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Adoption of smart technologies and circular economy performance of buildings

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Abstract

Purpose – This paper examines the use of intelligent technologies in buildings and whether the use of smart technologies impacts the circular economy performance of buildings in terms of energy and water consumption, their marginal cost and the management decision time and quality, for building management companies.

Design/methodology/approach – The study is initiated through the detailed build-up of the proposition that employs a systematic literature review and adopts the case study research design to make a cross-case analysis of the information extracted from data. The data are derived from the operating costs of two buildings in which most advanced smart technologies are used in Cape Town and interviews with their facility managers. These data provide two research case studies. The results of the investigation are then analysed and linked back to the literature.

Findings – The results of the research suggest that the implementation of smart technologies to create intelligent infrastructure is beneficial to the circular economy performance of buildings and the time taken for management decisions. The results of the study have proven that the impact of smart technologies on the circular economy performance of buildings is positive, as it lowers the cost of utilities and decreases the time required for management decisions.

Research limitations/implications – The research reported in this paper is exploratory, and due to its limited sample size, its findings may not be statistically generalizable to the population of high-occupancy buildings in Cape Town, which incorporate smart infrastructure technologies within their building management systems (BMSs). Also, the empirical data collected were limited to the views and opinions of the interviewees, and the secondary data were obtained from the selected buildings.

Practical implications – The findings suggest that investment in smart technologies within buildings is of significant value and will improve the circular economy performance of buildings in terms of low energy and water use, and effective management decisions.

Social implications – The results imply that there would be more effective maintenance decisions taken by facilities managers, which will enable the maintenance of equipment to be properly monitored, problems with the building services and equipment to be identified in good time and in improved well-being and user satisfaction.

Originality/value – The study provides evidence to support the concept that advanced smart technologies boost performance, the time required for management decisions and that they enable circularity in buildings. It supports the proposition that investment in the more advanced smart technologies in buildings has more positive rewards.

Keywords 4IR, Building maintenance, Building performance, Circular economy, Facility management, Management decision time, Smart technologies, Energy and water consumption

Paper type Research paper

1. Introduction

The implementation of smart infrastructure has been progressively adopted within building management systems (BMSs) over time (Dilanthi *et al.*, 2000). Smart infrastructure is the

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process of combining digital infrastructure with physical infrastructure while providing improved information to achieve the outcome of better decision-making, in less time and at a lower cost (Bowers *et al.*, 2016). Physical infrastructure is the foundation of modern society and includes all the infrastructure systems within the transport, energy, water, telecommunications and waste sectors. These systems are ultimately the backbone of society today and provide the basis for everyday life and ensure the harmonious flow of goods, services and information within society (Ogie *et al.*, 2017).

As the world advances into the 21st century, critical aspects of physical infrastructures are becoming smart and digitised through means of being able to monitor themselves, communicate and self-govern (Annaswamy *et al.*, 2016). This transition is enabled through various drivers which include sustainability concerns, scarcity of resources, economic considerations and rapid growth in the enabling technologies of sensor networks and computational and communication systems (Annaswamy *et al.*, 2016). The terms *smart technologies*, *smart infrastructure*, *digital infrastructure* and *smart buildings* are used interchangeably in this article.

Digital infrastructure tools comprise BMSs, which are smart integrated control and monitoring systems utilised for better management of the overall facility, systems and components, the Internet of Things (IoT) and sensor technology. The IoT is the interconnection of smart objects into a global network employing extended Internet technologies. The IoT is also an ensemble of intelligent applications and services leveraging these technologies to implement intelligent control of “things” (Ding *et al.*, 2013). Lastly, sensor technology is the product of a combination of sensors being utilised for a specific purpose. Sensors are smart devices that monitor environmental characteristics or physical parameters, such as humidity, quantity, temperature, movement and speed. These physical parameters are converted into a signal which is then measured electrically. A wireless sensor network (WSN) is described as a group of multiple sensors working simultaneously and interactively. WSNs may also contain gateways used to collect data from the sensors and pass it on to a server, along other multiple sensors (Whitmore *et al.*, 2014).

Physical infrastructures are confronted with problems such as high management costs, excessive time taken between critical decisions, a high degree of wastage with regards to resources (electricity and water), poor air control and quality, lack of adequate security and access control, poor understanding of the facility and reduced levels of communication (Zhang and Hu, 2011). These problems are all contributing factors which impact upon the overall performance of the facility in an adverse manner. According to Zhang and Hu (2011), the primary causes of the poor performance of facilities are the lack of advanced practical security technologies and management tools. The problems are also found to stem from the inefficient management of facilities through constant problems which arose, mismanagement of facilities, as well as a lack of sufficient knowledge and awareness around the implementation of smart infrastructure technologies.

Included in smart city programmes is the implementation of the smart infrastructure within buildings for improving their management and interaction with their surroundings. The result of being in the early stages of smart infrastructure development leads to limitations on the efficiency of facility management, through the limited number of smart tools available. Harnessing the ability to utilise smart infrastructure has been shown – although a high degree of initial capital is required – to produce long-term savings based on lower maintenance costs, through quicker and more effective management decisions (Cuff *et al.*, 2008). This therefore boosts the circular economy performance of the building. Also, it is imperative that digital infrastructure is incorporated into physical infrastructure in a developing country like South Africa, in line with the ideals of a fourth Industrial Revolution and the need for sustainability.

The concept of the circular economy has become one of the most recent proposals to address environmental sustainability (Murray *et al.*, 2017). This is done through addressing economic growth, while at the same time considering the shortage of raw materials and energy (Yuan *et al.*, 2008) as well as a new growing business construct (Murray *et al.*, 2017). The circular economy is based on the concept of closing loops through different types and levels of recovery (Yong, 2007; Yuan *et al.*, 2008) by transforming the material into useful goods and services through resource efficiency (Klettner *et al.*, 2014; Webster, 2013). Resource efficiency within the circular economy is achieved through the prudent use of raw materials and energy consumption throughout all stages of the value chain (Yuan *et al.*, 2008).

Cape Town's progress in implementing smart city programmes is still in the very early stages (Wyngaardt, 2018). It is not known whether digital infrastructure is being adopted in the management of buildings in the Cape Town metropole, and whether its adoption boosts the circular economy performance of built assets by enabling savings based on lower consumption of water and electricity and effective management decisions. Therefore, this research examines whether the implementation of the advanced smart infrastructure within BMSs enhances the circular economy performance of built assets. This paper views circular economy performance as the process of minimising resource consumption (energy and water) in built assets and enabling efficient and faster decision-making in their management, through high initial investment in advanced smart technologies.

According to Ogie *et al.* (2017), using appropriate smart technologies in managing building systems, based on their impact on the performance of operating buildings, is a contemporary topic in facility management that is progressing and expanding gradually. This technique involves evaluating and suggesting the most appropriate smart technology that best fits the built assets.

There is limited research that examines the advanced smart technologies used in BMSs in South Africa and particularly the Cape Town metropole. Therefore, this research investigates the impact of most advanced smart technologies incorporated in the BMSs of two buildings, on the consumption of energy and water, and on management decision time. To find out whether using the more sophisticated smart technologies will improve the circular economy performance of the building. Such technologies include smart meters and remote user interactive systems.

The novelty of this research is in the selection of advanced smart technologies incorporated into the BMS of buildings in Cape Town, as a pioneer city. The research aims to extend knowledge, not only about South African buildings but also about buildings on the African continent as a whole and to investigate the impact of advanced smart technologies on energy and water consumption, as well as on system feedback, analysis and decision-making time.

2. Types of smart infrastructure and performance in buildings

2.1 Overview of smart infrastructure

Smart infrastructure is the product of combining digital infrastructure with physical infrastructure, while providing improved information to achieve the outcome of better decision-making, in less time and at a lower cost (Bowers *et al.*, 2016). The concept of smart infrastructure is a result of the intelligent tools which are harnessed to create smart infrastructure or a smart building. The first of these tools is the Internet, which has been developing for over three decades and has undergone multiple evolving stages. Initially, it was only used as access shared information; it then developed further as human interaction increased and became a platform whereby the end-user also was a producer of information, with a more significant social interface (Al-Begain *et al.*, 2009).

An advancement which then furthered communication and connectivity was the mobile phone, which has allowed for access to information anywhere and at any time (Berners-Lee *et al.*, 2006). With the Internet now connecting the information to people, and people to people, the next step is connecting people to objects, systems, components and anything which proves beneficial. With the connections of these multiple assets via the Internet and with the inclusion of sensors, the systems become smart and aware resulting in an intelligent system which offers smart services (Balakrishna, 2012).

2.2 Building management system

A Building Management System (BMS) is a key enabler to transform a building into a smart building. A BMS is a control system which is used to virtually monitor and manage the electrical and mechanical services within the facility. These services include but are not limited to energy use, heating, air-conditioning, lighting, access control, water management and production. A basic BMS will house the combination of a database and sensors which are connected through an Internet-capable network, to manage the system. The BMS does this by multiple interconnecting systems to one platform or more, depending on the extent and complexity of the various systems. Information from the connected systems is then processed and analysed by the BMS, with results being presented through 3D models, graphs and data tables. This information is tracked live, and when sensors are triggered, they display on the central system allowing for adequate response time to attend to incidents or monitor efficiency (Wang *et al.*, 2002). Not only does it offer alerts but also the capability to control electrical and mechanical components integrated within the system.

With internet-enabled BMS, the intelligent building is capable of remote communication of high capacity. This communication is between the components and the central system (Wang *et al.*, 2002). Four main components form the BMS and they are as follow; energy management system; lighting and room occupancy control; heating, ventilating and air conditioning (HVAC) and security and monitoring. Smart technologies used to enhance BMS comprise of the IoT (the concept whereby physical hardware devices communicate with each other, with its software and with a communal digital network to facilitate the ease of use by the end-user); and wireless sensor technology (smart devices that monitor environmental characteristics or physical parameters, such as humidity, quantity, temperature, movement and speed). Table I outlines a summary of the service in which smart technologies are used, the type of network on which they run and their level of feasibility for implementation.

Through the use of smart infrastructure, the facilities manager can obtain live data from the BMS to monitor day-to-day operations and make adjustments where applicable. Over time the data collected forms averages, which are further utilised to make accurate predictions of future consumption.

Table I.
Summary of service, network type and feasibility of implementation

Service	Network type	Feasibility
Waste Management	3G, 4G and Wi-Fi	Smart sensors in garbage systems are harder and more expensive to implement
Air quality monitoring	Bluetooth and Wi-Fi	Greenhouse gas sensors may not be feasible
Noise Monitoring	Ethernet and sensor	Sound detection hard to implement
Movement Monitoring	Ethernet and Wi-Fi	Easily implemented
Energy consumption	PLC and Ethernet	Easily implemented
Smart parking	Ethernet and sensor tech	Readily available
Smart lighting	Wi-Fi, sensors and Ethernet	Already being implemented
Traffic monitoring	Wi-Fi, Ethernet and 4G	Expensive but easily accessible

Source(s): (Zanella *et al.*, 2014)

2.2 Building performance and measures of building efficiency

Building performance is defined as the building's ability to perform its function, based on its interaction with its environment and the occupants within it (Douglas, 1996). To measure building efficiency and effectiveness, there are five aspects to be considered, indicating whether the building meets the needs it was designed for, such as occupants' comfort – including temperature, fresh air flow, lighting, noise control and their health. Furthermore, the aspects dwell on the efficiency of function within the building with regards to response times, personal control of temperature and lighting as well as individual productivity at work (Cohen *et al.*, 2001). These aspects vary depending on the nature of the building (Preiser *et al.*, 2006).

In addition to these five pillars, for a building to achieve top performance, it needs to comply with the SANS (South African National Standards) 204 (energy efficiency in buildings) and SANS 10252 (water supply and drainage for buildings) National Building Standards in South Africa. These South African regulations provide a guide to having energy-efficient and sustainable buildings. These energy and water regulations target the building's overall design rather than the specific performance levels for the life cycle and management of the building. The regulations outline the requirements for the building's structural elements and services for improving energy efficiency. These regulations, as applied to existing buildings by improving the current infrastructure to reach regulatory energy efficiency and to meet sustainability requirements (Grove, 2013) are shown in Tables II and III. Accomplishing these goals is in effect creating an efficiently functioning building. Currently, there are no specific standards against which to measure a building's performance. However, the building regulations highlighted in SANS 2014 and SANS 10252 provide minimum requirements for energy demand and usage, to achieve a well-performing building.

Tables II and III contain specific indicators provided by the South African National Standards, which allow for the building performance to be measured. In Table II, the maximum annual consumption of electricity is represented. It can be used as a benchmark to deduce whether the implementation of the smart infrastructure within a building has worked towards decreasing the consumption of electricity or not. Figure 1 shows the relevant climatic zones. The climate is the most significant role player in terms of energy consumption, due to internal climate and comfort control systems.

In Table III, the maximum daily water demand is represented as a standard level, to determine whether the implementation of the smart infrastructure within a building has worked towards reducing the daily water usage, or not. For this study, the building performance indicators will consist of time taken for managerial decisions, levels of energy and water consumption, and the utility costs incurred by the building over a period.

		Maximum energy consumption kWh/m^2					
		Climatic zone (see Figure 1)					
Classification of occupancy of building	Description of building	1	2	3	4	5	6
A1	Entertainment and public assembly	420	400	440	390	400	420
A2	Theatrical and indoor sport	420	400	440	390	400	420
A3	Places of instruction	420	400	440	390	400	420
A4	Worship	120	115	125	110	115	120
F1	Large shop	200	245	260	240	260	255
G1	Offices	650	190	210	185	190	200
H1	Hotel	600	650	585	600	620	630

Source(s): (SANS, 2014:2016)

Table II.
Maximum annual consumption per building classification for each climatic zone of South Africa

Table III.
Maximum daily water demand for different premises

Premises	Water demand (including hot water)
Boarding schools, children's homes and residential nurseries	200 L per capita
Educational institutions	50 L per capita
Kitchens	12 L per meal prepared
Hotels, boarding houses, motels and nurses' homes:	
with resident staff	300 L per bed
without resident staff	250 L per bed
Commercial premises:	
Shops	15 L per 10 m^2 gross floor area
Superstores such as hypermarkets and warehouses	125 L per WC pan, or per 600 mm width of slab urinal
Offices	18 L per m^2 gross floor area
Clinic, hospitals, nursing homes and old-age homes	550 L per bed
Factory ablutions	200 L per capita

Source(s): (SANS 10252:2012)

2.3 The impact of smart infrastructure on management costs, decision-making time and the circular economy performance of built assets

According to Malidin *et al.* (2008), technology in the construction industry and building management industry is evolving towards better efficiency and advancement within existing systems. Higher efficiency means lower energy demand for the same utilisation level through technological advancement. The overall statistics deduced from Malidin *et al.* (2008) study, show that there is a reduction in energy demand when smart technologies are implemented, and similarly, the cost to satisfy that demand is also lowered. Although smart technologies such as sensors and monitoring systems make use of electrical energy, the electrical saving

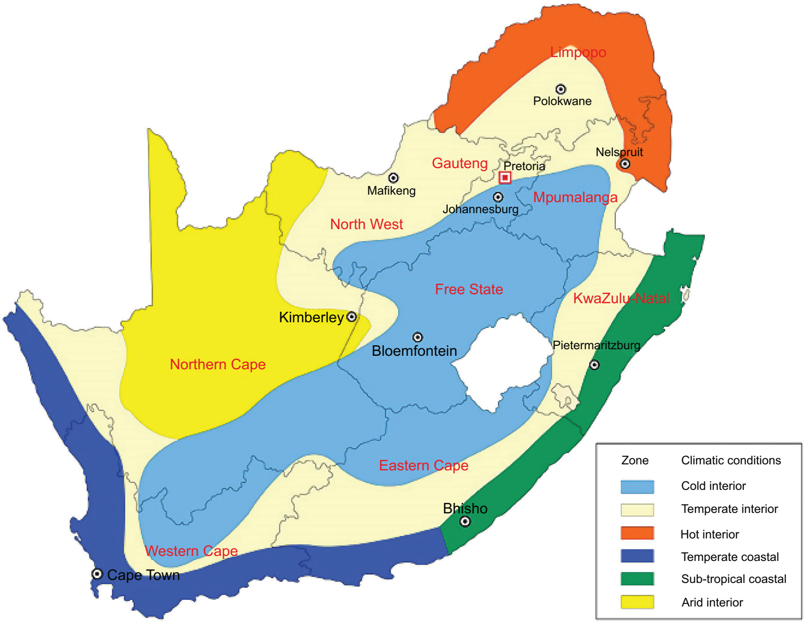


Figure 1.
Climatic zone map of South Africa

Source(s): *(SANS 204:2016)*

due to these infrastructures far outweighs the electrical input needed to run these systems (Malidin *et al.*, 2008). It is also acknowledged by Maïzi *et al.* (2006) that reduction of consumption due to smart infrastructure would inevitably reduce the management cost of a building.

Effective and relevant implementation of consumption management and conservation strategies is underpinned by an understanding and knowledge of how consumers perceive and use their energy and water (Willis *et al.*, 2010; Jorgensen *et al.*, 2009). Domènech and Saurí (2011) and Farrelly and Brown (2011) noted that the proactive consumption management approaches such as implementing the smart BMSs and installing the smart meters are more successful in managing and reducing the demand for energy and water compared to the reactionary approaches such as reducing consumption through regulations.

Roisin *et al.* (2008) established that implementing the BMS leads to 40–70 per cent energy savings of artificial lighting and HVAC in the building, when employed correctly. Bowers *et al.* (2016) proved that using proactive water demand management in Australia was able to reduce the water consumption of the buildings in the study by more than 20 per cent of the standard demand usage.

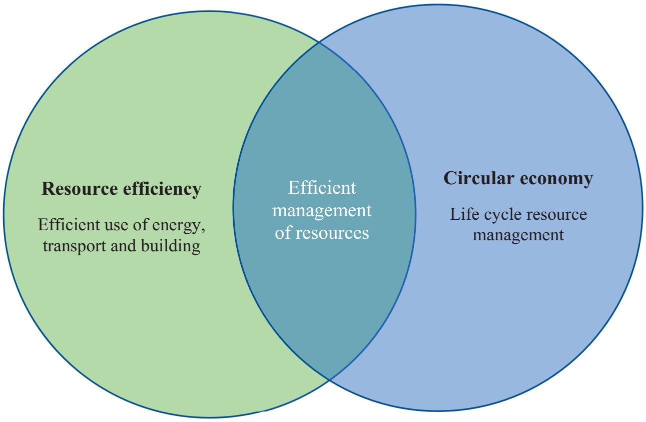
End-user satisfaction is based on the comfort of the consumer/end-user. This comfort may be satisfied by the production of useful energy by other forms of energy conservation to meet with the defined demand. The energy and water demand could thus be satisfied by the implementation of presence detectors such as light control, climate control sensors, motion sensors and smart meters. Smart control and monitoring systems such as those used in smart infrastructure developments autonomously assess factors such as internal comfort and reduce the usage of the resources (energy and water). A complex system would either display changes to be made by the management entity, or adapt automatically to the changes that are needed for ultimate internal comfort (Yang and Wang, 2012). The primary objective of the system is to balance resource usage efficiency, such as electricity and water consumption, obtain the highest possible comfort level for the user of the facility, and maintain the resource usage at the optimum level. The different control systems make it easier and quicker for building managers to make decisions based on these systems (Yang and Wang, 2012).

This study employs definitions of circular economy and resource efficiency as defined by the European Commission “Roadmap to a Resource Efficient Europe” (EC, 2011) and illustrated in Figure 2.

According to this approach, the circular economy aims to “reduce, reuse, recycle, substitute, safeguard and value” resources across all stages of a product life cycle. Resource efficiency is a broader term which encompasses improved use of energy, transport and buildings, as well as resources. In the context of this study, which focuses on managing the consumption of resources in buildings, the resource efficiency scenario includes the potential savings from implementing smart technologies in buildings. The preceding section suggests that the adoption of smart technologies in buildings will enable the circular economy performance of built assets, in terms of decreased energy and water consumption and their marginal costs, and improve management decision time, as illustrated in the research conceptual framework (see Figure 3). This proposition is further examined in the paper, using empirical data.

3. Research methods

This research into the impact of the adoption of most advanced smart infrastructure on the circular economy performance of buildings adopted the qualitative research approach, employing an extreme cross-case, multi-case research design. In the context of this research, the characteristics being researched do not exist within a large sample or a population. The characteristics relevant to this research only exist in a small selection of buildings that have



Source(s): *European Commission*

Figure 2.
Definitions of resource efficiency and circular economy

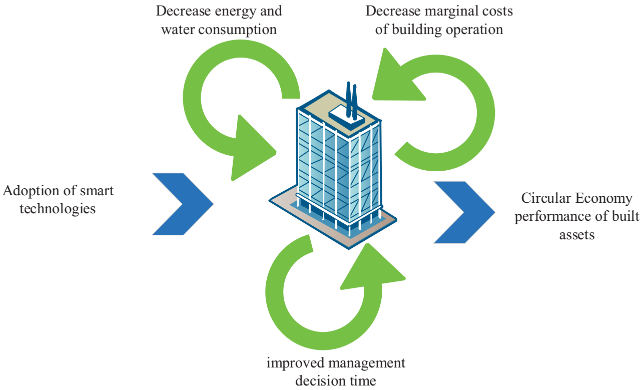


Figure 3.
Research conceptual framework

been chosen as case studies. Also, previous studies (such as Malidin *et al.*, 2008) in this area made use of the qualitative research approach. A qualitative long-term saving research approach enables the researchers to develop an in-depth understanding of how smart infrastructure technologies, in a building's management system, impact the circular economy performance of the built assets.

An extreme cross-case study is preferred over the singular approach, as Seawright and Gerring (2008) state that extreme cross-case selection and analysis should be used, as they provide extreme or unusual values/performance. The extreme cross-case research design includes an exploratory study of two high-occupancy buildings, both located in the Cape Town metropole, which incorporate more advanced smart infrastructure within their BMSs.

A convenient purposive sampling technique, which is a form of non-probability sampling technique, was therefore used in this research, because a list of all smart buildings in Cape Town does not exist. This sampling method is supported by the researchers' knowledge, access to and location of those buildings that use smart infrastructure. This means that the buildings that were sampled are those buildings that have been located by the researchers. This method of sampling allows units of analyses to be deliberately obtained in such a way that the sample could be representative of the population (Wellman *et al.*, 2005). The use of this sampling method, also referred to as judgment sampling, is further supported by the fact that the study will rely on the deliberate choice of particular informants due to their qualities and knowledge. (Naoum, 2007). The interviewees included all individuals directly involved in the management of the selected building and who were interested in participating in the study.

The sample consisted of two buildings selected by means of the purposive sampling technique. Building A is a high traffic, high occupancy entertainment facility that is long-spanning and is equipped with advanced smart technology with regard to its BMS. Building B, by contrast, is a long-spanning, five-storey, high traffic, retail development, located in Cape Town and equipped with advanced and user- smart interactive technologies. The following criteria were used in the selection of the buildings:

1. The building must be located in the same climate zone (zone 4).
2. The buildings must be equipped with advanced smart technologies such as IoT, sensors, smart meters and a remote user interactive system, which qualify the building as smart infrastructure.
3. Information should be easily accessible through knowledgeable interviewees who are willing to provide the researchers with the necessary information.

The methods of data collection used in this study were secondary data analysis as well as in-depth interviews which consisted of multiple open-ended questions. The secondary data were gathered from the confidential financial records of selected buildings and any relevant, measurable information that could show a resultant direct effect of the implementation of advanced smart technologies on the circular economy performance within each building. Besides the secondary data, a set of structured questions about the types of intelligent technologies adopted in the building and their level of performance in the building were drawn up before the commencement of the interview process. However, conversations and discussions between the participants were allowed to stem from the interviewees' responses, to gain further understanding and detail of the response. The discussions provided a forum where more in-depth information was gathered. The reason for not making use of the unstructured approach was because the responses needed to be kept relevant, following the topic at hand and within the parameters set out by the research aim. Besides, with this method of interview, the interviewees could validate their responses with secondary data.

Secondary data analysis of information gathered from the specific buildings and responses provided by the facility managers allowed for common occurrences to be drawn out from the results and offered essential points for comparisons. Through analysing the data, a cross-reference was made back to the literature, to expand on the results.

4. Results

This section presents the empirical data collected through the content analysis of the interviews conducted and through the financial records of the selected buildings equipped with smart technologies in Cape Town.

4.1 Background profile of the interviewees and buildings used in the study

The participating companies and interviewees are described below.

4.1.1 Case study A – Interviewee A, Company A and Building A. Case study A is based on Building A and was the first of the two buildings studied which incorporates smart infrastructure technologies within their BMS. Building A is a fully occupied, long-spanning, high traffic, two-storey, entertainment and retail development building. Company A, an in-house department of the company that owns Building A, manages the building and employs Interviewee A as the facility manager of this development. All information relating to case study A was received from Interviewee A.

4.1.2 Case study B – Interviewee B, Company B and Building B. Case study B is based on Building B and was the second of the two buildings studied, which incorporates smart infrastructure technologies within their BMS. Building B is fully occupied, long-spanning, high traffic, five-storey retail development. The management of the building is outsourced to Company B, which employs Interviewee B as the facility manager of this development. All information relating to case study B was received from Interviewee B.

4.2 Types of smart technologies adopted in the buildings

The companies make use of advanced smart technologies in managing their buildings. The smart technologies used in building A are the IoT, sensor technology to access and control the system remotely and enable user interactivity. Smart technologies incorporated into the BMS of Building A and Building B are the IoT and sensor technology to control the HVAC system and electricity infrastructure. Also, built-in sensors were used in security and access control of both buildings A and B.

Moreover, the water-pipes in Building A contain built-in sensors which notify the facility manager if the quantity of water drops below a certain level, and these allow the facility manager to determine their average usage. In contrast, Building B employs smart energy and water meters for the graphical representation of real-time consumption, which enables the management staff to access and control the HVAC system and electricity infrastructure remotely. Moreover, the smart meters provide the remote user interactive platform to the tenants, so that they have access and control of the HVAC temperature and lighting system. This also enhances the awareness of the tenants about the levels of energy and water consumed.

4.3 Level of performance of buildings studied – energy and water consumption and decision-making time for maintenance management

The study determined that the use of smart technologies affected the life cycle costs, efficiency, ease of decision-making for maintenance management, as well as overall building performance. Implementation of smart infrastructure technologies within the management of the buildings has led to increased efficiency, due to the constant monitoring of the efficiencies related to each particular service. This aids in the monitoring and management of the system, which is seen by the decrease in the number of breakdowns within the operational systems of the facility. Fewer breakdowns mean fewer costs incurred in the long run, as well as less strain on the equipment, which in turn decreases maintenance costs. It was found that smart technologies brought about many savings and advantages energy savings in both usage (kWh) and maximum demand (Kilovolts-Amps (kVA); extended lifespan of many critical components due to proper usage and sequencing; improved water consumption for HVAC systems (Building B); improved air quality especially in maintaining the set 22 °C air conditioning requirement; more control over air quality in tenancies, because temperatures can be controlled from various locations; graphically seeing what's happening (in terms of HVAC equipment and building temperature) on the BMS and also remotely from anywhere; and improve identification of problem areas within the system, thus improving maintenance decisions.

According to Interviewee A, "*where the cost-saving comes in is from the system giving alerts about faults and we are then able to fix the issue, while equipment breakdown is a lot less. If the technology were not there, we would have never been aware of it. It comes down to being more* *about efficiency and effectiveness.*" For Interviewee B, the focus on smart technologies was to contain the demand in energy, noting that "*it's difficult to get the exact figures, but our initial improvement was a drop in maximum energy demand (kVa) of about 24 per cent. Ever since 2006, we have dropped our kVa (and subsequent kWh) usage.*"

The responses received from both interviewees were consistent with the fact that both cases have experienced improvements in the time taken between maintenance decisions made at a managerial level. Interviewee A provides a more enthusiastic answer which implies that the extent of time saved between decisions is unusually large: "… *there was a massive improvement in time saved because before you had to go and find and look for the information and when you wanna take a decision then only go and put on the measuring systems to see and your comparison time is then two or 3 months when now with a BMS (you have) got a year's history you can work from. You can base it (maintenance decisions) on seasonal; you can base it on occupancy, you can pull all the different parts of information together.*" While Interviewee B also notes that "*the use of smart technologies allows for faster analysis. As there is constant feedback from the system, things such as space temperature can easily be adjusted. Maintenance improves.*"

4.4 Use of smart technologies and building performance (cross-case analysis)

The common features drawn from the interview questions and from the extreme cross-case analysis to compare the case findings are presented in Tables IV and V. The cross-case analysis draws upon the results of each case study and sets out to find literal replication across each case.

Table IV shows that a reduction in the amount of energy and water consumed during operations was a common occurrence within both cases. The interviewees both acknowledge the fact that these reductions in both energy and water were as a direct result of the implementation of smart infrastructure technologies. This reduction had a positive effect on the overall circular economy performance of the built assets in both cases. Data collected from secondary sources show that the annual consumption cost of electricity per sq. m (2017) in case A and case B is 54.24 kWh and 42.36 kWh, respectively.

Another common occurrence was the reduction in the level of water consumption within both facilities. This reduction was noted by the interviewees to be a direct result of the implementation of smart infrastructure technologies in the buildings. Overall, building performance was also impacted positively as a result of reductions in the amount of water consumed by these separate facilities. Secondary data shows that the average daily consumption of water per square metre (2017) in case A and case B is 14.3 and 10.1 L, respectively.

Another important common occurrence that was noted in this investigation was the big data that is received from these smart systems and the analysis that this data permits. The respective systems gather data and represent them in a graphical manner which gives the users constant feedback. This feedback allows the various companies the ability to analyse this data in a more effective manner which results in improved maintenance, easier and quicker identification of problems, faster analysis and shorter decision-making time. Overall, the implementation of smart infrastructure technologies brought about the circular economy performance of both facilities; and it also aided in extending the lifespan of the installed electrical and mechanical equipment.

Table V presents the tabulated energy and water consumption derived from the secondary data per square metre. The information provided by the interviewees represents the consumption of two specific items that contribute to the overall cost of managing the respective facilities. Table V also shows the actual consumption data that can be directly compared between case studies. It can be deduced from the data presented in Table V, that

Table IV.
Comparison between case studies

Occurrences	Case A	Case B
Non-uniformity in Smart BMS	Smart BMS is used for monitoring and control of water usage, electricity usage and HVAC systems	A smart BMS is only used to control and monitor the HVAC system. Sensors are used in monitoring the other services. Smart meters are used to control the energy and water remotely
Energy/electricity consumption	Smart BMSs are in place for electricity infrastructure. Managers can see how much is being used. The trends, peaks and troughs and the demand can be observed. Decisions can be made based on these observations to reduce electricity consumption. Savings on electricity have been realised, due to increased efficiency within the BMS	Smart meters are installed to manage energy usage. Energy savings have been observed both in usage and demand. Smart energy meters enable graphical representations to be produced which allows energy savings These data (graphical representations) can be accessed remotely from anywhere by management staffs and tenants
Water consumption	Smart BMSs are in place for water usage. Managers can see how much is being used The average consumption can be viewed. The system has alerts set on it so that if the water is below a certain level, management is aware	Smart meters are installed to manage water usage, enables water savings, and improvement in water consumption. Smart water meters enable graphical representations to be produced These data (graphical representations) can be accessed remotely from anywhere by management staffs and tenants
HVAC	The HVAC system was implemented when the facility was constructed	Make use of a BMS for the HVAC system. The first HVAC system was implemented in the year 2000. A software system was used to manage this HVAC system. The HVAC system was an enormous consumer of energy. Energy crisis required upgrades to the HVAC system to consume less energy. The old command-based BMS software system was upgraded to a graphical interface utilising at its core a Johnson Controls Software BMS which graphically illustrates the main components of the HVAC system which can access remotely from anywhere by management and tenants This new BMS improved the HVAC system with regards to energy consumption

(*continued*)

Occurrences	Case A	Case B
Management decision time	Decrease the management decision time due to availability of complete consumption data	Faster analysis and instant management decision due to providing graphical representations and prompt feedback from the system as well as access and control the system remotely
Performance statistics (electricity and water consumption) monthly	Electricity = ZAR 4.52/m^2 Water = ZAR 2.12/m^2	Electricity = ZAR 3.53/m^2 Water = ZAR 3.02/m^2
Annual energy consumption	54.24 kWh/m^2	42.36 kWh/m^2
Daily water consumption	14.3 lit/10 m^2	10.1 lit/10 m^2

Table IV.

the energy and water consumption per square metre is lower for case A and B than the comparable standard building consumption data (see Tables II and III). The comparative standard building of maximum annual energy and daily water consumption is found to generate higher usage and therefore, higher cost with regards to electricity and water.

However, the variation between the water and energy consumption and the difference in management decision time and efficiency in Building A and Building B are due to incorporating more advanced smart technologies in Building B, such as smart meters and a remote user interactive system.

A trend was also identified from the raw data obtained from Company B. Data of energy and water consumption from 2010 up to the end of 2017 for Building B were provided. The results from 2010 were included in the analysis because the implementation of smart infrastructures was at a minimum before this time. Advanced smart technologies such as smart meters, smart parking, water reticulation and energy-saving devices were implemented in the building from 2010 onwards. Although the initial capital outlay of this implementation was not shared or recorded, the raw data provided show that the amount spent on water and electricity declined significantly after 2010 – the year in which the retrofit was done (see Figure 4).

A cost reduction through the use of smart technologies is observed. This disparity in the square metre costs of electricity and water is directly attributed to the implementation of smart technology in the buildings, which corroborates the interview responses. It can, therefore, be inferred from the study results that the use of more advanced smart and interactive user technologies in buildings within the Cape Town metropole (zone 4) would bring about lower operating costs and decreased time used in decision-making for building management companies.

5. Discussion of findings

The study revealed that investment in smart technologies brings about a reduction in energy and water consumption, operating costs and time used in decision-making, which follows the

Case	Annual energy consumption in cases kWh/m^2	Daily water consumption in cases litres/m^2	Maximum annual energy consumption in an office building SANS 204 (kWh/m^2)	Maximum daily water demand in an office building SANS 10252 (litres/m^2)
A	54.24	14.3	185	18
B	42.36	10.1		

Table V. Electricity and water monthly consumption per square meter

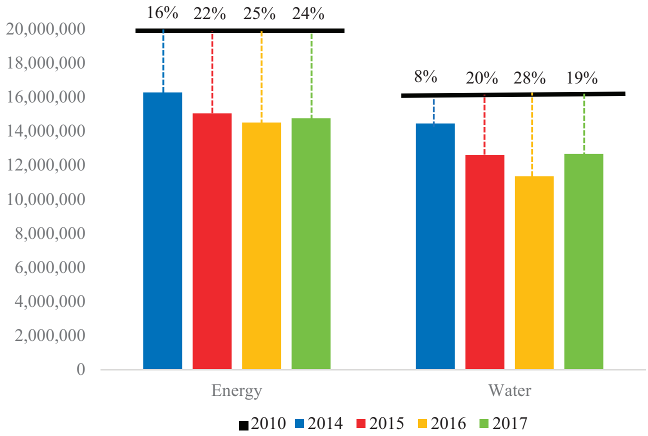


Figure 4.
Energy and water costs in case B

Source(s): *(1$ = 14.37 Zar – 27 April 2019)*

principles of the circular economy to address environmental sustainability and energy shortage. This investment paid back in proven lower energy and water consumption. The availability of more granular data has been instrumental in troubleshooting issues, problem-solving and decision-making. The overall strategy was to integrate the IoT and sensor technologies in the buildings. Smart technologies enhance the BMS used in managing the HVAC system and electricity infrastructure, and smart meters are used for energy and water usage. Also, built-in sensors are used for security and access control.

The integration of IoT and intelligent BMS as two leading smart infrastructure technologies in managing the buildings were able to reduce 71 and 77 per cent of the energy consumption in Cases A and B respectively, compared to the maximum standard energy consumption, while further analysis of Building B revealed that the implementation of smart meter technology significantly reduced the cost of energy (22 per cent). These findings are aligned with the results of earlier studies by Roisin *et al.* (2008). Moreover, employing smart management systems and smart water meters reduced the water consumption in Cases A and B by 21 and 49 per cent respectively, less than the standard daily water demand, which is consistent with the findings of Bowers *et al.* (2016).

6. Conclusion

The research examines the various types of smart infrastructure technologies that are currently being used for the management of buildings and whether the use of smart technologies impacts the circular economy performance of buildings and on the time between management decisions, for building management companies. The study established that two leading smart infrastructure technologies, the IoT and intelligent BMS are being used in buildings, and that the level of implementation of smart infrastructure technology within the two cases is quite advanced on a local scale, as these technologies are not found in many buildings within Cape Town, or in other cities in South Africa. It emerged that the cumulative impact of smart infrastructure technology is increased efficiency in building performance and resource usage; improved energy and water consumption; improved identification of problem areas within the system, and thus improved maintenance; and a high return on the initial setup costs which are relatively prohibitive due to the cost of the technologies.

It also emerged from the research findings that the impact brought about by the implementation of smart infrastructure is quite substantial regarding decreased costs of electricity and water. The two cases which implemented the use of smart infrastructure technologies have experienced large amounts of energy and water savings relating to the BMSs implemented. In addition to this, substantial reductions have been seen in the time taken to reach critical management decisions about maintenance and enabled in the form of faster maintenance detection and ease of control of all services through intelligent BMS. The information generated from a BMS is accurate and fast, allowing operatives to make use of the information quickly without having to do all of the calculations. This speed of gaining data brings about speedier decision-making.

The evidence presented shows that smart infrastructure reduces the life cycle costs of the building by producing continuous savings. These savings are a result of reduced energy consumption, improved resource management, early threat detection and quick decision-making, as well as awareness of users. The results suggest that smart technologies have boosted the circular economy performance of the built assets. By adopting smart technologies such as IoT, sensors and smart meters in buildings, the operating costs per year are reduced significantly. The technologies promote the circular economy performance of buildings in that the initial capital outlay resulted in the objective of a reduction in operating costs, thereby achieving a saving on utility and an improved effectiveness of managerial processes. The study implies that the adoption of smart technologies will close the loops in the context of building management by using the building services component as long as possible, reducing energy consumption and enabling resource efficiency.

Hence, the study recommends the use of smart infrastructure in buildings for the management of daily operations. All facility management entities should perform the necessary research to find what smart technologies would work best for their facility. The use of BMS and IoT smart infrastructures are very versatile and will allow for the facilities to start small, with their implemented technologies specific to the building, and further developing and adding on the technology. It is, however, necessary to recognise the limitations of this research. The two buildings used in the study may not be representative of all commercial buildings that use smart technologies in Cape Town, or in South Africa. This limits the extent of generalisation of the results. However, the findings from this research offer insight into the importance of using smart technologies in buildings and how smart technologies enable the circular economy performance of built assets.

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