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Examine the impact of green methods and technologies on the environmental sustainability of supportive education buildings, perspectives of circular economy and net-zero carbon operation

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Abstract

Purpose – This study investigates the barriers and drivers of using green methods and technologies (GMTs) in supportive educational buildings (SEBs) in South Africa, and assesses their impact on the circular economy (CE) in achieving net-zero carbon goals. While there has been extensive literature on green building technologies, there is limited research on the barriers and drivers of using GMT in SEBs, as well as their impact on the circular economy (CE) in achieving net-zero carbon goals.

Design/methodology/approach – This study adopts an interpretivist approach with an ontological basis, using an overarching case study of a SEB at the University of Cape Town (UCT). Semistructured interviews were conducted with executive UCT management, and a field survey of a UCT supportive education building was performed.

Findings – At UCT, multiple GMTs have been installed across various buildings to enhance monitoring and management of water and energy consumption. Moreover, initiatives to positively influence student behavior, such as water and energy-saving campaigns around UCT premises, have been introduced. The findings further indicate that UCT has recently emphasized the implementation of GMTs, resulting in improved resource efficiency, CE practices and progress toward achieving net-zero carbon targets for supportive education buildings and the university as a whole.

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Originality/value – This research highlights the positive impact of GMTs on a SEB's CE and net-zero carbon operations. As a result, facility managers should consider incorporating GMTs when planning the development or refurbishment of SEBs.

Keywords Circular economy, Green methods and technologies, Net-zero carbon, South Africa, Supportive educational buildings

Paper type Research paper

1. Introduction

In the new millennium, universities have made noticeable contributions to sustainability in a generation where society is assessed on its ability to evolve in response to global climate changes (Baker-Shelley *et al.*, 2017). Whilst environmental issues become more intensified as the built environment expands, many universities are responding to this through research and education. The importance of societal change in a future where modes of production and consumption of resources that respect the natural environment has become critical (Rockström *et al.*, 2009). Moreover, university buildings are places for academics and employees, making them ideal locations to embrace sustainability practices due to their activities and operations. However, in the global south these operations and activities do not fully embrace green practices, resulting in university buildings using abnormally high operational requirements (Abidin *et al.*, 2017).

Green methods and technologies (GMTs) in supportive educational buildings (SEBs), specifically in the global north, continually improve and cater to green practice advancements (Jafary *et al.*, 2016). The vast potential of GMTs used in university buildings overseas encourages the implementation of these practices and systems in South Africa, consequently decreasing energy and water demand (Jafary *et al.*, 2016).

However, the scope of green practices currently used in SEBs in South Africa are very limited. Various reasons account for this, such as restricted funding for management to carry out sustainable implementations, the lack of need and focus by university management to consider and implement GMTs within the campus environment (Struwig, 2014). Moreover, the lack of current GMT literature indicates that Struwig *et al.* (2014) observation is still relevant and many universities in South Africa are built upon conventional construction principles and techniques. Before viewing this statement as blanketing, South African universities have been embracing GMTs with University of Cape Town (UCT) constructing the first green star-rated residential building in South Africa (Swingler, 2020).

University campuses are made up of a multitude of different building types which have been segregated into three distinct classifications for this study, based on SANS 204–1 (2011) building classification:

(1) Educational buildings, which comprise of lecture theatres, libraries, science and computer laboratories, were derived from places of instruction.

(2) Administrative buildings that constitute offices and university operational activities were derived from the office classification.

(3) SEBs refer to student residences supplied by higher educational institutions and this building type has not been classified by SANS 204. Therefore, SEB will be referred to when student residences are acknowledged within this paper.

Educational and administrative buildings in universities are known to have a medium rate of water and energy consumption relative to SEB type buildings (Chung and Rhee, 2014).

Chung and Rhee (2014) further iterated that these buildings have high levels of water and energy consumption stemming from the challenges in controlling equipment loads and occupancy schedules. Given the high-density nature of student residences, SEBs have significantly high levels of utility consumption and waste generation driven by occupancy behaviors, inefficient mechanical system operations and low-performance building envelopes (Jami *et al*, 2021). These high utility consumption rates cause a direct proportional increase in green-house gas emissions and effectively increase the rate of climate change (Jafary *et al.*, 2016). Evidently, these high levels of resource consumption and waste production indicate that university campuses and SEBs have not embraced net-zero carbon goals or circular economy (CE) initiatives. Mendoza *et al.* (2019a) indicated that higher education institutions have not embraced circular economic frameworks to support campus and facility management operations to improve resource efficiency and environmental sustainability. CE frameworks can provide the foundation to integrate CE principles into future developments to improve the effectiveness of sustainable management processes and practices (Mendoza *et al.*, 2019a, 2019b). Given this link between the CE and improved facility management practices, facility managers should aim to develop strategies around CE initiatives which promote net-zero carbon operations and provide a foundation that supports future proof sustainable management.

GMTs refer to the building designs, construction techniques, practices, education and technologies that will improve the sustainable operation of a building. These GMTs are derived from the various advancements that can be implemented in achieving a sustainable, energy-efficient, environmentally accountable platform (Struwig *et al.*, 2014). Alexander (2014) indicated that these types of platforms will integrate factors such as renewable energy, sustainable materials, ecological value, passive strategies, transport, life-cycle costing and household health.

GMTs have the potential to reduce the excessive consumption of natural resources whilst providing a way forward through sustainable development (Kibert, 2004). Jami *et al.* (2021) argued that improved energy conservation methods and occupancy behavior changes will significantly improve operational efficiencies. This efficiency improvement will be propelled by technology installations, presenting real-time data reporting to building occupants and encouraging sustainable education and policies. Therefore, universities must aim to install GMTs to reduce utility consumption and improve their sustainable footprint. Indeed, GMTs can significantly improve the environmental sustainability of SEBs through alleviating increased water and electricity consumption. However GMTs have been scarcely implemented across university campuses in South Africa (Ralph and Stubbs, 2014), despite the increased attention given to environmental sustainability at higher educational institutions and the drive toward reducing environmental degradation. There is a knowledge gap in the research conducted on the impact of GMTs on SEB operations and the inherent impact on environmental sustainability, particularly in South Africa.

The research presented in this paper aimed to understand the impact of GMTs on the supportive education buildings' consumptions and performance particularly water and energy consumption in SEBs, and whether these methods improved the environmental sustainability of SEBs. This research investigated available GMTs, their level of adoption and effectiveness in reducing utility consumption and identified the drivers and barriers toward implementation.

The novelty of this research vested in evaluating the effect of various GMTs on improving the CE and net carbon zero goals. This paper aimed to provide more insight into the application of GMTs and the nexus between GMTs in SEBs and environmental sustainability. The balance of this paper is structured as follows: Section 2 provides a literature review, followed by the research methodology in Section 3. Attention is then paid to the findings and discussions in Section 4, and conclusions are drawn in Section 5 based on the findings. From the conclusion, recommendations and further avenues of research have been recommended.

2. Research background

2.1 The effect of circular economy initiatives on the sustainability of higher education facilities

Murray *et al.* (2017) iterated that the CE provides a fundamental strategy to achieve sustainable development by shifting the linear economic system toward a circular model where products and materials are continually repurposed until reasonably possible. By prolonging and re-using resources, an asset's value can be retained and maintained over a longer period (Bocken *et al.*, 2016). The emergence of the CE paradigm has gained support from policymakers, academia and professionals as an appropriate reaction to achieve a sustainable built environment (Rahla *et al.*, 2021). Joensuu *et al.* (2020) stated that buildings must be designed to be disassembled, repaired and reused to extend a building's lifecycle to achieve CE goals. This construction approach will reduce a building's embodied energy, however, the operational carbon produced by building facilities far exceeds the embodied carbon. Arvind and Geetanjali (2018) argued that the main goal of sustainable building design is to reduce the consumption of energy, water and raw materials in facilities that cause environmental degradation and rather develop a productive, safe environment that efficiently uses water and clean, renewable energy. Haoran *et al.* (2021) indicated that developers and facility managers must adopt lifecycle assessments to enhance the relationship between CE and sustainability, hereby improving the comprehensiveness of CE initiatives and their impact on the environment.

Noting the compelling nature between facilities management, CE and sustainability, Struwig *et al.* (2014) observed that South African universities need to become more proactive in providing green and sustainable buildings on campuses, because conventional educational building codes set the minimum resource efficiency standards. Despite, the Green Building Council of South Africa's (GBCSA) drive to develop and encourage an enhanced CE and sustainable built environment practices that exceed conventional building codes, South African universities have not adopted and implemented these sustainable initiatives (Struwig *et al.*, 2014). Consequently, universities have inefficient utility consumption practices and patterns, driven by challenges around controlling equipment loads and occupancy schedules (Chung and Rhee, 2014). Undoubtedly, universities need to adopt CE practices to support the efficient use of resources and the roll out of future sustainable buildings (Mendoza *et al.*, 2019a, 2019b). The adoption of sustainable practices through the CE will promote the future-proofing of universities by encouraging facility managers to implement systems that:

- reduce resource consumption;
- lower their building's demand for grid-tied electricity and reduce the impact of loadshedding on campus operations (Kenny, 2015);
- reduce the consumption of water which has become a scarce resource within South Africa (Dormido, 2019);
- leverage green and sustainable bonds to improve the financing models when upgrading current infrastructure or developing new campus buildings (Geral, 2022); and
- protecting their buildings against future retrofits induced by sustainable legislation (Geral, 2022).

Therefore, the adoption of the CE to promote the future-proofing of facilities management will protect and reduce the impacts of unforeseen circumstances and shifting sustainability paradigms on university facilities.

The link between sustainable higher-level institutions, CE and future-proofing facilities management strengthens the position that effective facility management is an essential function for long-term prosperity. This highlights the nexus between facilities management and a sustainable higher educational building's lifecycle.

2.2 Current sustainability practices at universities

The new age of universities is forecast to make a noticeable contribution to sustainability in a generation where society is assessed on its ability to evolve in response to global climate changes (Baker-Shelley *et al.*, 2017). While environmental issues become more intensified as human development increases, many universities respond to this through research and education. Therefore, it is suggested that more focus should be put on procedures that look toward the transformation of universities in connection with sustainability (Stephens and Graham, 2010). However, not much research has been conducted on how this transformation should take place efficiently, specifically how sustainable operations may be applied to the university's core functions (Hoover and Harder, 2015).

Universities should integrate the knowledge of environmental issues, like excessive water and energy consumption, into the student curriculum as well as operations within the university. This will help students realize the drivers of environmental problems and foster opportunities to discover and implement pro-environmental practices, both inside and outside the classroom domain (Forrant and Silka, 2017). Lawrence and Keime (2016) argue that SEBs provide an opportunity to meet these objectives by encouraging universities to set mandates for sustainability commitments through collaborative implementations in student residences and education on campus.

Currently, the main source of efficient water and energy consumption practices at SEBs is driven by curtailment and environmental relevant behavior (ERB) initiatives. These initiatives encompass actions such as unplugging electronic devices not in use from wall sockets, not allowing taps to run at maximum capacity when accessing water supply or switching off lights when leaving rooms. These actions appear a daunting concept to foster, as SEB occupants generally do not have the mentality or will to embrace ERBs, partly due to the perception that they are not liable for the water and energy bill because this is normally handled by the university's management (Occupants who use SEBs as accommodation generally pay a set monthly fee which is inclusive of utilities). This causes a conflict of ethos between university sustainability principles and occupants in SEBs because they are not liable for their own water and energy usage (Abrahamse and Steg, 2009).

This creates a challenge for facility managers when improving a SEB's environmental sustainability footprint when encouraging and applying ERBs amongst students and staff. Parece *et al.* (2013) argued that these individuals are not involved in designing and implementing sustainability initiatives that will be smoothly integrated into their daily activities. Moreover, the lack of incentives, particularly monetary incentives, surrounding sustainable ERBs prevented the exponential uptake of sustainable behaviors among SEB occupants (Nardo et *al.*, 2017).

Xiwang *et al.* (2015) quantified the student carbon footprint at 3.84 tons CO_2-eq which was an amalgamation of daily activities (65%), transport (20%) and academic activities (15%). In addition, dining (33%), showering (18%) and electricity consumption (14%) where the main individual carbon emission contributors (Xiwang *et al.*, 2015). Although the 3.84 tons CO_2-eq is modest, current university practices and systems are not carbon neutral.

Moreover, the challenges around encouraging building occupants to be proactive in reducing their carbon footprint indicates that other GMTs must be embraced to passively monitor and control sustainability initiatives to achieve a net-zero carbon footprint.

It is evident that a "Learning for sustainability" culture needs to be considered, which will become intertwined within institutional operations. For universities to effectively address sustainability, there needs to be a relationship between facility managers, administration, research entities and academic activities. This link should coincide with the "Learning for sustainability" culture that will drive a university to become sustainable in a synergistic approach (García-González, 2020).

Given the challenges surrounding ERBs and SEB occupants not being accountable for their own water and energy consumption have made universities high users, and more strategic approach needs to be prioritized (Ryan *et al.*, 2010). However, conflicting internal stakeholder perceptions and engagement about integrating environmental sustainability within organizations is arguably the main barrier for facility managers to achieve net-zero operational goals (Moghayedi *et al.*, 2022). Equally, it becomes apparent that financial limitations prevent universities from implementing sustainable practices appropriately due to competition for limited financial resources within the university (Alexio *et al.*, 2018). Moreover, Alexio *et al.* (2018) argued that successful sustainability initiatives would positively impact utility consumption, reduce operating costs, attract funding, promote more effective management strategies and meet societal challenges. Therefore, the challenge to promote environmental sustainable SEBs is to obtain coherent synergy between education, SEB operations and the university's community's engagement particularly students as occupants of SEB's.

2.3 Supportive educational buildings' sustainability performance

Water and energy are essential for the adequate functioning of any building, more specially SEBs which constantly require energy and water for various student- and operational-related functions. University buildings in South Africa receive their power from Eskom, a state-owned monopoly which relies on 92% of its electricity generated from fossil fuel and currently struggles to provide South Africa with its power demand (Kenny, 2015). The nonrenewable nature of this power indicates that SEBs need to reduce their energy consumption and integrate alternative renewable energy supplies into their operations to become net-zero carbon emitters. In addition, the power utilities inability to meet national energy demand and failing infrastructure has resulted in intermittent power outages, locally known as load-shedding, highlighting the significance for SEBs to reduce their energy demand from the grid (Kenny, 2015).

Typical water consumption patterns in SEBs indicates that bathroom facilities, specifically water closets constitute the highest water usage (Meireles and Sousa, 2020). The World Resource Institute (2015) ranked South Africa as the 53rd likeliest country to experience a water crisis by 2040. In 2019, an article published by Dormido (2019) expressed that this ranking had increased to the 48th most likely country to experience a water crisis. The timeline between these two reports indicates the increased probability that South Africa will face water shortages in the near future. This was realized in 2018 when the City of Cape Town was the first metropolitan district in South Africa to nearly run out of water (Rodina, 2019). In 2021, the Eastern Cape faced a similar water crisis where droughts prevented adequate rainfall to fill the municipality's dams (Rakhetsi, 2021). Therefore, it is apparent that SEBs need to reduce their water demand as potable water has become an increasingly scarce resource.

A study by Kontokosta and Jain (2015) revealed that factors influencing water and energy consumption include building size, type of building materials used, construction age, type of resident (tenant or owner), family income and demographic variables. This study is related to multi-story residential buildings; however, it can also be linked to SEBs due to the residential nature of operations. Odemakin and Alibaba (2018) iterated that building occupants influence operational efficiency rates more than building design due to their lifestyle habits. Conversely, Mackres (2016) argued that buildings are large, long-term investments, that if built efficiently with sustainable initiatives, will provide improved financial, social and environmental benefits. Proponents of Abdelwahab (2012) and Wahaso (2020) stated that alternative energy and water sources will improve a building's sustainability operations, provide improve utility security and support facility managers in achieving net-zero operations.

2.4 The nexus between the adoption of green methods and technologies, circular economy initiatives and sustainability at universities

GMTs embrace environmentally friendly building practices which uses any product or service that reduces utility consumption, is eco-friendly and improves the social element of a development. "Green methods" in GMT refers to various advancements and practices that can be implemented to achieve a sustainable, energy-efficient, environmentally accountable platform (Struwig *et al.*, 2014). The term "green technology" covers a broad spectrum of technologies, from photovoltaic installations, heating solutions, smart technologies and energy-efficient appliances (Usman and Gidado, 2015). King and Perry (2017) further support this evidence by stating that the use of green smart technologies allows facility managers and residents to foresee and proactively react to maintenance requirements, utility performance, comfort issues and higher occupant satisfaction.

However, a common misperception surrounding GMTs is that these initiatives and installations will solve sustainability issues. This leads building occupants to negligently use resources, effectively reducing the efficiency of GMTs (Iravani *et al.*, 2017). Kashyap *et al.* (2016) argued that facility managers must establish a clear link between assessment measurement and performance management by using an effective assessment mechanism. An assessment mechanism tool will support facility managers with daily operations and strategic decisions, thus, improving the future proofing of building operations through these decisions. In addition, developers must implement passive green building designs into their developments such as building orientation, insulating walls, windows and roofs and integrating other energy efficient designs and materials (Woo and Cho, 2018). These systems will support CE goals by reducing and re-using resources to reduce a SEB's environmental carbon footprint.

The advantages of using GMTs in buildings are widespread and comprehensive, providing benefits to existing buildings and new developments. Using GMTs allows buildings to become considerably more sustainably driven through increased efficiencies and decreased carbon footprints (Corp, 2017). By integrating GMTs into the planning, design and construction of a building, there will be noticeable financial savings, reductions in environmental impact and established long-lasting value within a development (Smith, 2020). Therefore, the purpose of GMTs is to create a system that uses innovative technology and methods to establish an environmentally friendly structure that will be used in a manner that conserves resources and supports facility manager operations (Jadhav, 2016). Consequently, developers and facility managers must collaborate to not only implement current GMTs, but also implement systems that account for the upgrading or installation of future GMTs, thereby improving the future-proof management of a building and the ability of a facility manager to achieve a CE and net-zero carbon goals.

3. Research methodology

An overarching methodology approach was chosen to research a single case study SEB, which, in turn, intends to summarize and understand the characteristics of multiple SEB's. The research summarizes an exploratory case study and aims to understand GMT implementation and influence on the environmental sustainability of the selected case study (UCT). The study follows an interpretivism approach that is ontologically based because the research has a larger focus toward the qualitative realm, with the use of supplementary data to support the findings. Conducive reasoning was also used to explore the qualitative observations that arose during the research which was summarized to conclude the study.

To achieve the objective of the study (determine the impact of GMTs on the environmental sustainability of SEBs), a qualitative approach was used to obtain relevant data and experts' opinions in the form of semistructured interviews to provide an overview of the state of GMT implementation and environmental sustainability. The qualitative data was attained through conducting five purposive, semistructured interviews with high-level executive management members, thus, capturing the responses from a top-down perspective. Since the UCT environmental sustainability strategy was developed with executive management as an action plan to reach UCT short-, mid- and long-term sustainability targets, the research adopted a top-down data collection method which involved creating an overarching system of data collection and analysis before detailing and fleshing out the necessary mechanism, initiatives and tools under it. The details of executive management participants in the study are summarized in Table 1.

To prompt data collection, the following five open questions about the sustainability strategy and targets of UCT, the adopted mechanisms, tools and GMTs, as well as a selected case study which was used to explore further themes of responses.

Q1. What are the UCT mission, policy, strategy and plan (short-term and long-term) for improving the university's sustainability and SEBs?

Q2. What specific initiatives and GMTs are currently being implemented in the – building to measure, monitor and manage resource consumption and building performance?

Interviewee	Education	Role	Profession	No. of years working at UCT
Interviewee 1	Master	Sustainability director	Electrical engineering	6
Interviewee 2	Master	Properties and services senior officer	Property and project management	15
Interviewee 3	Honors	Residences maintenance manager	Civil engineering	8
Interviewee 4	Bachelor	Residence manager	Civil engineering technology	17
Interviewee 5	Master	Maintenance and operations director	Facility management	21

Source: Created by authors

Table 1. Interviewees profile details

Q3. Are these initiatives, methods and technologies able to improve the sustainability of – and impact on residents? How?

Q4. What are the advantages and drawbacks associated with the use of these initiatives, methods and technologies?

Q5. What are the primary drivers that encourage implementing sustainable initiatives and GMTs at UCT, and what barriers might hinder their implementation?

These responses were then evaluated using thematic analysis to identify, describe, organize and detail the emergent themes. Moreover, the inductive analytical approach was used for analyzing the data as an emergent strategy with high adaptability to a novel study and the capability to identify new emerging themes and findings from the data that researchers may not have been aware of before. The inductive analysis is the most compatible analysis method for top-down collected data.

Observations were used to assess which GMTs are currently included in the selected case study that enhance the CE and support net-zero carbon goals. A formal observation approach was decided, in which a prepared checklist of items to observe was developed. The largest, self-catered student residence was chosen as the case study to maximize the relevant water and energy consumption data. Furthermore, energy and water consumption of the selected SEB was collected and compared to the relevant recommended consumption standard laid out by the South Africa National Standards (SANS) to assess the actual building performance compared to regulations.

This allowed assessing whether the used GMTs in SEBs are able to improve the CE and net-zero carbon of SEBs by reducing water and energy consumption.

3.1 Case study description

The case study was built in 2010 making it one of UCT's more modern SEBs. The residence is a female only SEB which accommodates 386 students across single and double rooms. The SEB has a typology structure where 8 residents will share a kitchen area, bathroom facilities, a lounge and other communal areas which covers a total floor area of 10,500 m^2. The case study details are summarized in Table 2, and Plate 1 displays photographs of the case study building and amenities.

4. Findings and discussion

The analysis of qualitative and quantitative data is presented and discussed below. The findings will first discuss the qualitative emergent themes from UCT executive management

Item	Description
Typology	Concrete structure with masonry partitioning
Number of floors	3
Capacity	386 students
Floor area (m^2)	10,500
Open area (m^2)	12,000
Number of rooms	245 (194 single rooms, 94 double rooms and 4 disable rooms)
Number of toilets	155
Number of bathrooms	102
Air-conditioning systems	21 Central condenserless units

Source: Created by authors

Table 2. Case study details

Plate 1.
Case study photographs

Source: Created by authors

interviews followed by the quantitative analysis to quantify the impact of GMTs on the environmental sustainability of selected SEB.

The main themes that emerged from the interviews and analysis were, namely:

- the ability of GMTs to improve utility monitoring;
- UCT's strategy and culture toward future proofing facilities management and developments;
- the impact of implementing GMTs;
- the drivers of GMTs;
- barriers preventing the implementation of GMTs; and
- types of GMTs used in the case study.

4.1 Monitoring utility consumption using green methods and technologies

The interviewees indicated that there are approximately 200 water and energy sensors and meters around the various UCT buildings. Smart meters facilitate the real-time monitoring of water and energy consumption from the various buildings to a central, online and analytical platform. This system was integrated into the facilities approach when Cape Town experienced a water crisis in 2018, which sparked the drive toward smart water meter installations. After their installation, it was observed that the data collected provided the facilities teams with insight into consumption patterns and supported decisions surrounding environmentally sustainable actions, utility challenge mitigation and the utility modeling of future initiatives. The installed GMTs have provided the facility team with valuable information to become more proactive at managing utility consumption patterns. In addition, the collected information and consumption patterns were also used for informing university communities (students and staff) about their water and energy footprints. It was noted that all participants agreed that the implementation of GMTs' like real-time monitoring consumption, proactive actions and educating communities would significantly enhance the CE and sustainability of UCT. However, the interviewees expressed that these meters are generally connected to a cluster of buildings which prevents individual building analysis. This has created challenges for facility managers as they try to identify high-utility consumption buildings and more individualized utility tracking systems need to be put in place to improve utility management. Despite this criticism, these systems have provided a foundation to track sustainable performance initiatives so that facility managers can make more informed decisions surrounding sustainable practices and 2050 net-zero targets, which is aligned with Windapo and Moghayedi's (2020) observations.

4.2 University of Cape Town's strategy and culture toward future proofing facilities management and development

In 2012, UCT began implementing strategies that would improve environmental sustainability in buildings by adopting the GBCSA's green star rating as a sustainable building guide, ensuring that all new buildings would achieve a GBCSA Level 4 green star rating or higher. This strategy saw the development of the university's first green star rated building which was completed in 2016, and South Africa's first green star student residence constructed in 2020. This new build's sustainability approach indicates that the university is open to future proofing the facilities management of new developments, not only by constructing buildings that have sustainability requirements above South Africa's national sustainable standards, but also by educating the university's communities about sustainability to enhance the university's sustainability culture and behavior, thus transforming them into green students and employees or even sustainability ambassadors. These proactive approaches will improve the sustainability performance of the university by significantly reducing utility consumption of SEB's, as well as prevent new buildings from requiring future retrofits to become more sustainable. This will, in turn, prevent them from becoming sustainably obsolete within the near future. The interviewees indicated that although there is an emphasis on the application of green practices in new building projects, there is much opportunity to expand within the current building stock.

The university's sustainability culture and behavior are a complex paradigm consisting of students, employees and executive management strategies. It is agreed amongst the interviewees that sustainability practices will reduce the universities carbon footprint and operating costs as observed with the university's water-saving campaign in 2018. Forrant and Silka (2017) stated that university management should try integrating knowledge of environmental issues into the student curriculum and operations. With the goal to foster an environment where sustainability is embraced by all facets of the university, not just through sustainable building design, but also through students and staff behavior.

The interviewees strongly emphasized the significance of educating students and employees about sustainable practices and activities. They firmly believe that this educational effort will play a pivotal role in achieving a 2–5% reduction in utility consumption over the long-term and aligning with the United Nations' net-zero carbon goal by 2050.

Moreover, the interviewees highlighted UCT's dedication to sustainable development, with the university actively participating as a member of the International Sustainable Campus Network (ISCN). This active involvement demonstrates UCT's commitment to promoting sustainable practices throughout the organization.

This commitment to sustainability is deeply ingrained within the university, evident in the integration of sustainable principles into its core mission, facilities, research and education:

> Since 2018, we have been practicing living laboratory for sustainability within UCT, and in 2022 UCT ranks 9th in the world for SDG 6, clean water and sanitations.

Over the past few years, UCT has made notable progress in this direction, offering numerous courses that use participatory and project-based training centered around sustainability. These innovative courses effectively use the campus as a dynamic "living laboratory," providing students with hands-on learning experiences. Notably, these sustainability-focused courses have been thoughtfully integrated into formal education curricula and short courses, as well as research projects, aiming to enhance students' knowledge and awareness of sustainability matters, which is aligned with sustainability transformation suggested by Stephens and Graham (2010).

4.3 The impact of implementing green methods and technologies

The integration and level of GMTs within UCT has exponentially increased over recent years. These systems have not only reduced operational costs and improved facility management efficiency, which aligns with the pragmatic paradigm of CE and serves as an initial step toward active net-zero carbon initiatives at UCT, but also enhanced the students' well-being and fostered a sense of belonging and social responsiveness among them. The interviewees mentioned that the type and number of installed GMTs are influenced by the three-pillar sustainability model, therefore, the nexus between environmental, societal and economic sustainability factors are considered when GMTs are integrated into buildings. Three emergent GMT themes, namely, Water reduction, Energy and emission reduction, Retrofits and Sense of belonging and social responsiveness arose from the discussion with the interviewees:

(1) Water reduction: Water reduction initiatives encompassed water flow rate plumbing, fixture fittings and rainwater harvesting. Plumbing and fixture fittings were used in water closets, hand basins, showers and baths which provided savings of up to 30%. Rainwater harvesting programs were developed with the environmental sustainability department to use rainwater for water closets, irrigation and to enhance the university's CE.

(2) Energy and emission reduction: Light fittings were one of the most effective energy reducing systems implemented with the supporting role of occupancy sensors. The installation of smart meters has improved utility reporting where they were integrated into a strategic project, referred to as an integrated workplace management system. The goal was to measure and identify fluctuations in utility consumptions and costs by detecting leaks and abnormally high consumption rates. This tool can be understood as a cost management mechanism enhancing the ability of a facility manager to conduct maintenance and daily operational tasks. The installation of photovoltaic systems has garnered increased interest by UCT as it has reduced the case study's municipal utility costs by almost 35% and has provided a platform for net-zero energy goals in the future. The conversion of conventional geysers to heat pumps within UCT's SEBs has further reduced energy consumption (52%) due to their high efficiencies. Overall, the above GMTs contributed to 39% emission reduction within three years at the university level.

(3) Retrofits: The interviewees all expressed that retrofitting of SEBs with GMTs are a feasible exercise and supports UCT's sustainability initiatives. However, it was observed that retrofit projects are often costly, but their benefits can be easily measured, and their costs are recouped over the GMTs life cycle. The interviewees further iterated that UCT has a significant maintenance backlog which has

provided an opportunity to integrate sustainability initiatives into maintenance schedules to improve the carbon and financial performance of the SEBs moving forward, which is also proved by Geral (2022).

(4) Sense of belonging and social responsiveness: According to the interviewees, the utilization of GMTs in student residences created a more socially responsible and interconnected community among students. It made a shared sense of purpose and responsibility, as students actively participate in environmentally friendly initiatives, feeling connected to a larger community working toward the common goal of promoting sustainability. Living in green residences encouraged students to develop a greater awareness and appreciation for environmental issues, such as saving water to avoid day zero, making them more socially responsive and understanding their role in preserving the environment.

Moreover, when students actively contribute to sustainable practices in their residences, they develop a strong sense of ownership and responsibility for their surroundings. This sense of ownership leads to increased pride in their living community, motivating them to maintain a clean and eco-conscious environment both in their residences and on campus. The green residences, designed to optimize natural light, ventilation and overall comfort, positively impact students' well-being, contributing to a sense of contentment and satisfaction with their living arrangements. The comfort and living experience of students in this building as green residence significantly surpass that of older residences at UCT, as highlighted by the interviewees. This observation is further supported by Chung and Rhee's (2014).

*As mentioned by the interviewees, integrating the principles of the CE and implementing GMTs in educational buildings can be a proactive approach to future-proofing these structures and their operations. This strategy effectively safeguards against potential disruptions caused by unforeseen events such as water and energy crises, as well as the ever-changing sustainability landscape. The findings underscore the significant positive impact of GMTs in ensuring the sustainability of buildings and the well-being of students, aligning with Arvind and Geetanjali (*2018*), Kenny (*2015*) and Dormido (*2019*) findings. Drivers of implementing GMTs.*

As indicated in the previous section (GMTs Implementation), GMTs are driven by three core sustainability elements, namely, environmental, economic and social sustainability. These initiatives were driven by a top-down approach; however, it was observed that the executive management were not as familiar with the operational performance benefits derived from these initiatives as the individuals who were "on the ground." This indicates that the strategic decisions made by the executive committee members do not fully realize the impact of GMTs on operations.

UCT's strategic goal to achieve net carbon zero by 2050 is driven by the environmental sustainability pillar which seeks to reduce utility consumption and waste production by improving operational efficiencies through GMTs. These initiatives seek to embrace the CE with greywater being redirected toward irrigation, and photovoltaic installations seeking to promote a net-zero carbon footprint within the university.

The improved financial savings and operational cost reduction provided the facility managers with the financial support to motivate the further installation of GMTs. The reduction in utility consumption derived from efficient GMT performance led to financial savings in respect to potable water and electricity. In addition, the installation of water efficient fixtures to hot water outlets not only reduced water consumption, but also electricity consumption as less hot water was consumed. Moreover, the installed photovoltaic plants produced electricity at a cheaper rate than the grid, resulting in increased financial savings. The strategy of implementing GMTs to reduce building consumption, operating costs and improve their performance as a sustainable practice for more effective management strategies and attracting additional funding to enhance the sustainability of buildings is also recommended by Alexio *et al.* (2018).The interviewees indicated that a strong sustainability culture needs to be developed at UCT and sustainability elements need to be integrated into the academic curriculum. This will educate and foster positive sustainability behavior that will promote the use of GMTs:

> My belief is that if you did bring elements of that into the curriculum, it would assist. Like I've been saying, it's all behavioral and cultural elements. You can have all the green practices and technology available, but if no one uses it, or wants to use it, then what's the point?

This statement highlights the important role that SEB occupants play in supporting sustainable efficiencies as technology alone will not improve the sustainability of SEBs. The point highlighted by the interviewee aligns with the concept of a "Learning for Sustainability" culture, as proposed by García-González (2020) to drive a university toward sustainability through a synergistic approach.

4.4 Barriers preventing the implementation of green methods and technologies

All the interviewees agreed that the primary barrier to implementing GMTs was the financial cost, attributed to both the high expenses involved and the constraints of a limited budget. This observation aligns with previous scholarly research by Alexio *et al.* (2018).

Although UCT has set goals toward environmentally sustainable practices, it was surprising to find that some GMTs do not align with the university's mandates. This practical implementation challenge reflects a conflicting response, given the university's strong commitment to sustainability since 2012. Similar conflicting perceptions and engagement among internal stakeholders regarding the integration of environmental sustainability within organizations have also been highlighted by Moghayedi *et al.* (2022). In addition, UCT owns a few heritage buildings that have construction and architectural restrictions in place. These heritage laws create a challenge around implementing GMTs within the confines of regulations and policies, for example, light fittings that have been deemed to have historical significance cannot be upgraded to light emitting diodes (LEDs). These restrictions limited the sustainability potential of heritage buildings resulting in these buildings not becoming net carbon zero or meeting with CE principles. Finally, the lack of human resources dedicated to implementing GMTs was highlighted by the interviewees even though there is a dedicated department who oversee the university's sustainability progression and performance. One of the interviewee's noted that there is a problem of "taking action to plans" within the university. Specifically, there are ideas and frameworks ready to be carried out to make UCT buildings more environmentally sustainable, but it requires all departments to work together to make it a reality. Sometimes, there is just not enough money available to carry out these sustainable initiatives, even if the improvements to the overall sustainability of UCT buildings are significant, as the funding pool is split between the various departments. The importance of collaboration in achieving sustainability goals has been emphasized by Lawrence and Keime (2016). Collaborative efforts among stakeholders play a critical role in advancing sustainability initiatives and overcoming financial constraints.

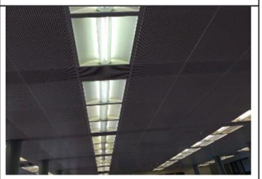
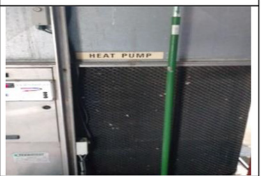
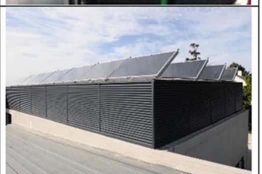
4.5 Types of green methods and technologies and their effects on building performance

A SEB site visit revealed that various implemented GMTs used to reduce utility consumption and operating costs improved the environmental sustainability of the case study. The below passage highlights the main implemented GMTs which have been summarized in Figure 1:

Green technology/ method	Description	Circular Economy	Carbon Neutral	Photo
Water and energy efficient washing machine	Energy consumption per cycle: 0.46 kWh Water consumption per cycle: 45L Savings: 100L (69%) of water and 750W (54%) of energy per wash	Reduced consumption of potable water. The last rinsing water is used for soaking in the next cycle. Greywater is effectively utilized for irrigating green areas.	Reduced fossil fuel energy consumption. Decreased carbon emissions.	
High aerated shower head	60 L (50%) reduction in water usage per shower.	Reduced consumption of potable water. Greywater is effectively utilized for irrigating green areas.	Reduced consumption of hot water. Reduced fossil fuel energy consumption. Decreased carbon emissions from heating.	
Dual flush water closet system	Water saving 5L (50%) per smaller flush.	Reduced consumption of potable water.	Less energy is consumed for filtration of water as less fresh water is consumed. Decreased carbon emissions.	
Rainwater harvesting system	Water saving up to 70% for irrigation.	Rainwater is used as an alternative irrigation source.	Less energy is consumed for filtration of water as less fresh water is consumed. Decreased carbon emissions.	

(*continued*)

Figure 1.
Green methods and technologies utilized in the case study

Smart water meter	Real-time water monitoring.	Minimizing water waste by detecting leaks and high consumers and educates occupants.	Less energy is consumed for filtration of water as less fresh water is consumed. Decreased carbon emissions.	
Passive design	Energy saving on air conditioning '35%' and artificial lighting '15%'.	Reduced resource and energy consumption.	Less energy is required to improve the indoor environment. Decreased carbon emissions.	
LED lights	90% energy savings compared to traditional lightbulbs.	Reduced consumption of energy.	Less energy is required to illuminate the indoor environment. Decreased carbon emissions.	
Heat pump	Heating energy is reduced by up to 40%.	Reduced consumption of energy.	Less energy is required for airconditioning. Decreased carbon emissions.	
Solar Photovoltaic	12 kWh (30 PV panels of 400W) Produces 20% renewable energy for the case study.	Using renewable resources	Produces zero carbon energy. Decreased carbon emissions.	
Smart electrical meters	Real-time energy monitoring	Minimising energy waste by detecting high consumers and educates occupants.	Less energy is consumed for generating energy	

Source: Created by authors

Figure 1.

(1) Water

- Laundry
  - Modern, efficient, washing machines with small drum sizes were installed. These washing machines use approximately 45 L per wash compared to the conventional washing machine that consumes an average of 145 L per wash. In addition, these machines have reduced energy demands as clothes come out drier than the older machines, removing the need for tumble driers. Students have also been encouraged to limit their washing to one load per week, thus, reducing their washing expenses and utility consumption.
- Bathroom
  - Aerated showerheads have been installed in all the bathrooms which has reduced water consumption by up to 50% in certain cases.
  - Water closets have been upgraded and/or retrofitted to dual flush systems providing a high and low flush setting. This system provides 5 L of saving whenever the low flush setting is used.
- Rainwater harvesting
  - Recently, rainwater tanks have been installed on the roofs to capture rainwater. These tanks will provide an alternative water supply for irrigation and improve the potential to use stormwater runoff.

(2) Electricity

- LED lighting
  - Lighting systems across the case study has been retrofitted to LED lights which consume less energy, have a longer life expectancy and can be installed indoors or outdoors, resulting in reduced lifecycle costs.
- Photovoltaic panels
  - Photovoltaic panels were installed as part of the university's sustainability initiative and goal to achieve a net-zero carbon footprint by 2050. These panels provide an alternative source of energy and subsidize the building's solar energy consumption by 20%.
- Heat pumps
  - Hot water boilers have been converted to heat pumps over a period of 10 years when a boiler's replacement was due. The heat pumps provide significant advantages over the conventional water boilers due to their lower operating costs, less scheduled maintenance, as well as being safer than the previous systems.
- Passive building design
  - The case study was designed in a manner that reduced direct insolation resulting in an estimated 35% heat and ventilation air-condition system (HVAC) saving over conventional building designs. Even though, the indoor environment received reduced direct insolation, the building's façade allowed indirect sunlight, which provided sufficient natural indoor lighting and resulted in an estimated 15%-day light savings.

(3) *Utility monitoring*

- Smart meters
  - Water and electricity smart meters were installed at the SEB which provided accurate utility consumption reports. These two systems provided insight into the performance of water and energy saving strategies and occupancy behavior patterns.

Based on the case study's dashboard, the above GMTs did reduce the water and electricity consumption below SANS 10252 and SANS 204, respectfully. The case study achieved an average 131 L consumption rate per building occupant which is 1.5 times more efficient than SANS 10252 requirement. The case study consumes 125 KW/m^2 compared to SANS 204 energy standard of 600 KW/m^2, resulting in a 4.8 times energy efficiency rating, a 503.5 kg CO_2e/kWh per m^2 reduction and 5,286,750 kg CO_2e/kWh total building square meter electricity CO_2 reduction. These findings highlight the GMTs contribution toward the case study's ability to achieve a CE and carbon neutral operational benchmark which is aligned with the findings of Moghayedi *et al.* (2022) and Windapo and Moghayedi (2020).

5. Conclusions

This study recognized different implemented GMTs in SEBs and their impact on the environmental sustainability by reducing water and energy consumption. It was evident that GMTs positively impacted the level of CE, positively affecting all three pillars of sustainability of the university and supported the university's net-zero 2050 goal by reducing the case study's electricity and water consumption.

The findings indicated that GMTs improved facility operations by making them more sustainable and by:

- reducing the demand for potable water;
- reducing the demand for grid tied electricity and the impact of loadshedding;
- enhancing the well-being of students; and
- future proofed the SEB from future sustainable retrofits.

These GMT initiatives and installations were driven by their financial benefits, followed by UCT's 2050 net-zero carbon footprint goal. Therefore, implementing the appropriate GMTs will not only improve an SEB's CE and economic sustainability, but will also enhance the environmental sustainability by reducing the demand for water and electricity. It will also enrich social sustainability by enhancing the sense of belonging and social responsiveness among students, boosting sustainability knowledge and lifestyles of university communities. It can be deduced from the study's findings that GMTs are a fundamental mechanism in achieving a future proof management approach toward sustainability.

Although GMTs provide many benefits to building operations and future proofing facilities management, their high capital cost was the main barrier to entry, driven by limited operational budgets. In addition, heritage restrictions prevent GMTs from being implemented because they do not comply with heritage regulations. Moreover, building occupants need to be educated about the benefits of GMTs otherwise these technologies will not be used correctly, preventing the full GMT sustainable benefits from being realized. Despite these challenges, GMTs have made SEB facilities more proactive than reactive by using real-time data for better decision-making and educating university's communities and delivering positive performance results. These systems will enhance a SEB's ability to achieve a net-zero carbon footprint and help facility managers to embrace a CE model. These systems have supported the future proofing of facility operations by reducing utility and operational costs and increasing the resilience of SEBs against loadshedding and water shortages.

There are several managerial underpinnings for university facility managers and policymakers to consider. As the study's findings indicate, there needs to be more than just using GMTs alone to ensure achieving the optimum CE and sustainability level due to the involvement of various stakeholders and communities. Therefore, the university management and SEBs facility managers should actively engage all stakeholders, particularly students in participating communities, in managing the facilities they use by adopting community-based facility management practices.

However, it is recommended that the facility managers should first educate the communities and enhance their CE and sustainability knowledge before engaging them in managing facilities or investing in GMTs. Although the adoption of GMTs to improve the SEBs' efficiency and sustainability in South Africa has increased, there is a need to develop national building standards, CE and sustainability policies for SEBs. It would also be necessary for local facility managers and built environment experts to align the universities' sustainability strategic plans with the South African 2050 net-zero emission target. The study's findings predicated that CE, three pillar sustainability aspects of universities and SEBs would serve as a precursor to developing the necessary building standards, CE and sustainability policies for South African SEBs. Furthermore, this study provides a common language to recognize by all stakeholders and make sense of what makes an SEB sustainable and net-zero emission emitter.

The research makes a significant scientific contribution through its thorough investigation and analysis of the impact of GMTs on the environmental sustainability of SEBs. By delving into the perspective of the CE and net-zero carbon operation, the study has provided valuable insights into the potential benefits and challenges of incorporating sustainable practices into educational infrastructure.

Furthermore, the study's findings offer valuable contributions to the fields of sustainability and facility management. The practical examples and future-proof strategies derived from a leading global university's successful implementation of innovative methods and technologies serve as an excellent benchmark for other educational organizations to follow. By adopting similar practices, educational institutions can enhance their sustainability efforts and align with the broader global goals of environmental responsibility and resource efficiency. These insights provide a practical roadmap for fostering sustainable practices within the education sector and advancing the collective mission toward a greener and more sustainable future.

The findings of this study, with respect to the case study was derived from a single building. Therefore, further research should be conducted on a larger sample size to improve the accuracy of the study. Moreover, newer SEBs which have modern GMTs installed should be evaluated to develop an accurate understanding of current GMT trends and impacts. In addition, the operating and capital costs of the implemented GMTs were not obtained due to the nondisclosure of intellectual property and further research with respect to GMTs capital outlay, energy consumption and maintenance costs will generate a comprehensive lifecycle model to determine a comprehensive CE impact model.

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