

In order to classify the stated objectives from each tool, the thirteen added values to which the tools contribute were presented to the interviewees and they were asked to prioritize them. The results show that almost all the smart tools that are integrated into a stadium focus on the functional perspective (both visitors and stadium operators) while also many tools have financial objectives. The functional goal of supporting user activities seems to be key for integrating new smart tools in the stadium. Besides this, various strategic goals are identified for various smart tools. This can be explained through the formulated main goal of the Johan Cruijff ArenA that it has the ambition to be the most innovative stadium in the world. Lastly, it seems that physical goals do not have priority: only three tools contribute to a reduction of CO2 footprints and the optimization of the m2 footprint.

Information to improve current and future stadium operation

When viewing the application and the goal of the smart tools, six of the nine smart tools are found to collect data on planned or actual space use. Each of the tools collects a specific kind of information related to the operation that will be improved through the smart tool. Three smart tools collect data on the real-time space use within the stadium: the crowd control, technical maintenance and ticketing tools. These are aimed at efficiently allocating staff to operations. The cash register tool also falls into this category, except that transaction data is a proxy of space use rather than actual data on the space use.

Finally, the cleaning tool and the staffing tool, use data from booking and check-in systems rather than data on the actual use to improve these operations.

The other four tools collect other types of data for the improvement of their operation:

- The energy consumption of the stadium to improve the energy performance of the stadium;
- The smart turf tool measures the quality of the grass on the stadium's pitch to determine when it needs replacement;
- The mobility portal measures the traffic on the routes towards the stadiums to advise visitors.

Progress since implementing the smart tools

There are some hypotheses as stated in the introduction of this paper that smart tools will contribute to the improvement of certain stadium progresses. In the interviews, the progress since implementing the smart tools were explicitly discussed. However, stating the progress since implementing the smart tools was quite difficult, as only five tools were operational at the time of the interview. For the smart tools that were operational, it was also quite hard for the interviewees to define the exact progress for each of the tools. The progress made since integrating the tools is also shown in table 2.

The smart tools can improve the effectiveness and efficiency of certain stadium operations. As seen from the case study, measuring real-time use of the pitch can lead to a reduction of pitch replacements. Besides this, the efficiency of both entering the stadium and buying food and beverages in the stadium kiosks can be improved; however, the progress mentioned for these tools are more insight into types of visitors and revenues than that they relate to their objectives, e.g. reduced waiting times or number of customers served per hour. Finally, measures can be taken to steer visitors based on real-time information, both on their way to the stadium and within the stadium. As a result, the visitors' experience is positively impacted.

Table 2a. Characteristics of the identified smart tools in the Johan Cruijf ArenA

Identified smart tool:	Application	Phase	Priority goal	Goal	Progress since implementing
Cash registers	Data from the payments is transferred to a dashboard, which shows the number of transactions.	Implementation	Financial	"Increase revenues, better service, cost reductions, more certainty and less risks."	"Based on the current information it can be confirmed that the extension on the second ring is generating more revenues."
Cleaning	A dashboard shows, based on the booking schedule, which spaces need cleaning.	Product development	Financial	"Reduce cleaning costs"	The tool is not implemented yet.
Crowd control	The Wi-Fi signal from mobile devices is used to estimate the crowd.	Research & Product development	Functional / Physical (Safety)	"To understand and possibility to control the behaviour of people within the stadium" "Safety"	The tool is not implemented yet.
Energy consumption & battery	Energy consumption of the Johan Cruijff ArenA is shown in a dashboard.	Implementation	Physical	"To reduce energy consumption"	"Better insight in the energy consumption" "More sustainable energy production"
Mobility portal	The mobility portal is a tool for the users to give travel advice, taking	Implementation	Functional	"Better travel experience for visitors to the area"	"750.000 travel advices given to people"

	into account the real-time situation.			"Reduce motorized transport"	
Smart turf monitoring system	The pitch is monitored based on different data sources. This is presented in a dashboard.	Implementation	Physical	"Higher quality of the pitch & higher utilization of the pitch"	"The pitch only needs replacement once a year instead of multiple times a year."
Staffing	Based on the type of event, staffing is requested through an IT system. This will be linked to the staffing check-in.	Product development	Financial	"Higher efficiency in communication and better idea of the time registration"	The tool is not implemented yet.
Technical maintenance	Sensors are placed in common areas, which shows the rooms in use.	Product development	Functional	"To realize a cost reduction for energy consumption, maintenance, facility management" "Improve quality of living areas"	The tool is not implemented yet.
Ticketing check-in	Data from stadium check-ins at the gates is represented in a dashboard. Shows how busy the gates are.	Implementation	Financial	"A more efficient ticketing check-in"	"Better insights in the attendance of visitors and type of visitors during events."

Table 2b. Characteristics of the identified smart tools in the Johan Cruijf ArenA (continued)

Identified smart tool:	**Access level**	**User information**	**Management information**
Cash registers	Only the operational management of the Johan Cruijff ArenA can access the cash registers app.	The number of people that check in in combination with the sold tickets, so how many still have to check-in.	The data in reporting goes from real-time to as far back as possible, and will be stored in order to do historical analyses and improve the catering offering during different types of events.
Cleaning	Only the facility management of the Johan Cruijff ArenA can access the cleaning dashboard.	The users, which are the cleaners, are informed which spaces must be cleaned	The management knows which spaces there are booked, cleaned, and for which price. This data is refreshed 4 times a day.
Crowd control	The Johan Cruijff ArenA management can access the crowd dashboard.	The Johan Cruijff ArenA itself has real-time insight in the location of the visitors and their density. It also gives clear insight in the behaviour of visitors, especially the moments when they do use their mobile device.	The data will be analysed over a longer period of time.
Energy consumption & battery	Only the management of the Johan Cruijff ArenA can access the energy dashboard.	The real-time the total energy consumption and supply of the (whole) Johan Cruijff ArenA	The data goes from real-time to as far back as possible, and will be stored in order to do historical analyses.
Mobility portal	Everyone can access the mobility portal. The back-end of the mobility portal are accessible to the management and an external company. This is translated in a real-time dashboard.	The user, which is the visitor, got advised on all the different transportation methods to the Johan Cruijff ArenA based on their preferences and location	The mobility management of the Johan Cruijff ArenA has insight in the visitors characteristics, such as their location and their chosen transportation method.

Smart turf monitoring system	Only the grass team of the Johan Cruijff ArenA can access the smart turf monitoring system.	The grass team of the Johan Cruijff ArenA got insight in the real-time status of the grass pitch.	The data of interventions as a result of the information from the dashboard are reported.
Staffing	Both the management of the Johan Cruijff ArenA and the employment agency can access the staffing dashboard.	The number and type of personnel needed and encoded for an event, as visible for the employment agency and the Johan Cruijff ArenA	The data for the management will be collected and compared to the different type of events. This can be used for reporting and predicting the needs for the organization of new events.
Technical maintenance	The facility management of the Johan Cruijff ArenA and the contractor can access the technical maintenance tool. Visitors and employees of the ArenA do have insight in the measurements of the living spaces.	Employees and visitors of the Johan Cruijff ArenA got insight in the different measurements of living spaces.	Facility management will receive the technical status real-time, and base their activities on this information.
Ticketing check-in	The management of the Johan Cruijff ArenA and the different parties that are involved in the control room can access the dashboard.	The number of people that check which reflects how busy the check-in gates are.	The data for the management goes from real-time to as far back as possible, and will be stored in order to do historical analyses. that can be used to optimize ticket-sell and check-in efficiency.

To improve the effects of the smart tools, and by this meet the objectives, points of improvement were identified in the case study. It was observed that some points of improvement occur more frequently for different tools, which are:

1. *Better use of historical data:* The next challenge for the smart tools is using historical data that is generated by the smart tool itself. This information is very valuable to predict and optimize events that will be held within the stadium. It will lead to a shift from a monitoring and control function of the smart tools towards a more optimizing role.
2. *Ability to respond real-time to the obtained insights from the smart tool:* At this moment, the stadium operators could not respond real-time to the information that is shown by the smart tool. This is also linked to the possibility to access the smart tools, as shown in table 2. Except for the mobility portal, all the other smart tools are only accessible for the stadium management, and not by the visitors. This makes it more difficult to steer them. In various interviews, this was stated as an important point of improvement.
3. *Link to other systems:* One of the characteristics of autonomy is the ability of self-coordination of operation with other systems. For three of the smart tools, the importance of linking the tools to other systems was mentioned. Combining different systems can lead to valuable insights and could stimulate automated processes.

Lastly, various points of attention were derived from the interviews. The following points seem to be crucial to successfully develop and integrate the smart tools in the Johan Cruijff ArenA:

1. *The importance of the technical layer:* The technical layer is also known as: ‘basic technology infrastructure’. The technical layer is the basic infrastructure that provides the right data. A well-functioning technical layer will reduce a lot of time and costs during the integration of a smart tool and will lead to a reliable accuracy for the measurement method.
2. *Privacy and security risks:* Smart tools collect a lot of personal data, which can lead to ethical challenge of violating the privacy of visitors. To prevent privacy issues, a good data governance structure could help in minimizing this risk. The point of departure for any smart tool is that

there are limitations of collecting data from the visitors and that all the data collection has to be treated carefully.

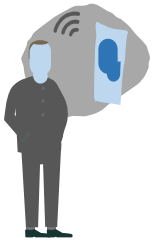
3. *Collaboration with partners*, *partner ecosystem*: To develop and integrate a smart tool, the collaboration with external partners seems crucial, whereby these partners use their services and expertise. As seen in this case study seven smart tools contain an extensive collaboration with partners.

5. Future developments

As concluded from the case study of the Johan Cruijff ArenA there are improvements to make to maximize the benefits of the tools. In addition to the existing smart tools various stadium innovations were analyzed. These stadium innovations can contribute to the various objectives and the smart stadium concept. The stadium innovations were selected from the 'Change the Game' innovation challenge. During this challenge different innovative start-ups, scale-ups and enterprises could submit their solutions around five different themes to improve the fan experience in stadiums. In total, 198 solutions were submitted from 32 countries between January 2019 and April 2019, whereby 35 solutions were selected by different juries. The solutions that were submitted are frontrunners for technologies that can be integrated into stadiums. Based on points of improvement, five innovations are highlighted in this section and in table 3 to emphasize how this will contribute to the current smart tools.

1. *Mobile ordering platform:* Mobile ordering platforms give customers the possibility to place their orders and pick-up by themselves, saving time, optimizing staff costs, and improving the visitor experience. The visitor can download a mobile application to do orders, pay cashless, track the order, and pick-up the order at the kiosk.
2. *Pro-active and adaptive visual communication:* This solution is focusing on informing the visitors in the stadium by showing relevant information on the screens inside and outside a stadium. Nowadays many of the content is scheduled and non-responsive to a changing situation. With this tool, real-time information from the smart tools can be communicated more efficiently to the visitor by using the different screens within the stadium.
3. *Guide users throughout a venue by using innovative features:* Various app-based solutions that can guide the user throughout a venue through different features, like Geo-referencing, Virtual and Augmented Reality, Gamification, 3D sounds. By this, the behavior of visitors can be steered.
4. *Smart map solutions:* Advice regarding mobility is often ending at the last public transport stop or parking lot. This "last-mile" describes the difficulty of getting people from a transportation hub to their destination, which is the seat in the stadium. Based on real-time updates, the visitor can be steered during their journey to their seat in the stadium.
5. *Facial recognition technology:* Due to the current state of the art of facial recognition technology, it can detect and verify individuals. This technology can be used for various potential applications for stadiums, such as access control, payments, and time registrations for human resources. The advantage of this tool is that it will improve the efficiency of checking in at stadiums. Moreover, it can improve the visitors' experience. Here, how to deal with privacy constraints is a key issue.

Table 3. Future developments that can contribute to the goals of the current smart tools

Visual					
Possible future application	Mobile ordering platform	Pro-active and adaptive visual communication	Guide users throughout a venue by using innovative features (such as Gamification, Augmented Reality, and Virtual Reality)	Smart map solutions for venues	Facial recognition technology
Perspective	Financial	Functional	Functional	Functional	Financial / Functional
Goal	"Increase catering revenues, better service, cost reductions, more certainty and fewer risks"	"To understand the behaviour of people within the stadium" & "Safety"	"To understand and the possibility to control the behaviour of people within the stadium" "Safety"	"Better travel experience for visitors to the area" "Reduce motorized transport"	"Higher efficiency in communication and a better idea of the time registration" & "A more efficient ticketing check-in"
Current Tool	Cash register smart tool	Crowd control	Crowd control	Mobility Portal	Ticketing check-in & staffing

6. Conclusion and discussion

6.1 Conclusion

The main research question of this paper was: which smart tools can be identified in stadiums and how can the use of these smart tools be optimized. Based on the results of the analysis of the Johan Cruijff ArenA, nine different smart tools can be identified. These results demonstrate the potential of these technologies for the smart stadium concept and the usefulness of investigating technologies within stadiums.

These nine different smart tools are analysed from different theories as found in the literature. It shows that the nine smart tools focus on different touch points: payments (cash registers), cleaning activities, crowd control, energy consumption, mobility, pitch quality, staffing, maintenance, and ticketing. Input for the tools is based on different frameworks that are obtained in the literature study. The focus of smart tools is mainly on reducing costs (financial), and supporting user activities and increase users' satisfaction (functional). In order to achieve their objectives, most of the smart tools measure space use – either real-time, via booking and check-in systems or a proxy of space use – in a way tailored to improve a specific operation. However, not all nine smart tools are already integrated and part of daily operations. Four out of the nine smart tools are still under development, which made it difficult to define the exact progress of the smart tools. The progress made on the implemented tools suggest that they can contribute to improving the visitors' experience, and effectiveness and efficiency in daily operations of stadiums.

The first advice on how the use of the smart tools can be optimized is to make a profile for different types of events, based on the historical data collected by the different smart tools. The second piece of advice is that the advantages of smart tools can be used more when the stadiums' visitors are steered based on real-time information. There are various ways to do so, such as pro-active and visual communication, guide visitors by innovative features, and smart map solutions. Moreover, technologies such as facial recognition and mobile ordering platforms can be used to improve the efficiency of the current tools. Lastly, the tools can be linked between each other or linked to performance goals, to create new valuable insights and to stimulate automation.

6.2 Discussion and implications

As experienced, previous research on the topic of smart stadiums was scarce. The most important publications that are linked to the development of smart stadiums were the research of Panchanathan et al. (2017) and the research of O'Brolcháin et al. (2019). The definition of the smart stadium was used as a base for this research. In their research five different 'smart stadium themes' were identified: (1) enhanced entertainment; (2) improved customer service; (3) commercial opportunities; (4) enhanced safety and security; (5) sustainability, reduced environmental impacts and energy costs. In table 4 the smart tools are compared to the five themes. When a smart tool contributes to one of the themes, it is reflected as a 'yes' in table 4.

Table 4. Identified smart tools show overlap with the 'smart stadium themes' as described in the research of O'Brolcháin et al. (2019)

5 themes as described in the research of (O'Brolcháin et al., 2019):	Smart turf monitoring system	Crowd control	Mobility portal	Technical main-tenance	Cash registers	Cleaning	Staffing	Ticketing check-in	Energy consumption & battery
Enhanced entertainment	no	no	no	no	no	no	no	no	no
Improved customer service	no	no	yes	no	yes	yes	yes	yes	no
Commercial opportunities	yes	yes	no	no	yes	no	no	yes	no
Enhanced safety and security	no	yes	no	no	no	no	yes	no	no
Sustainability, reduced environmental impacts, and energy costs	yes	no	no	yes	no	no	no	no	yes

As shown in table 4, all the tools that were identified in this research are fitting in at least a theme and in some cases in multiple themes. None of the tools fit within the theme of 'enhanced entertainment'. However, one of the conclusions of this research is that in the future the tools should focus more on the visitor, whereby solutions were given that focus on enhancing the entertainment. The findings support the smart stadium themes as stated in the research of O'Brolcháin et al. (2019).

Because of the scarce research in smart stadiums, this research viewed smart stadiums as a concept in development. For the term 'smart tool', the definition was repositioned in the context of smart stadiums. During the interviews, it was experienced that the 'smart tool' definition had to be explained. Furthermore, the results show that what is considered to be a 'smart tool' is not necessarily a tool that collects data about space use or that collects data real-time. This is a similar finding to Valks et al. (2018) who report different types of tools identified as 'smart'. The emphasis of what is 'smart' seems to not lie on the kind of data that is collected, but rather the extent to which the operation is improved.

When comparing the results to previous research at university campuses, differences are observed both in the interactions with end-users and building management. With regards to end-users, the interviews identified that integrating technology in stadiums can impact the live experience of the spectator. This tension was already mentioned in the research of Paramio et al. (2008). This may explain why the smart tools found in this study focus on minimising nuisance for the user at various touchpoints, mainly related to queuing (in traffic, in ticketing, and at cash registers), rather than improving visitors' experience. On campuses, services such as wayfinding and reserving spaces are found to be much more important. With regards to building management, smart tools focus on improving operational processes through real-time information. This also contrasts the findings at universities: although such smart tools are also found, at universities smart tools are often implemented to inform strategic or tactical decision making. What the smart tools have in common in both contexts is that they are implemented to improve the resource-efficient use of scarce facilities.

Lastly, the point that requires special attention is addressing privacy issues. In previous research by Valks et al. (2019) it was emphasized that all the interviewees indicate the importance of addressing

privacy issues. This is also the case for stadiums: in stadium development, it is important to find a balance between the commercial and technological development of clubs and their stadiums on the one hand and the traditional cultural, social and symbolic significance of football and the stadiums on the other (Paramio et al., 2008). Given the importance of the visitors' experience to the business model of stadiums, it is worthwhile to thoroughly examine the impact of smart tools; literature on hospitality management and its use of IT (Brotherton, 1999; O'Connor & Murphy, 2004) may help to structure an assessment of the added value of smart tools in relation to visitors' experience of the stadium.

6.3 Recommendations for further research

As stated at the beginning of this paper, the nature of this study is explorative due to the lack of a lot of previous research on this topic. There is a limited qualitative body of knowledge about smart stadiums. As a result, a qualitative research method is used whereby only one case is used, which is the Johan Cruijff ArenA. As such, this type of methodology can harm the external validity of this research. In further research, it is recommended to conduct a research on multiple stadiums. This can be done by conducting a cross-case analysis. An important remark to this statement is that stadiums are a homogeneous 'industry', which operates similarly worldwide, increasing the likelihood that this study will also be applicable in other cases.

Another limitation of the research on smart stadiums is that also in practice the smart tools are still in their infancy. Many smart tools that were assessed in this study were in the development phase. As a result, it is not possible to analyze the impact of the smart tools on the stadium operation. Therefore, we recommend repeating this study in 4-5 years. It is expected that at this time it will be possible to analyze the impact of the smart tools, and maybe even collect statistical evidence of the effects of smart tools using quantitative research.

Further research is needed to explore the implications of integrating smart tools in a stadium environment. On the one hand, these are implications that are relevant for operators: e.g. accuracy of the measurement methods, complexity of introducing technology infrastructure in existing stadiums, and stadium requirements for system performance. On the other hand, special attention needs to be paid to privacy issues. What if the introduction of smart tools impacts the experience of its visitors in a negative way and discourages them from (re)visiting the stadium, thereby achieving the exact opposite of what the stadium operator wants? Smart tools need to balance between improving the stadium operations and visitor experience and ensuring visitors' privacy in order to add value to stadium performance.

The integration of smart tools in the real estate industry touches various research topics, such as technological development (computer science), physical integration in real estate assets (architectural & engineering), impact on the user experience (design engineering), and the evaluation of the tools (management). Future research should be aware of this disjunction of different research fields, whereby specific attention should be paid to the context of multidisciplinary research to make sure these different elements are captured and incorporated in the research as much as possible.

Finally, the worldwide outbreak of COVID-19 and the response of governments, organizations and society has already had an enormous impact on stadiums, and will continue to do so. As governments slowly start loosening regulations, sport events may be resumed at some point in time, although if and when stadiums may be used again to their full capacity remains uncertain. The smart stadium tools identified in this research may support stadiums to host events with limited attendance while maintaining regulations. The crowd control, cash registers and ticketing check-in can be used to monitor the density

at various points within the stadium: entry points, seating areas and catering locations. Future developments such as the mobile ordering platform and smart map solutions may help to keep people spread throughout the stadium, by delivering orders in the stands and by directing users to the least used catering locations. Still, some issues need to be addressed, such as the safe use of public transport to get to and from the stadium, and the use of public restrooms within the stadium.

In this extraordinary situation, smart stadium tools may support the delivery of value to all perspectives by enabling a temporary situation: to stadium owners, as they would be able to generate some income; to stadium operators, as they can ensure safe operation; to visitors, as they can -to some extent- support their local team; to spectators, as they can watch sports events again; and finally to sports clubs and athletes, as they can compete again in partially filled stadiums. As such, stadiums with smart stadium tools may now be better positioned than those without. However, new business models will also be needed to ensure business continuity. Rather than competing with home-viewing options, stadiums may need to find new ways to engage people at home and generate new ways of income.

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