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Energy Efficient Design of Building Based on Building Information Modelling (BIM)

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Abstract

Building energy analysis is rarely carried out due to the complexity of building shape and materials. On the other hand, the urgency of environmentally friendly construction is increasing through the vision of the SDGs and Architecture 2030. The development of BIM technology is expected to provide accurate estimates of building energy consumption for projects undertaken, as well as recommendations for alternative designs and specifications to increase the energy efficiency of a building. The use of BIM technology for energy analysis during building design helps to implement green building sustainable design based on the analysis of BIM energy simulation software. Data of three-dimensional BIM model with the attributes of materials, project schedule and location are used in building energy consumption simulation analysis. Several scenarios of different materials and layout are carried out to determine the most efficient scenario for energy consumption and followed by its cost estimation. The results of this study are expected to be able to provide the energy value that can be saved through predetermined scenarios as well as the value of the costs required to run a more energy-friendly design scenario in a comprehensive manner.

1. Introduction

The construction industry plays a vital role in energy consumption across various sectors. It significantly contributes to global greenhouse gas emissions and resource depletion [1]. Approximately 40% of both emissions and resource consumption worldwide are attributed to construction [2]. However, sustainable initiatives like Architecture 2030 and the SDGs are driving innovation in this field.

Reducing carbon emissions and driving innovation requires adopting innovative strategies, such as building information modelling (BIM) in the construction industry [3]. BIM involves creating accurate virtual models of buildings using digital tools, supporting the design process at every stage [4]. These computer-generated models contain detailed geometry and data, enabling seamless collaboration among stakeholders and informed decision-making based on the latest information [5]. BIM revolutionizes the construction industry by streamlining the design and construction process, ensuring the creation of sustainable and energy-efficient buildings for the future [6].

BIM-based energy analysis provides a valuable tool for accurately estimating energy usage and analyzing energy consumption, reducing the environmental impact. Sometimes referred to as integrated BIM, this technology comprises detailed information on component manufacturers, installation dates, maintenance schedules, configuration details, and energy requirements, offering beneficial insights for future facility and operations management [7]. BIM revolutionizes the construction industry by streamlining the design and construction process, ensuring the creation of sustainable and energy-efficient buildings for the future [8].

2. Methods

2.1 Object of Study

This study focuses on accurate estimates for the initial design of a 7-story building under construction in Indonesia, specifically using energy use intensity (EUI) measurements [9]. Furthermore, design recommendations can be provided to reduce energy consumption. The study also analyses the building's lighting performance based on LEED criteria [8].

2.2 Methodology

This study falls under the category of simulation research, where a model is created with specific rules and structures to produce a desired output [10]. The research began by collecting and preparing data, followed by creating a 3D building geometry model and a building energy model (BEM) [11]. The BEM was then uploaded to the Autodesk Insight 360 cloud platform to calculate the energy use intensity (EUI) and explore alternative designs [12].

Using the lighting analysis platform in Autodesk Revit, lux acquisition simulations will be conducted for each room [13]. This data can be utilized for future research to plan efficient lighting instruments that meet the building's light supply and comply with LEED standards [14]. By incorporating these standards, designers can ensure that the building's lighting system is environmentally sustainable, promotes energy efficiency, and enhances occupant comfort and well-being [15]. Fig. 1 represents the research methodology used in this paper.

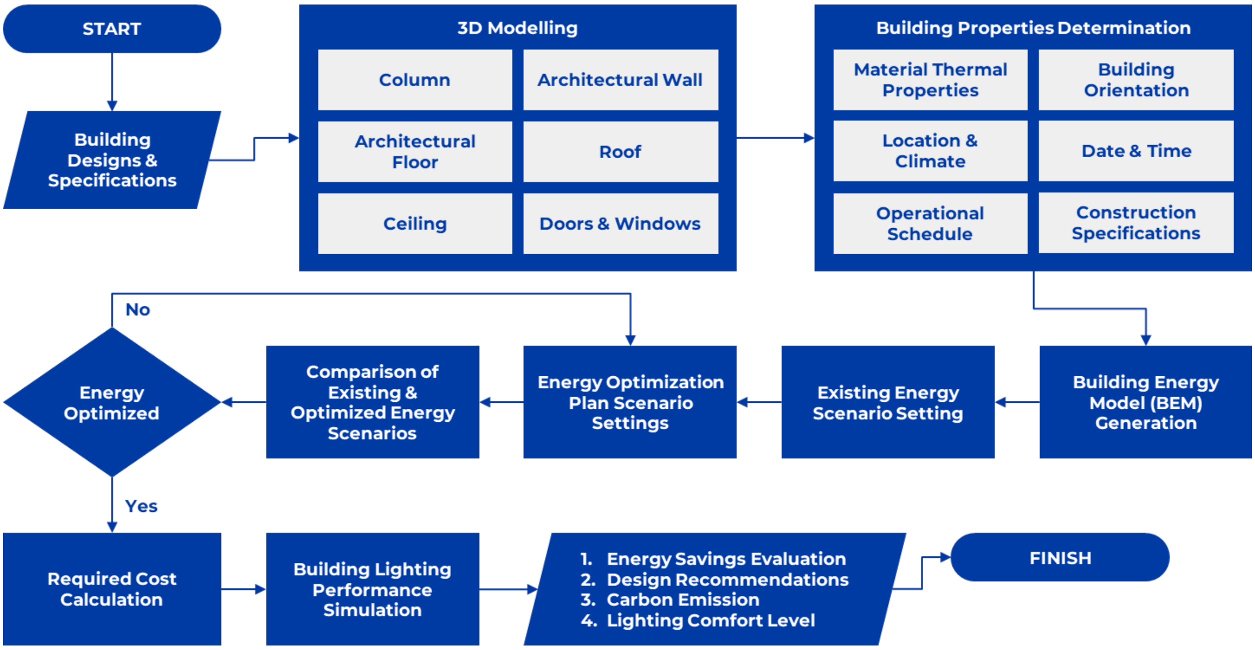

Fig. 1 *Research methodology*

3. Case Study

3.1 Object Details

The study focuses on the construction phase of the Faculty of Dentistry building at Universitas Brawijaya, located on Veteran Street, Ketawanggede, Lowokwaru District, Malang City, East Java, Indonesia. This seven-floor building has an area ranging from 1049 to 1225 square meters per floor. It is currently being constructed with PT Santoso Shafanara Graha as the main contractor and PT Kosa Matra Graha as the planning consultant. Made of reinforced concrete, the building's walls consist of brick pairs, plaster layers, and standard wall paint. Some walls incorporate shear wall construction and gypsum partition installations. The floors are also constructed with reinforced concrete. The building's facade features flexitile pairs made from modified clay heated at low temperatures.

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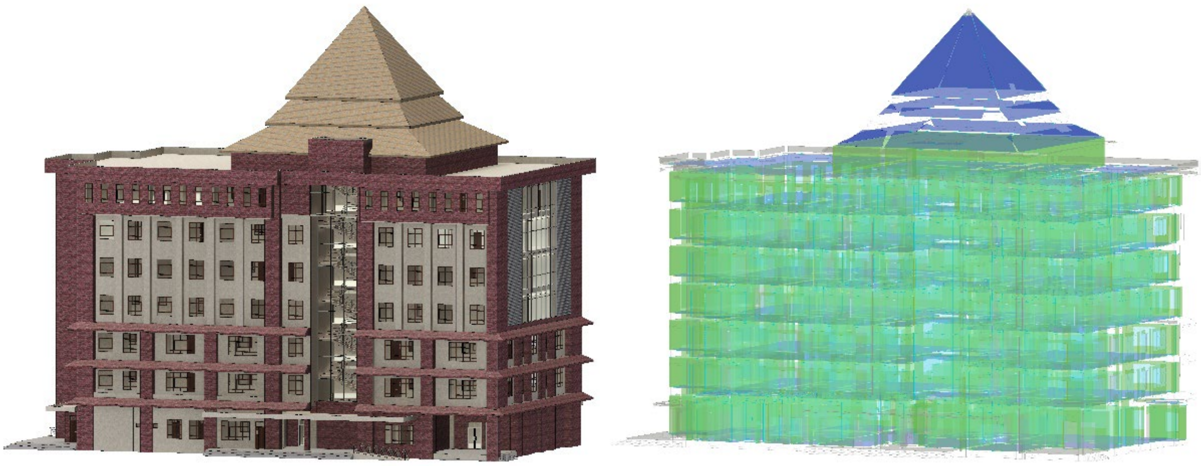
3.2 Model Setup

The 3D modelling in this study accurately represents the building's design specifications, including dimensions, element assembly, and material properties. To create an accurate building energy model (BEM), it is essential to incorporate geospatial and climatic factors that closely match the analyzed building [16]. This includes parameters such as thermal conductivity and resistance of materials, building orientation, location and climate of the surroundings, operating hours, and construction specifications for each building component [17]. Table 1 depicts all the parameter values inputted into the software.

Table 1 The values to be entered for several parameters that must be included in the software used

Parameter	Value
Location (Latitude, Longitude)	-7.96, 112.62
Building Orientation	350º to the north
Building Service	Split System(s) with Natural Ventilation
Building Type	School or University
Building Operation Schedule	12/5 Facility
HVAC System	12 SEER/0.9 AFUE Split/Packaged Gas, 5-11 Ton

A comprehensive building energy model (BEM) was developed. It identified 216 spaces and 2838 surfaces within the building envelope. Of these surfaces, 581 were openings, including fixed windows, non-sliding doors, and operable windows. The remaining 2257 surfaces were categorized as ceiling, exterior wall, interior wall, raised floor, roof, shade, and slab on edge. Fig. 2 shows a 3D model and a visualization used for energy consumption calculations.



(a) (b)

Fig. 2 *BIM visualization: (a) 3D modelling results from Autodesk Revit; (b) Building energy model (BEM) visualization*

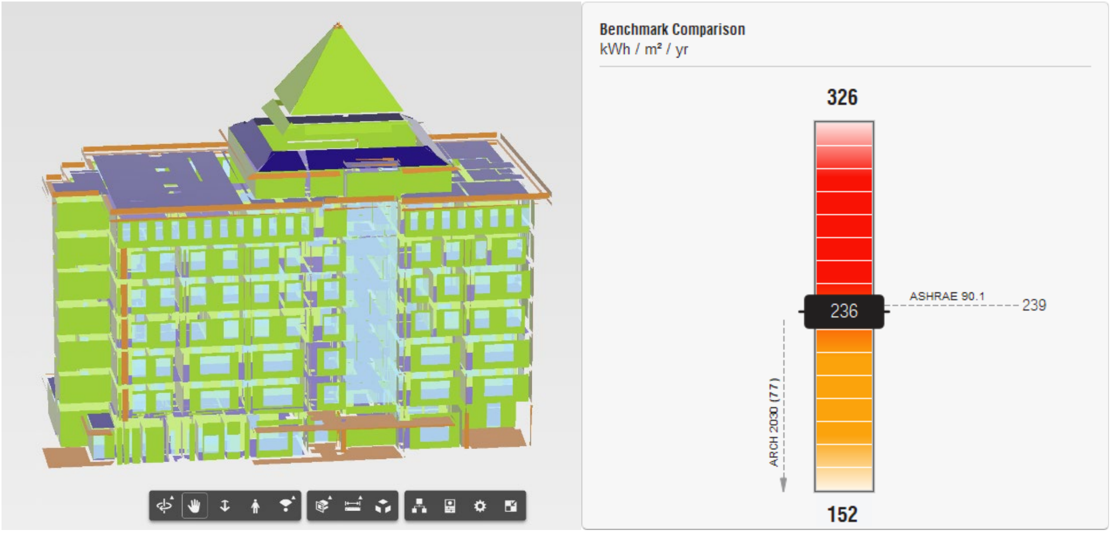
4. Results

4.1 Baseline Energy Use Intensity

Upon accessing the model in the Autodesk Insight 360 platform, adjustments were made to match the actual conditions of the building [18]. Each parameter displayed on the platform's widget was fine-tuned accordingly. The final simulation results revealed a baseline scenario with an energy usage intensity (EUI) value ranging from 152 to 326 kWh/m^2/year, averaging at 236 kWh/m^2/year. Fig. 3 shows the visualization and energy consumption value obtained from Autodesk Insight 360.

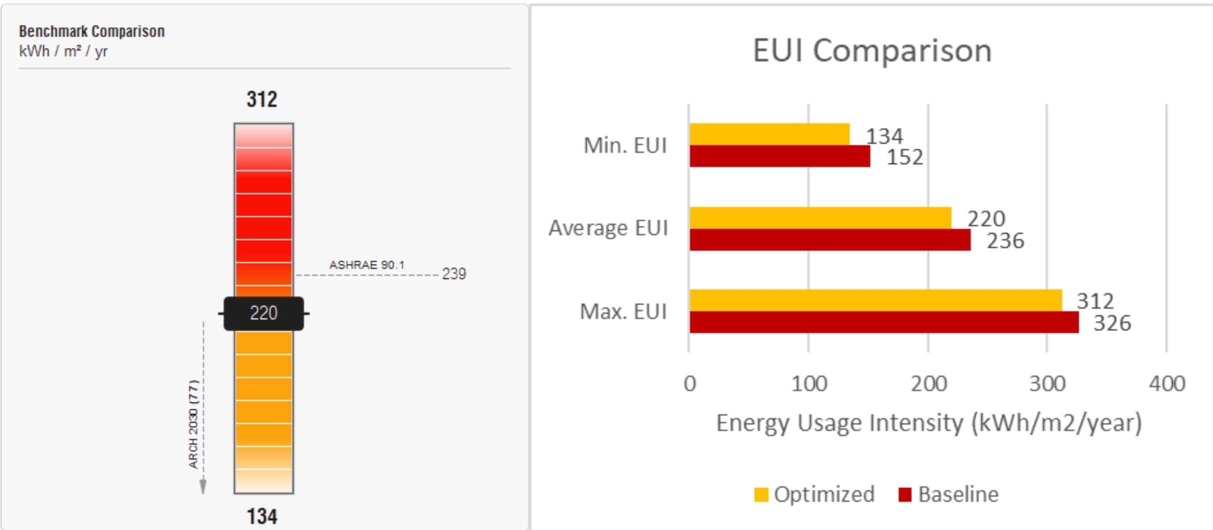
4.2 Optimized Energy Use Intensity

Considering the criteria established in this research and taking into account the ongoing construction phase of the building project, there are several feasible design adjustments that can be made for this structure. These adjustments involve the integration of shading devices on the western, eastern, and southern sides, with a recommended overhang height ratio falling within the range of 1/3 to 2/3. Additionally, it is advisable to replace the current glass material with triple low-E glass. This specific arrangement was simulated to determine the EUI values, resulting in a maximum threshold of 312 kWh/m^2/year, a minimum threshold of 134 kWh/m^2/year, and an average of 220 kWh/m^2/year. Fig. 4 depicts energy consumption value of the optimized scenario and the EUI comparison between the baseline and optimized design scenario.



(a) **(b)**

Fig. 3 *Visualization obtained from Autodesk Insight 360 (a) Building model visualization; (b) Energy consumption values*



(a) **(b)**

Fig. 4 *Optimized scenario result, (a) The EUI values for the feasible scenario; (b) The comparison of EUI between the baseline and optimized energy consumption scenario*

Based on the aforementioned graph, it can be observed that the optimized energy scenario yields an average savings of approximately 16 kWh/m^2/year in comparison to the baseline energy scenario. This finding highlights the significant potential for energy conservation and efficiency improvements through the implementation of the optimized energy strategy.

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5. Discussions

5.1 Calculation of CO_2 Emissions

In this study, carbon emissions from buildings were calculated using emission factors provided by the Department of Energy and Human Resources. The emission factor for the electricity system in Java, Indonesia, was found to be 0.891 tons of CO_2 per megawatt-hour (MWh) [19]. The resulting CO_2 emissions are summarized in Table 2.

Table 2 *The calculation of emissions involving the utilization of grade emission factors*

Scenario	EUI (kWh/m^2/year)	Total Building Area (m^2)	Conversion (tCO_2/MWh)	CO_2 Emission (ton/year)
Baseline	236	7611	0.891	1600.41
Optimized	220		0.891	1491.91

The comprehensive calculations indicate a significant reduction in CO_2 emissions with the alternative building design. The total emissions for the alternative design are 1491.91 tons of CO_2 per year, considerably lower than the initial design's emissions of 1600.41 tons of CO_2 per year. This represents a notable decrease of approximately 6.78% in CO_2 emissions.

5.2 Calculation of Required Costs

Energy usage intensity (EUI) was calculated using Autodesk Insight 360 to determine the material costs associated with implementing the design alternatives. The design alternatives primarily focus on the window elements within the building. Specifically, two types of windows in the Faculty of Dentistry Building at Brawijaya University were selected for shading. These windows were chosen because they are situated on the building envelope and directly exposed to the outdoor environment. Table 3 provides a description of both window types.

Table *3 The calculation of emissions involving the utilization of grade emission factors*

Window Type		1	2
Qty.		35	5
Visualization			
Opening Dimension	Width (m)	1.65	3.25
	Height (m)	2.05	2.05
Shades Dimension (7cm Thickness)	Width (m)	1.65	1.65
	Length (m)	0.70	0.70

The shades planned in this study consist of a simple concrete construction with a concrete grade of K-225. It is reinforced with wire mesh of M6, Ø10 reinforcement, and Ø6 reinforcement. BIM technology is employed to automatically obtain the necessary volume values for the redesign [20], saving time that would otherwise be spent on determining the quantities of concrete, reinforcement, and triple low emission glass required for an energy-efficient design. Once the quantities of materials are calculated, a cost estimation is conducted using a unit price approach. Each material's quantity is multiplied by its corresponding unit price to determine the total price [21]. Table 4 shows the required calculations to implement the alternative design.

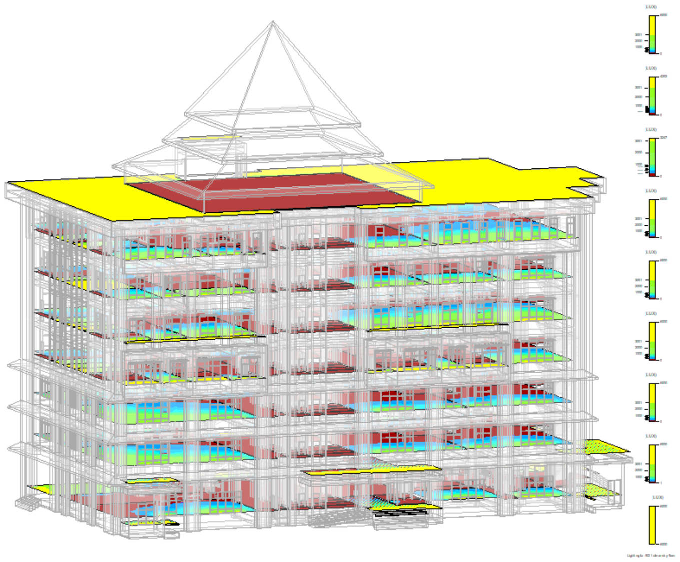
Table 4 *The unit prices of each material and the total cost value of the required materials*

Material	Unit Price (IDR)	Unit	Quantity	Required Cost (IDR)
Ø10 Steel Reinforcement	6,666.67	m	296.00	1,973,333.33
Ø6 Steel Reinforcement	2,916.67	m	404.53	1,179,888.89
Wire Mesh M6	35,000.00	m^2	50.57	1,769,833.33
Concrete (K-225)	800,000.00	m^3	3.54	2,831,733.33
Triple Low-E Glass	725,000.00	m^2	122.91	89,109,750.00
		Grand Total (IDR)		96,864,538.89

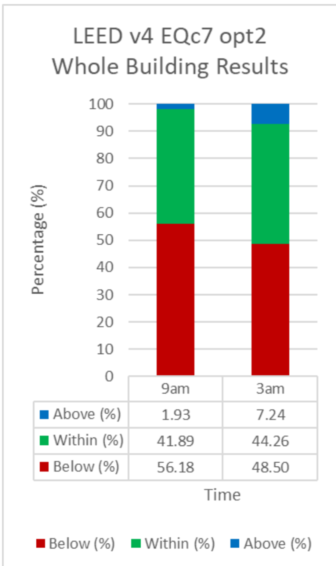
The implementation cost of the alternative design is approximately 96,864,538.89 IDR or roughly 6472.74 USD, based on the cost calculation. It is important to note that the material prices considered are specific to the Malang region in Indonesia and reflect the exchange rate around May 2023.

5.3 Evaluation of Building Lighting Performance

The lighting analysis in the studied building is performed using the insight lighting platform in Autodesk Revit. Specifically, the analysis utilizes LEED EQc7 option 2 [22]. The EQc7 category emphasizes the importance of incorporating daylighting and views in buildings to improve occupant comfort, well-being, and productivity, while also reducing the need for artificial lighting [23]. Fig. 5 presents a 3D visualization of LEED EQc7 option 2 lighting analysis as well as the threshold assessment for the same option.



(a)



(b)

Fig. 5 *Building lighting performance visualization (a) LEED EQc7 option 2 lighting analysis 3D visualization; (b) LEED threshold assessment*

Comprehensive analysis indicates that a substantial portion, approximately 24%, of the total building area meets the study's requirements. Specifically, during the 9:00 a.m. time period, around 42% of the area achieves the desired daylighting levels, surpassing the 300-lux threshold. By 3:00 p.m., the adequately lit areas expand to approximately 44% of the building area, indicating commendable daylight penetration improvement.

The light analysis reveals different spectrums: red for extremely low light levels below 100 lux, blue for relatively low levels ranging from 200 to 1000 lux, green for optimal lighting, and yellow for areas with excessive brightness or glare that may affect visual comfort. Insufficient natural lighting is observed throughout the building, highlighting the need for improvements to enhance quality and adequacy. Approximately 24% of the total area meets the required standards, leaving a significant portion without adequate natural lighting, which can have negative impacts on occupant well-being and productivity [24].

6. Conclusions

To summarize, this research illustrates how BIM can be effectively used to comprehensively evaluate the energy efficiency of a building. By implementing optimized energy strategies, significant energy savings of around 16 kWh/m^2/year can be achieved compared to the baseline scenario. This highlights the substantial potential for conserving energy and improving efficiency.

Additionally, the alternative building design presents a noteworthy decrease of approximately 6.78% in CO_2 emissions compared to the initial design. This alternative design showcases improved environmental sustainability and a reduced carbon footprint, resulting in total emissions of 1491.91 tons of CO_2 per year. Regarding costs, the estimated implementation expenses for the alternative design amount to roughly 96,864,538.89 IDR or around 6472.74 USD. However, a significant concern is the inadequate natural lighting throughout the building, as only 24% of the total area meets the prescribed standards. This emphasizes the need for enhancements to ensure sufficient and high-quality natural lighting, as insufficient lighting can negatively affect the well-being and productivity of occupants.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Giovanni Hertata Oktavian, Indradi Wijatmiko;* ***data collection:*** *Giovanni Hertata Oktavian, Christin Remayanti Nainggolan;* ***analysis and interpretation of results:*** *Giovanni Hertata Oktavian, Indradi Wijatmiko, Christin Remayanti Nainggolan, Yatnanta Padma Devia, Muhammad Ruslin Anwar;* ***draft manuscript preparation:*** *Giovanni Hertata Oktavian, Indradi Wijatmiko, Christin Remayanti Nainggolan, Yatnanta Padma Devia, Muhammad Ruslin Anwar. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Abanda, H., Vidalakis, C., Oti, A. H., & Tah, J. H. (2015). A critical analysis of building information modelling systems used in construction projects. Advances in Engineering Software, 90, 183-201. http://dx.doi.org/10.1016/j.advengsoft.2015.08.009

[2] Alami, N., Aziz, U. A., & Margiarti, D. (2021). Studi komparasi perbandingan rencana anggaran biaya antara metode analisa harga satuan pekerjaan (AHSP) dan standar nasional Indonesia (SNI). Jurnal Surya Beton, 5(1), 10-19.

[3] Alwan, Z., Jones, P., & Holgate, P. (2017). Strategic sustainable development in the UK construction industry, through the framework for strategic sustainable development, using building information modelling. Journal of Cleaner Production, 140 Part 1, 349-358. https://doi.org/10.1016/j.jclepro.2015.12.085

[4] Amoah, K., Nguyen, T., & Najafi, H. (2020). A multi-facet retrofit approach to improve energy efficiency of existing class of single-family residential buildings in hot-humid climate zones. Energies, 13(5), 1178. https://doi.org/10.3390/en13051178

[5] Apuke, O. D. (2017). Quantitative research methods : A synopsis approach. Open Access Journal, 6(10), 40-47. http://dx.doi.org/10.12816/0040336

[6] Autodesk Inc (2023). Autodesk product help. https://help.autodesk.com/view/RVT/2022/ENU/?guid=GUID-1F9669B3-338B-436D-B850-3FA4BC84A300

[7] Bagawanta, S. V. (2022). Evaluasi konsep green building dalam hal efisiensi dan konservasi energi pada Gedung Kantor Kepolisian Resort Kota Sidoarjo. Master Thesis, Universitas Brawijaya.

[8] Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). BIM Handbook - A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. John Wiley & Sons.

[9] Eberhardt, L. C., Rønholt, J., Birkved, M., & Birgisdottir, H. (2021). Circular economy potential within the building stock - mapping the embodied greenhouse gas emissions of four Danish examples. Journal of Building Engineering, 33, 101845. http://dx.doi.org/10.1016/j.jobe.2020.101845

[10] Fitriani, H., Rifqi, M., Indriyanti, C., Rachmandi, A., & Muhtarom, A. (2021). Energy Analysis of the educational building in Palembang Indonesia. Civil Engineering and Architecture, 9(3), 778-788. http://dx.doi.org/10.13189/cea.2021.090319

[11] González, J., Soares, C. A., Najjar, M., & Haddad, A. N. (2021). BIM and BEM methodologies integration in energy-efficient buildings using experimental design. Buildings, 11(491). https://doi.org/10.3390/buildings11100491
[12] Hafez, F. S., Sa'di, B., Gamal, S., Taufiq-Yap, Y. H., Alrifaey, M., Seyedmahmoudian, M., . . . Mekhilef, S. (2023). Energy efficiency in sustainable buildings: A systematic review with taxonomy, challenges, motivations, methodological aspects, recommendations, and pathways for future research. Energy Strategy Reviews, 45, 101013. http://dx.doi.org/10.1016/j.esr.2022.101013
[13] Hardin, B., & McCool, D. (2015). BIM and Construction Management: Proven Tools, Methods, and Workflows. John Wiley & Sons.
[14] Karimi, H., Adibhesami, A. M., Bazazzadeh, H., & Movafagh, S. (2023). Green buildings: Human-centered and energy efficiency optimization strategies. Energies, 16, 3681. https://doi.org/10.3390/en16093681
[15] Labaran, Y. H., Mathur, S. V., Muhammad, S. U., & Musa, A. A. (2022). Carbon footprint management: A review of construction industry. Cleaner Engineering and Technology, 9, 100531. https://doi.org/10.1016/j.clet.2022.100531
[16] Maglad, A. M., Houda, M., Alrowais, R., Khan, A. M., Jameel, M., Rehman, S. K., . . . Rehman, F. M. (2023). Bim-based energy analysis and optimization using insight 360 (case study). Case Studies in Construction Materials, 18, e01755. https://doi.org/10.1016/j.cscm.2022.e01755
[17] Moakher, P. E., & Pimplikar, S. S. (2012). Building information modeling (BIM) and sustainability – Using design technology in energy efficient modeling. IOSR Journal of Mechanical and Civil Engineering, 1(2), 10-21. http://dx.doi.org/10.9790/1684-0121021
[18] Montiel-Santiago, F. J., Hermoso-Orzáez, M. J., & Terrados-Cepeda, J. (2020). Sustainability and energy efficiency: BIM 6D. Study of the BIM methodology applied to hospital buildings. Value of interior lighting and daylight in energy simulation. Sustainability, 12(14), 5731. https://doi.org/10.3390/su12145731
[19] N., K. S., Razali, A., Zawawi, A., & Riley, M. (2017). Factors Affecting Indoor Environmental Quality and Potential Health Risks of Housing Residents. Conference: National Innovation and Invention Competition Through Exhibition, Jitra, Malaysia.
[20] Pan, Y., Zhu, M., Lv, Y., Yang, Y., Liang, Y., Yin, R., . . . Yuan, X. (2023). Building energy simulation and its application for building performance optimization: A review of methods, tools, and case studies. Advances in Applied Energy, 10, 100135. https://doi.org/10.1016/j.adapen.2023.100135
[21] Pásztory, Z., & Anh, L. D. (2021). An overview of factors influencing thermal conductivity of building insulation materials. Journal of Building Engineering, 44, 102604. https://doi.org/10.1016/j.jobe.2021.102604
[22] Truong, N.-S., Luong, D. L., & Nguyen, Q. T. (2023). BIM to BEM transition for optimizing envelope design selection to enhance building energy efficiency and cost-effectiveness. Energies, 16(10), 3976. https://doi.org/10.3390/en16103976
[23] U.S. Green Building Council (2023). LEED v4. (U.S. Green Building Council). https://www.usgbc.org/ leed/v4
[24] Zhang, J., Zhu, X., Khan, A. M., Houda, M., Rehman, S. K., Jameel, M., . . . Alrowais, R. (2023). BIM-based architectural analysis and optimization for construction 4.0 concept (a comparison). Ain Shams Engineering Journal, 14(6), 102110. http://dx.doi.org/10.1016/j.asej.2022.102110