# Integrating Sustainable Design and Contractor Cost Performance in Green Industrial Facilities

1st Author: Tommy Utama Natasasmita
1st Author: Graduate of The Civil Engineering Doctoral Program, Universitas Tarumanagara, Jakarta, Indonesia
1st Author: tommy.natasasmita@gmail.com

2nd Author: Dyah Erny Herwindiati
2nd Author: The Faculty of Information Technology, Universitas Tarumanagara, Jakarta, Indonesia
2nd Author: dyahh@fti.untar.ac.id

***Abstract*— The adoption of sustainable practices in industrial facilities faces obstacles in terms of energy efficiency and property values. This study examines the impact of GreenShip Certification on the cost performance of a sustainable manufacturing facility in Jakarta, which aims for net-zero emissions by 2060. The methodology involves a cost-performance assessment and document review using GBCI ratings in six categories: Site Development, Energy Efficiency, Water Conservation, Material Resources, Indoor Health, and Environmental Management. The plant achieved platinum certification with a score of 87 out of 101. The findings showed a 58.14% reduction in energy consumption via sustainable passive design and renewable energy, resulting in 3427 t of annual carbon dioxide emissions. Water conservation led to a 62.50% reduction, with efficient fixtures in 79.54% of locations. The plant uses prefabricated methods, non-toxic materials, and natural lighting, which aligns with green construction. The project was cost-effective, with the green design modification causing a cost overrun of 4.49% of the contract price, and the Final Cost-to-Initial Cost ratio was 103.22%. This study recommends a design approach that emphasizes effective cost planning from the outset to integrate sustainable design, energy management, and environmental awareness.**

***Index Terms*— GBCI, Green building, Energy efficiency, Water conservation, Material resources, Indoor health and comfort, Building environmental management, Renewable energy, Net-zero emissions.***

## I. Introduction

The sustainable construction of plant buildings in Indonesia boosts property values by reducing operational costs, enhancing corporate reputation, and promoting healthier work environments. Implementing green factory building practices is crucial for striving to align with the net-zero emissions roadmap by 2060 [1]. This is especially pertinent given the recent challenges posed by global warming in the country. The rising pollution contributing to global warming demands proactive measures from both the government and the public to mitigate its effects. Consequently, green buildings present a viable solution for addressing global warming in civil engineering.

Green building certification can enhance property values by reducing energy and water consumption, lowering operational costs, and increasing productivity. This approach aligns with Indonesia's Nationally Determined Contributions (NDCs) and net-zero emissions objectives by minimizing energy use [2] and optimizing resource efficiency. Economic benefits include reduced utility expenses owing to enhanced efficiency. Certified green buildings are associated with improved natural lighting and ventilation, contributing to the occupants' well-being. Energy efficiency can be achieved through the implementation of passive design strategies and advanced intelligent systems, whereas water conservation can be facilitated by using low-flow fixtures and rainwater harvesting techniques [3]. Therefore, environmentally sustainable manufacturing facilities reduce energy and water consumption compared to non-green buildings, thereby lowering operational costs and environmental impact [4].

This study aims to examine the process through which a manufacturing facility in Jakarta, Indonesia, achieved GreenShip certification and assess how green engineering design initiatives influence construction cost performance, with an emphasis on cost overrun likelihood.

## II. Literature Review

### *A. Engineering Challenges and Strategies in the Implementation of Sustainable Building Facilities*

This study examines the intersection of passive architectural design, renewable energy integration, water usage reduction, and the realities of green cost surcharges. Previous research has shown that green facilities achieve 25%-50% energy reduction through passive design and renewable energy [5], while commercial buildings reduce water usage by 38% [6]. However, challenges include high initial costs and complex system-integration requirements.

Empirical research conducted in Beijing has indicated that green residential buildings have resulted in a 5% increase in property values [7]. Premium costs vary based on location, building type, and certification standards [7], with an estimated premium cost of 10.9% [8]. Research from 30 Singaporean companies shows green cost premiums of 5-10%, with cost overruns of 4.5-7% [9]. Green cost surcharges across 11 countries average 7% [10], whereas UK green construction costs are 6.5% higher than those of traditional buildings [11]. The "green premium" for sustainable features, including insulation, HVAC systems, and solar solutions, ranges from 4 to 10% [9]. Higher certifications may increase initial costs but often result in operational savings for companies.

Engineering challenges include substantial construction costs and design system requirements. Energy Efficiency and Conservation (EEC) and water management strategies optimize resources while reducing costs [6]. The EEC reduces electricity expenses and emissions, whereas renewable energy integration enhances the energy security. Water management reduces costs through harvesting and recycling processes. These facilities follow Environmental, Social, and Governance (ESG) criteria [12] to evaluate the carbon footprint (E), treatment of individuals (S), and leadership (G). The EEC faces challenges in balancing energy security with renewable transitions. Public policies in Indonesia address water scarcity and its environmental impact. This innovation tackles scarcity through the self-recycling of gray water [13].

### *B. Why Choose Green Buildings?*

Green buildings offer a framework for enhancing performance while minimizing environmental impact. This ensures compliance with the energy, water, and sustainability standards. By improving efficiency and reducing waste, green buildings decrease their carbon footprints and meet regulations [14]. Energy efficiency reduces utility costs, whereas certified buildings have higher resale values and occupancy rates. This approach integrates sustainable materials into the entire lifecycle of a building. Life Cycle Assessment (LCA) evaluates the environmental impacts of raw material extraction to disposal, including site selection and demolition [15].

A building is considered "green" when it incorporates sustainable practices, such as renewable energy and water-saving systems, including solar power and rainwater harvesting systems. Consequently, integrating sustainable design, energy management, and environmental awareness [16]—key features that distinguish green buildings from conventional ones— has become a vital choice for new construction projects. In this regard, the participation of the internationally acclaimed Green Building Council is essential to advance Indonesia's green building initiatives.

### *C. GBCI's Globally Recognized as the Indonesian Green Building Council*

The Green Building Council Indonesia (GBCI) is an independent, non-governmental, non-profit organization and a permanent member of the World Green Building Council. As Indonesia's sole internationally recognized green building council, the GBCI educates the public on environmental practices and promotes sustainable building industry transformations. The organization works to transform the market and promote green building principles among the stakeholders. GBCI's GreenShip certification system encourages sustainable practices through six categories: New Building (version 1.2), Existing Building, Interior Space, Homes, Neighborhood, and Net Zero [17].

## III. METHODOLOGY

This study utilized a methodology document examination of the acquisition of green certificates and evaluated the reliability of construction costs associated with the implementation of multidisciplinary engineering designs in green building projects. To this end, this study utilizes an assessment tool method, as delineated in previous research [20], to analyze the impact of design on cost overruns in green industrial projects using an engineering-procurement-construction (EPC) system.

The Green Building Council Indonesia (GBCI) uses the GREENSHIP rating tool to certify new buildings. This process has two main steps: "Design Recognition" and "Final Assessment" [17], with the GBCI's Green Certification levels, as shown in Table 1.

TABLE 1.

TABLE OF GBCI'S GREEN CERTIFICATION LEVELS [17]

| No. | Certification Levels | Points |
|---|---|---|
| 1 | Certified | 40 to 49 |
| 2 | Silver | 50 to 59 |
| 3 | Gold | 60 to 74 |
| 4 | Platinum | 75 to 100 |

### *A. Data Collecting and Scope of Case Study*

The project spans 25 hectares, with a building footprint of approximately 105,000.00 m2 (10.5 hectares). This facility includes buildings for the Main Office, Motorcycle Parking, factory plant buildings A, B, C, and D, ME utility, and other auxiliary buildings. The project is located in the GIIC Industrial Area of Kota Deltamas, Bekasi Regency, West Java, Indonesia. factory plant operations commenced in early 2024.

The GreenShip certification process uses design drawings and GBCI data to certify the ships. During Design Recognition, documents are evaluated for initial approval. The Final Assessment reviews the design and construction for certification. The assessment included document reviews, interviews, and site visits [17]. Cost performance data were obtained from drawings, contracts, and final accounts, focusing on the PEB steel structure work package of the EPC contract.

The factory plant approach combines the Green Factory, Sustainable Factory, and Smart Factory concepts aligned with Industry 4.0 principles. This design focuses on energy efficiency, waste reduction, and digital technology to enhance manufacturing productivity by combining information technology (IT), communication, and automation to improve efficiency [18], [19].

### *B. The Contractor Involved in Construction Fast-track Method*

Factory plant construction was fast-tracked, with substructure and superstructure activities completed within 22 months by December 2023. The work packages were executed concurrently according to the acceleration strategy. The multidisciplinary design process continues, with MEP work requiring time for vendor selection of factory-process equipment. Land grading, piles, and civil works progress ahead of schedule after a fixed layout plan, reducing the project duration compared to conventional scheduling, which requires a completed design before construction.

The fast-track approach implements an innovative and effective strategy for construction management, ensuring a logical relationship between activities and work packages [20], [21].

### *C. Cost Assessment Method and Criteria*

This study examines the implementation of an assessment tool designed to evaluate the impact of cost overruns linked to the adoption of green construction on EPC lump-sum costs, with the aim of limiting these overruns to 10%. The previous assessment tool (2024) was developed using LASSO regression with double jackknife resampling, utilizing data from 40 industrial construction projects in Indonesia from 2013 to 2018. [20].

The assessment tool model was evaluated using Python and Scikit-Learn, with λ (lambda) values ranging from 0.8 to 1.0. The performance assessment was conducted on five test data points using the metrics of Mean Squared Error (MSE), Mean Absolute Percentage Error (MAPE), and $R^2$. The dataset was subsequently expanded to 80 and 160 points by resampling. The validity of the regression was tested by comparing the Y-predicted results with the Y-actual data, while maintaining a 5% threshold limit. The summary of the test results indicates a prediction value of MSE = 1.92296E+17, MAPE = 0.00736, and R-squared = 0.9959.

Equation 1 illustrates the cost performance model, where the dependent variable Y represents the final project cost. The

$$Y_{Predicted} = 1.0245X_1 + 0.0586X_2 - 0.0329X_3 + 0.0226X_4 - 108460.783X_5 + 201000000.00X_6 \quad (1)$$

predictor variables include initial contract value (X1, measured in Billion IDR), direct and indirect costs from design changes (X2, measured in Billion IDR), indirect costs for engineering service fees (negative variable of X3, measured in Billion IDR), direct costs due to unit price analysis errors (X4, measured in Billion IDR), company experience in EPC projects (negative variable of X5, measured in years), and availability of core personnel in engineering (X6, measured in number of personnel). Equation 2 illustrates the cost-performance assessment tools and scores.

$$Cost\ Performance = {(Ypredicted)}/{Contract\ Value} \quad (2)$$

with score categories are:

- Score 1 = Very Poor, comparative between Final Cost/Initial Cost > 110%;
- Score 2 = Poor, comparative between Final Cost/Initial Cost > 106.5% to =109.9%;
- Score 3 = Medium, comparative between Final Cost/Initial Cost > 103.5% to=106.5%;
- Score 4 = Good, comparative between Final Cost/Initial Cost < 103.4% to = 100 %
- Score 5 = Very Good, comparative between Final Cost/Initial Cost < 100%.

### D. Limitations of the Study

The results of this study are confined to a manufacturing project in Jakarta, Indonesia, and should not be extrapolated to industrial projects in general, as each project has distinct circumstances.

## IV. Result and Discussion

The factory plant project sought GreenShip New Building Certification (Version 1.2) from the Green Building Council of Indonesia (GBCI). This presented challenges, as no heavy industry building had previously received GreenShip certification with sustainability commitments. On September 22, 2025, the factory plant became the first facility to receive the Platinum GREENSHIP New Building V.1.2 Certificate for a Manufacturing Factory Building from GBCI.

### A. GreenShip Assessment Result

*a)* The factory plant achieved Platinum GreenShip certification with 87/101 points (86.14%). The Appropriate Site Development system secured 13/17 points, Energy Efficiency and Conservation achieved 26/26 points, Water Conservation received 19/21 points, Materials and Resources Conservation obtained 10/14 points, Indoor Health and Comfort scored 9/10 points, and Building Environment Management achieved 10/13 points, as shown in Table 2.

TABLE 2.

TABEL OF SUMMARY OF ACHIEVEMENT POINTS

| No. | Description | Avhievement Point (Received/Submitted) |
|---|---|---|
| 1 | Appropriate Site Development (ASD) | 13 of 17 |
| 2 | Energy Efficiency and Conservation (EEC) | 26 of 26 |
| 3 | Water Concervation (WAC) | 19 of 21 |
| 4 | Material Resource and Cycle (MRC) | 10 of 14 |
| 5 | Indoor Health and Comfort (IHC) | 9 of 10 |
| 6 | Building Envronment Management ((BEM) | 10 of 13 |

*b)* The plant follows GreenShip guidelines by implementing innovative approaches to sustainable design, including landscaping, building facades, energy efficiency, waste management, and conservation measures. The factory incorporates landscaping according to the Minister of Public Works Regulation No. 5/PRT/M/2008, which addresses microclimate management, public facilities and stormwater management.

TABLE 3.

TABLE OF SAMPLE SITE LANDSCAPING DESIGN RECOGNITION

| CODE | RATING | EVALUATION GUIDE | | REVIEW RESULT (POINT) | | REMARK |
|---|---|---|---|---|---|---|
| | | POINT | MAX POINT | Achieved | Process | |
| | Maintaining or expanding urban greenery can improve microclimate quality, reduce CO2 and pollutants, prevent soil erosion, reduce the burden on drainage systems, and maintain a balanced water and groundwater system. | | | | | |
| 5.2 | Use locally cultivated plants at a provincial scale, at 60% of the mature canopy area of the landscape area in ASD 5, benchmark | 1 | 3 | 1 | | **COMPLY,** Total green area = 51,656.32 m2 Total canopy area = 35,962.25 m2 Percentage of total canopy area/total green land = 69.62% |

*c)* The green space at the factory plant encompasses an area of 51,656.32 m², constituting 69.62% of the total land area, as specified in Table 3 of the Site Landscaping Analysis of Design Recognition. This space includes trees, shrubs, and grass. These green spaces include vernal gardens located in the vehicle parking area, on both sides of the pedestrian bridge, within the inner courtyard of the office building, and large canopied trees along the pedestrian paths. The integration of green spaces is a crucial component of microclimate management, where factory buildings are designed with roofing and paving materials with high albedo values, alongside green areas. The large-canopy trees offer

FIGURE 1.

SAMPLE CALCULATION OF ENERGY CONSUMPTION AND $CO_2$ REDUCTION

**ENERGY CALCULATION**

| Plant and Buildings Name | Baseline | | | | | Design | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | Main | A | B | C | D | Main Office |
| Plant Building area ($m^2$) | 23,122.84 | 17,387.81 | 4,331.68 | 7,231.56 | 4,292.46 | 23,122.84 | 17,387.81 | 4,331.68 | 7,231.56 | 4,292.46 |
| Description | | | | | | | | | | |
| New Plant Electricity Consumption (kWh) | 3,055,600 | 1,976,000 | 461.70 | 582.36 | 691.86 | 1,576,800 | 685.30 | 207.66 | 151.35 | 575.51 |
| Energy Consumption Intensity/ECI Each Building | 132 | 114 | 107 | 81 | 161 | 68 | 39 | 48 | 21 | 134 |
| Solar Panel Capacity | | | | | | 363,840.26 | | | | |
| Total Electricity Consumption (kWh/year) | 6,767,520 | | | | | 2,832,780 | | | | |
| Total ECI (kWh/year/$m^2$) | 120 | | | | | 50 | | | | |
| Savings | **58.14%** | | | | | | | | | |
| Points | 20 | | | | | | | | | |
| Conversion ($CO_2$/kWh) | 0.000871 | | | | | | | | | |
| $CO_2$ Emissions tons/year | | | 5,894.51 | | | | | 2,467.35 | | |
| $CO_2$ Emission Reduction | **3,427.16** | | | | | | | | | |

**MEASUREMENT**

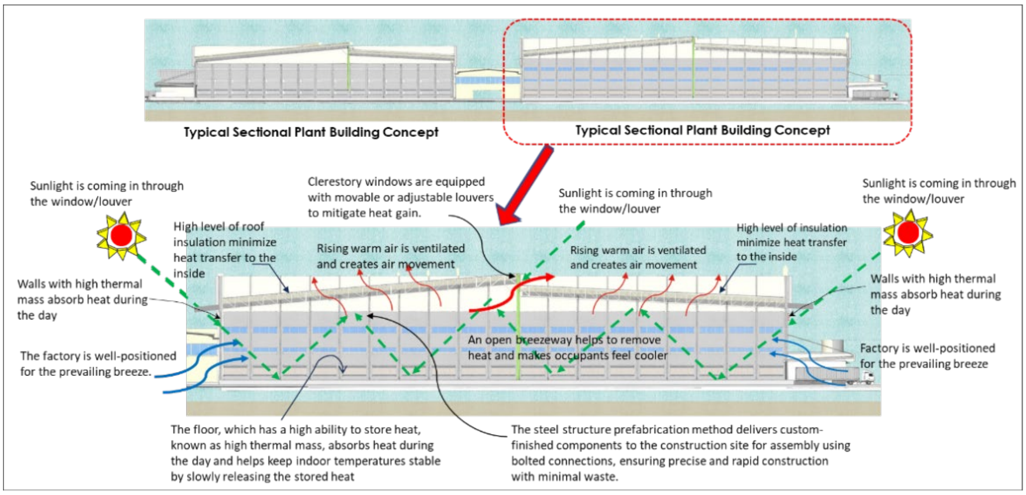
| Plant Building Name | Measurement | | | | |
|---|---|---|---|---|---|
| | Assembling | Painting | Machining | Diecasting | Main Office |
| **Building Area ($m^2$)** | 23,122.84 | 17,387.81 | 4,331.68 | 7,231.56 | 4,292.46 |
| **Total Electricity Consumption (kWh/year)** | 2,253,813.00 | | | | |
| **Total Energy Consumption Intensity/ECI (kWh/years.$m^2$)** | **40** | | | | |

shade and comfort to pedestrians and employees within the factory plant.

*d)* The factory plant offers a range of public amenities, including shuttle buses for staff, integrated walkways, bicycle parking, and facilities such as showers and changing rooms for employees. Additional public amenities include ATMs, places of worship, healthcare facilities, and canteens. The area of the factory plant also features bicycle shelters for employees who use bikes to travel between the buildings.

FIGURE 2.

PASSIVE SUSTAINABLE DESIGN CONCEPT OF THE FACTORY BUILDING




*e)* The factory building achieved 58.14% energy savings through an optimized façade design with low-E laminated glass, thereby enhancing the efficiency and comfort, as shown in Figure 1. Factories typically use single-clear glass to allow natural light. The overall thermal transfer values (OTTV) in [W/m²] were 25.42, 22.81, 19.8, 17.97, and 20.32 for the main office, and buildings A, B, C, and D, respectively. Natural lighting accounted for over 30% of the coverage of each building. By utilizing Sunergy Blue Green #2 Low-E and Indofloat Clear glass, which offer high light transmission (90%), the OTTV across buildings was reduced.

*f)* The building is equipped with an air-conditioning system characterized by a high Coefficient of Performance (COP) and solar panels with a capacity of 1,893.33 kWp, producing 1.89 MWp of electricity. These measures have resulted in a reduction in carbon emissions of 3,427 t CO2 per year, as illustrated in Figure 1. Figure 2 presents the Solar Radiation Analysis.

*g)* The factory plant integrated equipment with a Building Automation System (BAS) through Digitalization 4.0. All mechanical, electrical, and production systems have kWh meters for energy monitoring via BAS, whereas plumbing systems include water meters for consumption tracking.

*h)* The building achieved a 62.50% reduction in water consumption through sanitary fixtures, with 79.54% efficiency (see Table 4). The building processes blackwater, graywater, and rainwater through a Zero Liquid Discharge (ZLD) system, including Pretreatment, Reverse Osmosis, evaporator, and crystallizer/dryer. The factory uses rainwater sensor-based sprinklers for irrigation. The ZLD system uses two ponds to collect and process rainwater, graywater, and blackwater to manage municipal runoff.

*i)* In the Material Resource and Cycle (MRC), the factory uses sustainable materials, including non-ozone-depleting refrigerants, non-Halon fire extinguishers, and regional materials (97.66 percent of waste). Additionally, 89.99% of the materials had environmental certifications, 47.86% were recycled, and 38.83% were prefabricated system materials.

TABLE 4.

TABLE OF WATER FEATURE CALCULATION

| Sanitary Ware | Aplication | | Total | (%) |
|---|---|---|---|---|
| | **Saving** | **No** | | |
| Toilet | 60 | 25 | 85 | 28% |
| Urinal | 15 | 37 | 52 | 17% |
| Sink Faucet | 85 | 0 | 85 | 28% |
| Ablution Faucet | 67 | 0 | 67 | 22% |
| Shower | 14 | 0 | 14 | 5% |
| TOTAL | **241** | **62** | **303** | **100°/o** |
| WAC Calculation 2 | **79.54°/o** | **20.46°/o** | | |

*j)* The prefabricated system for factory construction under the MRC category, Section MRC 5, encounters challenges because of steel materials weighing up to 7500 t. According to the internal findings of the engineering study, a Pre-Engineered Building (PEB) system was implemented, where the structural design, procurement, and fabrication were all carried out within a single workshop as an EPC contract system. This prefabrication approach involves delivering custom-finished components to the construction site for assembly using bolted connections, thereby ensuring precise and rapid construction. A steel structure profile was designed to meet the load requirements of the factory.

*k)* This finding regarding the prefabrication system is consistent with previous research [22]; [23], which showed that it aligns more closely with green building principles than traditional methods, primarily because of its minimal waste generation. Fieldwork is largely confined to steel assembly and minor repetitive tasks.

*l)* In the Indoor Health and Comfort (IHC) category, the factory building enhanced indoor comfort by utilizing stack ventilation in the plant buildings of A, B, C, and D, and by incorporating fresh air into the Main Office. The building boasts over 75% indoor visibility and aligns its artificial lighting levels with SNI 03-001 6197-201of the Indonesia's National Standards. Regarding indoor health, factory buildings employ finishing materials, such as paint and ceilings, that are low in Volatile Organic Compounds (VOCs), such as water-based and formaldehyde-free paint. Previous research has claimed that these materials have minimal carbon, mercury, and asbestos contents [24]. Additionally, the building enforced a no-smoking policy and featured CO2 sensors integrated into the fresh air system.

*m)*In the Building Environment and Management (BEM) sector, the factory plant effectively managed waste during the construction phase by implementing waste reduction strategies. This commitment involves adopting measures to minimize waste during the construction phase. The waste management plan encompasses a comprehensive approach to handling construction and demolition waste, which may include reducing waste at the source and reusing and recycling materials.

*n)* Following the construction phase, factories implement waste-management systems. This commitment involves managing waste generated during factory operations through integrated management systems, which can be achieved using environmental management systems and lifecycle assessments. As highlighted in previous research [25]; [26], waste management is an integral part of a comprehensive life-cycle approach to building management that considers the environmental impact at every stage.

### *B. Cost Performance Assessment Result*

The cost simulation findings reveal that implementing the cost-added substitution model led to a 4.49% increase in direct costs due to design modifications in the Total Contract Value (Table 5). Simultaneously, the project's performance, assessed by comparing the final account with the contract value, reached 103.22%, indicating a high level of achievement. When applying the cost-performance prediction Equation 1, two negative variables, X3 (engineering service fee) and X5 (company experience), contributed to a reduction in the project's final value. This outcome facilitates cost balancing, despite the fact that the individual cost overrun (X2 = Increase in direct costs due to design changes) percentage exceeds cost performance.

The increased costs associated with implementing green design changes in this study are consistent with previous international studies. These studies indicate an average cost increase of 4% to 10% compared to conventio nal, non-green building factory projects [7]; [8]; [9]; [10]; [11].

Cost overruns primarily stem from design modifications needed to comply with green building standards not incorporated during initial engineering design. This study found that 30% of material costs are attributable to materials certified by an Environmental Management System (EMS). A building material certificate was valid if effective during procurement and construction phases. Additionally, recycled materials must comprise 5% of total material costs. This requirement is supported by the bill of material, technical specifications, and Delivery Order (DO) for recycled and wasted materials, as mandated by green building standards.

`This scenario has led to cost overruns due to overhead delays from manpower and standby equipment, as well as design evaluations affecting process-related material prices compared with the original contract. The costs increased owing to direct expenses, such as design changes and engineering fees during the modification. Additionally, the project faced delays in completion, resulting in cost overruns while awaiting re-procurement processes before the commencement of construction.

TABLE 5.

TABLE CONTRACTOR COST PERFORMANCE

| Variable Description | Cost Percentage (%) | Cost Performance Ratio (CPR) |
|---|---|---|
| Y = Final Project Cost | 103.222% | |
| X1 = Initial Contract Cost (XY0) | 100.000% | |
| X2 = Increase in direct costs due to design changes | 4.489% | |
| X3 = Increase in engineering fees | 3.800% | |
| X4 = Increase in direct costs due to errors in unit price analysis | 2.000% | |
| X5 = EPC Company Experience | 15 | |
| X6 = Number of core planning personnel (MM) | 15 | |
| **COST PERFORMANCE (CP)** | | **103.222%** |

## V. CONCLUSION

The results of this study identified that the factory plant attained notable greenship certification by emphasizing energy efficiency and reducing its environmental impact. Furthermore, the assessment results indicate the robust construction cost performance of green buildings within manufacturing plant projects in Jakarta.

The factory plant follows the GreenShip guidelines for net-zero emissions through sustainable design in landscaping, energy, and waste management. The plant factory integrates Green and Smart Factory concepts with Industry 4.0, focusing on energy efficiency and digital manufacturing. The Fourth Industrial Revolution combines information technology (IT), communication, and automation to enhance the manufacturing process. The prefabrication of steel structures follows green principles, generating minimal site waste through steel assembly and repetitive tasking.

The cost simulation concluded that adopting the cost-added substitution assessment tool model increases the direct costs by 4.49% owing to design modifications in the Total

Contract Value. The project's performance, comparing the final account with the contract value, was 103.22%, indicating a high achievement.

However, the implementation of EEC innovations faces challenges, such as balancing energy security with a shift to renewable sources, integrating new technologies with existing infrastructure, and overcoming economic barriers to effective public policy and regulation.

This study underscores the commitment of the Owner's Top Management to advance sustainable industrial development in Indonesia. This accomplishment may serve as a catalyst for other heavy industrial facilities to adopt similar practices in the future.

To prevent project cost failure, this study recommends the adoption of an innovative methodology and effective planning from the project's inception. This approach is intended to ensure the integration of sustainable design, energy management, and environmental awareness into future green building projects.

## Conflict of Interest

The authors declare no conflict of interest.

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