Quest Journals
Journal of Architecture and Civil Engineering
Volume 11 ~ Issue 8 (August 2026) pp: 58-63
ISSN(Online): 2321-8193
www.questjournals.org

Research Paper

BIM 6D-Based Energy, Carbon, and Life-Cycle Energy Cost Assessment Using Sensitivity Scenarios: A Government Office Building Case Study in Indonesia

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ABSTRACT: *Building Information Modeling (BIM) 6D extends model use toward energy and sustainability assessment, but the reliability of decisions depends on transparent model boundaries, validation, and explicit treatment of uncertainty. This study develops a traceable BIM 6D workflow for a government office building in Malang Regency, Indonesia, using Autodesk Revit 2026, Forma Carbon Insights, Bim.com, and Microsoft Excel. The planning model was used to establish a predictive baseline (R0), while four sensitivity scenarios (R1-R4) represented 5-20% reductions in energy use. Forma reported an Energy Analytical Model area of 823.03 m2, a baseline EUI of 380.73 kWh/m2/year, annual energy use of 313,352.21 kWh, embodied carbon of 161,015.33 kgCO2e (A1-A3), and annual operational carbon of 85,566.19 kgCO2e. Under R4, annual energy use decreased to 250,681.77 kWh, operational carbon to 68,452.95 kgCO2e/year, and annual energy cost to Rp426.04 million. At a 5.75% discount rate, the 20-year Life-Cycle Energy Cost decreased from Rp6.234 billion to Rp4.987 billion, yielding a potential present-value saving of Rp1.247 billion. The scenarios are sensitivity targets rather than verified technical retrofit outcomes, so actual savings require audit, simulation, and measurement.*

KEYWORDS: *BIM 6D, energy efficiency, Energy Use Intensity, operational carbon, Life-Cycle Energy Cost*

Received 04 Aug., 2026; Revised 14 Aug., 2026; Accepted 16 Aug., 2026

I. INTRODUCTION

Buildings consume substantial energy for lighting, cooling, ventilation, and electrical equipment. In government office buildings, energy demand is shaped by the building envelope, lighting system, air-conditioning performance, occupancy, and operating schedules. As public agencies increasingly adopt digital construction workflows, Building Information Modeling (BIM) provides an opportunity to connect building geometry and material information with energy and environmental assessment rather than using the model only for three-dimensional visualization [1].

Green BIM research has shown that model-based information can support energy analysis and environmental decision making across the building life cycle [2]. BIM-energy integration is especially valuable during planning because design information can be linked with analytical tools before operational decisions become fixed. Jalaei and Jrade [3] demonstrated the value of connecting BIM, energy analysis, and green-building assessment, while Mahaaraja and Renuka [4] showed how Revit-based models can be transferred to energy-analysis environments for sustainable-design evaluation.

Recent Indonesian studies also show the expanding role of multidimensional BIM. Tanne et al. [5] applied BIM from 3D to 6D to evaluate productivity, clashes, and embodied carbon, whereas Rani et al. [6] highlighted the importance of institutional strategies for broader BIM implementation in Indonesia. These developments support the use of BIM 6D as a decision-support framework, but they also emphasize that software outputs must be interpreted within their analytical boundaries.

This issue is critical in the present case study because the available digital tools do not read the same model scope. Forma Carbon Insights reported an Energy Analytical Model area of 823.03 m2, whereas Bim.com reported a gross floor area of 2,957 m2 and a substantially different embodied-carbon result. Directly combining these outputs would therefore create a misleading energy or carbon intensity. In addition, actual electricity bills, detailed HVAC and lighting loads, operating schedules, and investment costs were not available. The study consequently treats the results as predictive model outputs and sensitivity scenarios rather than measured operational performance.

The objective of this study is to develop and evaluate a transparent BIM 6D workflow that links a Revit planning model with energy and carbon outputs, arithmetic validation, sensitivity-based energy-saving scenarios, and 20-year Life-Cycle Energy Cost (LCEC). The contribution is not a claim that a specific retrofit will automatically save 5-20% of energy, but a traceable method for showing the energy, carbon, and cost consequences if defined efficiency targets are achieved.

II. LITERATURE REVIEW

2.1 BIM 6D, energy, and carbon assessment

BIM provides a digital representation of physical and functional building characteristics and can support information exchange throughout design, construction, and operation [1]. In a sustainability context, 6D BIM commonly extends model use toward energy, environmental performance, and life-cycle decision support. Wong and Zhou [2] describe green BIM as a model-based process that supports coordinated environmental information across the building life cycle. The practical benefit is strongest when geometry, materials, and analytical assumptions remain traceable between the BIM model and the performance tool.

Energy-analysis integration is sensitive to model preparation and interoperability. Jalaei and Jrade [3] emphasized early-stage BIM-energy integration for evaluating design alternatives, and Mahaaraja and Renuka [4] linked Revit data with cloud-based energy analysis and green-building assessment. These studies support model-based evaluation, but they do not eliminate the need to verify analytical area, material matching, and the scope of components included by each application.

2.2 Life-cycle energy cost and sensitivity analysis

Long-term energy decisions should be evaluated on a consistent time-value basis. Life-cycle costing converts future costs to present value and is commonly applied to energy-efficiency decisions [7]. In this study, the economic scope is intentionally narrower than a complete life-cycle cost analysis. Only electricity-related operating cost is available; capital investment, maintenance, replacement, financing, and residual value are not. The term Life-Cycle Energy Cost (LCEC) is therefore used to distinguish the analysis from a complete investment appraisal.

Sensitivity analysis is appropriate when technical retrofit data are incomplete. Rather than assigning unsupported savings to a particular lighting, HVAC, or envelope intervention, this study evaluates target reductions of 5%, 10%, 15%, and 20% from the common baseline. This approach preserves transparency: the scenarios quantify consequences of achieving a target, while subsequent audit, simulation, and measurement are required to determine whether a proposed technical measure can actually deliver that target.

III. RESEARCH METHOD

3.1 Case study and analytical boundary

The case study is the Malang Regency Public Prosecutor's Office Building in Kepanjen, East Java, Indonesia. A planning BIM model developed in Autodesk Revit 2026 was used as the common building-information source. The research adopted a quantitative descriptive-comparative single-case design. The analytical units were the BIM planning model, the Energy Analytical Model area, annual energy use, EUI, embodied carbon A1-A3, operational carbon B6, sensitivity scenarios, annual electricity cost, and 20-year LCEC.

Forma Carbon Insights was the primary source for EUI, embodied carbon, operational carbon, and total carbon. Bim.com was used only as a comparison for embodied carbon because its scope, gross floor area, and material-matching rate differed from Forma. Microsoft Excel was used to verify arithmetic consistency, derive the implicit electricity emission factor, generate R1-R4, calculate energy cost, and discount 20-year energy expenditures. Figure 1 summarizes the workflow.

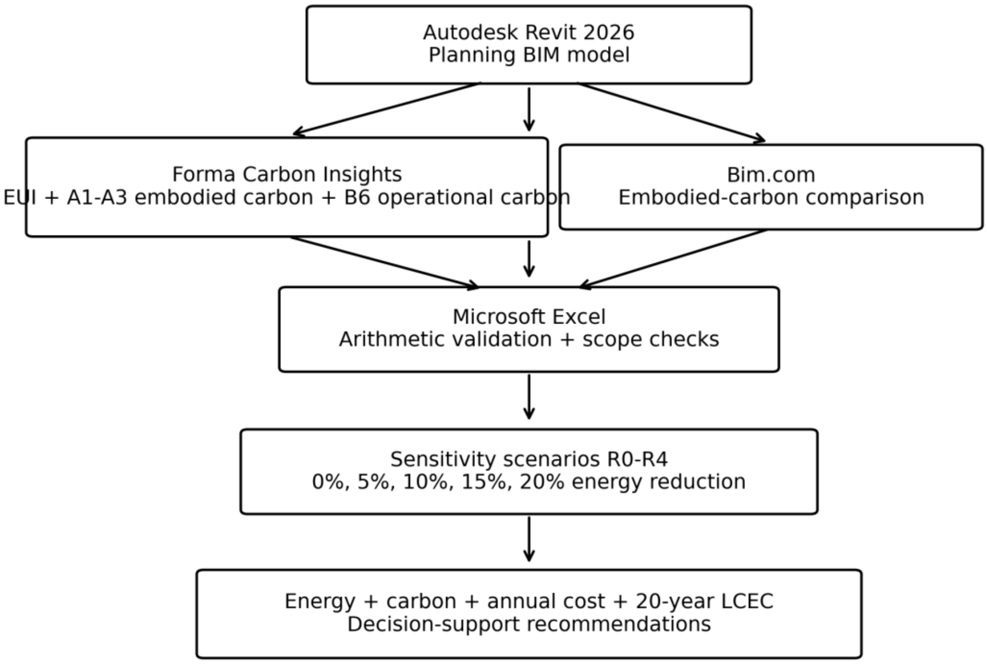

Fig. 1 Integrated BIM 6D research workflow.

3.2 Baseline validation and scenario formulation

The baseline R0 was defined from the final Forma output for the planning model. Arithmetic validation converted EUI to annual energy consumption using the Energy Analytical Model area:

$$E\_R0 = EUI\_R0 \times A = 380.73 \times 823.03 = 313{,}352.21 \text{ kWh/year} \quad (1)$$

The implicit electricity emission factor was derived from annual operational carbon and baseline energy because Forma did not expose the factor as a separate input:

$$EF = OC\_R0 / E\_R0 = 85{,}566.19 / 313{,}352.21 = 0.2731 \text{ kgCO2e/kWh} \quad (2)$$

Four sensitivity scenarios were then calculated as proportional reductions from R0, where eta_n is the target energy-saving fraction:

$$E\_Rn = E\_R0\ (1 - eta\_n)\ ; \quad EUI\_Rn = EUI\_R0\ (1 - eta\_n) \quad (3)$$

$$OC\_Rn = E\_Rn \times EF\ ; \quad TC\_n{,}20 = EC + (OC\_Rn \times 20) \quad (4)$$

Embodied carbon EC was held constant at 161,015.33 kgCO2e because the sensitivity scenarios changed energy use only and did not alter materials. Therefore, reductions in total 20-year carbon are smaller than reductions in operational carbon.

3.3 Energy cost and LCEC calculation

Annual energy cost was calculated using an electricity tariff of Rp1,699.53/kWh, which was the tariff basis adopted in the research dataset for the government-office tariff category during the study period:

$$C\_e{,}n = E\_Rn \times T\_e \quad (5)$$

The economic evaluation was limited to electricity-related operating cost. A 20-year period was used to match the longest carbon-analysis horizon available in the source output. With zero tariff escalation and a base discount rate of 5.75%, the present-value annuity factor was 11.70638. Thus:

$$PV(C\_e{,}n) = C\_e{,}n \times PVAF(i{,}n) \quad (6)$$

Discount-rate sensitivity was tested at 4%, 5%, 6%, 7%, and 8%. Because investment, maintenance, replacement, and residual value were unavailable, the analysis does not calculate payback period, benefit-cost ratio, investment NPV, or IRR. R4 can therefore be identified as the lowest-energy-cost sensitivity scenario, but not as the most feasible investment alternative.

IV. RESULTS AND DISCUSSION

4.1 Baseline energy and cross-platform model scope

The baseline validation confirmed that an EUI of 380.73 kWh/m2/year over the 823.03 m2 Energy Analytical Model corresponds to 313,352.21 kWh/year. Forma reported annual operational carbon of 85,566.19 kgCO2e and embodied carbon A1-A3 of 161,015.33 kgCO2e. The 20-year total carbon calculated in Excel was

1,872,339.13 kgCO2e, differing from the Forma dashboard by only 0.09 kgCO2e because of display rounding. Table 1 summarizes the baseline and the cross-platform boundary.

Table 1 Baseline and Cross-Platform Analytical Boundary

Parameter	Forma Carbon Insights	Bim.com / interpretation
Analytical area	823.03 m2	2,957 m2 GFA
Baseline EUI	380.73 kWh/m2/year	Not reported
Annual energy	313,352.21 kWh/year	Not reported
Embodied carbon A1-A3	161.02 tCO2e	791 tCO2e
Embodied-carbon intensity	195.64 kgCO2e/m2	267.50 kgCO2e/m2
Model scope	Envelope + interior in Energy Analytical Model	Architecture + structure
Material matching	Not displayed	25% matched; 11,984 unmatched elements

The difference between 161.02 tCO2e and 791 tCO2e is therefore not treated as an error or averaged into one value. Bim.com covers a broader architectural-structural model and reported only 25% matched elements, whereas Forma uses the Energy Analytical Model scope. This comparison is useful as a data-quality finding: embodied-carbon output is highly dependent on model scope, material matching, and emission-factor databases. For the same reason, the 2,957 m2 GFA is not used as the divisor for the main EUI result.

4.2 Energy, operational carbon, and annual cost under R0-R4

The sensitivity scenarios produce a linear reduction in energy use because each scenario is defined as a fixed percentage of R0. With a constant emission factor and electricity tariff, operational carbon and annual energy cost decline by the same percentage. Table 2 presents the integrated results.

Table 2 Energy, Carbon, and Cost Results for R0-R4

Scenario	Target	EUI (kWh/m2/y)	Energy (kWh/y)	Operational carbon (kgCO2e/y)	Energy cost (Rp/y)	20-y PV energy cost (Rp)
R0	0%	380.73	313,352.21	85,566.19	532,551,485	6,234,250,435
R1	5%	361.69	297,684.60	81,287.88	505,923,910	5,922,537,913
R2	10%	342.66	282,016.99	77,009.57	479,296,336	5,610,825,391
R3	15%	323.62	266,349.38	72,731.26	452,668,762	5,299,112,870
R4	20%	304.58	250,681.77	68,452.95	426,041,188	4,987,400,348

R4 yields the largest sensitivity benefit. Relative to R0, annual energy use falls by 62,670.44 kWh, annual operational carbon by 17,113.24 kgCO2e, and annual energy cost by approximately Rp106.51 million. Because embodied carbon is constant, total 20-year carbon falls from 1,872,339.13 to 1,530,074.33 kgCO2e, an 18.28% reduction rather than the full 20%. This distinction shows that operational-efficiency measures alone cannot eliminate the material-related component of whole-building carbon.

4.3 Life-Cycle Energy Cost and discount-rate sensitivity

At the 5.75% base discount rate, the 20-year present value of energy cost decreases progressively from R0 to R4. The baseline LCEC is Rp6.234 billion, while R4 is Rp4.987 billion, producing a potential present-value saving of Rp1.247 billion. Figure 2 shows the monotonic cost reduction across scenarios.

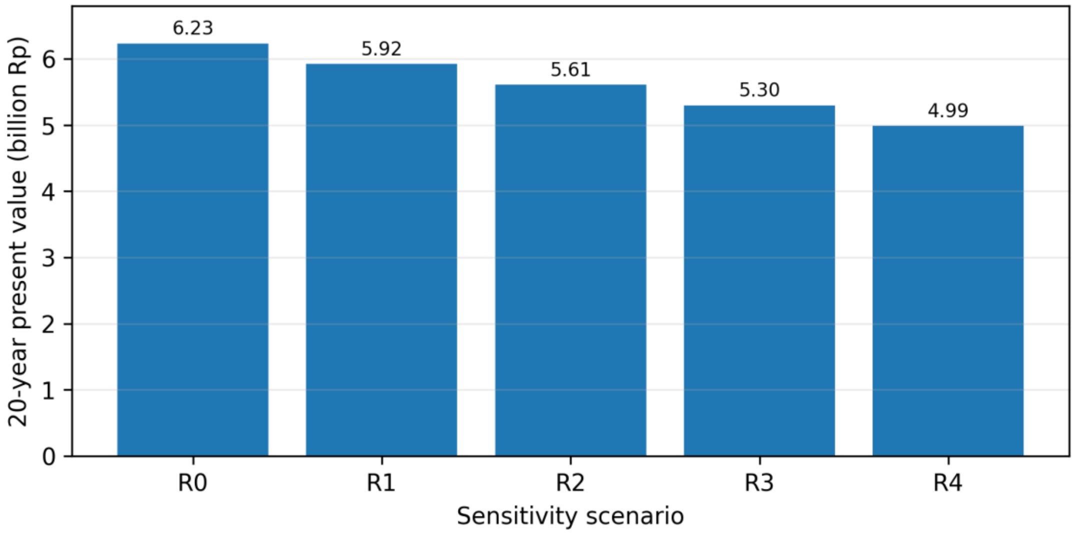

Fig. 2 Twenty-year Life-Cycle Energy Cost for the sensitivity scenarios at a 5.75% discount rate.

The discount-rate test confirms that the ranking is robust to the selected rate. Higher discount rates reduce the present value of future electricity expenditures, but R4 remains lower than R0 throughout the 4-8% range. The magnitude of the R4 present-value saving varies from approximately Rp1.046 billion to Rp1.448 billion, as shown in Table 3.

Table 3 Discount-Rate Sensitivity of R0 and R4

Discount rate	PV R0 (Rp)	PV R4 (Rp)	R4 saving (Rp)
4%	7,237,548,472	5,790,038,778	1,447,509,694
5%	6,636,768,620	5,309,414,896	1,327,353,724
6%	6,108,323,574	4,886,658,859	1,221,664,715
7%	5,641,858,015	4,513,486,412	1,128,371,603
8%	5,228,668,979	4,182,935,183	1,045,733,796

These results should not be interpreted as investment feasibility. A lower LCEC indicates a lower discounted electricity expenditure if the target energy reduction is achieved, but the study does not know the capital cost required to achieve that reduction. A technically aggressive measure could have a higher investment cost than its energy-cost saving. A complete project decision therefore requires equipment costs, installation, maintenance, replacement, service life, residual value, and financing assumptions in addition to the energy-cost stream [7].

4.4 Decision-support implications and implementation priorities

The principal value of the BIM 6D workflow is traceability. The Revit model provides the geometry and element information; Forma supplies the primary energy and carbon outputs; Bim.com serves as an embodied-carbon comparator; and Excel exposes the arithmetic and assumptions used to translate the outputs into scenarios and long-term cost. This makes it possible to identify where a result comes from and where its interpretation must stop.

The implementation sequence should begin with evidence that is currently missing from the model-based study. First, monthly electricity consumption and operating schedules should be recorded for at least a representative annual period. Second, low-investment operational measures such as HVAC scheduling, temperature control, shutdown of idle equipment, and preventive maintenance can be tested. Third, lighting inventory and zoning can support LED, daylight, and sensor strategies. More capital-intensive HVAC replacement and envelope improvement should follow after technical simulation and cost data become available. These priorities are consistent with the principle that energy-efficiency decisions should combine model information with measured performance and economic evaluation [3], [7].

The R1-R4 values are therefore best used as performance targets. If a future audit demonstrates an actual 10% reduction, the observed result can be compared with R2. If a proposed HVAC or envelope measure is claimed to deliver 20%, that claim should be demonstrated by a technically equivalent baseline-and-alternative simulation and then verified after implementation. This distinction prevents scenario analysis from being mistaken for measured savings.

V. CONCLUSION

This study developed a BIM 6D workflow that integrates an Autodesk Revit 2026 planning model, Forma Carbon Insights, Bim.com, and Microsoft Excel for predictive evaluation of energy use, carbon emissions, and long-term energy cost in a government office building in Malang Regency, Indonesia. The baseline R0 had an EUI of 380.73 kWh/m2/year over an 823.03 m2 Energy Analytical Model, equivalent to 313,352.21 kWh/year. Annual operational carbon was 85,566.19 kgCO2e and embodied carbon A1-A3 was 161,015.33 kgCO2e.

The 5-20% sensitivity scenarios showed a direct relationship between energy reduction, operational-carbon reduction, and annual electricity-cost reduction under constant emission and tariff assumptions. R4 reduced modeled annual energy use to 250,681.77 kWh, operational carbon to 68,452.95 kgCO2e/year, and annual energy cost to Rp426.04 million. At the 5.75% base discount rate, 20-year LCEC fell from Rp6.234 billion for R0 to Rp4.987 billion for R4, corresponding to a potential present-value saving of Rp1.247 billion. The R4 cost advantage remained under discount rates from 4% to 8%.

A key methodological finding is that cross-platform BIM outputs cannot be combined without checking analytical scope. Forma and Bim.com used different areas and model coverage, and Bim.com reported only 25% material matching. The study therefore keeps the outputs separate and uses Bim.com only as an embodied-carbon comparison. Finally, R1-R4 are sensitivity targets, not verified retrofit outcomes. Actual performance should be established through electricity records, energy audit, detailed HVAC/lighting/envelope simulation, and post-implementation measurement before investment feasibility is claimed.

Acknowledgements

The author acknowledges the project stakeholders and data providers who made the planning model and analytical outputs available for academic evaluation.

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