University of Things: Opportunities and Challenges for a Smart Campus Environment based on IoT Sensors and Business Processes

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Keywords: Internet of Things, Business Processes, Learning Environments, Smart Data, Data Lake.

Abstract: The university of things is an academic institution full of sensors, data, and automated processes. The collection of information and states about objects and things enables diverse research and studies in the field of information systems. This paper presents a research project, where we have set up a Smart Campus infrastructure based on Internet of Things (IoT) sensors and Long Range Wide Area Network (LoRaWAN) communication technology. From our real-world deployment, as well as from academic literature, we have identified 6 opportunities and 11 challenges for the integration and use of sensor data for business processes at universities, which are shown in this paper.

1 INTRODUCTION

Over the years, the Internet of Things (IoT) concept has gained a lot of academic and industrial interest and attention. It drives technological innovations and creates significant challenges for governments, organizations, and societies. IoT is cross-cutting various scientific disciplines, such as Computer Science and and Information System (IS) research. In particular, the IS discipline is multi-faceted, focusing on social, business, and technical aspects of Information Technology (IT) (Baiyere et al., 2020; Baskerville et al., 2018; Benbasat and Zmud, 2003; King and Lyytinen, 2006).

Given its overarching scale, the IoT can address a wide range of societal, technological, and business challenges and opportunities (Avital et al., 2019). IS research might contribute meaningfully to the IoT area from a variety of perspectives and to scholarly work (Baiyere et al., 2020).

With the emergence of IoT, a large amount of interconnected and smart devices arises that might enhance and improve business processes in organizations (Del Giudice, 2016; Meyer et al., 2013). In this paper, we are focusing on opportunities and challenges for existing and novel business processes with the use of IoT sensor data for teaching, research, and administration in the university context, which is referred to Smart Campus or University of Things (UoT) in the scientific literature. During our research, different types of IoT sensors are gradually distributed and installed.

A Smart Campus can be considered a part of a Smart City (Zhang et al., 2022). Both are sharing a similar structure; a Smart Campus can be seen as a small-scale Smart City (Fortes et al., 2019; Silva-da-Nóbrega et al., 2022; Vasileva et al., 2018).

In our real-world setup, IoT can simplify and improve processes and workflows in research and administration and at the same time, a teaching platform is built for students to study the field of IoT and its applications.

Although a full-scale installation of IoT sensors is not yet completed (installation of all sensors across the university campus), a lot of interesting data and information were created for further investigation and research. Our research questions for this work can be described as follows:

RQ1: How can an IoT sensor-based Smart Campus infrastructure be implemented to support existing and new business processes and workflows at the university from a bottom-up perspective?

RQ2: What are the opportunities and challenges for using sensor data for existing and new business processes and workflows from a top-down perspective?

Different types of IoT domains are defined to classify and structure the use of sensor data in different fields of human endeavor (Gardašević et al., 2017; Ibarra-Esquer et al., 2017). However, we found the context of UoT and Smart Campus interesting and challenging, since there are many opportunities on our campus

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Blazevic, M. and Riehle, D.
University of Things: Opportunities and Challenges for a Smart Campus Environment based on IoT Sensors and Business Processes.
DOI: 10.5220/0011761900003482
In *Proceedings of the 8th International Conference on Internet of Things, Big Data and Security (IoTBDS 2023)*, pages 105-114
ISBN: 978-989-758-643-9; ISSN: 2184-4976

to explore the topic of IoT in combination with the IS discipline.

In the next chapter, a brief overview of the concepts of IoT and Business Process Management (BPM) is given as well al related work in the Smart Campus/UoT field. After that, the adapted Design Science Research (DSR) approach of Peffers et al. (2007) is provided. In the following chapters, the usage of IoT sensors at the university and the setup of the sensor infrastructure are presented. Opportunities and challenges for enhancing Business Processes (BP) with IoT data are discussed afterward.

2 BACKGROUND

2.1 IoT, Smart Campus and BPM

A wide variety of definitions for IoT exists in scientific and non-scientific literature (e.g. Atzori et al., 2010, and Baiyere et al., 2020). Mostly, the definitions have the interconnection between physical objects and digital technologies in common.

According to Baiyere et al. (2020), IoT can be defined as "a system of interconnections between digital technologies and physical objects that enable such (traditionally mundane) objects to exhibit computing properties and interact with one another with or without human intervention" (Baiyere et al., 2020, p. 557). Additionally, different IoT domains were defined, such as Smart City, Smart Agriculture, Smart Manufacturing and many more (Gardašević et al., 2017; Ibarra-Esquer et al., 2017). A Smart Campus can be seen as an indispensable part of a Smart City (Zhang et al., 2022), which consists of various subdomains, e.g. Smart Education, Smart Assessment, Smart Learning, Smart Teaching, etc. These subdomains are supported by different IT technologies (Martínez et al., 2021; Mircea et al., 2021).

The sharing of IoT sensor data for various platforms and IS might contribute largely to BPM systems and concepts (cf. Janiesch et al. (2020)). According to Weske (2012), BPM includes concepts, methods, and techniques to support the design, administration, configuration, enactment, and analysis of business processes. The explicit representation of business processes with their activities forms the basis of BPM. Business processes that are defined might be the subject of analysis, improvement, and enactment.

In contrast, Becker and Kahn (2011) add the customer as an additional entity. According to them, the efficiency of the process is measured by the customer himself or herself, rather than by the controllers within the company. Newer definition approaches of BPM are adding more dimensions and entities. Hammer (2010) a Process Management Cycle, consisting of a Process Compliance activity as well as measuring process performance and continuous business process improvement.

The BPM field can largely benefit from IoT technology and vice versa, as presented by Janiesch et al. (2020). The authors underline the importance of the development of application scenarios for IoT-driven BPM in a general manner. With sensor data, BPM can contribute to environmental challenges, as in Green Information Systems (Brendel et al., 2022). In our research work, we delve into the university context and investigate challenges and opportunities for IoT and BPM applications.

2.2 Related Work

Several studies have been conducted in the field of IoT applications in the UoT/Smart Campus context. A Smart Campus based on IoT sensors enables a teaching and research platform for students and researchers, where IoT use cases are implemented and evaluated.

Gao (2021) describes a Smart Campus setup based on a ZigBee wireless sensor infrastructure. The data of this sensor network is stored in a Postgre SQL environment, the main sensors are a gyroscope and an electronic compass from mobile phones carried by students. The teaching effect of the ZigBee network is evaluated in the research work using Artificial Intelligence (AI) and Big Data technology, concluding that the ZigBee infrastructure has greatly improved the teaching process. However, the author does not describe limitations and ethical issues in tracking the location of students using the sensors of mobile phones.

Martínez et al. (2021) introduce an IoT infrastructure based on Long Range Wide Area Network (LoRaWAN) that focuses on measuring air quality and energy consumption. The IoT infrastructure presented can help to achieve energy efficiency, cost savings, and low energy consumption by adjusting air conditioning systems and prediction models of energy consumption and air quality in university buildings. The authors conclude that the approach presented in their research work is extendable to smart buildings and smart cities.

Cheong and Nyaupane (2022) provide an empirical study of IoT ecosystems in universities by conducting focus group interviews. From the authors' research results, requirements from the student's point of view for a Smart Campus system can be derived. While this study focuses only on the survey of students, however, the inclusion of other stakeholders of

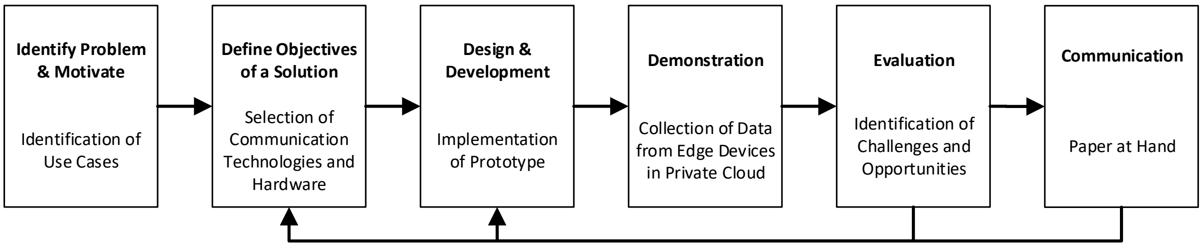

Figure 1: Design Science Research Cycle (adapted from Peffers et al. (2007).

a university is mentioned as a limitation and future research work.

Sneesl et al. (2022) conduct an Analytical Hierarchical Process (AHP) on 25 factors derived from scientific literature regarding IoT based Smart Campus systems. The research outcomes reveal that the most significant factors are governmental support, privacy concerns, social influence, and service collaboration. As the research work of Cheong and Nyaupane (2022), requirements and processes such as support activities can be derived from the findings from Sneesl et al. (2022).

Furthermore, data from IoT sensors and devices, so-called IoT data, enables big data analytics. Such data ha special, multi-scale and multi-level characteristics and corresponding analytics have gained more interest by organizations in the last decade (Williams et al., 2019). Moreover, IoT data can be integrated into a single storage, a Data Lake, around which an analytical ecosystem ca be built. Such systems have been named Analytics as a Service (Aaas) in previous research (Riehle et al., 2020).

3 RESEARCH METHOD

The goal of our research is to build a UoT by setting up a sensor-based Smart Campus. As such, we aim at designing an IT artifact and, hence, we follow the principle of DSR. Our work adapts the DSR approach by Peffers et al. (2007), who suggest six different steps to follow (cf. Fig. 1).

Following the first step according to Peffers et al. (2007), we have already contributed to the motivation in section 1, and a more detailed identification of use cases of sensors at Smart Campuses will follow in the next section. Besides, in section 4, we define the objectives of your solution by selecting an appropriate stack of communication technology and hardware to use. Section 5 holds the development and demonstration of our prototypical platform and, hence, contributes to steps three and four of Peffer's DSR cycle. In section 6, we analyze and evaluate our prototype by identifying and describing both challenges and opportunities that occurred in the previous steps. This correlates to an evaluation phase according to the research method. Lastly, this paper itself contributes to the communication of your research results.

The DSR approach by Peffers et al. (2007) consists of several feedback loops, which allow for multiple iterations of the overall process. Our research has been conducted between June 2021 and May 2022. During this time, we improved the implementation of our prototype continuously to reflect changing requirements (i.e., due to Covid19). However, in this paper, we only report the latest iteration for the sake of simplicity and comprehensibility.

4 USAGE OF IoT SENSORS AT A SMART CAMPUS

For the research of socio-technical and cyber-physical systems at our university, a computer cluster with a LoRaWAN infrastructure was procured in 2020, which includes a variety of different sensors for obtaining objects/things data and information. In the first step, use cases for a broad deployment of sensors on the campus were identified as shown in Table 1. The use cases were identified through discussions with relevant stakeholders at the university, for example, facility management staff. Before that, various sensors and gateways from different manufacturers were investigated in a test environment as well as data transmission technologies. Finally, sensors and gateways from two different manufacturers were selected.

Based on that, the communication technology and communication method were selected, where the energy consumption for transmitting the data from the sensors distributed on campus is crucial. For example, sensors for tracking inventory and items can be powered by batteries rather than statically via a cable connection. Therefore, LoRaWAN with a license-free transmission frequency was selected and it was tested on the campus in advance. IoT devices from

Table 1: Use cases and sensors for a smart campus.

Use Case	Sensor type(s)
Tracking inventory, tools, and equipment used by the university administration.	GPS Tracking sensors
Measuring the air quality of workrooms, seminar rooms, and lecture halls	Air quality sensors with the following sensor measurements: Humidity, Air Pressure, Temperature, Carbon Dioxide level, Particulate matter/dust
Measure whether fixed objects/things fall from a height (May be sensors themselves)	Accelerometers
Person Counter	Combination of various sensors, e.g.: Carbon Dioxide Sensor, Light Sensor, Radio-Frequency Identification Reader
Locating sensors (2D/3D geolocation methods using the LoRa gateways)	Technology or method to locate sensors in 2D or 3D, e.g., geolocation. Might also be GPS Tracking sensors

Pycom[1] were selected, which include sensors, microcontrollers, and boards. Pycom's devices are especially beginner-friendly for students, who can install and try out the devices for study and practical work. They can be programmed by students and are food for studying the field of IoT and sensors.

The Pycom "Expansion Board 3.0" is needed for programming sensors and microcontrollers. Furthermore, Pycom offers different types of sensor devices, which contains a combination of various sensors. For example, the Pycom Pyscan device consists of an accelerometer, light sensor and RFID-NFC. In contrast, the Pysense 2.0X device contains an accelerometer, air pressure, temperature, and humidity sensors. In addition, carbon dioxide sensors were procured as add-on modules from third-party manufacturers. The Pycom devices can be expanded with such modules. The accelerometer might be useful for detecting the falling of a Pysense 2.0X device from its mounting point. All in all, for the collection of sensor data, the devices "Pyscan", "Pysense 2.0X" and "Pytrack 2.0X" were selected and purchased. The sensors operate with the LoPy4 microcontroller, which can be programmed using the Expansion Board 3.0. Various cases and lithium polymer batteries allow the deployment of devices across the whole campus.

LoRaWAN gateways from Kerlink[2] are chosen for the data transmission of the sensors. The installation process can be done quickly due to well-written documentation from the manufacturer. Furthermore, they can be operated via Power-over-Ethernet. We use the product Kerlink "iFemtoCell" for indoor use, as well as the product Kerlink "iBTS" for outdoor use. In addition, the geolocation of sensors can be tested with the outdoor gateways.

[1]see https://pycom.io

[2]see https://www.kerlink.com/

5 INFRASTRUCTURE SETUP AND IMPLEMENTATION

After the selection of sensors and gateways for a Smart Campus infrastructure, a concept for the technical and spatial infrastructure was created. Fig. 2 shows the spatial distribution of four Kerlink iBTS outdoor gateways on the campus to ensure sufficient signal coverage of the LoRaWAN sensors and to test the possibility of 2D and 3D geolocation. If the signal quality is not sufficient for sensors located deeper in the buildings, Kerlink's indoor gateways are used for this purpose. Subsequently, a concept for transmitting the sensor data via the LoRaWAN gateways to the Private Cloud infrastructure was created.

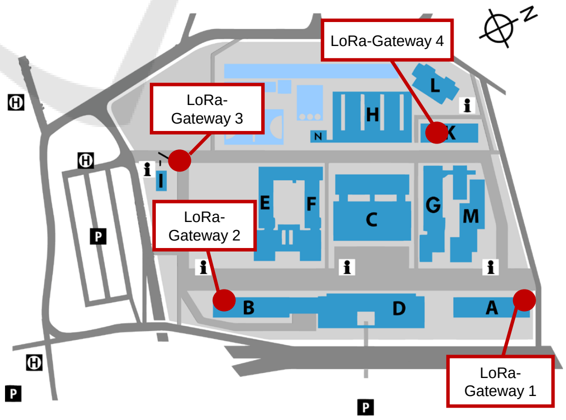

Figure 2: Spatial distribution of the LoRa gateways on the University Campus.

As shown in Fig. 3, the IoT architecture can be structured into the concept of Edge, Fog and Cloud Computing (Bittencourt et al., 2018). The various Pycom sensors with the LoPy4 as a microcontroller form the edge devices. Using the Lo-

RaWAN protocol, the sensor data is transmitted to the Fog layer, which represents the LoRaWAN gateways. Subsequently, the data packets are transmitted via TCP/IP protocols to the "The Things Stack Version 3" network server, which is an open-source-based LoRaWAN network server.[3]

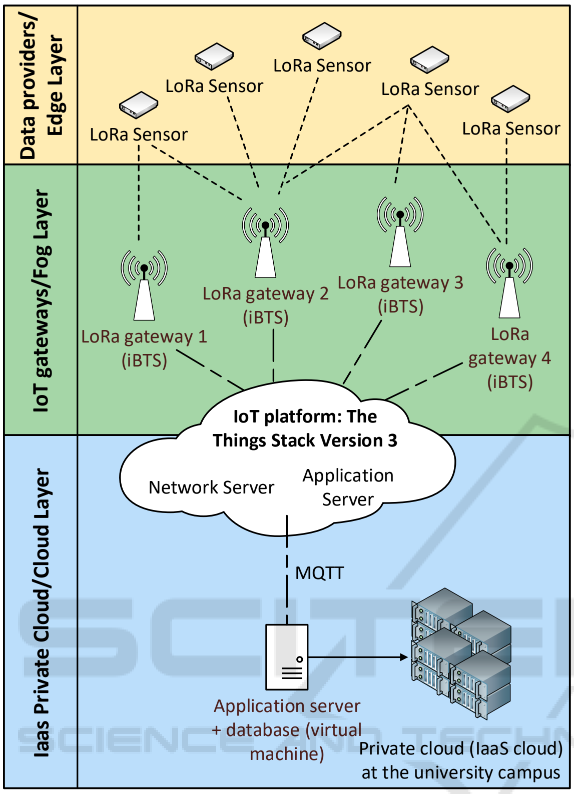

Figure 3: Rough representation of the IoT infrastructure at the University campus.

According to the The Things Network Documentation, the network server operates the LoRaWAN network layer, which includes MAC commands, regional parameters and Adaptive Data Rate (ADR) and consists of a Gateway Server. It maintains connections with LoRaWAN gateways that support User Datagram Protocol (UDP), MQ Telemetry Transport (MQTT), and more. It forwards the uplink traffic to the network server directly or indirectly.

The processing of sensor data forwarded by the gateways is not a direct part of the Fog layer, but rather an intermediate step between the fog and the cloud layer. On the cloud layer, a private Infrastructure as a Service (IaaS) cloud based on Apache Cloudstack[4] and Kernel-based Virtual Machine (KVM) is being built as the cloud infrastructure for central sensor data processing at the university.

By now, 31 sensors are currently in operation on campus, and a virtual machine based on Ubuntu 22.04 was set up as a prototype for storing and representing IoT data. For storing the sensor data, a MySQL database is used initially. Although other database systems might be more suitable for the purpose, e.g. time-series databases, the MySQL database is used for testing the Smart Campus architecture. For a graphical representation of the sensor data, Grafana is used. To receive sensor data from The-Things-Stack, an MQTT broker based on Node-RED is run on the virtual machine. Node-RED is a flow-based programming tool originally developed by IBM and consists of a Node.js runtime environment. The flow editor can be operated via a web browser. In our case, the Node-RED application also runs on the virtual machine.

6 OPPORTUNITIES AND CHALLENGES FOR ENHANCING BUSINESS PROCESSES WITH IoT DATA

Since the first appearance of IoT, many IoT systems have been developed in different IoT domains. Prominent examples include Smart Home, Smart City, Smart Agriculture, and others. Currently, not much research has been conducted regarding IS and BPM applications in the UoT/Smart Campus domain. Therefore, it is particularly interesting for us what possibilities IoT sensors offer for the design of business processes and IS within our university.

The Smart Campus infrastructure based on IoT data is installed and implemented on the bottom-up principle. In the first step, use cases were identified based on the opportunities provided by our procured IoT hardware. The research work of Janiesch et al. (2020) offers suggestions, guidance, and approaches for our work.

Six opportunities and 11 challenges for building a Smart Campus setup with IoT devices and business processes were discovered during our research by deploying the sensors on the university campus.

For linking information generated by IoT sensors with business processes, a top-down approach is conducted in the context of this research work. In the first step, the main task areas of the university are identified. Subsequently, some individual tasks are assigned to the respective higher-level task area. Fig. 4

[3]https://www.thethingsindustries.com/docs/getting-started/what-is-tts/ (accessed 21st Feb. 2022)

[4]https://docs.cloudstack.apache.org/en/4.16.1.0/conceptsandterminology/concepts.html (accessed 15th Aug. 2022)

shows the main task areas of the university with a selection of relevant business processes.

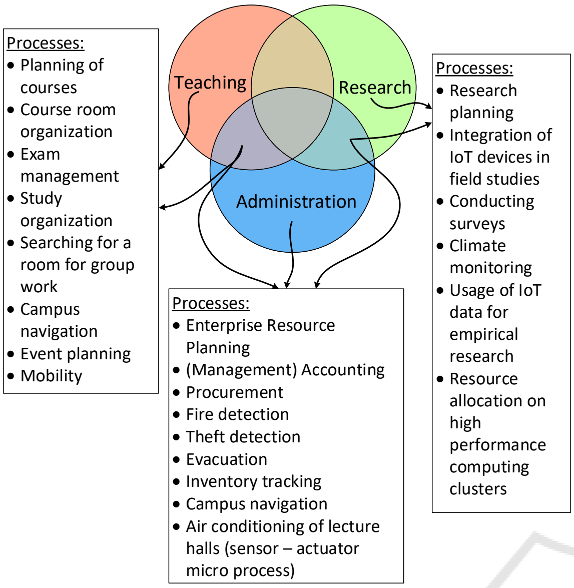

Figure 4: Responsibilities of the university and selection of business processes (own illustration).

Many processes within the university cannot always be assigned precisely to one task area; rather, the various task areas overlap, which in turn leads to numerous different processes. Compared to other public institutions, students, researchers, and administrators in particular interact with each other at universities. The interaction and communication between these actors vary a lot and result in different requirements. Consequently, various information systems are used, such as groupware systems and university information systems, which are used by various stakeholders and students. In addition, there are other IS that are mainly used by administrative staff and teaching staff, such as an accounting system and an Enterprise Resource Planning (ERP) system. The IS for teaching and examination management is used in particular by students and teaching staff.

Marakas and O'Brien (2013) introduced the concept of the roles of the business applications of IS, which is shown in Fig. 5. The representation is modified to the UoT/Smart Campus context.

The authors provide three fundamental roles for all business applications in IT, which IS can fulfill for a business enterprise (or organization). First, the support of strategies of the university (role "A"). The role formulation was adapted for the university context. Here, IS should primarily support strategies for improving study and teaching conditions, and research conditions, as well as strategies in the area of administration.

Second, IS should support Business Decision Making (role "B"). In our context, IS is intended to support decision-making for students (study planning), faculty (teaching and research planning), as well as administrative leaders.

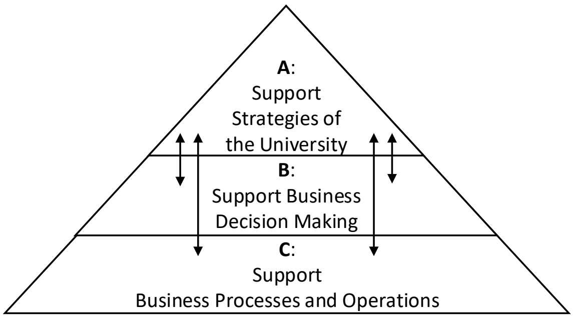

Figure 5: Roles of Business Applications in IS (cf. Marakas and O'Brien (2013)).

Last, IS should support of business processes and operations (role "C"). Many business processes of the universities are already implemented in the existing IS. Data from IoT sensors may contribute meaningfully to these processes. However, new processes might be created with the use of sensor data.

The starting point for collecting opportunities, challenges, and requirements is defined by the data of the Pycom sensors about different information of the objects, which are: air quality, humidity, temperature, location of sensors and objects (GPS), values of the accelerometers, and RFID scanners.

The opportunities and challenges for a Smart Campus infrastructure consisting of sensors, data, and automated processes are shown in Table 2 and Table 3, each of them mapped to one or more Business Application roles in IS as shown in Fig. 5.

In our real-world application, we also see the possibility of triggering various micro-processes (Janiesch et al., 2020) through sensor data (**O1**). In the search for a learning and working place, for example, different sensors could indicate the availability of a free working place, or provide suitable information about it in a Workflow Management System. A student or employee can mark the place as reserved. As soon as a workstation has been occupied, sensors would register the status and indicate the workstation as no longer available. Therefore, we assign this opportunity (**O1**) to the Business Application role **C** (Fig. 5).

In addition to the development of micro business processes, sensors can provide real-time data about the condition of a room (lecture or seminar room) to facilitate decision-making (**O2**) for all members of the university. For example, another room may be sought for a meeting or class if thermal comfort is not given

Table 2: Opportunities for enhancing business processes with IoT data.

No.	Description	IS roles (Fig. 5)
O1	New (micro)-processes and workflow can be triggered by sensor data as event inputs	C
O2	Objects and things at the campus, e.g., rooms, offices, and labs can provide real-time data for improving decision making	B
O3	New methods of computer science (e.g. Big Data Analytics, Machine Learning & AI) can be applied to analyze the enormous amount of sensor data collected over time to discover new insights and knowledge that lies in the data	A and B
O4	From the strategic to the operational layer, sensor data can add value to information systems, such as ERP systems and collaborations systems at the university	A, B, and C
O5	Since the IoT infrastructure on the university campus is mostly based on open technologies (open source IaaS cloud, extensibility of Pycom sensors with third-party devices, TTN as an open IoT platform, LoRaWAN as license-free data transmission technology), the Smart Campus can be extended with additional sensors and applications fast and at low cost.	C
O6	Green IS: Reducing energy consumption for the university through sensor-driven BP and workflows	A

due to heating failure or outside weather conditions. Business Application role **B** is assigned to this opportunity.

Collecting sensor data over a long period generates an enormous amount of data (Big Data, **O3**). This allows modern methods of processing large amounts of data to be applied in order to gain further insights. In our opinion, this opportunity corresponds to roles **A** and **B**, as data analytic methods can be useful for strategic alignment of IS, and at a lower level, they can support decision-making.

Moreover, sensor data can enrich existing IS on campus, e.g. procurement systems for inventory or groupware systems used by employees, researchers, and students (**O4**). For example, a room for group working can be searched using a groupware system or a web dashboard, and sensor data can provide real-time information. This opportunity is assigned to all Business Application roles. The current setup of the IoT sensor network on campus is by no means complete or perfect. Based on the LoRaWAN standard and the sensors and actuators available on the market from different manufacturers, the Smart Campus can be constantly expanded and improved with new actuators and sensors (**O5**). This opportunity corresponds to the Application role **C**, as it is fundamentally essential for integrating sensor data into business processes.

Because sensors can provide real-time data about the state of a building or thing, resource-saving (micro)processes can be delivered (**O6**). A possible use case would be monitoring indoor temperature, carbon dioxide content, and humidity in indoor spaces (lecture hall, library) with a fresh air supply. By determining the demand for fresh air in the interior, this can be regulated variably so that it remains as efficient as possible and only consumes as much energy as necessary (cf. Martínez et al., 2021). From our point of view, this opportunity is to be assigned to Application role **A**, since a possible adjustment of the strategic orientation of an IS is required here.

In addition to the six opportunities, we encountered 11 challenges and problems during our research, which we have summarized in Table 3. Currently, few, if any, business processes at the university are comprehensively documented and modeled (**C1**). For us to identify the business processes where sensor data can provide added value for improvement, a complete set of processes must first be modeled and documented centrally. Therefore, we have assigned this challenge to the Business Application role **C**. Once the business processes are collected, modeled, and documented, we need to identify which processes may be suitable for the integration and use of sensor data (**C2**). In our view, this challenge would also correspond to the Business Application role **C**.

As mentioned earlier, existing processes may be enhanced and improved with sensor data, but additionally, micro-processes can also be modeled using information from the sensors as a starting event (**C3**). Such micro processes may be modeled and realized using Workflow Management Systems. Therefore, we classify this challenge in the Business Application role **C**.

Table 3: Challenges for enhancing business processes with IoT data.

No.	Description	IS roles (Fig. 5)
C1	Collecting and modeling existing BP at the university	C
C2	Identification of existing BP to be supported by sensor data, so that the number of manual interactions to the process is reduced	C
C3	Identification of micro-processes and "habits" from employees and students which can be derived from sensor data	C
C4	In order for sensor data to be reliably collected and made available for critical BP, the data quality (cf. Liu et al. (2020)) of the sensors must be ensured	A, B, and C
C5	Smart data: The collection and processing of data should be targeted and accurately designed for the area of application	B and C
C6	Data Lake: A data storage platform should be developed to reliably store a large amount of sensor data	C
C7	The distribution of sensors poses infrastructural requirements, such as energy supply, mounting points	C
C8	Since a comprehensive sensor data infrastructure needs to be maintained and monitored at all times, this poses new challenges in terms of financial, time, and human resources	C
C9	Collection of sensor data from objects and things must be in accordance with the data protection rules of the EU	A
C10	Collection of sensor data for BP and workflow modeling must be done in accordance with existing ethical guidelines	A
C11	Smart Campus applications, BP and workflows with sensor data poses safety and security requirements	A

For our IoT Smart Campus infrastructure that needs to provide real value and benefit to members of our university, an adequate sensor data quality (cf. Liu et al., 2020) is essential (**C4**). Since we believe this affects all levels of Business Application roles, we assign this challenge to the roles **A**, **B**, and **C**. The installation of sensors and the definition of sensor data transmission should be designed thoughtfully and purposefully, also with regard to the corresponding business process or micro process, a data processing concept is necessary (**C5**). Therefore, this challenge applies to role **B** and **C**.

At the application level, sensor data needs to be stored in a sort of a data lake that can reliably and efficiently store a large amount of sensor data in our cloud (**C6**), which corresponds to the Business Application role **C**. As we distributed and installed the sensors based on some use cases in a bottom-up manner, we encountered problems at the infrastructure layer. For example, it is difficult to securely install the sensors in the rooms, the sensors need to be protected from thieves. Usually, there is no power supply nearby, and sometimes, sensors fell off their mounting points (**C7**). In addition, the sensors must always be checked and maintained (**C8**), recharging the battery and detecting erroneous sensors. Powered with 2000 mAh lithium polymer batteries, the Pycom devices need to be recharged every 12 weeks. In contrast, the carbon dioxide sensor which may be operated with the LoPy4 microcontroller has a recharge interval of 2 weeks. These challenges require financial, human, and time resources. In our opinion, the safe installation and maintenance of the Pycom sensors is a basic requirement for a Smart Campus System, therefore, we assign **C7** and **C8** to the Business Application role **C**.

Installing a Smart Campus infrastructure poses not only technical and organizational challenges but also legal ones. The collection of object data through sensors should be in line with the European data protection regulations (**C9**). This challenge is assigned to role **A**. In addition, any ethical hurdles to building the Smart Campus infrastructure must be addressed. It is imperative that all university members should be involved in the installation process. At no time should the collection of sensor data lead to a disadvantage for the stakeholders. Information should be provided at appropriate points in the process (**C10**). Since both of these problems (**C9**, **C10**) are strategic challenges from our perspective, they take on the Business Applications role **A**.

Our Smart Campus infrastructure is built on open IT and networking standards such as LoRaWAN and TCP/IP. Therefore, further challenges and problems arise regarding IT security requirements (**C11**). For example, the integrity of the sensor data must be protected, and access rights need to be managed. Other opportunities and challenges can be identified, but the above provides a foundation for further research in our Smart Campus setup.

7 DISCUSSION AND CONCLUSION

In this work, the planned setup of a smart campus infrastructure using IoT sensor data, LoRaWAN technology, the IoT platform The Things Stack, and an in-house operated IaaS cloud infrastructure were presented. In the first research question, the selection of IoT devices, communication technologies, and data transmission were presented according to the bottom-up scheme. In the first research question, it was determined which sensor data should be collected for which use cases. The later use of the information of the objects was not considered in this step. However, the aim is about finding meaningful data from objects and things at the university.

The Smart Campus setup we present includes an in-house cloud infrastructure as a private cloud. Compared to public cloud infrastructures, operation poses additional challenges such as installation, commissioning, and maintenance. This delays the development of a Smart Campus infrastructure. However, operating a private cloud has many advantages, e.g., sensitive data can be stored in compliance with EU data protection law. In addition, there is no longer any dependence on public cloud providers. Although we have already installed dozens of sensors, opportunities for improving the infrastructure in terms of energy supply are becoming apparent. We have found in our setup that the lithium polymer batteries with 2000 mAh capacity each can power the Pycom sensors for about 12 weeks. In contrast, the carbon dioxide sensors can only be supplied with energy from the batteries for two weeks. The power consumption of these sensors is too high, so for carbon dioxide measurement, we need to connect the sensors to a permanent power supply. Above that, some cases of the sensors we ordered are less suitable for outdoor use than others.

Nevertheless, the setup and installation of sending sensor data and processing were done quickly as expected. The data is also sent and received at reliable intervals. The LoRaWAN transmission technology we use turns out to be sufficient for sending and receiving sensor data and provides a more energy-efficient way to operate Pycom devices than WiFi or Bluetooth. In addition, the LoRaWAN network with the sensors would relieve the university's WiFi network.

The collected sensor data can then be used for various purposes. In the second research question, 11 challenges and 6 opportunities were gathered for the integration of sensor data in business processes. The opportunities and challenges gathered in this research work are not comprehensive, and in the ongoing research, more opportunities and challenges may arise.

The development of a concept to ensure an adequate quality of the sensor data, reliable and efficient storage, as well as the sensible processing of the data for further use (smart data) are the subject of further research. As in the first research question, a bottom-up approach should be chosen here, the quality of sensor data and efficient data storage open up a wide range of uses. In addition, data protection and data security must be guaranteed during development. For the use of sensor data in business processes, as in the second research question, the challenges and opportunities presented should be tackled to explore the possibilities of sensor data integration into the business processes of the university.

ACKNOWLEDGEMENTS

This research has been supported by the Deutsche Forschungsgemeinschaft (DFG) under Research Grant No. 432399058.

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