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REVOLUTIONIZING FACILITIES: A REVIEW OF SUSTAINABLE BUILDING OPERATION AND MAINTENANCE INNOVATIONS IN TERTIARY INSTITUTIONS

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Abstract:

The need for Sustainable Facility Management (SFM) in tertiary institutions is crucial in reducing environmental impact and optimizing efficiency in Operation and Maintenance (O&M). This Systematic Literature Review (SLR) analyse and synthesize research on current practices of SFM in tertiary institutions which focusing on innovative approach applied in improving building O&M. The comprehensive understanding, their contributions and challenges faced in implementation are discussed. Researchers analyse, synthesize and report the results from 13 final selected studies whereby the screening, selection, and identification were based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The corresponding data extraction and analysis were performed using the Evidence for Policy and Practice Information (EPPI). Result of the study demonstrates that innovative approach applied in building O&M such as Artificial Intelligent (AI), Internet of Things (IoT), Building Information Modeling (BIM), Building Management System (BMS) significantly contributed to SFM.

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Keywords:

Sustainable Facility Management, Operation and Maintenance, Innovation, Tertiary, Higher Education, University

Introduction

O&M in facility management involves people, process, place, and technology are a necessity action to ensure function, safety, and sustainability of the built environment (Støre-Valen & Buser, 2019). Tertiary institutions require best practices of O&M for conducive and productive learning spaces (Okoro, 2023). O&M has gone through revolution by implementing innovative approach such as integrating smart technology whereby creating a predictive and data-driven O&M practices. This approach shifts conventional reactive O&M to a predictive and proactive process which uses data analysis and automation to enhance building performance over its entire lifecycle. For example, BIM can provide a "digital thread" of comprehensive building information that can be used to integrate and automate O&M activities, while IoT can augment and make building data more accurate and readily automated with sensors (Fialho et al., 2023). This data-driven, predictive and automated O&M approach ensure the real-time monitoring, predictive maintenance and efficient allocation of resources (Fialho et al., 2023). It also makes O&M more efficient and ultimately making FM as a strategic and value-added operation that supports sustainable and cost-effective. Additionally, BMS or Building Automation System (BAS) adapted advance data-driven techniques such as Machine Learning (ML), edge and cloud computing and timetabling software whereby significantly divert the conventional method to predictive, adaptive and responsive that monitor, analyse and react to changes in the indoor environment (Cureau et al., 2022; D'Orazio M. et al., 2024; Park et al., 2024; Tariq et al., 2024). This advance data-driven techniques can predict impending critical conditions and the scheduling of equipment and personnel for such events, fine-tune task schedules to minimize uncertainties, improve decision-making and provide dynamic building systems that operate at high efficiency with minimal downtime (D'Orazio M. et al., 2024). The integration of the above-described approaches can drastically improve O&M in tertiary institutions.

The need for tertiary institutions to adopt innovative approach in their O&M is due to unique factors in tertiary environment. The size, complexity and diversity of building functions such as teaching and learning, research and laboratory, administration, student accommodation, cafeteria and other more are make them require an effective FM service and even more complex and sophisticated than other types of buildings (Fialho et al., 2023). Current O&M practices in tertiary sector have integrate some advanced approaches as described including BIM, IoT, ML, cloud computing and AI-based energy prediction models (Cureau et al., 2022; Fialho et al., 2023; Park et al., 2024; Tariq et al., 2024). However, these practices have encountered some problems such as integration issues among systems and devices, high initial setup and implementation costs, financial constraints, resistance to technology changes and complexity of integration (Cureau et al., 2022; Fialho et al., 2023; Lok et al., 2021; Park et al., 2024; Yasuoka et al., 2023). Some of the additional problems are inaccuracy of AI models, poor performance of outsourced FM service providers, lack of stakeholder engagement and interest

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in sustainability initiatives and lack of benchmarks to compare the performance with diverse buildings (Arafat et al., 2023; Sonetti & Cottafava, 2022; Tariq et al., 2024).

Besides of above issues, the innovative approach of O&M remains as a reliable practice that assist institutions to maintain it building performance, optimize indoor air quality as well as optimize energy efficiency. These advantages directly affect the health, productivity and well-being of the students, staff and the larger university community (Arafat et al., 2023; Shoukry et al., 2024). Furthermore, with rising energy costs and the need for more sustainable operations on campus, innovative approach O&M which adopting advanced technologies will influence the reduction of energy consumption and consequently achieve energy cost savings (Shoukry et al., 2024). Therefore, it is pertinent for a tertiary institution to adapt innovative in their O&M practices to achieve efficiency and sustainability.

Theoretical Background

There are three essential details will be discussed in this theoretical section which are the overview of O&M, the O&M practices in tertiary institutions and the research questions derived from its current practice.

Overview

O&M refers to the maintenance, real-time monitoring and predictive maintenance of building systems and services to ensure that a building is designed, operated and maintained at a high efficiency, safely and optimally throughout its lifetime. O&M stage represents the greatest operational phase for built environments due to its impact on performance and sustainability. The resource-intensive phase of operation starts when buildings begin to use substantial amounts of energy, water, and materials once they become occupied (Amaral et al., 2020). Furthermore, O&M is the costliest stage of a building's lifecycle which accounting for 50% to 70% of annual operating expenses and around 60% of the overall cost (Abideen et al., 2022; Chew et al., 2020; Pedral Sampaio et al., 2022). Therefore, Piselli et al. (2020) and Corvalan et al. (2020) acknowledge an efficient O&M is not only about maintaining, but it also provides a high potential for operational efficiency, cost savings, energy optimization, and improved services. While according to Cureau et al. (2022) and Fialho et al. (2023), O&M is about efficiently operating and maintaining the building by adopting technology to automate and optimize facility management processes such as BMS or BAS. Through effective O&M, institutions such as tertiary institutions can reduced operational expenses and maintenance which enhances building reliability and safety conditions leading to better occupant comfort and sustainability of structures (Fialho et al., 2023; Lok et al., 2021; Shoukry et al., 2024).

O&M in Tertiary Institution

The existing reviews on building O&M in tertiary institution showcase that with the integration of technology such BIM and the IoT has been moving from reactive model to predictive and proactive model of maintenance. BIM leverages a comprehensive digital representation of building information to effectively facilitate building FM processes throughout its lifecycle, while IoT-based O&M involves real-time monitoring of building systems and with the addition of ML and the use of RFID tags for predictive maintenance (Fialho et al., 2023). Existing assessments emphasize optimizing building performance and minimizing operational expenses while promoting sustainable energy utilization to maintain efficient tertiary institution operations.

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The reviews also note that a lot of technological, procedural and policy issues must be addressed to get the most out of implementing advanced O&M building strategies and new innovations. The main problems discussed include system integrations, open platforms and lack of skill and the need to upskill FM staff (Fialho et al., 2023). High indoor air quality and energy efficiency remain critical aspects for effective building operations according to Shoukry et al. (2024). Utilizing IoT sensors combined with ML and Augmented Reality (AR) technology in conjunction with cloud computing allows for significant improvements in building management through optimal O&M strategies which monitor Indoor Environmental Quality (IEQ) (Cureau et al., 2022). Data-driven class timetabling in order to maintain high occupancy in lifts for O&M (D'Orazio M. et al., 2024) is an excellent example of the innovative approach to optimising FM in building O&M, and such data-based strategies would give insight into the behaviour of users and their occupancy patterns which can be used to optimise other O&M systems and maintenance for cost and safety savings. The effective management of relationships when FM processes are outsourced also affects the quality of the O&M provided in the tertiary institutions in terms of efficiency and sustainability (Lok et al., 2021).

Research Questions

Advanced technologies in buildings have been an integral part of improving O&M of tertiary buildings and facilities. With advanced data use and predictive and proactive maintenance as against a reactive one has led to excellent optimisation and improved efficiencies in building operations (Fialho et al., 2023). Innovative approach to O&M in tertiary buildings provide excellent levels of environmental, economic and social sustainability with their effective energy optimisation, operation expenditure reduction and high Indoor Air Quality (IAQ) (Shoukry et al., 2024). However, barriers and challenges including integration of different systems in buildings, financial constraints, lack of stakeholder support and the need for upskilling of FM personnel are some of the main constraints in being able to get the best practice of FM. By overthrow these barriers and challenges, it can lead to remarkable energy savings and savings in operational costs as well as improved occupant comfort and user satisfaction (Arafat et al., 2023; Cureau et al., 2022).

Hence, the following research questions were addressed in this study:
RQ1: What are the dominant [1]research methodologies, subject areas and data collection methods employed in O&M studies conducted in tertiary institutions?
RQ2: What [2]innovative approaches are currently being implemented in building O&M for tertiary institutions?
RQ3: How do SFM practices in tertiary institutions [3]contribute to environmental, economic and social sustainability?
RQ4: What are the primary [4]challenges and barriers hindering the implementation of SFM in tertiary institutions and how can these be addressed?

Methodology

This section will discuss on search strategy, selection criteria, quality assessment and data extraction which are mainly adopting PRISMA and EPPI method for selecting and analyse relevant literature.

Search Strategy

For this systematic review, a search strategy was developed to identify relevant academic papers on innovative approach for O&M in tertiary institution. A tailored keyword search was

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conducted on databases namely Scopus, Web of Science, Science Direct, IEEE Xplore and Mendeley using ‘Sustainable Facility Management’ AND ‘Operation and Maintenance’. The different scholarly databases electronic search was utilized since they contain high-quality peer-reviewed published academic journals across discipline. The search without data parameters defined for inclusion and exclusion of the study initially resulted in 16,712 articles. However, a total of 4,592 documents consisting of conference papers, conference reviews, dissertations, book chapters, editorials, magazines, reports and lecture notes were excluded from the initial search. Therefore, from the search parameters using the string search: ‘peer-reviewed’ academic journal articles and review articles in English language documented and published between 2020 to 2024 emerged from these criteria totalling 12,120 (16,712-4,592=12,120). Henceforth, a specific string ‘Tertiary’, ‘Higher Education’, ‘University’ were used from the existing search and excluded another 11,838 from 12,120 articles resulting in the end of 282 articles.

Selection Criteria

The selection criteria for the mapping were guided by the PRISMA guidelines from David Moher et al. (2009) to ensure the process transparent and consistent. There are four-phase in PRISMA flow diagram which are Identification, Screening, Eligibility, and Inclusion that facilitates the critical assessment of published systematic reviews. Since PRISMA is designed for systematic reviews, it was used to build a framework for this literature mapping. The search initially focused on mapping existing literature and empirical studies on SFM, particularly in O&M. This search then was subsequently refined to concentrate on tertiary, higher education, and university contexts.

The papers included in this study were screened according to the following inclusion criteria:

- studies that are related to O&M in tertiary/ higher education/ university settings
- studies that describe an enhancement to O&M approaches in tertiary/ higher education/ university settings
- studies that evaluate O&M methods and strategies in tertiary/ higher education/ university settings
- studies that were published in peer-reviewed journals and written in English
- studies that were published between 2020 and 2024

While the following were exclusion criteria:

- studies in the format of book chapters, conference proceedings, or grey literature such as opinion pieces, technical reports, blogs, presentations etc.
- studies that did not focus on O&M in tertiary/ higher education/ university settings
- studies that were not published in reputable (i.e., peer-reviewed) sources
- studies that were not written in English
- studies that mentioned sustainability in tertiary/higher education/university settings but did not specifically focus on facility management

The above criteria were used to select high-quality, relevant, and recent studies in the context of O&M in tertiary institutions and to exclude less rigorous and non-specific literature from the review. After being through all phases in PRISMA flow diagram, the final articles selected for review in this study are listed in Table 1.

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Quality Assessment

In the process of assessing review quality, researcher identify duplicate records across utilised five electronic databases. The result of 282 articles in identification phase then reach to 271 articles after removing 11 duplicate articles in screening phase. Afterwards in eligibility phase, the screening of the 271 articles excluded another 190 articles in the context of irrelevant titles. Subsequently, another 68 articles were removed after reviewing their abstracts and content. This makes a total number of another 258 articles excluded due to not focusing on O&M and SFM. Finally, 13 articles (271-258=13) studying O&M and SFM in tertiary institutions available to be used for this systematic review and this is presented in the PRISMA framework (Author, Year, Title, Context, Subject area) in Figure 1.

Data Extraction

EPPI is appropriate for this SLR due to it detailed set of specific questions for coding during keywording and data extraction which aid in mapping and synthesizing primary research. The guideline also supports mapping and synthesis of the primary research and help to report the primary research to enhance the coding process of the systematic reviews (Bennett & Anderson, 2003). The final selected 13 articles were analysed and input into an excel spread sheet for analysis.

The range of the methodologies in selected articles were quantitative, qualitative and mixed method. The varied types of research methodologies of the studies reviewed are appropriate for recognizing the innovative approach of building O&M in tertiary institutions. This review of methodology evaluates the effectiveness of O&M strategies in tertiary institutions through quantitative studies while providing detailed explanations in qualitative that are valuable for both theoretical and practical insights. The dual approach which is mixed method formed the foundation for deriving conclusions and recommendations from the collected evidence.

Researchers created specific theme based on predefined criteria which guided the thematic segmentation of content for subsequent classification and coding toward synthesis. This crucial process is necessary to comprehensively and reflectively synthesize the articles that are diverse in study criteria (Hollander & Seldman, 2017). The thematic classification adopted to extract precise data rows for each selected article based on the four research questions during the review process. The information has been saved in excel spread sheet for the analysis which provide a detailed explanation of the trend in studies reviewed.

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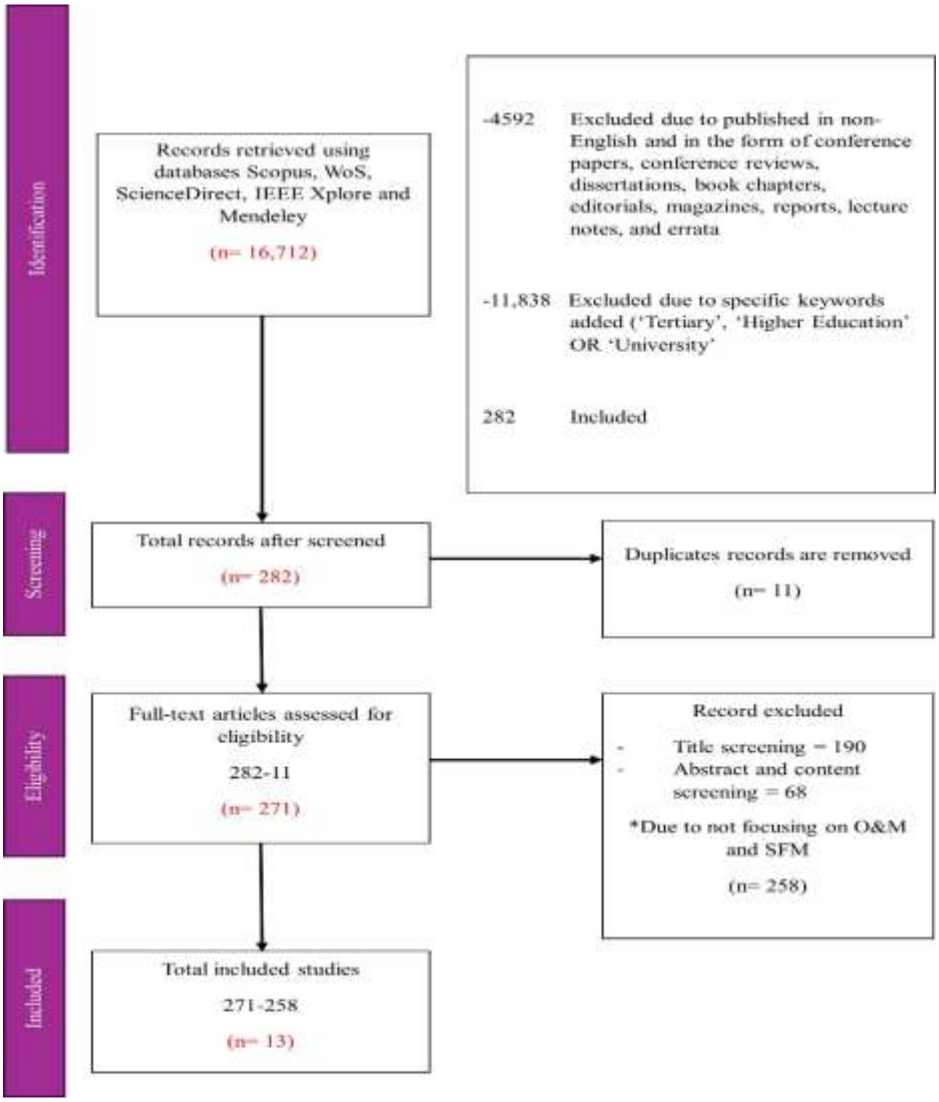

Figure 1: PRISMA Flow Diagram

Source: Adapted from David Moher et al. (2009)

Results

The systematic review focusing on SFM and O&M in tertiary institutions discovered 11 empirical research articles and 2 review articles from educational research studies between 2020 and 2024. The selected studies formed the foundation which answered the research questions for this review.

Research Methodologies

Figure 2 presents the analysis of type of research methods involved in the selected 13 studies. The study synthesis was guided by the research typology by Creswell & Creswell (2018) and Margarete Sandelowski (2000). The most common form of research method was quantitative, as this research design was used in six studies. Quantitative method was used to explain and interpret the innovative approach of O&M for tertiary institutions using numerical data. Qualitative method followed in second place as this method was used in three studies. The qualitative method has been used in collecting and analyse non-numerical and unstructured data which in this review specifically on the implementation of innovative approach for

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O&M. The other two research methods were mixed method and systematic review, with two studies identified for each method. In the mixed method, both quantitative and qualitative method was utilised and merged in one study. This approach brings a much better understanding of research problem (Tashakkori & Teddlie, 2010). On other hand, systematic review uses a specific and clear method of identifying and combining current studies that provide evidence to answer a pre-determined research question.

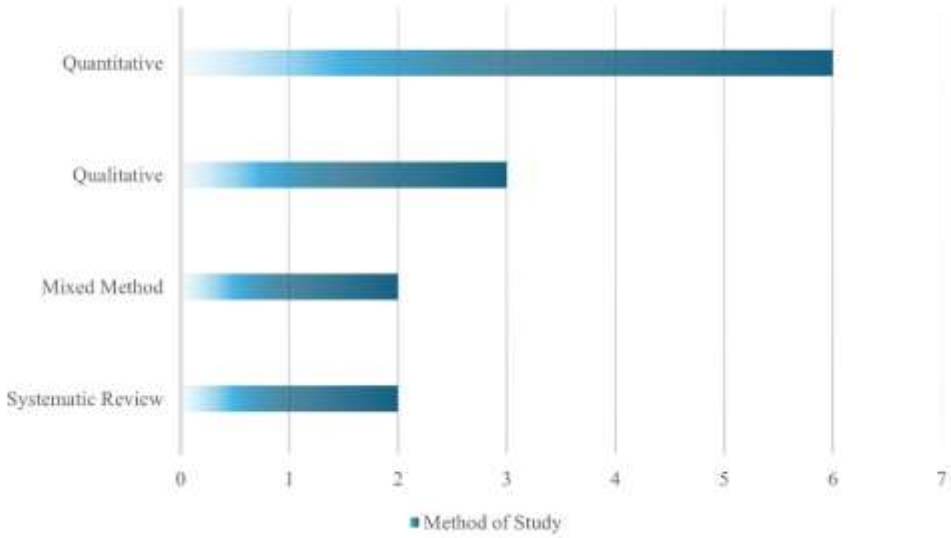

Figure 2: Article Distribution Based on the Methodology

Subject Areas

Subject areas included in the reviewed papers (Table 1) present a scope to be covered in any significant study to promote SFM in tertiary institutions. Five articles in the Energy and Sustainability subject area examine complex alternative solutions including adopting AI for energy sustainability in educational building (Tariq et al., 2024) together with energy cluster approach to enhance accountability and comparability of campus energy data usage (Sonetti & Cottafava, 2022). According to Shoukry et al. (2024), an adoption of simplified AI model in energy management can predict energy trade-offs in indoor air quality (IAQ) and synergies energy ventilation. Besides AI, another practical solution discussed in two case studies in this area are IoT solutions which significantly optimize energy usage in Brazilian universities (Yasuoka et al., 2023) and an integrated energy management system that can monitor the performance of higher education buildings to support sustainability, including the campus carbon footprint (Maulidevi et al., 2023). In specific SFM subject area, four papers have discussed and concerned on its customization. Arafat et al. (2023) has customized green pyramid rating system (GPRS) for university buildings as shown in table 2 while D'Orazio M. et al. (2024) suggested the building occupancy data as an improvement approach of facility management. Additionally, to overcome challenges and barriers in SFM, Fialho et al. (2023) and Lok et al. (2021) have strongly suggested the integration of BIM and IoT as a technology enabler.

Meantime, two papers are related to Human Comfort Studies. Cureau et al. (2022) investigating the potential of living laboratories in promoting sustainability and Hwang & Lim (2023) studying on university students' opinion on public housing which consist of student

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accommodation in tertiary institution. Integrated Environmental Management (IEM) is the next identified subject area represented by Park et al. (2024) in their case study on the implementation of IEM and its specialized engineering education in Korea. Finally, in Urban Infrastructure, (Ranzato & Broggini, 2024) discussed on the adaptive reuse of urban infrastructures which is at the core of the Floating University Berlin.

Collectively, these various subject areas underscore the diverse approaches applied to innovate O&M and achieve sustainability in facility management specifically in tertiary institution.

Data Collection Methods

Six different data collection methods were identified, as presented in Table 3. They include literature review (seven studies), interview (seven studies), questionnaire (six studies), data mining (six studies), and observation (four studies). Literature review and interviews have been identified as the most used data collection method. Literature reviews provide an extensive background of information obtained from secondary sources, while interviews are useful for obtaining expert knowledge. However, interviews can be influenced by the researcher's personal bias. On the contrary, questionnaires can avoid bias besides as a fast and easy method to collect data. Another identified method are data mining and observation whereby data mining has been used to collect and examine large amounts of data while observation is hands-on research approach that offers direct evidence of facts. Nevertheless, these data mining and observation data collection methods may be time-consuming.

Evaluation and validation would have provided additional value in this review. Additionally, it was noted that five studies employed the case study, while two studies and one study respectively adopted focus group discussion and pilot test to obtain data, evaluate and validate outcomes. Case study was used to provide details and specificity to identified issues and to obtain overall knowledge on issues of the study. On the other hand, focus group discussion involves discussions among small groups of expertise or professionals to obtain data or validate outcomes on the topics of study. Pilot test is a method which involved experimentation on small-scale models to test for their validity before a complete application. Details of the frequencies of the different data analysis methods are provided in Table 3.

The methods used by reviewed researchers are varied which necessarily depend on suitability of study. However, further research is needed to explore the optimal combination of methods for addressing specific research questions and to assess the reliability and validity of the findings.

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Table 1: List of the 13 Selected Articles Reviewed in This Study

No	Author	Year	Title	Subject of Study	Country
1	Ranzato and Broggini	2024	Adaptive reuse of an operating urban infrastructure: a conversation with raumlabor about the Floating University Berlin	Urban Infrastructure	Germany
2	Cureau et al	2022	Bridging the gap from test rooms to field-tests for human indoor comfort studies: A critical review of the sustainability potential of living laboratories	Human Comfort Studies	Multiple
3	Tariq et al	2024	Complex artificial intelligence models for energy sustainability in educational buildings	Energy and Sustainability	Mexico and Saudi Arabia
4	Arafat et al	2023	Customizing the green pyramid rating system for assessing university buildings' sustainability: A stakeholder-involved weighting approach	Sustainable Facility Management (SFM)	Egypt
5	Sonetti and Cottafava	2022	Enhancing the accountability and comparability of different campuses' energy profiles through an energy cluster approach	Energy and Sustainability	Japan
6	Park et al	2024	Implementation of Integrated Environmental Management and Its Specialized Engineering Education in Korea: A Case Study	Integrated Environmental Management (IEM)	South Korea
7	D'Orazio et al	2024	Improving Sustainable Management of University Buildings Based on Occupancy Data	Sustainable Facility Management (SFM)	Italy
8	Shoukry et al	2024	Indoor Air Quality and Ventilation Energy in University Classrooms: Simplified Model to Predict Trade-Offs and Synergies	Energy and Sustainability	Egypt
9	Yasuoka et al	2023	IoT solution for energy management and efficiency on a Brazilian university campus - a case study	Energy and Sustainability	Brazil
10	Maulidevi et al	2023	Modeling Integrated Sustainability Monitoring System for Carbon Footprint in Higher Education Buildings	Energy and Sustainability	Indonesia

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11	Fialho et al	2023	Required Changes to Unlock Value Generation through Implementing BIM and IoT for Universities FM Services	Sustainable Facility Management (SFM)	United Kingdom and Brazil
12	Lok et al	2021	The Challenges of Sustainable Development on Facilities Management Outsourcing Services: An Investigation in Educational Facilities	Sustainable Facility Management (SFM)	Hong Kong
13	Hwang and Lim	2023	University Students' Lifestyle and Opinions for University-Affiliated Public Housing: Focusing on Auxiliary Welfare Facilities and Residential Services	Human Comfort Studies	South Korea

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Table 2: GPRS Categories and Criteria

Categories		Criteria
CATEGORY 1: SUSTAINABLE SITES [SS]	SS.01	Site Selection.
	SS.02	Community Services & Connectivity.
	SS.03	Public Transportation Access& Pedestrian Access.
	SS.04	Dedicated Bicycles Tracks and Parking.
	SS.05	Storm / Rainwater Design (Quantity and Quality Control).
	SS.06	Heat Island Effect (Green Space, Hardscape & Building).
CATEGORY 2: ENERGY EFFICIENCY [EE]	EE.01	Building Envelope Improvement.
	EE.02	Passive Heat Gain Reduction.
	EE.03	Renewable Energy Sources.
	EE.04	Energy-Efficient HVAC Systems.
	EE.05	Efficient Artificial Lighting Systems.
	EE.06	Vertical Transportation.
CATEGORY 3: WATER EFFICIENCY [WE]	WE.01	Wastewater Reuse.
	WE.02	Water Efficient Landscaping.
	WE.03	Water Efficient Fixtures.
	WE.04	Metering & Leak Detection System.
CATEGORY 4: MATERIALS AND RESOURCES [MR]	MR.01	Renewable Materials and Materials Manufactured Using Renewable Energy.
	MR.02	Regionally Procured Materials and Products.
	MR.03	Reduction of Overall Material Use.
	MR.04	Alternative Building Prefabricated Elements.
	MR.05	Environment – Friendly, Sound and Thermal Insulation Materials.
CATEGORY 5: INDOOR ENVIRONMENTAL QUALITY [IEQ]	IEQ.01	Enhance Ventilation Performance.
	IEQ.02	Smoking Control.
	IEQ.03	Thermal Comfort.
	IEQ.04	Visual Comfort.
	IEQ.05	Acoustic Comfort.
CATEGORY 6: MANAGEMENT PROTOCOLS [MP]	MP.01	Building Information Modeling.
	MP.02	Life Cycle Assessment.
	MP.03	Building User Guide.
	MP.04	Solid Waste Management.
	MP.05	Building Management System.
CATEGORY 7: INNOVATION AND ADDED VALUE [IN]	IN.01	Innovation and Added Value

Source: Arafat et al., (2023)

Table 3: Method of Data Collection

No	Method of Data Collection	Frequency
1	Literature Review	7
2	Interview	7
3	Questionnaire	6
4	Data Mining	6
5	Observation	4
6	Case Study	5
7	Focus Group Discussion	2
8	Pilot Test	1

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Innovative Approach

For instance, Yasuoka et al. (2023) has developed the GENIIOT Project which is an IoT-enabled application for energy management, which majorly monitors the air-conditioning system. The Project monitors and analyses energy consumption, users' behaviour and feedback to encourage energy efficient in system. In addition, Maulidevi et al. (2023) has developed an intelligent carbon footprint monitoring model, which can monitor energy consumption and carbon emissions to achieve energy management and emission reduction. This model implements design thinking to anticipate energy consumption prediction and sustainability status. While Ranzato & Broggini (2024) applied the approach namely adaptive reuse which has been seen as the transformation of infrastructure such as existing urban infrastructure building for new utility with public engagement and ecological concepts. Meantime, (Park et al., 2024) introduced the IEM which is an online application that can be use in industries with numerous environmental permits. The IEM is implemented through Best Available Technologies (BATs) which combine emission impact analysis to check environmental requirements in industries and at the end can be use in evaluating, reaching and optimizing environmental performances.

Another technological approach is AI. The main goal of AI is to enable machines to perform tasks that typically require human intelligence. AI applications have come a long way, providing a wide range of benefits for personal and professional tasks (Lavidas et al., 2024). According to Tariq et al. (2024), AI-based energy prediction models utilized ML algorithms, including decision trees, K-nearest neighbours, gradient boosting, and long-term memory networks to predict and optimize energy consumption in academic buildings. On the other hand, Fialho et al. (2023) further proposed combining BIM and IoT to model and analyse facility data. BIM provides a detailed and comprehensive digital representation of building information, while IoT enables real-time data collection and monitoring through sensors and connected devices (Fialho et al., 2023). Integrating BIM and IoT in FM allows for proactive maintenance by leveraging data analytics to predict equipment failures or maintenance needs before they occur (Fialho et al., 2023). In addition, Predictive analytics can be used to optimize resource allocation and maintenance schedules, ensuring that interventions are carried out at the right time, reducing downtime and costs while AI-based energy prediction model can predict optimal energy usage of educational institutions using real-time sensor information (Fialho et al., 2023; Tariq et al., 2024). Meanwhile, Shoukry et al. (2024) in their study have utilizes Grasshopper software to model and predict the trade-offs between IAQ and mechanical ventilation energy consumption, optimizing energy use while maintaining healthy indoor environments. The results of the simulation model showed that it is viable to expect the trade-off of IAQ and mechanical ventilation energy consumption to achieve energy optimization (Shoukry et al., 2024).

Furthermore, Cureau et al. (2022) stated that IoT devices, ML methods, and cloud computing can be integrated in O&M practices to gather and analyse real-time data which contributes to more precise and responsive O&M processes. A pilot experiment in living laboratory showed significant energy consumption reduction and improvement in thermal comfort in the buildings under a smart heating system and improved control algorithms (Cureau et al., 2022). In this regard, D'Orazio M. et al. (2024) used open-source free timetabling software tool known as a best fit scheduler (BFS) in their study which combined data-driven correlations between a building's occupants' presence and asset preventative maintenance prerequisites. This approach allowed building managers to possibly double the efficacy of certain tasks such as

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elevator maintenance by focusing on proactively handling critical conditions and better planning for execution of the task (D'Orazio M. et al., 2024). Furthermore, the BFS resulted in a mean net gain in maintenance time of 20% or more, and the efficiency of the maintenance operation was further enhanced by adding intelligent elevator settings for optimum performance (D'Orazio M. et al., 2024).

Besides technology enabler, innovative approach also can be adopted in O&M with delve into process improvisation. For instance, the lifestyle-based facility planning methodology is suggested by Hwang & Lim (2023) to analyse the lifestyles of university students and provide options for appropriate auxiliary welfare facilities and residential services based on the lifestyle. It is to ensure that the facilities and services provided are compatible with the user's lifestyle in a practical and cost-effective manner (Hwang & Lim, 2023). While Lok et al. (2021) focusing on outsourcing strategies in their study and introduced the Sourcing and Developing Critical Success Factors (CSFs) for the sourcing of FM services. It ranges from building maintenance, security, cleaning and catering, and many more. Additionally, Lok et al. (2021) developed the Contingency Outsourcing Relationship (CORE) model which manages clients or firm by seeking FM Services and FM service provider relationship through ownership, control, competitive positioning and long-term strategies. Other than that, Arafat et al. (2023) customized a green rating system which is an extensive assessment method that overcame some of the issues associated with generic Green Rating Systems. Namely Green Pyramid Rating System (GPRS), it was customized to accommodate the special characteristics of university buildings and the opinion of the stakeholders which the criteria were prioritized (Arafat et al., 2023). Meanwhile, Sonetti & Cottafava (2022) improvising building energy management through energy cluster approach which is a benchmarking method used to categorize buildings into energy consumption patterns or energy consumption profile. It goes further in saying that the approach allows for more meaningful comparisons with other buildings rather than just using absolute values. For optimal performance of this approach the researchers have also conducted additional research on smart metering which is an energy management approach for accurate energy readings supported with data mining and big data analytics to collect and evaluate energy to find energy-saving and energy-efficient opportunities (Sonetti & Cottafava, 2022).

Collectively, these innovative approaches will improve the current performance of building O&M in Tertiary institutions and influencing in sustainability achievement. Depending on suitability and ability, various tools and techniques can be adopted which will lead to a positive environmental impact and cost-effectiveness. Table 4 illustrates the innovative approaches introduce by various researchers.

Table 4: Innovate Approach for O&M

Author (Year)	Project/Model	Description
Yasuoka (2023)	GENIIOT Project	Utilizes IoT for energy management, focusing on air-conditioning systems to monitor energy consumption, user behaviors, and feedback to promote energy efficiency.
Maulidevi (2023)	Intelligent Carbon Footprint Monitoring Model	Implements design thinking to manage energy consumption and reduce emissions, using digital

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		technology to monitor and predict energy usage and sustainability status.
Ranzato (2023)	Adaptive Reuse of Infrastructure	Involves transforming existing urban infrastructure for new uses, integrating public engagement and ecological considerations to enhance sustainability.
Park (2024)	Integrated Environmental Management (IEM)	Combines multiple environmental permits into a single system, using Best Available Technologies (BATs) and emission impact analysis to optimize environmental performance.
Tariq (2024)	AI-Based Energy Prediction Models	Employs machine learning algorithms like decision trees, K-nearest neighbors, gradient boosting, and long-term memory networks to predict and optimize energy consumption in educational buildings.
Fialho (2023)	BIM and IoT Integration	Uses BIM for digital representation of building information and IoT for real-time data collection and monitoring, enabling predictive maintenance and efficient resource allocation.
Hwang (2023)	Lifestyle-Based Facility Planning	Analyzes university students' lifestyles to tailor auxiliary welfare facilities and residential services, ensuring practical and cost-effective solutions.
Shoukry (2024)	Simulation Models for IAQ and Energy Efficiency	Utilizes Grasshopper software to model and predict the trade-offs between indoor air quality and mechanical ventilation energy consumption, optimizing energy use while maintaining healthy indoor environments.
Cureau (2022)	IoT Devices and Sensors	Utilization of IoT devices and sensors for real-time monitoring and control of indoor environmental quality (IEQ).
	Machine Learning and Cloud Computing	Application of machine learning techniques and cloud computing to analyze data and optimize building systems.
	Living Labs	Implementation of living labs to test and optimize human-centric solutions for comfortable and energy-efficient buildings.
D'Orazio M. (2024)	Data-Driven Timetabling	Integration of open-source timetabling software with data-driven correlations between occupant presence and maintenance needs to optimize elevator maintenance and reduce costs.
	Predictive Maintenance	Use of data-driven approaches to predict critical conditions and optimize maintenance schedules, thereby improving safety and reducing maintenance needs.
Lok (2021)	Outsourcing Strategies	Development of critical success factors for outsourcing facilities management (FM) services, including building maintenance, security, cleaning, and catering.

	CORE Model	Introduction of the Contingency Outsourcing Relationship (CORE) model to manage relationships between clients and FM service providers, focusing on ownership, control, competitive positioning, and long-term strategies.
Arafat (2023)	Customized Green Rating Systems	Customization of the Green Pyramid Rating System (GPRS) to better suit the unique characteristics and needs of university buildings.
	Stakeholder Involvement	Active involvement of diverse stakeholders in the weighting and prioritization of sustainability criteria to enhance the acceptability and feasibility of sustainable practices.
Sonetti (2022)	Energy Cluster Approach	Implementation of an energy cluster approach to categorize buildings based on their energy consumption profiles, enabling more meaningful comparisons and better evaluation of energy performance.
	Smart Metering and Data Analysis	Use of smart meters and data analysis to monitor energy consumption and identify opportunities for energy savings and efficiency improvements.

Discussion

This section will discuss on the contribution, and the challenges and barriers of adopting innovative approach in O&M which lead to SFM practices. It will be answering third and fourth research question.

Contribution

SFM practices in tertiary institutions improve environmental, economic, and social sustainability, as shown in Figure 3. SFM can contribute to a reduction in CO2 emissions, lower energy costs, encourage responsible energy use, and promote and encourage social engagement and responsibility.

From an environmental point of view, improving energy efficiency in air-conditioning (AC) systems is considered an important aspect that contributes to a reduction of CO2 emissions and lower energy costs (Yasuoka et al., 2023). Maulidevi et al. (2023) also use an intelligent monitoring model that controls energy consumption and emissions to provide a cost-effective view and energy management. Besides, Study by Ranzato & Broggini (2024) shown the adaptive reuse of infrastructure is important in enhancing ecological sustainability through the preservation of existing infrastructure and the incorporation of natural elements, rather than new constructions. On the other hand, IEM optimized control of pollutant which also contribute to improve the overall environmental performance, while encouraging self-monitoring by users to monitor industry-specific emissions (Park et al., 2024). In the aggregate, optimizing energy usage, lowering Carbon footprint and sustainability education and awareness in tertiary institution are the main contribution of adopting innovation approach in O&M.

In economic perspective, technology enabler is the main contributor. For instance, by integrating BIM with IoT, it can optimize energy and resource consumption while lowering operating costs through incorporating predictive maintenance and efficient resource allocation without compromising service performance and user satisfaction (Fialho et al., 2023). Furthermore, timetabling also important in optimizing building occupancy and maintenance schedule. By implementing data-driven timetabling, it will significantly reduce unnecessary energy and maintenance costs (D'Orazio M. et al., 2024). Besides, according to Lok et al. (2021), efficient performance of O&M through managing outsourcing relationships can provide cost-effective and sustainability in facility management.

For social view, education and awareness initiatives that targeting users of the campus community can contribute to promoting social sustainability through responsible energy consumption (Yasuoka et al., 2023). Hence, facility planning which encouraging sustainable living practices and community engagement must be customized to promote social sustainability (Hwang & Lim, 2023). IEQ also must be optimized as it is not less important for a healthy indoor environment for students and staff (Shoukry et al., 2024). Cureau et al. (2022) also supports this by integrating IoT devices and sensors for the real-time monitoring and control of IEQ parameters, such as temperature, humidity, CO2 levels, and air quality. Furthermore, GPRS are customized by Arafat et al. (2023) to promote the use of renewable energy sources and promote water management in university buildings, which means involving all stakeholders in sustainability practices for resource efficiency, lower operating costs, and IEQ improvement.

Figure 3: Sustainable Facility Management Practices in Tertiary Institutions

Challenges and Barriers

Implementing SFM within the tertiary education sector encounters multiple difficulties and obstacles. Figure 4 illustrates the essential obstacles within technology, procedures and policy that require solutions to advance efficiency.

One of the technology-related issues is the interoperability and integration of different systems and tools (Fialho et al., 2023). For example, lack of compatibility between BIM, IoT and Management Systems software can lead to inefficiencies and data silos. The integration of new digital tools can be challenging due to the rigid structure and technical limitations of some systems that may not be adapted to the specificities and needs of the FM sector in tertiary institutions (Fialho et al., 2023). These may create discouragement and mistrust in the use of such technologies. One way to address interoperability issues is to develop open platforms and strengthen the link between IT developers and FM users. By designing FM systems that are flexible and adaptable to specific needs, institutions can reduce challenges in technology integration.

Cultural resistance to change is another challenge. FM staff who have been working in a certain way for years may be resistant to adopt new technologies and processes (Fialho et al., 2023). Additionally, they may lack the skills to manage and use digital information, making it difficult to leverage the full potential of latest FM systems and tools (Fialho et al., 2023). A knowledge gap is a barrier to FM digitalization and innovative approach adoption. According to Cureau et al. (2022) Integrating digital tools with existing IT infrastructure and other conventional systems may require specific skills and competencies that are not always available. The staff responsible for building management and control may not have the necessary knowledge and experience in innovation and digital tools (Cureau et al., 2022). To solve the lack of skills, investment in upskilling and knowledge development of the FM staff can help them develop the required skills and knowledge to manage digital information and use modern FM tools. Upskilling can be achieved through training courses, workshops, webinars and other capacity-building activities. For instance, The Computer Simulation in Education (CoSinE) workshop which focusing on computer simulation, AI, and modeling systems and The Cloud-based Smart Technologies for Open Education (CSTOE) workshop which deals with cloud-based learning resources, platforms, and infrastructures are great to attend since both workshops are peer-reviewed international workshop highlighting on theory and practice (Papadakis et al., 2023). Moreover, Fialho et al. (2023) suggested to perform return on investment (ROI) analysis which can help FM companies and tertiary institutions to provide proof and evidence of the long-term financial benefits and positive economic impact of SFM practices and demonstrate the payback period for initial capital investment. While involvement and collaboration with all stakeholders in digital transformation shown more inclusive and democratic environment.

Constraints on public budgets and long investment cycles in the public FM such in tertiary institution can create financial barriers for FM public companies and FM providers to acquire new technologies and information systems and invest in human resource upskilling (Fialho et al., 2023). On the other hand, Ranzato & Broggini (2024) mentioned legal barriers on repurposing of existing FM infrastructure and assets and a lack of flexibility in local and regional planning regulations and administrative procedures can prevent FM companies from moving to more sustainable practices and regenerative FM models. In sustainability perspective, lack of evidence in the benefits of flexible use of existing building is also a major factor contributing to the low acceptance of regenerative FM and adaptive reuse of existing building infrastructure (Ranzato & Broggini, 2024). By emphasizing the cost savings, energy efficiency, and other potential ROI, insititutions can build a solid business case to receive funds and support from key stakeholders, including public budgets and municipal administrations. According to Arafat et al. (2023), raising awareness among all stakeholders, end-users and institutions managers through education, information campaigns and by involving them in the process through all stages of planning and implementation can increase the acceptance and implementation of sustainable FM practices. Working close with governments, including regulatory bodies to contribute ideas in shaping policies and regulations that support transition to SFM approaches can contribute to addressing the legal and administrative barriers.

Another challenge in adopting innovative approach is integrating tools into a single system. For example, study by Park et al. (2024) in developing IEM systems facing barriers such complexity of consolidating several software and tools into a single system. Moreover, the limited availability of expertise in operating, maintaining and managing the systems makes the

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implementation process more complicated and presents another barrier (Park et al., 2024). Furthermore, barriers to implementing IoT systems for building management system involves high budget allocation for establishing it infrastructure and facilities (Yasuoka et al., 2023). Lack of user involvement and awareness in the operation and not fully utilize of the installed system can also act as a barrier to optimizing the full potential of IoT in the system. To overcome this, a cost-benefit analysis of the total cost of ownership of such systems can be provided to the concerned FM decision-makers in the public sector to justify and motivate the initial investment in IoT (Yasuoka et al., 2023). Moreover, user training and awareness programs can be established and carried out to increase the visibility of the installed systems and attract the users to actively take part in their operation to ensure the optimization of such facilities.

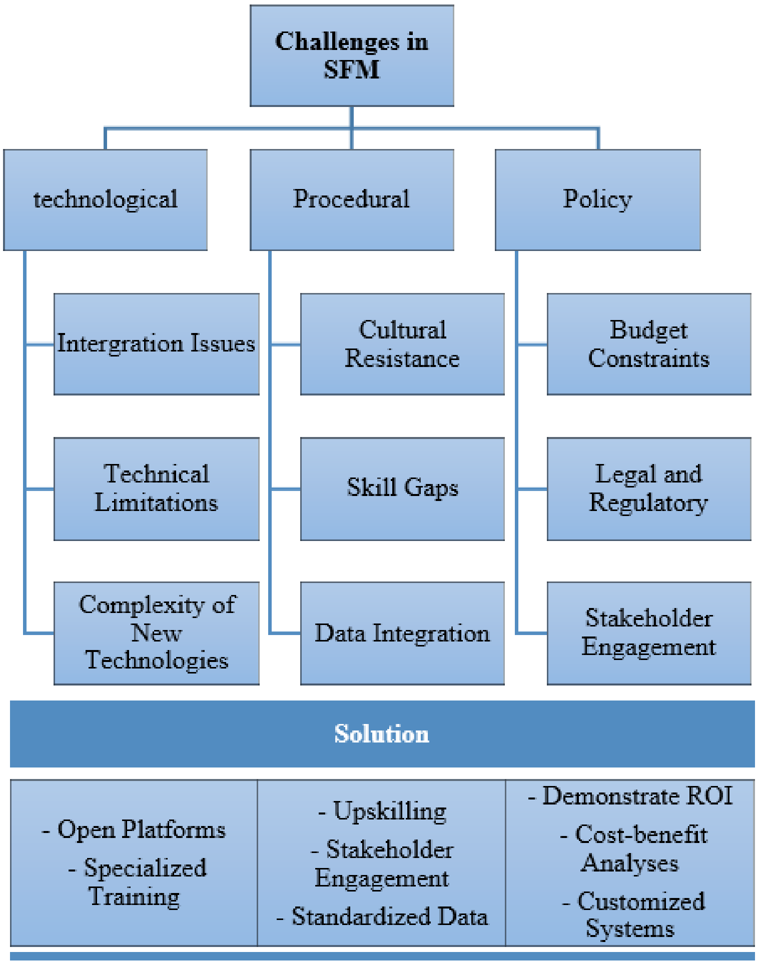

Figure 4: Overcoming Challenges in Implementing Sustainable Facility Management

Limitations of the study

The study has several limitations. One limitation of the study is the use of secondary data and the reliance on existing literature. This limits the depth of insights that can be obtained from primary data collection. Another limitation is the focus on tertiary institutions, which may limit the generalizability of the findings to other educational settings. The study may also be limited by changes in technology and regulatory environments, which may affect the relevance of the findings over time. Finally, the variability in research methodologies among the included

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studies limited the scope of comparative analysis. Future research can address these limitations by incorporating a diverse range of data sources, including primary data collection, and adopting a longitudinal research design.

Conclusion and Recommendations

In conclusion, this SLR highlights the crucial role of SFM in advancing environmental, economic and social sustainability in tertiary institutions. The emerging technologies of AI, IoT and BIM, as well as current practices improvisation, adaptive reuse and intelligent management systems, have shown to be effective strategies for innovative and sustainable O&M of buildings. These approaches not only improve energy efficiency and reduce costs but also promote a culture of sustainability among users on campus. Moreover, the findings of this review suggested a holistic approach to SFM which goes beyond technology and equipment to include human and organisational factors, as well as the underlying culture and values of all stakeholders. By addressing the identified gaps, tertiary institutions could position themselves as champion in sustainable development and contribute to a greener and more sustainable future. It is also recommended that training and capacity building programmes for key personnel is necessity, stakeholder engagement in awareness must be encourage, and lastly specific innovative approaches that consider the unique needs and challenges of different buildings must be consider. Continuous monitoring and evaluation of implemented strategies are also essential to ensure their effectiveness and adaptability to emerging challenges in the future.

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References

Abideen, D. K., Yunusa-Kaltungo, A., Manu, P., & Cheung, C. (2022). A Systematic Review of the Extent to Which BIM Is Integrated into Operation and Maintenance. In *Sustainability (Switzerland)* (Vol. 14, Issue 14). MDPI. https://doi.org/10.3390/su14148692

Amaral, A. R., Rodrigues, E., Rodrigues Gaspar, A., & Gomes, Á. (2020). A review of empirical data of sustainability initiatives in university campus operations. *Journal of Cleaner Production*, *250*. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.119558

Arafat, M. Y., Faggal, A. A., Khodeir, L., & Refaat, T. (2023). Customizing the green pyramid rating system for assessing university buildings' sustainability: A stakeholder-involved weighting approach. *Alexandria Engineering Journal*, *82*, 446–458. https://doi.org/10.1016/j.aej.2023.10.013

Bennett, N. D., & Anderson, L. (2003). *Developing Educational Leadership: Using Evidence for Policy and Practice*. Sage Publications Ltd. http://digital.casalini.it/9781446276204

Chew, M. Y. L., Teo, E. A. L., Shah, K. W., Kumar, V., & Hussein, G. F. (2020). Evaluating the roadmap of 5g technology implementation for smart building and facilities management in singapore. *Sustainability (Switzerland)*, *12*(24), 1–26. https://doi.org/10.3390/su122410259

Corvalan, C., Prats, E. V., Sena, A., Campbell-Lendrum, D., Karliner, J., Risso, A., Wilburn, S., Slotterback, S., Rathi, M., Stringer, R., Berry, P., Edwards, S., Enright, P., Hayter, A., Howard, G., Lapitan, J., Montgomery, M., Prüss-Ustün, A., Varangu, L., & Vinci, S. (2020). Towards climate resilient and environmentally sustainable health care facilities. *International Journal of Environmental Research and Public Health*, *17*(23), 1–18. https://doi.org/10.3390/ijerph17238849

Creswell, J. W., & Creswell, D. J. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications.

Cureau, R. J., Pigliautile, I., Pisello, A. L., Bavaresco, M., Berger, C., Chinazzo, G., Deme Belafi, Z., Ghahramani, A., Heydarian, A., Kastner, D., Kong, M., Licina, D., Luna-Navarro, A., Mahdavi, A., Nocente, A., Schweiker, M., Vellei, M., & Wang, A. (2022). Bridging the gap from test rooms to field-tests for human indoor comfort studies: A critical review of the sustainability potential of living laboratories. In *Energy Research and Social Science* (Vol. 92). Elsevier Ltd. https://doi.org/10.1016/j.erss.2022.102778

David Moher, Alessandro Liberati, Jennifer Tetzlaff, Douglas G. Altman, & the PRISMA Group. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *Annals of Internal Medicine* , *151*(4), 264–269. https://www.acpjournals.org/doi/full/10.7326/0003-4819-151-4-200908180-00135?download=true&journalCode=aim

D'Orazio M., Bernardini G., & Di Giuseppe E. (2024). Improving Sustainable Management of University Buildings Based on Occupancy Data. *Journal of Construction Engineering and Management*, *150*(1). https://doi.org/10.1061/JCEMD4.COENG-13563

Fialho, B. C., Fabricio, M. M., & Codinhoto, R. (2023). Required Changes to Unlock Value Generation through Implementing BIM and IoT for Universities FM Services. *Buildings*, *13*(9). https://doi.org/10.3390/buildings13092150

Hollander, M., & Seldman, J. (2017). *Methods in Built Environment Research: A Systematic Review Approach*. Routledge.

Hwang, J. H., & Lim, H. (2023). University Students' Lifestyle and Opinions for University-Affiliated Public Housing: Focusing on Auxiliary Welfare Facilities and Residential Services. *Sustainability (Switzerland)*, *15*(6). https://doi.org/10.3390/su15065519

Lavidas, K., Voulgari, I., Papadakis, S., Athanassopoulos, S., Anastasiou, A., Filippidi, A., Komis, V., & Karacapilidis, N. (2024). Determinants of Humanities and Social Sciences Students' Intentions to Use Artificial Intelligence Applications for Academic Purposes. *Information (Switzerland)*, *15*(6). https://doi.org/10.3390/info15060314

Lok, K. L., Smith, A., Opoku, A., & Chen, C. (2021). The challenges of sustainable development on facilities management outsourcing services: An investigation in educational facilities. *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158156

Maulidevi, N. U., Aji, B. S. K., Hikmawati, E., & Surendro, K. (2023). Modeling Integrated Sustainability Monitoring System for Carbon Footprint in Higher Education Buildings. *IEEE Access*, *11*, 135365–135376. https://doi.org/10.1109/ACCESS.2023.3333890

Okoro, C. S. (2023). Sustainable Facilities Management in the Built Environment: A Mixed-Method Review. In *Sustainability (Switzerland)* (Vol. 15, Issue 4). MDPI. https://doi.org/10.3390/su15043174

Papadakis, S., Kiv, A. E., Kravtsov, H. M., Osadchyi, V. V, Marienko, M. V, Pinchuk, O. P., Shyshkina, M. P., Sokolyuk, O. M., Mintii, I. S., Vakaliuk, T. A., Striuk, A. M., & Semerikov, S. O. (2023). *Revolutionizing education: using computer simulation and*

Volume 7 Issue 27 (October 2025) PP. 372-393
DOI: 10.35631/IJMOE.727024
cloud-based smart technology to facilitate successful open learning. http://mpz.knu.edu.ua/pro-kafedru/vikladachi/224-andrii-striuk

Park, D. S., Kang, M. S., Chae, C. B., Sunwoo, Y., & Hong, K. H. (2024). Implementation of Integrated Environmental Management and Its Specialized Engineering Education in Korea: A Case Study. *Sustainability (Switzerland), 16*(5). https://doi.org/10.3390/su16052140

Pedral Sampaio, R., Aguiar Costa, A., & Flores-Colen, I. (2022). A Systematic Review of Artificial Intelligence Applied to Facility Management in the Building Information Modeling Context and Future Research Directions. In *Buildings* (Vol. 12, Issue 11). MDPI. https://doi.org/10.3390/buildings12111939

Piselli, C., Guastaveglia, A., Romanelli, J., Cotana, F., & Pisello, A. L. (2020). Facility energy management application of HBIM for historical low-carbon communities: Design, modelling and operation control of geothermal energy retrofit in a real Italian case study. *Energies*, *13*(23). https://doi.org/10.3390/en13236338

Ranzato, M., & Broggini, F. (2024). Adaptive reuse of an operating urban infrastructure: a conversation with raumlabor about the Floating University Berlin. *Journal of Cultural Heritage Management and Sustainable Development*, *14*(1), 127–136. https://doi.org/10.1108/JCHMSD-04-2023-0040

Shoukry, F., Raafat, R., Tarabieh, K., & Goubran, S. (2024). Indoor Air Quality and Ventilation Energy in University Classrooms: Simplified Model to Predict Trade-Offs and Synergies. *Sustainability (Switzerland)* , *16*(7). https://doi.org/10.3390/su16072719

Sonetti, G., & Cottafava, D. (2022). Enhancing the accountability and comparability of different campuses' energy profiles through an energy cluster approach. *Energy Efficiency*, *15*(4). https://doi.org/10.1007/s12053-022-10024-1

Støre-Valen, M., & Buser, M. (2019). Implementing sustainable facility management: Challenges and barriers encountered by Scandinavian FM practitioners. *Facilities*, *37*(9–10), 550–570. https://doi.org/10.1108/F-01-2018-0013

Tashakkori, A., & Teddlie, C. (2010). *Handbook of Mixed Methods in Social and Behavioral Research* (2nd ed.). SAGE Publications.

Tariq, R., Mohammed, A., Alshibani, A., & Ramírez-Montoya, M. S. (2024). Complex artificial intelligence models for energy sustainability in educational buildings. *Scientific Reports*, *14*(1). https://doi.org/10.1038/s41598-024-65727-5

Yasuoka, J., Cordeiro, G. A., Brittes, J. L. P., Cooper Ordóñez, R. E., Bajay, S. V., & Nunes, E. (2023). IoT solution for energy management and efficiency on a Brazilian university campus – a case study. *International Journal of Sustainability in Higher Education*, *24*(2), 426–448. https://doi.org/10.1108/IJSHE-08-2021-0354