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Cultivating Sustainability Facility Management in Malaysian Higher Education Institutions: A Review on Operation and Maintenance (O&M) Practices

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ABSTRACT

This review examines the current practices of Operation and Maintenance in Malaysian Higher Education Institutions, emphasizing sustainability and efficiency of facility management. Despite the increasing adoption of technologies such Building Information Modelling, several technical, organizational, financial and environmental barriers hinder their full integration. Using systematic literature reviews (SLR) of recent studies, this research identifies emerging trends in Operation and Maintenance (O&M) practices in Malaysia, alongside challenges and actionable solutions. The findings underscore the transformative potential of integrating advanced technologies including Building Information Modelling (BIM) to revolutionize sustainability in campus operations. Key insights include the strategic importance of energy conservation measures (ECMs), predictive maintenance frameworks and multi-criteria decision-making (MCDM) models in optimizing resources and reducing environmental footprints. This study uniquely advocates for a holistic integration, combining these technologies with tailored frameworks for Malaysian HEIs to address their distinct challenges. By advancing these innovative solutions, the research contributes to the broader discourse on sustainable facility management and positions Malaysian HEIs as potential leaders in sustainability and green campus initiatives.

Keywords: *Practices; building information modelling; sustainability; operation and maintenance; green campus; Malaysia; university*

1. Introduction

The increasing need for sustainable operations within higher education institutions has driven Malaysian universities to prioritize efficient Operation and Maintenance (O&M) practices. These institutions aim to optimize resource use while ensuring the resilience and functionality of their campus infrastructure. Most of the institutions face unique challenges, including rising energy consumption, aging infrastructure and limited financial resources, all of which have placed pressure on their ability to maintain functional and sustainable facilities. With growing energy consumption and aging facilities, O&M strategies must be evolved to address sustainability challenges and minimize the operational costs [1,2].

A key trend in modern O&M practices is the integration of technology, particularly Building Information Modelling (BIM). BIM facilitates better information management throughout the

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building lifecycle, improving data accessibility and enhancing decision making processes. However, technical complexities, lack of skilled personnel and financial constraints have hindered its widespread implementation in Malaysian Higher Education Institutions (HEIs). These barriers have resulted in inefficient maintenance practices and often relying on outdated methods which negatively impact the sustainability of campus operations [3,4].

Besides technological hindrance, many Malaysian HEIs encounter organizational and environmental challenges. Issues such as limited budgets, lack of environmental awareness and inefficient communication systems further complicate the implementation of sustainable O&M practices. Many HEIs continue to struggle with high energy consumption and inadequate waste management strategies. While some universities have made strides through energy conservation measures and green campus initiatives, the overall implementation of sustainable O&M practices remains inconsistent [2,5]. Despite these challenges, some universities have introduced successful initiatives including energy efficiency programs and waste management strategies, showcasing a shift toward a green campus operation. This review explores current O&M practices in Malaysian HEIs, the associated challenges and the potential solutions for enhancing sustainability and the recommendation in enhancing operation and maintenance efficiency and environmental performance.

1.1 Theoretical Background

1.1.1 Overview

Building operation and maintenance (O&M) in Malaysian higher education institutions (HEIs) prioritize the resiliency, functionality and sustainability of campus facilities. Effective O&M practices encompass regular inspections, preventive maintenance and energy efficient strategies such as using LED lighting and PIR sensors to optimize resources use and reduce operational costs [3,5,6]. Institutions like Universiti Pertahanan Nasional Malaysia and Universiti Malaya demonstrate the importance of infrastructure resilience, energy efficiency and emergency preparedness to create a conducive and sustainable learning environment while ensuring safety, comfort and operational efficiency [2,7].

1.1.2 Current practices in Malaysian HEIs

The current practice of building O&M in HEIs shows various levels of integration of advanced methodologies, with BIM implementation still emerging as a tool for improving information management. Some universities have made strides in integrating tools like BIM for information management and predictive maintenance, while others continue to rely on more traditional, paper-based methods [3,4]. While BIM presents significant potential for enhancing O&M, its integration is hindered by technical, organizational and legal barriers [8]. Traditional methods such as paper-based documentation remain as a widely used limiting the effectiveness of facility management processes [3].

BIM is currently recognized for its potential to streamline information management in O&M by providing a centralized, digital model of the building. However, in many Malaysian HEIs, BIM is still in its early stages of implementation. The integration of BIM for tasks such as asset management, energy monitoring and maintenance scheduling has not been fully realized [3,4]. Some universities may have partially adopted BIM but lack full integration across all O&M activities. For instance, they might use BIM for facility design and construction but not yet for the operation and maintenance phases. This inconsistency reflects differing levels of resource availability, technical expertise and

institutional support for the technology [8]. In contrast, many universities continue to rely on conventional O&M approaches, such as manual inspections and paper-based maintenance records. These traditional methods limit the ability to optimize facility management and reduce operational costs, highlighting the gap between institutions that have begun integrating advanced technologies and those that have not [3].

Additionally, public universities face challenges such as insufficient budget allocation which negatively impacts maintenance outcomes [9]. However, multi-criteria decision-making (MCDM) models, which listing by rank 11 critical criteria for building maintenance processes offers a promising approach for improving decision making and prioritization [10]. This highlights the importance of condition assessment practices in enhancing O&M outcomes across Malaysian HEIs.

Besides that, several innovations have been developed in Malaysian HEIs to make O&M more effective. For instance, study on Universiti Malaya has developed a Practical Framework for Evaluating Campus Resilience by focusing on building characteristics, age, population density and location vulnerabilities [7]. Efforts like Universiti Teknologi Malaysia which introducing the Sustainable Campus Preservation Policy, implementation of Energy Management Systems (EnMS) based on ISO50001 standards and creating the Composting Center infrastructure highlights the shift towards sustainability [2,5,11]. These innovations are complemented by energy efficiency programs, seminars and individualized billing systems which encourage better resource management [1,6].

The integration of these innovative approach and the identification of key criteria through MCDM models can contribute to more effective and sustainable O&M practices in Malaysian HEIs.

1.1.3 Research question

The current practices of building O&M in Malaysian HEIs demonstrate a mixed of traditional and emerging methods, with some institutions incorporating innovative approaches to enhance sustainability and efficiency. However, significant gaps identified particularly in the integration of advanced tools like BIM which is still in its early stages of implementation due to technical, organizational and legal barriers [8]. Furthermore, even MCDM frameworks are being developed to prioritize maintenance processes, challenges like insufficient budgets, outdated infrastructure and limited awareness of sustainable practices occurs. As institutions strive to optimize O&M practices through energy efficiency programs, campus resilience frameworks and condition assessment models, there is a growing need to explore the effectiveness of these strategies and address the barriers that obstructing the progress.

Hence, the following research questions are addressed in this study:

RQ1: What are the dominant research methodologies employed in selected studies and the current practices of O&M identified by subject area?

RQ2: How do the O&M practices in Malaysian HEIs contribute to environmental, economic and social sustainability?

RQ3: What are the primary barriers and challenges hindering the implementation of effective O&M Malaysian HEIs and how can these be addressed?

2. Methodology

2.1 Search Strategy

For this review, a search strategy was developed to identify swift relevant literature on current practices for building Operation and Maintenance (O&M) in Malaysian HEIs. The search was using AI-powered research and discovery tools namely Semantic Scholar and Elicit.com. Keywords used

included 'Practices' AND 'Building' AND 'Operation and Maintenance' AND 'Malaysia' AND 'University' for Semantic Scholar electronic databases while the Elicit.com prompt is 'Current Practices on Building Operation and Maintenance in Malaysian Higher Education Institution'. These tools were chosen for their comprehensive coverage of high-quality databases such as Scopus, Science Direct, Emerald, Springer and MDPI which peer-reviewed academic literature across various disciplines. As one of the processes in search strategy, selected papers then will be checked it sources of database by hit the tab of 'view via publisher'. It ensuring a thorough and reliable search for relevant studies on O&M in Malaysian tertiary institutions. The initial search in Semantic Scholar without data parameters defined for inclusion and exclusion by David Moher resulted 4.790 articles. Afterward, range of date for 5 years (2019-2024) has been inserted and had reduce the articles to 1170. However, from this figure only 761 has a PDF document to review. Henceforth, top journals were selected as shown in Table I and exclude another 686 articles to the end of 75 articles. While in Elicit.com, 40 articles were generated with filtered of 5 years database and journal quality Quartile 1 (Q1) and Quartile 2 (Q2) of Scimago Journal Rank (SJR).

Table 1
Top journal selected

No	Journal
1	Journal of Facility Management
2	Journal of Information Technology in Construction
3	International Journal of Building Pathology and Adaptation
4	Sustainability
5	Building
6	Journal of Physics: Conference Series
7	International Journal of Academic Research in Business
8	IOP Conference Series: Materials Science and Engineering
9	IOP Conference Series: Earth and Environment

2.2 Selection Criteria

The selection criteria followed the PRISMA guidelines to ensure a transparent and reproducible process [12]. A PRISMA flow diagram was employed to detail each step of the study selection, from identification to final inclusion. Although PRISMA is typically used for systematic reviews, its framework offered a well-organized method for this literature mapping exercise. The initial search covered O&M studies from a broad range of contexts, which was later refined to focus specifically on the tertiary education sector in Malaysia.

The papers reviewed in this study were selected based on the following inclusion criteria:

i. Studies related to O&M in tertiary/ higher education/ university settings
ii. Studies that describe current practices of O&M in tertiary/ higher education/ university settings
iii. Studies evaluating O&M methods and strategies in tertiary/ higher education/ university settings
iv. Studies published in peer-reviewed journals with journal quality of Q1 and Q2 in SJR.
v. Studies published between January 2019 and September 2024

While, exclusion criteria included studies as below:

i. In the format of book chapters, conference proceedings, or grey literature (opinion pieces, technical reports, blogs, presentations, etc.)
ii. Did not focus on O&M in tertiary/ higher education/ university settings
iii. Not published in reputable (i.e., peer-reviewed) sources
iv. Not published in English

These criteria were established to ensure the inclusion of high-quality, relevant, and recent studies specifically focused on O&M practices in tertiary institutions, while excluding less rigorous or non-specific literature to maintain the review's focus and reliability. The articles selected for review are presented in Table II.

2.3 Quality Assessment

To ensure the quality of the review, the initial pool of studies was refined by eliminating records other than Q1 and Q2 in SJR by using Elicit.com. This process reduced the sample from 75 to 40 articles. The titles of the remaining articles were then screened, followed by a comprehensive review of the titles and abstracts to further assess the relevance and quality of the articles. This rigorous assessment led to the exclusion of an additional 29 papers. In the end, 11 articles specifically focused on O&M in Malaysian tertiary institutions were included in the final review. The entire process is illustrated using the PRISMA framework in Figure 1.

2.4 Data Analysis

Data extraction and analysis emulate the EPPI guideline. EPPI provides a comprehensive guideline featuring detailed sets of questions for coding during keywording and data extraction, which aid in mapping and synthesizing primary research. The guideline also assists in reporting primary research, facilitating the coding process for systematic reviews [13]. In this review, selected studies were entered into an Excel spreadsheet structured around the defined inclusion and exclusion criteria. The reviewed papers encompassed a range of research methodologies, including quantitative, qualitative, mixed-method and review approaches, with the majority presenting mixed quantitative and qualitative analyses of their results.

The diverse research methodologies utilized in the reviewed papers allow for the identification of current practices of building O&M in Malaysian tertiary institutions. The review methodology evaluates the effectiveness of O&M strategies through quantitative studies while providing detailed qualitative explanations that are valuable for both theoretical and practical insights. This dual approach formed the foundation for deriving conclusions and recommendations from the collected evidence.

Organizing the content into thematic categories based on predetermined criteria, classification and coding are crucial steps in this process. This ensures a structured synthesis of findings, making the analysis comprehensive and reflective of the diverse studies reviewed [14]. This method was applied in conjunction with the three research questions to systematically extract detailed information from each selected article. All data were compiled and analyzed using an Excel spreadsheet. The analysis provided a thorough description of the trends emerging from the reviewed studies, supporting the four research questions with relevant examples.

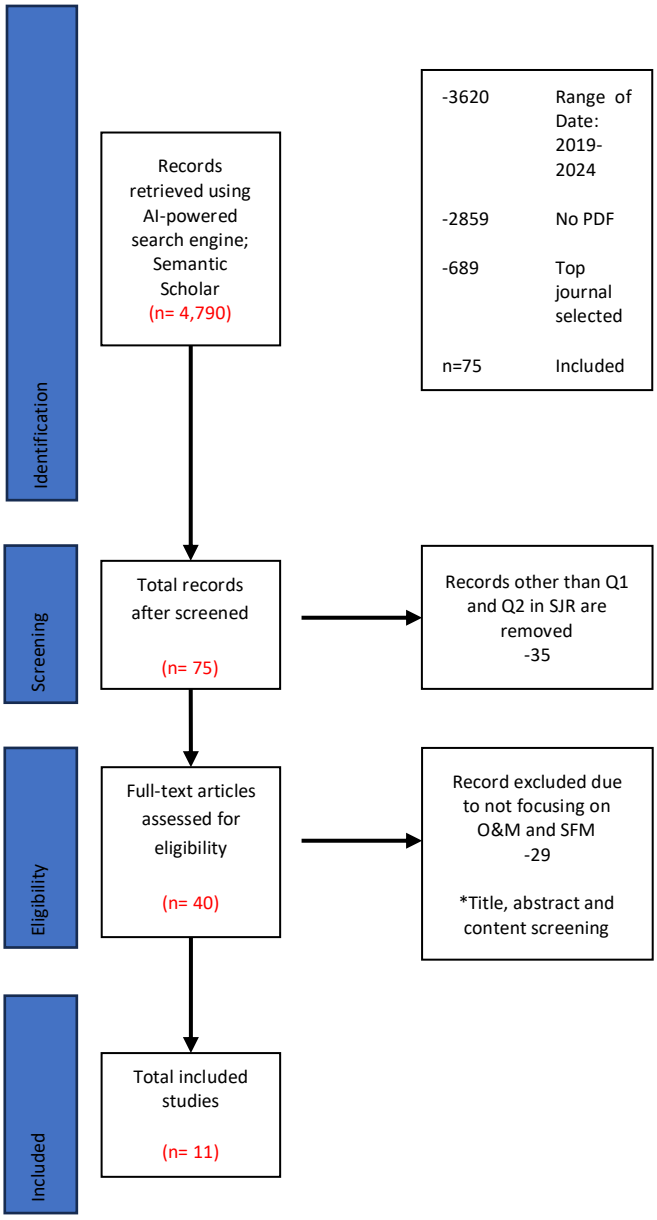

Fig. 1. PRISMA flow diagram [12]

3. Results

A systematic literature review (SLR) since 2019 to 2024 on Operation and Maintenance (O&M) in Malaysian tertiary institutions has identified a total of 10 empirical studies and 1 review articles. These studies served as the foundation for addressing research questions posed in this review. This chapter will be answering the RQ1 regarding the dominant research methodologies employed in the reviewed studies and the current practices of O&M identified by subject area. The Sustainability of O&M later will be recap as far as the current practices in Malaysian HEIs has discovered. While RQ2 and RQ3 will be analytically and synthesis discuss in Discussion chapter.

3.1 Dominant Methodologies in Reviewed Studies

Based on the research classification by Creswell *et al.,* [15] and Sandelowski *et al.,* [16], an analysis of the types of research methods used in these 11 reviewed studies is presented in Figure 2. The

dominant research methodology identified was mixed method, utilized in 5 studies. This method aims to clarify and interpret current practice of O&M in Malaysian tertiary institutions through analyzing quantitative and qualitative research within a single project to offer a comprehensive understanding of the research problem [17]. Following this, qualitative research design was employed in 3 studies which focuses on unstructured and non-numerical information to provide a deep understanding of the current practices of O&M. Quantitative method were identified in 2 studies which analysis the numerical data while systematic reviews found only in 1 study used explicit methods to identify and synthesize existing studies that address predefined research questions.

The subject areas identified in the 11 reviewed papers cover a range of subject areas essential for Operation and Maintenance towards Sustainability Facility Management. The sequence is as follows:

- Energy Efficiency : 3
- Building Maintenance : 3
- BIM : 2
- Green : 2
- Waste management : 1

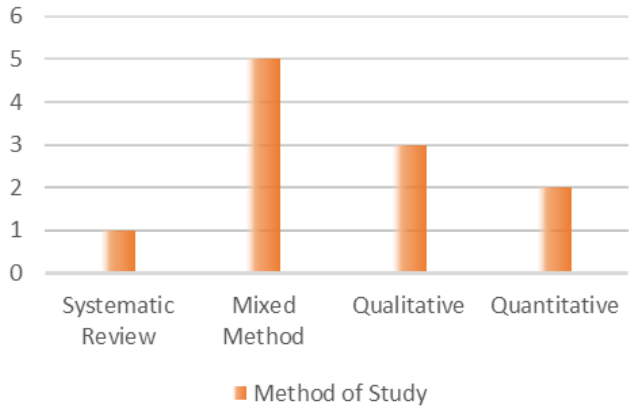

Fig. 2. Article Distribution Based on Methodology

3.2 Current Practices Identified by Subject Area

3.2.1 Energy efficiency

Energy efficiency in buildings, particularly in educational institutions, has become a significant focus due to the high energy consumption in this sector. Current practices include the implementation of:

i. Energy Conservation Measures (ECMs)
ii. Building Energy Performance

Several ECMs are being implemented to address this. Chiller optimization, including the use of chiller plant control systems and ice storage has shown significant potential with energy savings of up to 15.4% and 68.5% in tropical climates respectively. Lighting retrofits, particularly LED replacements have also proven effective, offering energy savings ranging from 9.4% to 50%. Additionally, Energy Management Systems (EnMS) based on ISO50001 standards, incorporating strategies like energy committees and awareness campaigns, yield around 5% annual energy savings [11].

Building Energy Intensity (BEI) is used to evaluate building energy performance, with the Malaysian Standard MS1525:2019 setting a benchmark of 200 kWh/m²/year for office buildings [6].

Energy labeling systems, like Malaysia's 1–5-star rating help gauge building efficiency, with 5-star buildings being the most energy-efficient. Regular energy audits also play a key role in identifying energy-saving opportunities, while sensor installations such as Passive Infrared (PIR) sensors in parking lots, further reduce unnecessary energy use. Additionally, maintaining air-conditioning temperatures between 24°C-26°C helps optimize energy consumption [6].

Finally, promoting energy awareness through campaigns, seminars, and incentives is critical to effective energy management in educational institutions [6]. These combined practices, involving technological upgrades, management systems, and behavioral changes, present a comprehensive approach to reducing energy consumption in buildings [1].

3.2.2 Building maintenance

Current building maintenance practices in educational institutions focus on optimizing limited budgets and improving student satisfaction through maintenance prioritization. Universities often prioritize utilities and floor components which have the greatest impact on student satisfaction [9]. Condition assessments are primarily conducted through visual inspections which assess for nearly 50% of all assessments through the help of consultants and in-house staff. Other methods include analyzing maintenance records, energy use, repair costs and occupant feedback [10].

While, decision making in building maintenance is largely based on past experience and expert opinions influencing about 45% of facility managers. Another 20% of managers rely on run-to-failure strategies and other 20% have adopted multi-criteria decision-making (MCDM) models for more systematic prioritization. Institutions are increasingly combining corrective and preventive maintenance strategies with a growing focus on aligning facility management with organizational objectives [10].

The main challenges in building maintenance include budget constraints, aging infrastructure and a shortage of qualified personnel particularly affecting the maintenance [9,10]. However, emerging trends emphasize sustainability in maintenance practices and the integration of technologies such as Building Information Modelling (BIM) to enhance efficiency. Additionally, there is an increased focus on assessing the impact of failure in maintenance decisions and incorporating resilience thinking which takes into account building characteristics, accessibility and environmental factors as well [7,10].

In conclusion, while traditional approaches dominate building maintenance, there is a shift toward more data-driven, systematic, and resilience-oriented methods in educational institutions.

3.2.3 BIM

Current practices of BIM in O&M primarily focus on information management, advanced technology integration, and maintenance optimization. BIM facilitates the creation of databases for crucial O&M information throughout a facility's lifecycle, enhancing data accessibility and supporting fault detection and decision-making processes. Advanced technologies such as augmented reality (AR), the Internet of Things (IoT) and cloud-based BIM are being integrated to improve collaboration, real-time data collection and interaction with building components [3,8]. BIM is also increasingly applied in maintenance and asset management whereby it helping to develop predictive maintenance frameworks, improve scheduling and optimize budgeting and cost estimation. Additionally, BIM aids in building performance assessments and infrastructure visualization as well as supporting disaster management efforts [8].

Despite these benefits, BIM adoption in O&M faces challenges including a lack of learning materials from academic institutions, unresolved copyright issues and interoperability difficulties with existing O&M systems. Quantifying the return on investment for BIM in O&M also remains a challenge [8]. BIM adoption in O&M is still emerging, with most research conducted in recent years, particularly in the UK, USA and China [3,8]. Institutional buildings have seen the most significant BIM applications, while other sectors such as residential and industrial, remain underexplored [3].

In conclusion, while BIM shows promise in O&M through improved information management and technological integration, challenges in standardization, interoperability and demonstrating tangible benefits continue to limit its widespread adoption.

3.2.4 Green

Universities are increasingly adopting green practices in O&M to promote sustainability and reduce environmental impact. Energy management initiatives include campaigns to lower CO2 emissions and encourage energy conservation through strategies such placing energy-saving reminders on light switches and establishing campus-wide energy efficiency programs [18]. Waste management is a popular green initiative, with universities implementing recycling programs, composting centers and the Reduce, Reuse, Recycle (3R) approach [2].

In terms of green infrastructure, universities are investing in planting and maintaining trees, creating green spaces and establishing composting infrastructure. Green transportation is also promoted through the use of bicycles even though infrastructure remains a challenge. Water conservation measures are part of campus sustainability efforts [18] and awareness campaigns, seminars, and sustainability talks aim to engage the university community although changing mindsets remains difficult [2].

Additionally, universities participate in sustainability rankings and awards to monitor and benchmark their green performance. While some have implemented environmental management systems to manage their environmental impacts systematically [2,18].

Despite these efforts, universities face challenges such as funding limitations, lack of awareness and resistance to change which making the implementation and maintenance of green O&M practices difficult. However, the green campus approach is viewed as a crucial strategy for universities aspiring to be sustainability leaders.

3.2.5 Waste Management

Malaysian university also has implemented various waste management practices in O&M with a focus on environmental protection, education, and community engagement. One key initiative is the establishment of an Environmental Protection and Education Hub (EPEHub) which promotes activities like recycling, repurposing and composting, while serving as a learning space for students and the public on sustainable practices. Additionally, Environmental Protection and Education Points (EPEPs) are strategically placed recycling corners on campus, where staff and students can segregate materials, such as paper, plastic and e-waste with Green Ambassadors monitoring their cleanliness and use [5].

The university also launched a laboratory plastic recycling program in 2019 aimed at decontaminating and recycling non-hazardous plastic waste from labs and succeed to collect approximately 50 kg of plastic by 2021. It turning waste management into a revenue-generating activity. Education and awareness efforts are another focal point, with seminars, webinars and micro-credential courses on waste reduction and recycling aimed at raising sustainability awareness among

the university community. Community engagement is encouraged through the recruitment of Green Ambassadors and the systematic management of recyclables, fostering participation and driving behavioral change towards sustainability [5].

These kinds of practices reflect the university's commitment to integrating sustainable waste management into its operations, prioritizing both practical solutions and educational outreach.

3.3 Sustainability in O&M

Sustainability in Operation and Maintenance (O&M) practices within Malaysian Higher Education Institutions (HEIs) has gained increasing importance due to the growing need for efficient resource management and environmental responsibility. Sustainable O&M practices focus on reducing energy consumption, minimizing waste and optimizing facility performance to align with environmental, social and economic sustainability goals. The integration of sustainability into O&M is driven by the global focus on environmental preservation, operational efficiency and the long-term viability of campus infrastructure [3,5]. HEIs are crucial in promoting sustainability by implementing green campus initiatives that enhance the quality of campus life while reducing their environmental footprint [2].

One of the key areas of sustainability in O&M is energy efficiency. Malaysian HEIs face high energy consumption, especially in large, multi-building campuses. Several institutions have adopted Energy Conservation Measures (ECMs), such as chiller optimization, LED lighting retrofits, and energy monitoring systems, to lower energy usage [1]. Some universities have also implemented Building Energy Intensity (BEI) benchmarks and energy labeling systems to track and improve energy performance. These efforts contribute to reducing electricity consumption, lowering carbon emissions and promoting a culture of responsible energy use within the campus community [1,11].

Another important aspect of sustainability in O&M is waste management. Many Malaysian HEIs are actively implementing waste reduction initiatives, such as recycling programs, composting centers, and the 3R approach [5]. Universities like Universiti Teknologi Malaysia (UTM) have established dedicated hubs, such as the Environmental Protection and Education Hub (EPEHub), to engage students and staff in sustainable waste management practices. These initiatives not only reduce the amount of waste generated on campus but also educate the university community about the importance of environmental protection and responsible waste handling [2].

The integration of technology like Building Information Modelling (BIM) into O&M also plays a pivotal role in advancing sustainability. BIM helps improve the management of building data throughout the lifecycle, optimizing energy consumption and maintenance scheduling [3]. Although BIM adoption is still emerging in Malaysian HEIs, its potential to enhance sustainability is significant, particularly in improving the efficiency of facility management processes and supporting long-term decision-making. The use of BIM for predictive maintenance and fault detection further contributes to the sustainability of campus operations by reducing resource wastage and minimizing downtime [4].

In conclusion, the focus on sustainability in O&M within Malaysian HEIs encompasses energy efficiency, waste management and technological integration. However, challenges such as insufficient financial resources, limited technical expertise and resistance to change continue to hinder the full implementation of sustainable O&M practices. To fully realize the potential of sustainability in O&M, Malaysian HEIs must overcome these barriers through collaborative efforts, investment in modern technologies, and a commitment to fostering a culture of environmental responsibility across campuses [2,18].

Table 2
List of selected articles reviewed in this study

No	Author	Title	Subject Area	Journal	Aim	Main Finding
1	Musarat *et al.,* 2023	Applications of Building Information Modelling in the Operation and Maintenance Phase of Construction Projects: A Framework for the Malaysian Construction Industry	Building Information Modelling	Journals Sustainability Volume 15 Issue 6 10.3390/su15065044	to evaluate the factors that influence the implementation of BIM technology during the operation and maintenance phase of a construction project	The lack of learning materials and equipment prepared by academic institutions is the most significant barrier to the implementation of BIM technology during the O&M phase of construction projects in Malaysia
2	Chan *et al.,* 2022	Integrating Environmental Protection and Sustainable Waste Practices Among the Communities in Higher Education Institutions: Case Study in a Malaysian University	Waste Management	Front. Environ. Sci., 17 May 2022 Sec. Environmental Economics and Management Volume 10 - 2022 https://doi.org/10.3389/fenvs.2022.886060	to explore how Malaysian University promoting environmental protection and sustainability, showcase practical initiatives and programs to implement a sustainability model and suggest concepts and practices for effectively implementing waste management	The successful implementation of various sustainability initiatives and programs at Malaysian university, including the establishment of sustainability-focused centers, councils, academic programs and a comprehensive sustainability model that has helped the university achieve high rankings in global sustainability rankings
3	Abideen *et al.,* 2022	A Systematic Review of the Extent to Which BIM Is Integrated into Operation and Maintenance	Building Information Modelling	Journals Sustainability Volume 14 Issue 14 10.3390/su14148692	to use a systematic approach to provide valuable insights regarding the current literature surrounding BIM in the O&M phase	The application of BIM within the O&M phase is still an emerging area of research, with the majority of studies focusing on information management (IM) functions, while other functions such as lean management (LM) are underrepresented
4	Shukri *et al.,* 2022	Benchmarking the Energy Efficiency of Higher Educational Buildings: A Case Study Approach	Energy Efficiency	International Journal of Energy Economics and Policy ISSN: 2146-4553 https://doi.org/10.32479/ijeep.11941	to develop an energy efficiency benchmark for university buildings using statistical analysis	The standard practical range for energy efficiency of buildings at the Universiti Tun Hussein Onn Malaysia (UTHM) campus is between 72.5-141.0 kWh/m2/yr.

5	Mohamad Munir *et al.,* 2023	A Rational Plan of Energy Performance Contracting in an Educational Building: A Case Study	Energy Efficiency	Journals Sustainability Volume 15 Issue 2 10.3390/su15021430	to develop an energy performance contracting (EPC) model for an educational building in Malaysia using regression analysis	The implementation of an EPC model developed using regression analysis can lead to significant energy and cost savings, as well as environmental benefits, for a commercial building like the University A case study. The EPC model with a 95%:5% ESCO:University A quantum sharing ratio was estimated to save 25.6% in energy use, reduce electricity consumption by 5,672,057 kWh/year, save RM 2,762,291.76/year, mitigate 3,771,061.22 kgCO2/year, and achieve a 4.2 year return on investment. The building's energy index (BEI) was also reduced by 74% to 93.55 kWh/m2/year, which is lower than the national standard
6	Au-Yong *et al.,* 2023	Prioritizing the Maintenance of University Hostels to Improve Students' Satisfaction	Building Maintenance	Journal of Construction in Developing Countries https://doi.org/10.21315/jcdc-10-21-0160	to develop a maintenance prioritization framework for university hostels by measuring the level of students satisfaction towards the conditions of building components	The building components that require the highest maintenance priority in university hostels are utilities (power, internet, water) and floor
7	Gholami *et al.,* 2020	An ISM Approach for the Barrier Analysis in Implementing Green Campus Operations: Towards Higher Education Sustainability	Green	Sustainability 2020, 12, 363 10.3390/su12010363	to identify and analyze the barriers in campus operations implementation within a university system	Lack of awareness, lack of knowledge, resistance to change and inefficient communication are the dominant barriers with high driving power and low dependence power in implementing green campus operations in higher education institutions.
8	Besiktepe *et al.,* 2020	Identification of the Criteria for Building Maintenance Decisions	Building Maintenance	Buildings 2020, 10, 166 10.3390/buildings10090166	to develop and rank a set of criteria needed for constructing a multi-criteria	The study identified and ranked a set of 11 criteria for building maintenance decision-making in

		in Facility Management: First Step to Developing a Multi-Criteria Decision-Making Approach			decision-making (MCDM) model for use in building maintenance processes in facility management	facility management, with the top 3 most important criteria being health and safety, code compliance and condition
9	Thanakodi *et al.,* 2024	A Case Study on Energy Efficiency of Lestari Building at UPNM	Energy Efficiency	Journal of Advanced Research in Applied Sciences and Engineering Technology Vol. 35 No. 2 https://doi.org/10.37934/araset.35.2.1121	to explore and present a case study of the energy consumption and its pattern at the Lestari Building in Universiti Pertahanan Nasional Malaysia (UPNM) over a two-year period	The Lestari building at Universiti Pertahanan Nasional Malaysia (UPNM) improved its energy efficiency rating from a 2-star to a 3-star rating between 2019 and 2020, which attribute to the impact of the COVID-19 pandemic and lockdowns leading to reduced energy consumption in the building
10	Talebloo & Alias, 2021	The Evaluation of Physical Dimension on the Design of Campus Buildings towards Resilience Initiative at the University of Malaya	Building Maintenance	Journal of Design and Built Environment Vol. 21 No. 2 (2021) https://doi.org/10.22452/jdbe.vol21no2.6	to create a practical framework for examining factors that specifically impact the physical characteristics of campus resilience, with the Universiti Malaya as a case study	Universiti Malaya campus has a moderate level of resilience based on an assessment of the physical dimension of campus resilience
11	Mahdee *et al.,* 2022	Green campus universities: case studies on problems and prospects	Green	F1000Research 2022, 11:1200 https://doi.org/10.12688/f1000research.73381.1	to examine the problems and prospects of creating a green campus university	Most universities in Malaysia have plans towards sustainability and the green campus approach and the awareness of going green and creating sustainability on university campuses has gradually increased over the years

4. Discussion

Current practices of Operations and Maintenance (O&M) in Malaysian higher education institutions reveals a gradual shift towards integrating sustainable and innovative approaches though traditional methods still dominate. Despite the contributions emerge from these practices, there are also challenges and barriers which hinder the implementation.

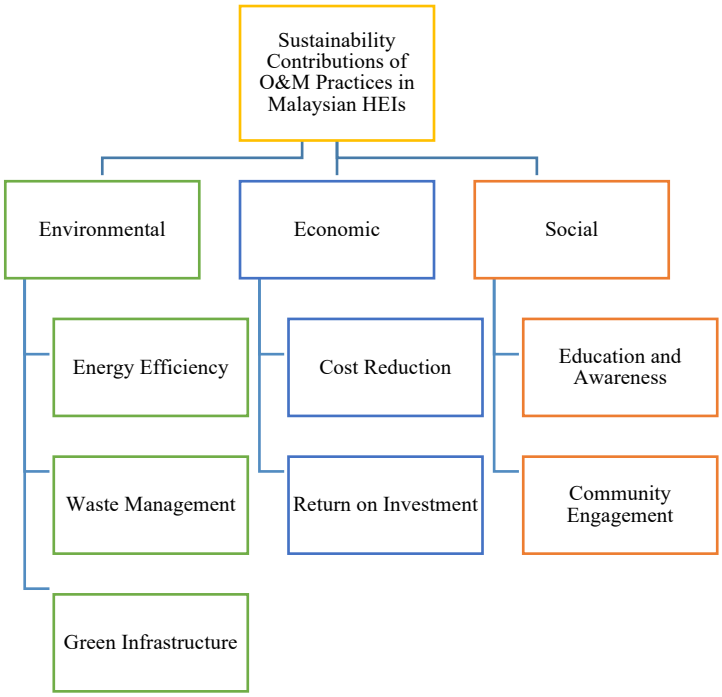

Fig. 3. Sustainability contributions of O&M practices in Malaysian HEIs

4.1 Contribution

Sustainability practices in Operation and Maintenance (O&M) within Malaysian higher education institutions (HEIs) contribute significantly across environmental, economic and social dimensions (Figure 3). These contributions reflect a comprehensive approach to building long-term sustainability and resilience in campus operations. By adopting a various sustainability strategy, Malaysian HEIs have taken key steps toward addressing global sustainability challenges while improving the quality of campus life [2,5].

4.1.1 Environmental sustainability

One of the main focuses of environmental sustainability in O&M is energy efficiency. Many Malaysian HEIs have implemented Energy Conservation Measures (ECMs) and energy performance contracting (EPC) to optimize their energy use. These measures include upgrading HVAC systems, installing LED lighting and employing smart building systems for real-time energy monitoring. By reducing energy consumption and lowering carbon emissions, these programs contribute to both environmental sustainability and financial savings [1].

While waste management has also become a critical part of sustainability efforts in Malaysian HEIs. Universities are establishing recycling programs, composting centers and promoting the

Reduce, Reuse and Recycle (3R) to minimize their environmental impact [5]. Initiatives like the Environmental Protection and Education Hub (EPEHub) at Universiti Teknologi Malaysia serve as educational centers where students and staff can learn about proper waste segregation and sustainable waste practices. These efforts play a crucial role in reducing campus waste and promoting a culture of environmental responsibility [2].

Green infrastructure is another vital component of environmental sustainability in O&M practices. Malaysian universities are increasingly investing in the development and maintenance of green spaces, such as tree planting and sustainable landscaping, to improve biodiversity and reduce the urban heat island effect [3]. These green spaces not only provide environmental benefits but also enhance the well-being of the campus community by offering aesthetically pleasing and ecologically friendly environments [11].

4.1.2 Economic sustainability

In the economic dimension, O&M practices focus on cost reduction through the optimization of resource use and facility management. Energy efficiency programs, such as the use of ECMs and EPC models, have resulted in significant reductions in utility costs [11]. By upgrading infrastructure and adopting smart building systems, universities can achieve long-term financial savings while also improving operational efficiency. This dual benefit underscores the importance of aligning economic sustainability with technological advancements in O&M [4].

While investing in sustainable O&M practices especially through technology integration such as Building Information Modelling (BIM), has demonstrated a positive return on investment for Malaysian HEIs. BIM allows for better facility management, predictive maintenance and energy monitoring, leading to reduced operational costs and extended building lifespans [3]. These cost savings contribute to the overall economic sustainability of universities and assisting in reinvest in further sustainability initiatives [4].

4.1.3 Social sustainability

Social sustainability in O&M practices is strongly tied to education and awareness-raising initiatives. Universities frequently organize campaigns, seminars and sustainability-themed events to promote responsible energy use, waste management and environmental awareness [5]. These efforts not only conveying information to students and staff about sustainable practices but also encourage them to take active roles in campus sustainability programs. Education and awareness are essential for creating a culture of sustainability within the university community [1].

Community engagement is another critical aspect of social sustainability. Malaysian HEIs collaborate with non-governmental organizations (NGOs), industry partners and local communities to implement sustainability projects, such as Wellness Campus initiatives and green campus networks [5]. These partnerships not only enhance campus sustainability efforts but also extend their impact beyond the university, fostering stronger ties with external stakeholders and promoting sustainable development in surrounding areas [18].

4.1.4 Towards O&M sustainability

A key factor contributing to both environmental and economic sustainability is the integration of advanced technologies like BIM in O&M practices. BIM offers improved information management, enhances building performance and supports predictive maintenance by allowing facility managers

to monitor energy consumption and maintenance needs in real time [3]. Despite its potential, the adoption of BIM remains uneven across Malaysian HEIs, with several institutions still facing barriers such as technical complexities and financial constraints [4].

Another important aspect of sustainability in O&M is campus resilience. The ability of universities to adapt to environmental and infrastructural risks is essential for long-term sustainability. Research by Talebloo *et al.,* [7] highlights the importance of developing resilient campus infrastructure by focusing on building characteristics, accessibility and sustainable design. These efforts ensure that HEIs can restrain the natural disasters and operational disruptions, maintaining functionality while minimizing environmental impact.

The long-term environmental impact of sustainable O&M practices in Malaysian HEIs is significant. By reducing energy consumption, minimizing waste and promoting green infrastructure, these institutions are lowering their carbon footprints and contributing to national and global sustainability goals [1]. These efforts align with the United Nations Sustainable Development Goals (SDGs), particularly SDG 11, which focuses on making cities and human settlements inclusive, safe, resilient and sustainable.

At the same time, the economic benefits of sustainable O&M practices extend beyond immediate cost savings. By optimizing resource use, HEIs can achieve greater financial stability and allocate resources toward further development and expansion of sustainability initiatives. This cyclical benefit not only improves operational efficiency but also ensures that sustainability remains a central component of university planning and policy [4].

Creating a sustainable campus culture is essential for ensuring the long-term success of O&M sustainability initiatives. Through education, community engagement and the promotion of sustainable behaviors, Malaysian HEIs are fostering a culture of responsibility and environmental awareness [5]. This cultural shift is crucial for embedding sustainability into the core values of universities, ensuring that future generations continue to prioritize sustainability in campus operations and beyond.

In conclusion, the sustainability practices in O&M within Malaysian HEIs contribute significantly to environmental, economic and social dimensions. The integration of technologies like BIM, the promotion of energy efficiency, waste management and green infrastructure, as well as the focus on education and community engagement, underscore the critical role that universities play in advancing sustainable development. By continuing to address the challenges and barriers to sustainability, Malaysian HEIs can strengthen their position in championing the sustainable O&M and contribute to broader national and global sustainability goals.

4.2 Barries and Challenges

The Operation and Maintenance (O&M) practices in Malaysian higher education institutions (HEIs) face various barriers that hinder their effective implementation. These barriers can be categorized into technical, organizational, financial and environmental dimensions, as illustrated in Figure 4. At the same time, challenges in energy management, legal and contractual issues and stakeholder engagement further complicate efforts to establish efficient O&M practices. Addressing these barriers and challenges is essential to fostering sustainability and efficiency within HEIs, although the obstacles remain significant.

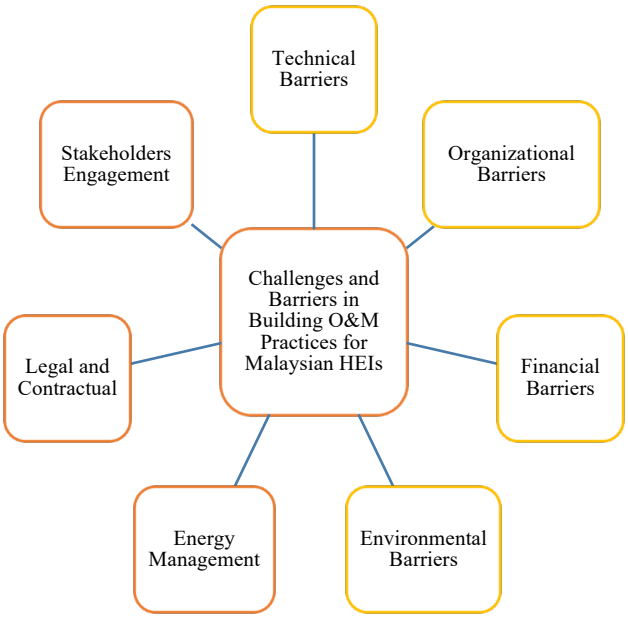

Fig. 4. Challenges and barriers in building O&M practices for Malaysian HEIs

Technical barriers primarily revolve around data management complexities and the adoption of advanced tools like Building Information Modelling (BIM). While BIM holds great potential to streamline O&M processes, its implementation remains challenging due to the intricacies of managing vast amounts of facility-specific data, including energy consumption and maintenance records. The absence of standardized systems for handling this data exacerbates the problem, making it difficult to ensure consistency across platforms. Moreover, the lack of interoperability between BIM and other facility management systems complicates data integration, creating further inefficiencies in managing building operations [3,4].

Organizational barriers are also significant in the study. Resistance to adopting new technologies, including BIM is prevalent in many HEIs. The traditional and rigid culture within HEIs blocked the transition to more sustainable practices. A lack of clarity in the management systems related to BIM, undefined Key Performance Indicators (KPIs) and benchmarks makes it difficult for universities to evaluate the effectiveness of BIM in O&M processes. Moreover, insufficient learning resources and equipment within academic institutions prevent future engineers and facility managers from acquiring the skills necessary for BIM applications [5]. This skills gap becomes a major barrier to the broader adoption of BIM technology in the Malaysian HEI sector.

Financial barriers are another major obstacle to advancing O&M practices in HEIs. The high initial cost of implementing BIM software together with the expenses associated on upgrading aging campus infrastructure, limits many institutions ability to embrace digital solutions for facility management. Moreover, budget constraints and cuts which are common in the education sector, restrict the available funding for ongoing maintenance activities and the adoption of advanced energy management systems. As a result, universities often find themselves prioritizing urgent and short-term needs at the expense of long-term, sustainable O&M practices [9]. The challenge of maintaining aging infrastructure, such as hostel facilities and utilities under a fixed budget adds another layer of complexity [10].

Environmental barriers also hinder the implementation of sustainable O&M practices in HEIs. One of the major issues is the lack of environmental literacy and awareness among the campus community. Many students, faculty and staff lack of understanding of proper waste segregation,

leading to the contamination of recycling bins and improper disposal of waste materials. Negative perceptions surrounding recycling such as the association of recycling bins with unpleasant odors further discourage sustainable practices [5]. Despite efforts to promote environmental awareness through campaigns and educational initiatives, cultivating sustainability within university communities remains a significant challenge. The evident can be clearly seen in both waste management and energy consumption practices across campuses.

Malaysia HEIs also facing challenges in energy management, legal and contractual and stakeholders' engagement. Energy management poses specific challenges, particularly due to the high energy consumption of university buildings. HEIs often struggle to optimize the energy usage of various building systems, such as heating, ventilation, air conditioning, lighting and electrical loads. The large number of occupants together with the diverse activities taking place in institutions, makes it difficult to manage energy efficiently. Many institutions lack of individual building electricity billing which reducing accountability and awareness of energy consumption [1,6]. External factors, such as unpredictable usage patterns further complicate a long-term energy efficiency planning. Additionally, the absence of robust energy performance contracting (EPC) models tailored specifically for tropical climates and educational institutions in Malaysia limits the availability of tested solutions for optimizing energy use [11].

While legal and contractual challenges arise in BIM and O&M practices. The issue of data ownership, particularly in the case of shared BIM models creates complications regarding intellectual property rights and data security. Cybersecurity concerns related to the reliability of BIM models are also significant especially when sensitive facility information is at risk of unauthorized access [8]. The legal frameworks surrounding data usage in BIM integrations are often unclear while institutions lack in contractual knowledge make it more difficult to overcome these challenges effectively.

In terms of legal challenges, Malaysian HEIs also face complications when establishing clear contracts for O&M activities. The legal ambiguities regarding the ownership and usage rights of facility data can delay or prevent the full implementation of BIM and other digital solutions. Additionally, the lack of expertise in drafting and managing contracts related to O&M practices increases the risk of miscommunication and legal disputes, which can hinder collaboration between universities and external service providers [3,4].

Finally, stakeholder engagement is often limited and hindering sustainable O&M practices. Collaboration between universities, local authorities and industry partners is essential for overcoming challenges related to sustainability and building management. However, a lack of support from external stakeholders such as local governments and utility providers can slow down the implementation of energy-saving measures and waste management initiatives. Additionally, the resistance to change within university communities and the limited financial resources available to keep up with rapidly evolving sustainability technologies create further obstacles [2].

The resistance to change within many HEIs poses a major barrier to successful stakeholder engagement. In many cases, faculty, staff and students are hesitant to adopt new O&M technologies and sustainable practices, which further delays the implementation of modern solutions like BIM and smart energy systems. This cultural resistance not only obstructs the adoption of best practices but also limits the ability of universities to involve stakeholders in collaborative efforts toward achieving sustainability goals [5].

Another significant challenge in stakeholder engagement is the difficulty of coordinating efforts between the various parties involved in campus O&M. Universities often struggle to align the interests of their internal stakeholders with those of external partners, such as local authorities, utility providers and industry experts. This lack of coordination can slow the pace of sustainability

initiatives, reducing the effectiveness of efforts to integrate modern O&M technologies and practices [7,18].

External support also crucial for the successful implementation of sustainable O&M practices. Local governments, industry partners and utility providers play essential roles in providing financial support, technical expertise, and resources for university O&M activities. However, the lack of consistent engagement from these external stakeholders has limited the success of many sustainability initiatives within Malaysian HEIs. The absence of financial incentives, grants and subsidies further complicates the implementation of cost-effective, sustainable O&M practices [2].

In conclusion, overcoming these barriers and challenges requires a various approach involving technical, organizational and financial reforms. Universities need to invest in advanced tools such as BIM while ensuring proper training and skill development among their facility management teams. Additionally, increased collaboration between academic institutions, industry experts and policymakers are necessary to drive sustainable practices forward. Securing sufficient financial resources, whether through government funding or private sector partnerships will also be crucial to the long-term success of O&M practices in Malaysian HEIs [3,18]. Through an integrated effort to address these barriers and challenges, universities can enhance their operational efficiency and contribute to broader environmental and sustainability goals.

4.3 Solution of O&M Barries and Challenges

To address the wide array of barriers and challenges in O&M practices within Malaysian Higher Education Institutions (HEIs), several solutions have been proposed across technical, organizational, financial, environmental and legal and contractual dimensions (Figure 5). These solutions aim to enhance the efficiency, sustainability and resilience of campus operations while promoting a culture of sustainability among the campus community.

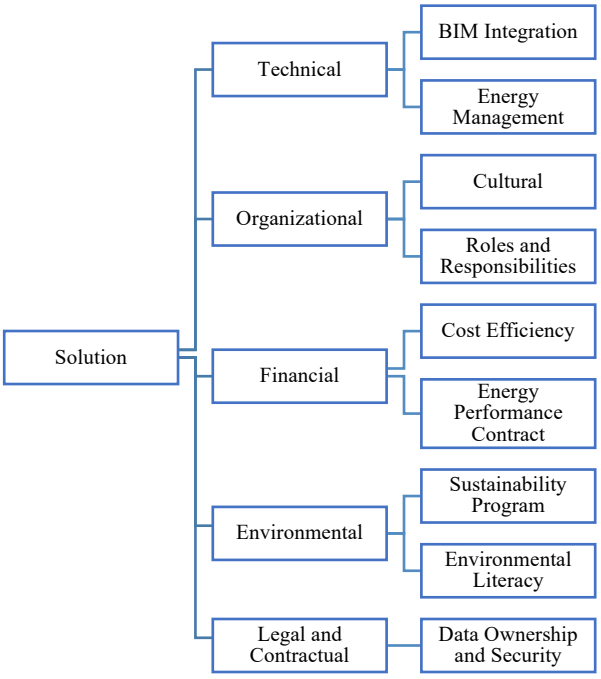

Fig. 5. Addressing challenges and barriers in building O&M practices for Malaysian HEIs

4.3.1 Solution for technical barriers

A major technical barrier in O&M practices involves the complexity of managing BIM data and the lack of integration between different software platforms. To overcome this, it is essential to develop a standardized BIM workflows for the O&M phase that ensure seamless integration between BIM and other facility management systems. This can be achieved by investing in interoperable software that allows data to flow seamlessly across different platforms, ensuring that facility managers can access and update building information efficiently [3]. Furthermore, universities can collaborate with BIM software providers to offer customized training programs that equip facility management teams with the necessary skills to handle complex BIM systems during the O&M phase [8]. These training initiatives are crucial, as they help mitigate the technical challenges that arise from the steep learning curve associated with advanced BIM tools.

In terms of energy management, a critical technical solution is the implementation of smart building systems that monitor and optimize energy usage in real-time. Building automation systems (BAS) can be employed to control air conditioning, lighting and plug loads which can helping universities reduce energy consumption during off-peak hours. Educational campaigns aimed at encouraging energy-efficient behavior among building occupants together with incentive programs for energy savings can also help addressing high energy consumption [1]. Universities should also conduct an energy audit to identify inefficiencies and implement upgrades that can reduce electricity costs [6]. By combining smart energy systems with behavioral incentives, HEIs can significantly improve their energy management practices.

4.3.2 Solution for organizational barriers

In organizational barrier, addressing the cultural barriers to adopting innovative O&M practices in Malaysian HEIs requires fostering a culture of innovation and openness. Many institutions face resistance to change, particularly when it comes to implementing advanced technologies such as Building Information Modelling (BIM). To overcome this, universities can establish a pilot projects or case studies that demonstrate the economic and operational benefits of BIM and other advanced O&M tools. For instance, showcasing successful BIM integration through small-scale projects can illustrate its effectiveness in improving efficiency and sustainability. These real-world examples can help persuade stakeholders of the long-term value of such technologies. Additionally, fostering a culture of continuous learning is essential. Offering workshops and seminars that focus on the importance of sustainability and digital technologies in facility management can help shift perceptions, making staff and faculty more open to change.

While to overcome the organizational resistance related to undefined roles and responsibilities in O&M practices, it is essential to establish clear and well-defined roles for all stakeholders involved in facility management. One effective solution is to develop Key Performance Indicators (KPIs) specifically for O&M operations, providing a concrete framework to measure the effectiveness of different teams and initiatives [5]. This ensures that everyone, from facility managers to maintenance staff, understands their roles in achieving sustainability goals. Assigning specific responsibilities for BIM implementation and facility management helps create accountability and ensures that the technology is used effectively. Moreover, regular communication between departments such as operations, maintenance, and IT facilitates better coordination and ensures that responsibilities are aligned with sustainability objectives. Universities should also create cross-functional teams that can handle O&M tasks collaboratively, enhancing the overall performance of facility management. Additionally, academic institutions should provide dedicated courses and workshops on BIM and

sustainable facility management (SFM) to prepare the next generation of engineers and facility managers with the necessary skills [1].

4.3.3 Solution for financial barriers

For addressing financial barriers related to cost efficiency in O&M practices within Malaysian HEIs requires strategic financial planning and resource allocation. One viable solution is the implementation of a phased approach to technology adoption, particularly in areas such as Building Information Modelling (BIM). By focusing on key areas that offer the highest return on investment, HEIs can manage costs effectively while gradually integrating advanced technologies into their O&M processes. For example, institutions can initially invest in BIM tools that address critical maintenance tasks, thereby providing immediate benefits and allowing for reinvestment of the savings into further technological enhancements [9]. Additionally, HEIs should actively seek public-private partnerships and external funding sources to support their sustainability initiatives [11]. By collaborating with industry stakeholders, universities can share the financial burden while accessing expertise and resources that can help improve cost efficiency in O&M operations.

Energy Performance Contracts (EPCs) also offer a compelling solution to the financial barriers faced by HEIs when it comes to improving energy efficiency in their facilities. Under an EPC, a university partners with an energy service company (ESCO) that assumes the financial risk associated with energy efficiency upgrades. The ESCO funds the initial investment for energy-saving measures and is paid back through the cost savings generated from reduced energy consumption over time [11]. This approach allows HEIs to undertake significant upgrades without upfront capital expenditure, thereby aligning financial resources more effectively with long-term sustainability goals. Moreover, universities can benefit from tailored EPC models that specifically cater to the unique needs of educational institutions in tropical climates, ensuring that the solutions implemented are both effective and relevant. By leveraging EPCs, HEIs can not only enhance their energy efficiency but also improve their overall financial health by reducing operating costs associated with energy consumption.

4.3.4 Solution for environmental barriers

In addressing environmental barriers, particularly the lack of waste management awareness, universities should implement a comprehensive environmental education campaign. These programs should encompass a wide range of initiatives that promote environmentally responsible practices among students, faculty and staff. One effective approach is to establish a dedicated Sustainability Office or committee within the university, tasked with overseeing sustainability initiatives and coordinating efforts across various departments. On-campus workshops, seminars and interactive exhibitions can be utilized on waste management, energy efficiency and resource conservation. By integrating sustainability into the university's strategic planning, HEIs can ensure that these initiatives are aligned with broader institutional goals. Green Ambassadors from volunteer students and staff can be appointed to monitor recycling stations and promote sustainability initiatives [5]. Furthermore, engaging the campus community in sustainability efforts through competitions, workshops and awareness campaigns can foster a culture of environmental stewardship. For example, initiatives like "Green Weeks" or "Sustainability Fairs" can encourage participation and provide a platform for sharing knowledge and resources. These programs can also include incentives for departments that demonstrate significant progress in sustainability efforts, thereby encouraging healthy competition and collaboration among various stakeholders [18].

Improving environmental literacy within the campus community is another critical solution to overcoming environmental barriers in HEIs. Institutions should prioritize the integration of environmental education into the curriculum across various disciplines, ensuring that all students receive a foundational understanding of sustainability concepts and practices [5]. This can be achieved by developing interdisciplinary courses that focus on sustainability challenges relevant to the local and global context. Additionally, universities can offer extracurricular activities, such as workshops, seminars, and sustainability clubs, to further engage students in discussions about environmental issues and solutions [2]. Collaborating with local environmental organizations to provide guest lectures and field trips also can enhance students' real-world understanding of sustainability challenges. Furthermore, establishing mentorship programs that connect students with faculty and industry experts in sustainability can foster deeper learning and encourage proactive involvement in environmental initiatives. By promoting environmental literacy, HEIs can cultivate a generation who are equipped to tackle sustainability challenges both within their institutions and in broader society.

4.3.5 Solution for legal and contractual

To address legal and contractual challenges related to data ownership such in BIM, it is critical to establish clear contractual agreements that define the rights and responsibilities of all parties involved. These agreements should explicitly outline data ownership, including intellectual property rights over BIM models and facility management data [4]. Universities need to collaborate with legal experts to develop standardized contracts that specify who owns the data generated through BIM and how it can be used by different stakeholders such as contractors, facility managers and external vendors. This clarity will prevent disputes over ownership and ensure that HEIs retain control over crucial facility data. Additionally, HEIs should adopt open data-sharing policies that promote transparency while respecting intellectual property rights. These policies can also facilitate collaboration between universities and external partners by creating clear terms under which data can be shared for research, facility improvements or other collaborative projects [8].

Cybersecurity measures also essential to address concerns over the security of BIM data and facility management systems. HEIs must implement robust security protocols, including encryption, multi-factor authentication (MFA) and regular security audits to protect sensitive data from unauthorized access or cyberattacks [4]. These measures ensure that only authorized personnel can access or modify BIM models, reducing the risk of data breaches. Furthermore, universities should work closely with IT security professionals to establish a BIM data governance framework that includes data access controls, security incident response plans and continuous monitoring of data systems [3]. Training staff on cybersecurity best practices and raising awareness about potential threats is another critical step in maintaining the integrity of BIM data. By integrating cybersecurity considerations into the early stages of BIM implementation, HEIs can better safeguard their facility data while complying with local and international regulations on data protection.

4.3.6 Stakeholders engagement

In addition, collaboration with stakeholders also is an essential matter for advancing sustainable O&M practices. Universities should engage with local authorities, industry partners and NGOs to secure support for sustainability initiatives such as energy-efficient building retrofits and waste management programs. Public-private partnerships can be particularly useful in obtaining funding for sustainability projects while knowledge-sharing networks between universities can facilitate the

exchange of best practices and successful case studies [2]. Furthermore, universities should work to increase transparency and communication within their communities to foster greater buy-in from students, staff and faculty members [7].

By addressing these barriers and challenges to effective O&M practices, Malaysian HEIs can significantly improve their sustainability and operational efficiency. The integration of BIM, the promotion of environmental awareness and the engagement of stakeholders are crucial steps in overcoming these challenges. Through continued innovation, investment in technology and a strong commitment to sustainability, HEIs can become a leading role in sustainable development in Malaysia.

4.4 Limitation of Study

This study is subject to several limitations. Primarily, the reliance on existing literature and secondary data restricts the depth of insights that could be obtained through primary data collection. Focusing solely on HEIs may limit the generalizability of findings to other educational contexts. Furthermore, the rapid evolution of technology and regulatory frameworks could impact the applicability of study results over time. Finally, inconsistencies in research methodologies across the selected studies hindered a comprehensive comparative analysis. To address these limitations, future research should incorporate diverse data sources, including primary data collection and adopt longitudinal research designs to capture the dynamic nature of the field.

5. Conclusions

In conclusion, the current practices of Operation and Maintenance (O&M) in Malaysian Higher Education Institutions (HEIs) reveal a strong commitment to sustainability but face several technical, financial and organizational barriers. Energy management, waste reduction and green campus initiatives have made significant progress contributing to environmental sustainability. However, issues such as outdated infrastructure, lack of skilled personnel, high implementation costs and limited awareness continue to hinder the full integration of modern technologies like Building Information Modelling (BIM). These barriers are further worsened by insufficient financial resources, inefficient communication and resistance to change within the institutions.

The study identifies critical gaps in the current O&M practices of Malaysian HEIs and proposes innovative pathways to address them. These include underutilization of BIM and other advanced technologies, despite their potential to enhance efficiency and sustainability. Key findings include the successful integration of Energy Performance Contracting (EPC) models tailored for educational institutions and the development of a sustainability framework that integrates technological, organizational and financial dimensions.

This study recommends that Malaysian HEIs to adopt phased technological implementation, leverage multi-stakeholder partnerships and establish clear legal frameworks to manage BIM data ownership. Fostering a campus-wide culture of sustainability through targeted education and incentivization is also crucial. These approaches address immediate challenges and position Malaysian HEIs as global benchmarks in sustainable O&M practices, aligning with the United Nations Sustainable Development Goals (SDG 11).

To further enhance O&M practices in Malaysian HEIs, it is recommended that universities implement the integration of current FM system with advanced technologies such as BIM. universities must invest in interoperable BIM software that allows seamless integration with other

FM systems. It is also recommended that customized training programs should be developed for FM teams to ensure that they are proficient in using BIM tools for their daily operations.

Malaysian HEIs also should have a standardized legal framework that define the rights and responsibilities of all parties involved such as in BIM project. HEIs should establish clear contractual agreements before implementing BIM systems, specifying ownership of data and outlining the protocols for data sharing and intellectual property rights. Furthermore, cybersecurity protocols should be integrated into the early stages of BIM adoption to protect sensitive facility data from unauthorized access or breaches. Continuous collaboration with legal experts and IT security professionals is essential to ensure that these measures are effective and compliant with both national and international data protection regulations.

University also should foster a culture of innovation and openness by highlighting the long-term benefits of advanced O&M tools like BIM and energy management systems. Roles and responsibilities for the implementation must be clearly defined with clear Key Performance Indicators (KPIs) to monitor performance. Opportunities such as public-private partnerships and government grants also should be explored by HEIs to support the adoption of advanced technologies and sustainable energy solutions. Energy Performance Contracts (EPC) are a highly recommended financing mechanism for energy efficiency projects. These contracts enable universities to finance building upgrades using savings from reduced energy consumption, thus providing a cost-effective solution to implement energy-efficient technologies.

It is also recommended that Malaysian HEIs implement the environmental education campaigns that encourage behavioral change in proper waste management, recycling and energy conservation. Establishing sustainability task forces can further promote awareness and accountability. Incentive programs that reward sustainable behavior, such as energy-saving competitions or waste management rewards, should be introduced to foster active participation in sustainability initiatives.

As a final, Malaysian HEIs can significantly improve the efficiency, sustainability and resilience of their O&M practices. Implementation of these recommendations will optimize campus operations and contribute to broader sustainability, innovation and resource efficiency goals. Future research should further explore the longitudinal impacts of these strategies to refine their implementation in dynamic educational contexts. In the long term, Malaysian HEIs can possibly be a benchmark for other educational institutions globally as well as contributing to Malaysia's sustainability agenda.

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