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Comparative Analysis of BIM Tools and Manual Practices in Enhancing Energy Efficiency for Achieving a Sustainable Campus

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ABSTRACT

Building Information Modeling (BIM) plays a pivotal role not only in construction but also in the continuous evaluation of building energy dynamics. BIM methods provide precise energy performance assessments and consumption evaluations. This study focuses on assessing Energy Use Intensity (EUI) using Autodesk Insight 360 for a case study building and comparing it with traditional manual practices for energy optimization. The UMS Library, which received an Energy Audit Conditional Grant under the RMK11 initiative by KeTTHA, previously relied on manual methods to reduce energy consumption. A detailed 3D model of the UMS Library was created using Autodesk Revit 2023 and analyzed with Autodesk Insight 360 to demonstrate the effectiveness of BIM strategies in enhancing the building envelope, retrofitting, and equipment efficiency. The utilization of BIM tools resulted in a significant reduction in EUI to 60.5 kWh/m²/year compared to the traditional manual methods, which measured 176.27 kWh/m²/year. This improvement significantly enhances energy efficiency per square meter annually. BIM tools prove to be crucial for swift and accurate energy performance assessments, offering superior outcomes compared to manual practices.

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1. Introduction

Building Information Modelling (BIM) is not a new concept in the built environment. It started gaining traction with the rise of visual representation techniques and the advancement of programming for sustainable environments. In the last decade, BIM has gained prominence in the construction industry due to its ability to enhance collaborative work environments. Despite the increasing adoption of BIM in the building sectors of the US and the UK, its adoption in Malaysia remains relatively low. This is largely due to the limited number of individuals with BIM qualifications who also have practical experience using BIM software and technology in the construction sector (Tanko & Mbugua, 2021). This scarcity is attributed to the small proportion of recent graduates with proficiency in and understanding of BIM. To address the growing demand for BIM knowledge, higher education institutions must prioritize BIM education. According to Kordi *et al*. (2020), there are currently no standards and a low level of practice for integrating BIM into higher education curricula.

BIM is recognized as a crucial tool for integrating and combining intelligent and informative models, all within a shared data environment. According to Pereira *et al*. (2021), it offers numerous benefits, including enhanced collaboration, accurate modelling, and a deeper understanding of the inherent design process. This paper explain that adoption of BIM strategies emphasis building envelops, using efficiency equipment in building design and suggest that this process should also include operation can enhance energy efficiency. Ali-Ashgar *et al*. (2022) outline that there are two (2) groups of management and technical aspect using BIM strategies or methods impact to sustainable campus by reducing energy. According to Gao *et al*. (2019), new and existing buildings should also receive energy performance assessments at the earliest stages of design, where the most effective and efficient methods for energy-efficient design can be incorporated into the building design process across all phases.

While previous research has primarily explored the use of BIM in architecture and construction projects outside campus settings, this study addresses the gap in understanding BIM's role in advancing energy sustainability specifically within campus environments. The BIM approach introduces a novel method for evaluating green building performance and developing sustainable campuses, offering a valuable opportunity to improve energy efficiency in educational institutions (Liu & Wang, 2022).

This paper investigates the accuracy of Energy Use Intensity (EUI) generated by BIM tool, specifically using Insight 360 in Autodesk Revit, through a case study of a campus library building, and compares it to the actual EUI obtained through manual practices. The results will help to identify the comparison of strategies to increase energy efficiency and thus help practitioners in the choice and application of energy assessment in both design and maintenance.

1.1 Building Information Modelling and Energy Analysis in Buildings

Since the introduction of the "Our Common Future" report and the concept of sustainability, many global institutions have started setting sustainability targets for their campuses (Eby & Rangarajan, 2023). This shift has led to a focus on performance-based building sustainability, particularly regarding energy use, encouraging collaboration among clients and professionals in the architecture, engineering, and construction sectors to achieve carbon efficiency in built environment. To support these initiatives, technology has been developed and adapted to ensure that energy savings and carbon dioxide emission reduction targets can be met through efficient building design.

With advancements in technology, BIM has emerged as a leading tool for monitoring and managing energy consumption issues. BIM provides a digital representation of a building's design, utilizing intelligent and intuitive components. According to Putri *et al*. (2024), Building Information Modeling (BIM) can effectively optimize the planning of construction projects, with the potential to enhance building sustainability. However, the construction sector has yet to fully capitalize on this capability, as noted by Omar and Dulaimi (2021). Even in this context, using BIM can lead to faster and more efficient processes, improved management of lifecycle costs and energy data, and integrated planning and implementation . These benefits can contribute to a more competitive industry with sustainable long-term growth and greater client satisfaction.

Boloorchi (2022) proposes using Energy Analysis BIM Autodesk, also known as Insight 360, as a tool for evaluating energy performance by measuring and predicting energy use in both existing buildings and operational buildings. For the sector to benefit from reliable and usable results, this method of energy assessment needs to be as precise as possible. Consequently, this BIM-based energy performance evaluation can serve as a more efficient and accurate alternative to manual calculations and traditional assessment methods.

1.2 BIM Strategies of Technical Elements in Enhancing Energy Efficiency

Retrofitting plays a crucial role in enhancing the energy efficiency of existing buildings. Given that most physical features of a building are permanent, improving energy efficiency is complex. BIM technologies have been utilized to assess the energy performance of existing structures. Through simulation, it is possible to compare current performance with projected performance after proposed renovations and identify the most suitable renovation options (Sadeghifam *et al*., 2016).

The building envelope is the most commonly analyzed factor in building information modeling (BIM) technologies, as it significantly impacts the building's energy efficiency (Veronika *et al*., 2024). Buildings that qualify as near-zero energy buildings (NZEB) have a high level of energy efficiency, as evidenced by their low thermal coefficients and highly efficient equipment (Shari *et al*., 2023; Attia *et al*., 2022). BIM technologies can help designers to construct more sustainable structures, even in the early design stages, by expediting the estimation of energy requirements and the optimization of materials through comparison.

Implementing BIM strategies to enhance energy efficiency requires precise integration of technical elements, such as efficient equipment selection, optimized HVAC systems, and efficient data management. Skilled IT professionals play a key role in supporting BIM tools by managing hardware selection, software installation, and addressing interoperability issues, which are common due to the variety of BIM software used in projects. The expertise level in setting up and maintaining BIM tools can serve as a benchmark for an organization's ability to leverage BIM for energy efficiency (Ali-Ashgar *et al*., 2023). Within mechanical systems, BIM strategies facilitate effective coordination across project teams, particularly for HVAC optimization, which is essential for achieving thermal comfort with minimal energy use. Standardization of components, data models, and processes is crucial to reducing energy consumption, as it allows consistent application of energy-efficient practices throughout the building's lifecycle. Therefore, standardized BIM rules and protocols are necessary to ensure the successful implementation of energy-focused strategies across all technical elements (Okereke *et al*., 2021).

2. Methodology

For this study, the UMS Library was selected as a case study. The Universiti Malaysia Sabah (UMS) library was chosen as a focal case study due to its role as a high-occupancy institutional building on campus, serving as a representative example of educational structures where energy efficiency is of paramount importance. Its extensive usage patterns and prior dependence on manual energy audits, as demonstrated through initiatives under the Energy Audit Conditional Grant (EACG), highlight its suitability for comparison with BIM-based energy analysis. By focusing on this large-scale, complex structure, the study aims to investigate BIM's potential to streamline energy assessments, reduce inefficiencies, and enhance energy management within educational facilities facing similar energy optimization challenges.

2.1 Framework for Comparative Analysis

Ali-Ashgar *et al*. (2022) primarily established a framework that focuses on technical and management elements in Building Information Modelling (BIM) impacting energy efficiency and sustainable campus initiatives. This study further validates Ali-Ashgar's conceptual model by applying a case study to compare the effectiveness of BIM tools with traditional practices in terms of Energy Use Intensity (EUI). By assessing metrics across both BIM and manual methods, this evaluation strengthens the framework, offering actionable insights for sustainable campus planning through energy efficiency advancement

2.2 Development of 3D Model

A detailed 3D model of the UMS Library was created using Autodesk Revit 2023 (see Figure 1). The 3D model of the UMS Library was developed in Autodesk Revit 2023, focusing on accurately capturing the physical and functional aspects of the building. Key architectural and structural component including walls, windows, floors, and the roofing system were modelled to reflect their actual dimensions, materials, and thermal properties.

In this process, building-specific details were inputted, including material properties for insulation, glazing types, and specifications for thermal zones. Revit's user interface allowed for a clear layout of the building's spatial structure, ensuring an accurate representation of areas such as ventilation zones and lighting systems. Each zone was defined to match real-world usage patterns, which would later support an accurate foundation for energy analysis. The building envelope's components, such as wall thickness and thermal resistance, were carefully specified to reflect their energy impact.

2.3 Energy Model Development and Simulation in Autodesk Insight 360

After completing the 3D model in Revit, the model was transferred seamlessly to Autodesk Insight 360 for energy analysis. An energy model was subsequently developed (Figure 2), and the Energy Use Intensity (EUI) was analyzed using Autodesk Insight 360. Integrated with Revit, Insight 360 was chosen for its seamless energy analysis capabilities, enabling an efficient process from model creation to simulation without data transfer issues. This cloud-based tool provides reliable, real-time analysis of multiple design variables, making it particularly suitable for energy-intensive educational buildings such as the UMS Library. Compared to other BIM tools, Insight 360 offers advanced capabilities in simulating tropical climate-specific energy factors, which is crucial for the study's focus on campus energy sustainability.

Within Insight 360, the energy modeling process began by entering operational data, such as occupancy schedules, internal heat gains from equipment and lighting, and ventilation requirements. These inputs were necessary to reflect the real usage patterns of a high-occupancy building like the UMS Library. Climate data specific to the building's location was also incorporated, allowing the simulation to account for typical environmental conditions that influence energy use.

To optimize the energy simulation, various parameters impacting Energy Use Intensity (EUI) were adjusted using Insight 360's optimization tab, allowing for iterative modifications to different approaches and variables. The study applied seven targeted energy optimization strategies: (1) air conditioning type, (2) lighting efficiency, (3) plug load management, (4) roof insulation, (5) wall insulation, (6) installation of daylighting and occupancy controls, and (7) an integrated approach combining selected variables. Each strategy was simulated both individually and in combination to assess its impact on the EUI of the UMS Library. This process allowed for the adjustment of various strategies in each iteration to determine the configurations that led to the lowest energy consumption (EUI) for the library.

The baseline EUI was initially measured at 167 kWh/m²/year, exceeding the Malaysian standard MS1525:2007 limit of 135 kWh/m²/year. By testing each approach separately and in combination, the study identified configurations that significantly reduced the EUI, aligning the library's energy performance with national standards. Figure 3 illustrates the initial EUI measurement of 167 kWh/m²/year, which surpassed the maximum recommended level under Malaysian guidelines (Munir *et al.*, 2023)

Figure 1. 3D modelling for library, UMS

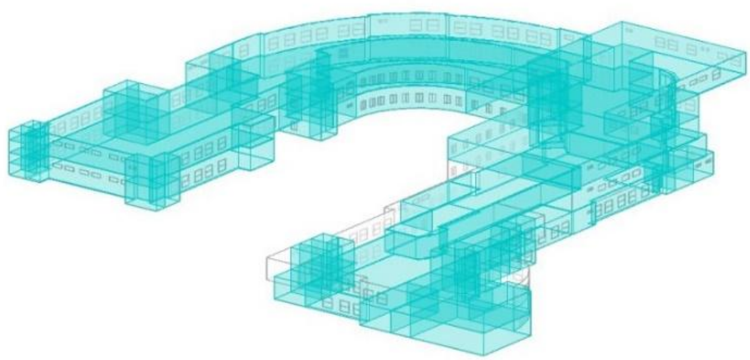

Figure 2. Building energy model for library, UMS

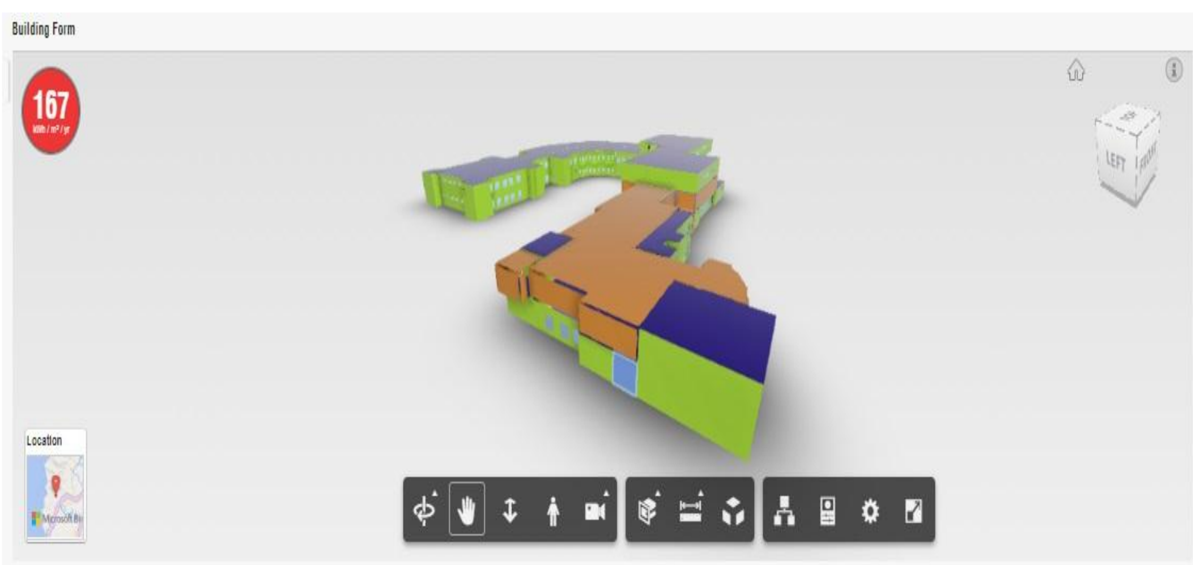

Figure 3. EUI value for the UMS library building before optimization

3.0 Result and Analysis

Figure 4 depicts the Energy Use Intensity (EUI) value for the UMS Library after applying the combined optimization approach using BIM tools. This approach integrates all selected energy-saving measures, the optimized EUI of 60.5 kWh/m²/year achieved through this comprehensive strategy marks a significant reduction from the baseline EUI of 167 kWh/m²/year, demonstrating a 63.8% improvement.

This figure highlights that Approach 7, which combines multiple strategies, is the most effective in optimizing energy performance. It underscores the advantage of using BIM tools to evaluate combined measures, enabling a holistic energy-saving strategy that aligns with sustainable campus goals and exceeds Malaysian energy standards. These findings demonstrate the potential of a comprehensive BIM-based approach to deliver substantial energy savings in educational facilities.

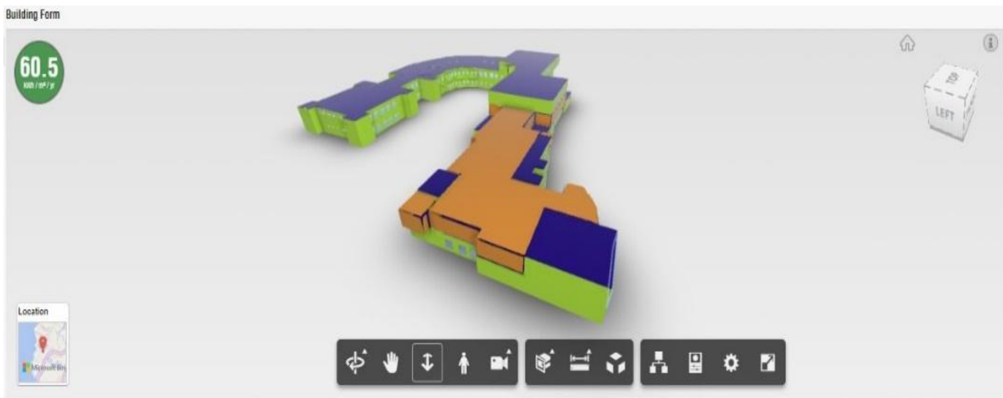

Figure 4. 7th Approach: Combination of all approaches is the EUI value after optimization by BIM tools

Table 1 presents the EUI outcomes generated by BIM tools in Autodesk Insight 360, displaying the results for each energy-saving approach applied. The table includes data on each strategy, showing the adjusted EUI values and the percentage of energy savings achieved. The approaches range from specific interventions, such as installing high-efficiency lighting and optimizing plug loads, to comprehensive strategies that combine multiple measures. The 7th approach, which integrates all variables, demonstrates the highest energy efficiency with an EUI reduction to 60.5 kWh/m²/year, reflecting a significant 63.8% improvement from the baseline. This table underscores the effectiveness of BIM tools in identifying and implementing comprehensive, data-driven energy solutions for substantial performance improvements in educational facilities.

Table 1. The Results Obtained using BIM tools in Autodesk Insight 360

No.	Approaches	Variable/Alternatives	EUI kWh/m²/yr	Energy saving kWh/m²/yr	% Energy Efficiency Contribution
-	Base line (Before Optimization)	Base line	167		0.00%
1-	HVAC	High Eff. VAV	144	23	13.8%
2-	Lighting Efficiency	3.23 W/m²	121	46	27.5%
3-	Plug Load	6.46 W/m²	140	27	16.2%
4-	Roof Construction	R60	156	11	6.6%
5-	Wall Construction	R2 CMU	134	33	19.8%
6-	Daylight And Occupant Control	Install Daylight and Occupant Controls	159	8	4.8%
7-	All variables (Best Approach After Optimization)	High Eff. VAV + 3.23 W/m2+6.46 W/m²+ Install Daylight and Occupant Controls + R20 roof + R2 CMU	60.5	106.5	63.8%

3.1 EUI Results by BIM Tools

3.1.1 Approach 1: HVAC - High-Efficiency Variable Air Volume (VAV) System

To optimize HVAC operations within the library, choosing a high-efficiency Variable Air Volume (VAV) system is suggested. This system would adjust airflow based on real-time occupancy levels and thermal demands, ensuring that only the necessary amount of conditioned air is delivered when and where it is needed. By modulating fan speeds during low-demand periods, the VAV system reduces energy use, especially in fan operation, thereby cutting down on unnecessary consumption. In simulated results, this approach led to a decrease in Energy Use Intensity (EUI) from 167 to 144 kWh/m²/year, yielding an energy savings of 23 kWh/m²/year or a 13.8% improvement in overall energy efficiency.

3.1.2 Approach 2: Lighting Efficiency - LED System with Power Density of 3.23 W/m²

Choosing to retrofit the existing lighting to LED technology, with a target power density of 3.23 W/m², would significantly enhance lighting efficiency throughout the library. LEDs are more energy-efficient than traditional lighting, such as T8 fluorescent lamps, and offer longer lifespans, reducing both operational and maintenance costs over time. The simulation results showed a reduction in EUI to 121 kWh/m²/year, with energy savings of 46 kWh/m²/year. This measure produced a 27.5% improvement in energy efficiency, representing the highest individual impact among the evaluated measures.

3.1.3 Approach 3: Plug Load - Plug Load with Power Density of 6.46 W/m²

To reduce the energy usage associated with plug loads, choosing a plug load optimization strategy focused on minimizing the power density of office equipment, computers, and other plug-in devices is suggested. By incorporating energy-efficient devices and promoting energy-saving habits among staff, plug load power density was reduced to 6.46 W/m². Simulation results showed that this measure decreased the EUI to 140 kWh/m²/year, yielding an energy savings of 27 kWh/m²/year, or a 16.2% increase in efficiency.

3.1.4 Approach 4: Roof Construction - 60 Insulation (Rated R-60 High Thermal Insulation Roofing System)

For the building envelope, choosing R60 roof construction is suggested due to its high capacity to minimize heat transfer. This insulation would help maintain stable indoor temperatures, reducing the building's cooling load and enhancing energy efficiency. According to simulation results, implementing R60 roof construction lowered the EUI to 156 kWh/m²/year, achieving energy savings of 11 kWh/m²/year, or a 6.6% improvement in efficiency.

3.1.5 Approach 5: Wall Construction - R2 CMU(R2 Concrete Masonry Unit Wall)

Choosing R2 CMU walls is suggested due to their excellent thermal mass properties, which are particularly beneficial in tropical climates. These walls absorb and gradually release heat, reducing peak cooling loads and contributing to better overall thermal efficiency. Simulation results indicated that the R2 CMU wall implementation reduced the EUI to 134 kWh/m²/year, realizing energy savings of 33 kWh/m²/year, or a 19.8% improvement in energy performance.

3.1.6 Approach 6: Daylighting and Occupant Controls - Advanced Daylighting and Occupancy Sensor Control System

Choosing advanced daylighting and occupancy control systems is suggested to reduce reliance on artificial lighting by ensuring that lights are only activated when necessary. This system maximizes the use of natural daylight, minimizing unnecessary lighting operation and further decreasing energy consumption. Simulation data showed that this measure led to an EUI reduction to 159 kWh/m²/year, with energy savings of 8 kWh/m²/year, corresponding to a 4.8% improvement.

3.1.7 Approach 7: Combination of All Approaches

Using Autodesk Insight 360, this study achieved a significant EUI reduction from 167 kWh/m²/year (Figure 3) to 60.5 kWh/m²/year (Figure 4), demonstrating the effectiveness of BIM strategies. This 65.7% improvement, as shown in Table 1, exceeds the typical reductions reported in other studies.

Notably, studies such as Yusuf *et al*. (2023) and Maglad *et al*. (2022) also illustrate the potential of BIM in energy optimization, but their reported EUI reductions (averaging 30-35%) fall short of the improvements observed in this research. This discrepancy may be attributed to our comprehensive integration of multiple strategies (Approach 7) and the specific use of tools like Autodesk Insight 360, tailored for tropical climates.

3.2 EUI Results by Manual Practices

Table 2 illustrates the Energy Use Intensity (EUI) results for the UMS Library obtained through manual practices, with data provided for each month of 2016. The EUI values, expressed in kWh/m²/year (kilowatt hours per square meter annually), vary monthly, reflecting the building's energy consumption patterns. These results are sourced from the Sustainable Energy Development Authority Malaysia (SEDA) and are documented in the UMS Energy Audit Conditional Grant Report (2015 - 2017).

Universiti Malaysia Sabah (UMS) was selected by the Sustainable Energy Development Authority (SEDA) as one of the sites to implement the Energy Audit Conditional Grant (EACG) under the RMK11 project by the Ministry of Energy, Green

Technology, and Water (KeTTHa). Throughout this project, UMS implemented initiatives to reduce electricity consumption in three case study buildings, with the library being one of them. This project spanned from January 2015 to October 2017.

Table 2. Energy Use Intensity (EUI) results by manual practices for UMS library

Month	EUI ($kWh/m^2/yr^2$)
January	15.28
February	12.90
March	16.83
April	15.97
May	15.79
June	14.21
July	11.68
August	13.29
September	9.24
October	20.64
November	15.79
December	14.64
Total EUI in year (2016)	**176.27**

Source: Report on the Conditional Grant for Energy Audit at UMS (SEDA, 2019)

3.3 Manual Practices of Energy Reduction for UMS Library

In the UMS library, an estimated 5.52% of the overall energy cost is attributed to the use of T8 fluorescent tubes (36 W) (SEDA, 2019). This cost can be reduced by upgrading the current T8 fluorescent tubes to LEDs (16 W), which have a longer lifespan, thereby decreasing maintenance costs associated with lighting systems (Liu *et al.*, 2023).

The Chiller Management System has been implemented to optimize energy use in the library's cooling systems. This automated system efficiently controls and sequences the operation of individual chillers based on the temperature difference between the inlet and outlet of chilled water at a common header. It allows users to monitor and set schedules for better control, achieving energy savings by switching off one chiller and its ancillary equipment for four hours (6:00 pm - 10:00 pm) on weekdays when cooling demand decreases. During peak times, AHU motors typically run at a frequency of 48 Hz to handle the area's cooling load. As ambient temperatures drop in the evening (6:00 pm - 10:00 pm), the AHU motor can ramp down to as low as 28 Hz with VSD installation, reducing cooling supply capacity and further saving energy.

A voltage regulator has also been installed to adjust the incoming power supply to the optimal level required by the library's electrical equipment, reducing energy consumption and improving efficiency. Typically, energy from the grid is provided at elevated voltages due to older electrical distribution networks and regulatory requirements. Receiving voltage higher than necessary can lead to energy wastage, increased carbon emissions, and premature equipment wear (Nagarajan & Senthilkumar, 2021). Voltage optimization in the library not only reduces energy usage, carbon footprint, and electricity costs but also improves power quality by balancing phase voltages and filtering out harmonics and transients from the network supply.

Voltage optimization technology is installed in series between the distribution transformer and the main low-voltage distribution board in the library, ensuring a stable and efficient power supply for all electrical equipment. For larger facilities like UMS, voltage optimizers have been installed on the high-voltage side to manage power supply issues at the source (Murray *et al.*, 2021). This approach includes the replacement of older HV transformers with super-low-loss amorphous core transformers integrated with voltage optimization technology, further contributing to energy savings and improved power quality. Another energy-saving initiative in the library involves enhancing chiller plant efficiency through retrofitting. The current chiller plant COP in the library is measured at approximately 1.37 kW/RT, with an achievable target of 0.85 kW/RT or lower, significantly improving cooling efficiency and reducing energy costs.

3.4 Comparative Analysis of EUI Results Between BIM Strategies and Manual Practices

Figure 5 presents the Energy Use Intensity (EUI) results for the UMS Library, highlighting significant differences between the outcomes achieved through Building Information Modelling (BIM) tools and manual practices. The analysis shows that the EUI obtained using BIM tools is considerably lower, at 60.5 kWh/m²/year, compared to 176.27 kWh/m²/year from manual practices.

This discrepancy underscores the advantages of BIM tools, which enable a more detailed and accurate assessment of the library's energy performance. Through precise digital modeling and simulation, BIM tools facilitate a comprehensive analysis of key parameters such as building geometry, materials, HVAC systems, and occupant behavior. This level of granularity provides deeper insights into energy consumption patterns and helps identify effective optimization strategies.

3.4.1 Key Factors in the Disparities Between BIM and Manual Practices

The comparative analysis of EUI results for the UMS Library highlights several key factors contributing to the significant disparities between BIM tools and manual practices. These factors reflect the inherent strengths of BIM in delivering accurate, detailed, and dynamic energy performance evaluations.

- Data Accuracy

In the UMS Library case study, manual data collection was prone to errors, such as inconsistent meter readings and inaccuracies in recording monthly energy consumption. Conversely, BIM tools automated much of the data entry, minimizing the risk of such errors and ensuring more reliable EUI values.

- Detailed Modelling

BIM tools provided a highly detailed digital model of the UMS Library, capturing intricate aspects of its geometry, materials, and systems. This level of precision enabled a more accurate assessment of energy usage compared to the simplified representations often used in manual calculations.

- Comprehensive Analysis

The UMS Library's energy performance involved complex interactions between its building components, such as the HVAC system and building envelope. BIM tools accounted for these interdependencies, while manual practices tended to isolate factors, potentially overlooking critical contributors to overall energy consumption.

- Dynamic Simulation

Using BIM, dynamic simulations were conducted to analyze the UMS Library's energy performance under various operational scenarios and environmental conditions. Manual strategies, relying on static calculations, failed to capture the building's real-time energy behavior, leading to less accurate projections.

- Optimization of Design

BIM tools facilitated optimization by testing various design variables, including window orientation, material selection, and HVAC systems, to enhance the UMS Library's energy efficiency. For this case study, Autodesk Insight 360 was used to simulate and evaluate energy-saving measures across multiple design scenarios. Specific optimizations included adjusting the building's roof and wall types, improving lighting efficiency with LED systems, and implementing daylighting and occupancy controls. These interventions significantly reduced the EUI of the library, demonstrating the potential for tailored design refinements. Unlike manual practices, which often focus on static solutions, BIM allowed for iterative testing and optimization, ensuring that the most energy-efficient combination of design elements was achieved.

- Systematic Analysis

BIM enabled a systematic approach to evaluating energy-saving measures for the UMS Library, integrating data from various systems into a unified analysis. Manual practices, by contrast, lacked the framework to assess all potential strategies holistically, increasing the risk of oversight.

- Lifecycle Considerations

BIM tools allowed lifecycle analysis for the UMS Library, projecting energy use and cost implications over the building's lifespan. This analysis supported long-term energy efficiency planning, an aspect often neglected in manual assessments, which typically focus only on immediate energy consumption**.**

3.5 Integration of Sustainable Energy Efficiency Strategies to Achieve a Sustainable Campus

It is recommended that campus facilities consider integrating Building Information Modelling (BIM) tools with traditional manual practices to enhance energy efficiency. This combined approach leverages the strengths of advanced digital simulations with practical, hands-on implementation measures. BIM tools, such as Autodesk Revit and Insight 360, enable precise energy performance assessments by simulating a variety of design scenarios, helping to predict the impact of each strategy on energy use. When paired with manual practices, like retrofitting T8 fluorescent lights with LEDs or implementing voltage regulators, this integration yields immediate energy-saving benefits while allowing for a data-driven approach to optimization.

Beyond individual upgrades, BIM tools facilitate a comprehensive analysis of a building's energy systems, from thermal modeling to HVAC simulations, enabling accurate forecasting of energy savings and system efficiency improvements (Abdul Jalil *et al*., 2024). Unlike manual practices, which typically focus on straightforward hardware-based retrofits like voltage regulation or chiller plant upgrades, BIM tools allow for a deeper exploration of system-wide energy improvements. This capability is essential for evaluating critical components, such as thermal energy performance and envelope design, which are often overlooked in manual retrofits.

Manual practices address specific energy inefficiencies, but they generally lack the insights needed for optimizing the building envelope, an essential element in minimizing energy consumption. BIM tools fill this gap by providing data on the thermal performance of walls, roofs, and glazing, enabling targeted adjustments to reduce heat transfer and increase insulation efficiency. This approach fosters informed decisions regarding materials and design enhancements, ultimately driving down energy usage.

While the UMS Library has not yet adopted this integrated approach, the potential benefits are significant. For instance, BIM-supported simulations could inform the optimization of mechanical systems like the Chiller Management System, reducing energy waste and improving operational efficiency. Similarly, HVAC system performance could be enhanced through BIM-driven adjustments to setpoints and operational parameters, complementing manual upgrades like the installation of variable-speed drives. Adopting this integrated strategy at the UMS Library could establish it as a model for energy-efficient practices in institutional settings. By combining BIM's analytical power with the practical impact of manual interventions, campus facilities could move closer to achieving comprehensive sustainability goals.

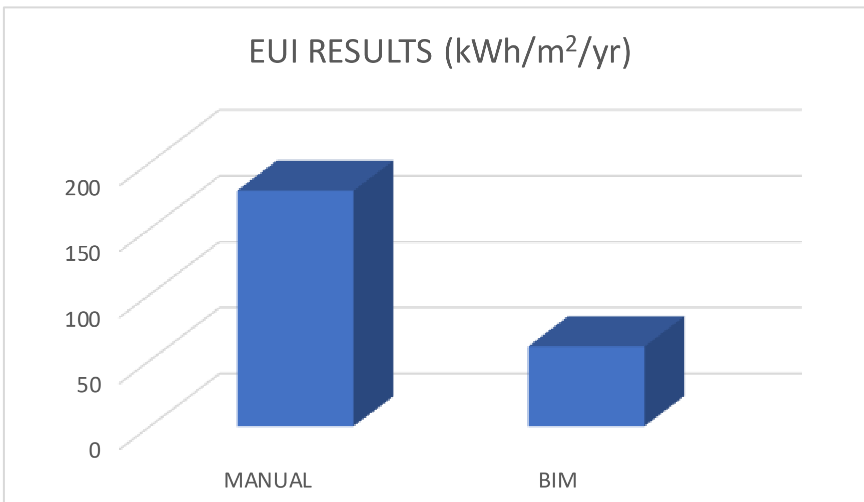

Figure 5. Comparison of EUI results between BIM and manual practices

3.6 *Enhancing Energy Management Policies and BIM Training Program*

The findings of this study provide valuable insights into optimizing energy efficiency in campus buildings, with significant implications for energy management policies in educational institutions. Building on the work of Truong *et al*. (2023), this research showcases the measurable benefits of employing Building Information Modeling (BIM) and Building Energy Model (BEM). It highlights the pivotal role these technologies play in transforming the design and operational practices of campus facilities. By achieving notable reductions in Energy Use Intensity (EUI) and substantial cost savings, the study lays a strong foundation for the development of energy management policies that not only lower operational expenses but also align with institutional commitments to reducing carbon footprints.

From study by Júnior *et al*. (2022), educational institutions can incorporating BIM into institutional sustainability goals could drive long-term operational efficiencies and contribute to achieving national and global sustainability targets. Policies promoting the adoption of these tools could be implemented to ensure that new buildings and retrofits adhere to energy-efficient standards, making sustainability a core part of institutional planning.

In terms of BIM training programs, the study's findings can be used to highlight the practical applications of BIM in energy performance analysis. By integrating energy optimization techniques into BIM curricula, training programs can better equip architects, engineers, and sustainability professionals with the necessary tools to design energy-efficient buildings. Incorporating energy simulation tools such as Autodesk Insight 360 into BIM training will enable professionals to make informed decisions on energy-efficient building design and retrofitting, enhancing the skill set of those involved in the AECO industry.

4. Conclusion

In summary, the significant disparity in energy efficiency results between BIM tools and manual practices underscores the critical role of advanced technologies like BIM in achieving sustainable campus goals. The study highlights that BIM tools can deliver superior outcomes by providing accurate, efficient, and detailed energy performance assessments, as evidenced by the UMS Library case study. The Energy Use Intensity (EUI) achieved through BIM-based analysis was significantly lower at 60.5 kWh/m²/year compared to 176.27 kWh/m²/year from manual methods.

This difference underscores the efficiency gains associated with BIM, particularly in evaluating technical elements such as the building envelope, efficiency equipment and mechanical systems. The integration of BIM strategies with manual practices at the UMS Library demonstrates a holistic approach to energy efficiency, leveraging advanced digital simulations, collaborative decision-making, and practical retrofitting measures like LED lighting upgrades and voltage regulation.

Furthermore, the study reinforces the need for a technology-driven approach in sustainable campus initiatives. BIM's capabilities extend beyond energy performance analysis, supporting lifecycle assessments and enabling continuous monitoring of building energy consumption. This aligns with the growing emphasis on environmental sustainability in higher education institutions, where campuses are increasingly seen as living laboratories for sustainability.

The findings suggest that adopting BIM for energy performance analysis offers a viable and cost-effective alternative to traditional methods, providing a pathway to enhanced energy efficiency in institutional buildings. By integrating BIM strategies with sustainability goals, educational institutions like UMS can achieve significant energy savings while contributing to broader environmental objectives.

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