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A BIM-Based Optimization Model for Enhancing Building Energy Performance in Green Construction

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Abstract The construction sector plays a significant role in global energy consumption and environmental degradation, necessitating innovative approaches to improve building energy performance in green construction. Building Information Modeling (BIM) has emerged as a powerful platform for integrating design, analysis, and decision-making throughout the building lifecycle. This study proposes a BIM-based optimization model aimed at enhancing building energy performance to support green construction objectives. The proposed model integrates BIM with building energy simulation and optimization techniques to evaluate and optimize key design parameters, including building orientation, envelope characteristics, material selection, and mechanical system configurations. The model is validated through a case study of a building project, where energy performance scenarios are simulated and compared. The results demonstrate that the BIM-based optimization model can significantly reduce annual energy consumption and improve overall energy efficiency compared to conventional design approaches. The findings highlight the effectiveness of BIM as a decision-support tool for energy-efficient design and provide practical insights for architects, engineers, and project stakeholders in implementing green construction strategies. This research contributes to the development of integrated BIM-based methodologies for sustainable building design and supports the advancement of energy-efficient construction practices.

Keywords BIM, Optimization, Building, Energy Performance, Green Construction

1. Introduction

The building sector is one of the largest consumers of energy and a major contributor to greenhouse gas emissions worldwide [1]. According to international energy reports, buildings account for approximately 30–40% of global energy consumption and a significant share of carbon emissions throughout their life cycle [2]. As a response to climate change and environmental degradation, green construction has gained increasing attention, emphasizing energy efficiency, resource optimization, and reduced environmental impacts. Improving building energy performance has therefore become a critical objective in sustainable development policies and green building rating systems such as LEED, BREEAM, and Greenship [3].

Building energy performance is strongly influenced by early design decisions, including building orientation, envelope design, material selection, and mechanical system configuration [4-6]. Conventional design approaches often treat these parameters independently and rely heavily on designers' experience, which may lead to suboptimal energy outcomes [7]. Moreover, traditional workflows lack effective integration between design information and energy performance analysis, making it difficult to evaluate multiple alternatives systematically. This fragmentation highlights the need for integrated tools and methods that can support informed decision-making during the design stage of green construction projects.

Building Information Modeling (BIM) has emerged as a transformative technology in the architecture, engineering, and construction (AEC) industry by enabling the creation of digital representations of physical and functional characteristics of buildings [8-11]. BIM facilitates data integration, visualization, and collaboration across project stakeholders and throughout the building life cycle. In recent years, BIM has increasingly been adopted for sustainability-related applications, including energy analysis, daylight simulation, and life cycle assessment [12]. By serving as a centralized data platform, BIM offers significant potential to support energy-efficient building design and green construction objectives.

In Indonesia, the rapid pace of urbanization and construction activity has amplified building energy demand, driving national concerns about sustainability and climate change. Indonesia's building sector has been estimated to consume a high share of total electricity and contribute substantially to national emissions, highlighting the urgent need for energy-efficient practices across design, construction, and operation phases [13]. In response, the Government of Indonesia and industry stakeholders have increasingly promoted green building initiatives, aligning with national energy efficiency goals and broader decarbonization agendas.

To accelerate sustainable building practices, Indonesia has launched policy and regulatory frameworks that encourage energy efficiency and green building implementation. For example, the National Roadmap for Green Building Implementation was introduced to guide low-carbon transitions in the construction sector and to support energy-conserving design and operational strategies [14]. Moreover, green building certification schemes such as GREENSHIP—developed by the Green Building Council Indonesia (GBCI) provide comprehensive performance criteria, including energy efficiency and conservation, water management, material use, indoor environmental quality, and environmental management, tailored to the Indonesian context [15]. Several landmark projects illustrate the effectiveness of green building practices in Indonesia, achieving significant energy reductions and high GREENSHIP ratings (e.g., Gold and Platinum) compared to conventional structures [16].

Despite these policy drivers and certifications, energy performance optimization remains a significant challenge in practice. Green building efforts in Indonesia are often constrained by fragmented workflows, limited integration of performance simulation tools, and the reliance on manual, trial-and-error evaluation of design alternative factors that impede the systematic improvement of building energy performance [17, 18]. While traditional energy assessment and simulation methods provide valuable insights, they frequently lack iterative optimization capabilities that can efficiently explore design spaces and balance competing performance objectives. This limitation is particularly evident in the Indonesian context, where green building adoption is still emerging, and stakeholders may not fully leverage advanced computational tools to optimize energy performance from early design through construction. However, the integration of optimization methods with BIM environments remains limited and underdeveloped, particularly in practical green construction applications. Therefore, this study proposes a BIM-based optimization model for enhancing building energy performance in green construction. The model integrates BIM with building energy simulation and optimization techniques to support data-driven decision-making during the design phase. By optimizing key design parameters, the proposed approach aims to reduce energy consumption while maintaining occupant comfort and compliance with green building standards. This research contributes to the growing body of knowledge on BIM-enabled sustainable design and provides a practical framework for improving energy performance in green construction projects.

2. Literature Review

Building Information Modeling (BIM) has become a cornerstone in modern construction practice due to its capability to integrate multidisciplinary data and facilitate collaboration throughout a building's lifecycle. Early research established BIM as more than a 3D visualization tool, highlighting its capacity to centralize geometric and performance data for design analysis and simulation [19]. BIM enables designers to parameterize key building elements, for example, orientation, envelope material, and HVAC systems, which are critical determinants of energy consumption patterns [20]. These integrated data features allow for richer analysis of performance criteria compared to traditional CAD techniques, laying the groundwork for research into optimization rather than simple evaluation.

Within green building research, BIM has been utilized to support sustainability objectives by enabling energy performance simulation and identifying opportunities for efficiency improvements. Systematic reviews show that BIM applications in green construction contexts span early design assessment, building performance simulation, and lifecycle sustainability evaluation [21]. For example, BIM-driven tools have been applied to simulate and compare multiple design scenarios to reduce energy demand through passive and active strategies such as improved insulation, daylight optimization, and more efficient HVAC design [21]. Case studies in both tropical climates and arid environments demonstrate that BIM-based modeling can result in measurable energy savings when simulation insights inform design decisions, indicating a positive role for BIM in sustainable design strategies.

Despite these advances, most BIM research has focused primarily on energy analysis for assessment and prediction rather than optimization of building energy performance. While BIM provides rich simulation input, the step of systematically evaluating design alternatives and identifying optimal configurations remains underdeveloped in many studies. Integrative frameworks that combine BIM with structured optimization techniques such as orthogonal testing, genetic algorithms, or multi-objective heuristics are emerging but still relatively limited in scope and scale [22]. For instance, the integration of BIM with orthogonal test methods has been used to reduce annual energy use and life cycle costs in a campus green building context, demonstrating the importance and potential of optimization methodologies [22]. However, broader adoption of such integrative models across varied building types and climatic zones is still an ongoing research challenge.

Another important strand of literature highlights how parameterization and data interoperability within BIM facilitate multi-objective optimization for low-carbon and energy-saving design. Advanced frameworks leverage BIM parameterization coupled with optimization algorithms such as NSGA-II to explore trade-offs between energy consumption, daylighting, and other performance metrics [23]. These studies illustrate that optimization strategies driven by parametric BIM models can produce Pareto-optimal solutions that outperform conventional design approaches, yet they also underscore the complexity involved in coupling performance simulations with automated optimization workflows. Challenges such as high computational demand, integration of diverse software tools, and the need for user-friendly interfaces remain active areas for research and development.

In the context of green construction practice, especially in regions where green building adoption is still expanding, such as Indonesia, localized studies have applied BIM for energy analysis and simulation but often stop short of full optimization models [5, 24]. These case studies reinforce that BIM can uncover inefficiencies and suggest design improvements, such as optimal orientation and HVAC configurations, which result in significant energy savings. However, they also highlight gaps in integrating optimization algorithms into BIM workflows that can systematically generate and evaluate alternative designs. Addressing this gap is essential for translating BIM's analytical potential into practical decision-support tools that can effectively enhance energy performance in green construction projects across diverse climatic and regulatory environments.

3. Methodology

The methodology for this research is structured around the development and implementation of a BIM-based optimization model designed to enhance building energy performance within a green construction context. The overall workflow in this study integrates BIM authoring, energy simulation, parameter extraction, and optimization algorithms. The structured process ensures that energy performance considerations are incorporated early in the design phase, aligning with sustainable design strategies and Green Building Council criteria such as GREENSHIP and LEED. The BIM-based optimization model in this study is developed using Autodesk Revit as the central platform for parametric modeling, data integration, and interoperability with energy simulation and optimization tools. The method consists of a structured workflow that connects parametric BIM modeling, energy simulation, and algorithm-driven optimization into a unified decision-support framework.

A detailed BIM model of the study building, as shown in Figure 1, was created using a commercial BIM authoring tool such as Autodesk Revit. The model includes architectural geometry, construction materials, building orientation, and basic mechanical systems. Relevant design parameters that significantly influence energy performance, such as wall insulation levels, glazing ratios, shading devices, HVAC system types, and orientation, are defined as parametric variables. The BIM environment serves as a central data repository, enabling consistent and coherent data exchange with downstream analysis tools and maintaining an interoperable model through open standards.

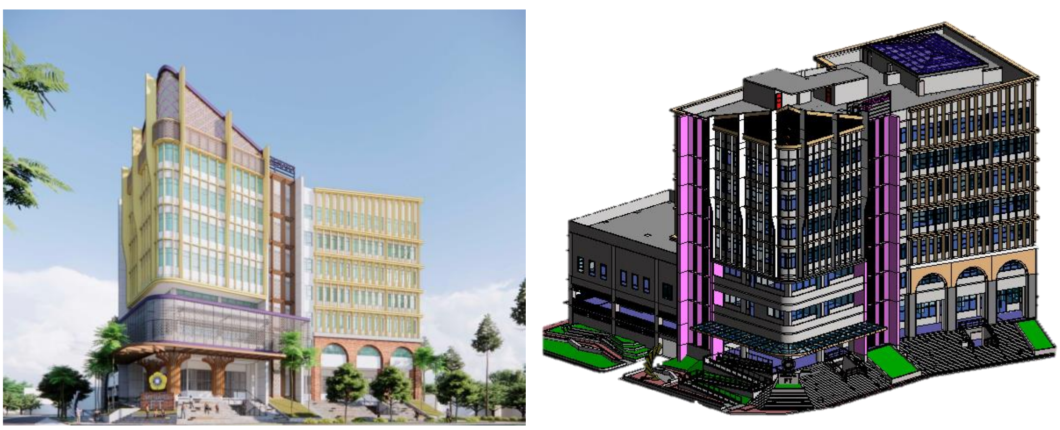

Figure 1 Visualization of 3D BIM Model

Once the parametric BIM model is established, the next step involves building energy simulation using performance analysis integrated plugins using Autodesk Insight. The BIM model is exported or linked to the simulation engine to generate baseline predictions of annual energy consumption and thermal behaviour under local climatic conditions. A Geographic Information System (GIS) dataset and local weather file (e.g., EPW) are employed to ensure that simulations reflect Indonesian climatic contexts due to targeting local green construction implications. This simulation provides the foundational performance data necessary for subsequent optimization processes.

For optimization, a multi-objective algorithmic approach is applied to explore design alternatives efficiently and identify solutions that minimize annual energy use while satisfying thermal comfort and green building certification guidelines. The algorithm iteratively evaluates candidate design solutions by looping between the BIM parameter set, energy simulation outcomes, and objective function assessments. This closure of the optimization loop allows the system to converge toward high-performance design configurations. Sensitivity analysis is also conducted to evaluate the influence of individual design parameters on energy outcomes, providing insights to decision makers on priorities for sustainable design improvements.

This study adopts a single case study approach to validate the proposed BIM-based optimization model. The use of a single building is intentional and aligns with the primary objective of this research, which is to develop and demonstrate the effectiveness of an integrated optimization framework rather than to generalize results across multiple building typologies. BIM-based optimization requires intensive computational processes due to the iterative coupling between parametric modeling and energy simulation, often involving thousands of simulation runs. Therefore, focusing on one representative building enables controlled experimentation, reduces computational complexity, and allows detailed analysis of the relationships between design variables and energy performance outcomes. Furthermore, the selected case building reflects typical characteristics of buildings in tropical climates, particularly in the Indonesian context, making it suitable as a baseline model for methodological validation. While this approach limits generalizability, it provides a robust proof-of-concept, and future research is recommended to extend the framework to multiple building types and climatic conditions to enhance external validity.

In summary, this methodology blends parametric BIM modeling, rigorous energy simulation, and systematic optimization to support energy-efficient design decisions in green construction projects. By leveraging interoperable workflows and advanced computational techniques, the proposed framework addresses limitations in traditional design approaches, enhancing the capability to produce high-performance building designs that align with sustainability goals and certification requirements.

4. Results and Analysis

The baseline energy performance analysis was conducted on the existing building condition prior to the implementation of any BIM-based optimization strategies. This baseline assessment represents the actual operational characteristics of the building and serves as a reference point for evaluating potential energy efficiency improvements. The analysis employed a building energy simulation model developed from the as-built BIM data, incorporating existing architectural layouts, envelope properties, mechanical systems, occupancy schedules, and local climatic conditions. Building energy performance was evaluated using Energy Use Intensity (EUI), expressed in kWh/m^2/year, which is widely recognized as a key indicator of building energy efficiency.

The simulation results indicate that the baseline EUI of the existing building is relatively high, which is about 210 kWh/m^2/year, much higher than the standard 120 kWh/m^2/year). This shows the limited energy efficiency considerations during the original design and construction stages. The total annual energy consumption, when normalized by gross floor area, demonstrates that the building exceeds recommended benchmarks for energy-efficient buildings in similar climatic regions. This elevated EUI can be attributed to several factors, including suboptimal building orientation, high window-to-wall ratios without adequate shading, insufficient thermal insulation of the envelope, and the use of conventional HVAC systems with relatively low efficiency. These characteristics are commonly observed in existing buildings that were not designed with green construction principles in mind.

Further breakdown of the baseline energy consumption reveals that cooling energy demand dominates total energy use, which is typical for buildings located in tropical climates. A significant portion of the annual energy consumption is allocated to air-conditioning systems, driven by high external temperatures, solar heat gains through glazing, and internal heat gains from occupants and equipment. Lighting and plug loads also contribute substantially to the overall EUI, particularly due to the use of non-energy-efficient lighting fixtures and limited applications of daylighting strategies. This energy distribution highlights the critical influence of both envelope design and mechanical systems on building energy performance.

From a green building perspective, the baseline EUI indicates that the existing building does not yet meet the energy efficiency thresholds commonly required by green building certification systems such as GREENSHIP, LEED, or equivalent standards. The baseline performance underscores the absence of integrated energy-efficient design strategies and the lack of systematic performance evaluation during early design stages. Consequently, the baseline analysis provides clear evidence of significant opportunities for energy performance enhancement through design optimization, system upgrades, and improved operational strategies.

Overall, the baseline energy analysis establishes a critical reference for this study by quantifying the existing building's energy performance using a standardized and comparable metric. The relatively high EUI value confirms the necessity of applying a BIM-based optimization model to systematically explore alternative design scenarios and identify optimal solutions for reducing energy consumption. Subsequent optimization results will be evaluated against this baseline to quantify energy savings, assess performance improvements, and demonstrate the effectiveness of the proposed BIM-based optimization framework in supporting green construction objectives.

When compared with the GREENSHIP Energy Efficiency and Conservation (EEC) criteria issued by the Green Building Council Indonesia (GBCI), the baseline energy performance of the existing building falls below the expected performance threshold. In general, GREENSHIP certification encourages significant reductions in building EUI relative to national or regional baseline values, with energy-efficient office buildings typically achieving EUI values below 150 kWh/m^2·year, and high-performance green buildings often targeting ≤ 120 kWh/m^2·year. With a baseline EUI of 210 kWh/m^2·year, the existing building exceeds these indicative benchmarks, implying that it would achieve low or no points under the EEC category without substantial energy efficiency improvements. This performance gap highlights the necessity for systematic energy optimization measures to reduce operational energy demand and improve compliance with GREENSHIP requirements.

To better understand the sources of energy consumption, the baseline EUI was disaggregated into major end-use components, including cooling systems, lighting, and equipment (plug loads). The breakdown reveals that cooling energy dominates total consumption, which is consistent with buildings located in tropical climates.

Table 1 shows that cooling accounts for approximately 60% of total annual energy use, indicating that envelope performance and HVAC system efficiency are the most critical factors influencing overall energy consumption. Lighting and equipment loads together contribute around 40%, suggesting additional opportunities for improvement through efficient lighting systems and demand management strategies. Following the baseline analysis, the proposed BIM-based optimization model was applied to identify energy-efficient design and system configurations. The optimization process focused on improving building orientation, reducing window-to-wall ratio, enhancing envelope insulation, optimizing glazing properties, and increasing HVAC system efficiency, while maintaining thermal comfort requirements. The optimized simulation results indicate a significant reduction in overall energy consumption, with the post-optimization EUI recorded as optimized EUI = 135 kWh/m^2·year. This represents an approximate 35–36% reduction in EUI compared to the baseline condition, demonstrating the effectiveness of the BIM-based optimization framework (Table 2).

Table 1. Baseline EUI Breakdown of Existing Building

Energy End Use	EUI (kWh/m^2·year)	Percentage (%)
Cooling (HVAC)	126	60%
Lighting	46	22%
Equipment / Plug Loads	38	18%
Total	210	100%

Table 2. Comparison of Baseline and Optimized EUI

Scenario	EUI (kWh/m^2·year)	Reduction (%)
Baseline (Existing Building)	210	–
Optimized Design	135	35.7%

The most substantial energy savings were achieved in the cooling energy component, resulting from reduced solar heat gain, improved envelope thermal performance, and higher HVAC efficiency. Lighting energy demand also decreased due to improved daylight utilization and optimized lighting design. As a result, the optimized building performance approaches the energy efficiency levels required for GREENSHIP EEC compliance, significantly increasing the potential certification score.

The comparison between baseline and optimized results clearly demonstrates that the existing building exhibits considerable inefficiencies when evaluated using standardized energy performance metrics. The high baseline EUI underscores the limitations of conventional design approaches that lack integrated performance evaluation. In contrast, the optimized results confirm that the proposed BIM-based optimization model provides a systematic and data-driven approach for reducing building energy consumption. These findings reinforce the role of BIM not only as a modeling and visualization tool but also as an effective decision-support platform for green construction. By quantifying energy savings relative to a clearly defined baseline, this study provides practical evidence of how BIM-based optimization can support national energy efficiency goals and facilitate compliance with green building certification systems such as GREENSHIP.

This study evaluated the energy performance of an existing building and assessed the effectiveness of a BIM-based optimization model in enhancing building energy efficiency for green construction. Energy performance was quantified using Energy Use Intensity (EUI) expressed in kWh/m^2·year, allowing direct comparison between baseline and optimized scenarios as well as alignment with green building benchmarks. The combined results and discussion presented herein demonstrate both the magnitude of energy savings achieved and the underlying factors contributing to performance improvements.

Overall, the combined results and discussion clearly demonstrate that the proposed BIM-based optimization model is effective in significantly reducing building energy consumption and improving alignment with green building performance criteria. The substantial reduction in EUI from 210 to 135 kWh/m^2/year underscores the importance of integrated, data-driven design approaches in achieving sustainable construction outcomes. These findings support the adoption of BIM-based optimization as a key strategy for enhancing building energy performance and advancing green construction practices in both national and global contexts.

5. Conclusions

This study proposed and validated a BIM-based optimization model for enhancing building energy performance in the context of green construction. By integrating parametric BIM modelling, building energy simulation, and multi-objective optimization techniques, the proposed framework enables systematic exploration of design alternatives and supports data-driven decision-making during the early design stages. The energy performance of an existing building was evaluated using Energy Use Intensity (EUI) as the primary metric, providing a robust and comparable basis for performance assessment. The baseline analysis revealed that the existing building exhibited a relatively high energy demand, with an EUI of 210 kWh/m^2/year, indicating limited consideration of energy efficiency in the original design. Cooling energy demand was identified as the dominant contributor to total energy consumption, reflecting the strong influence of envelope performance and HVAC efficiency in tropical climatic conditions. These findings underscore the necessity of integrated design approaches to address energy inefficiencies in existing buildings.

Following the application of the BIM-based optimization model, the building's energy performance improved significantly, achieving an optimized EUI of 135 kWh/m^2/year, corresponding to an approximate 35.7% reduction relative to the baseline condition. The optimized design approaches the performance thresholds encouraged by GREENSHIP Energy Efficiency and Conservation (EEC) criteria, demonstrating the practical potential of the proposed framework to support national green building certification and energy efficiency objectives. The results confirm that meaningful energy savings can be achieved without compromising thermal comfort, reinforcing the effectiveness of optimization-driven design strategies. Overall, this research contributes to the advancement of BIM-enabled sustainable construction by moving beyond descriptive energy analysis toward systematic optimization. The proposed framework strengthens the role of BIM as an integrated decision-support platform and provides a replicable methodology for improving building energy performance in green construction projects, particularly in tropical and developing-country contexts.

Although the results of this study demonstrate significant improvements in building energy performance through BIM-based optimization, it is important to acknowledge that the findings are primarily based on simulation outputs generated using Autodesk Insight. Simulation-based assessments inherently rely on predefined assumptions regarding occupancy schedules, internal loads, HVAC operation, and user behavior. In real-world conditions, these factors can vary significantly, potentially leading to discrepancies between predicted and actual energy consumption. Therefore, while simulation provides a reliable basis for comparative analysis and design optimization, it may not fully capture the complexity of operational performance in occupied buildings.

While the findings demonstrate the effectiveness of the proposed BIM-based optimization model, several opportunities for future research remain. Future studies should incorporate post-occupancy evaluation (POE) and real operational data to validate simulation-based optimization results and reduce uncertainty related to occupant behavior and system operation. Integrating measured energy consumption data would enhance the robustness and practical relevance of the framework. Finally, future work should examine the scalability and applicability of the proposed framework across different building typologies, climatic regions, and regulatory environments. Comparative studies involving multiple case studies and green building rating systems would help generalize the findings and strengthen the contribution of BIM-based optimization models to global sustainable construction practices.

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