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USING SEM TO ENSURE SUSTAINABILITY AND PREDICTION MODELS IN GREEN BUILDING

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Abstract

This study investigates the integration of Structural Equation Modelling (SEM) to improve decision-making in sustainable building practices in Indonesia. By incorporating Value Engineering (VE) and Building Life Cycle (BLC), the model aims to guide investors and developers in optimizing green building projects to achieve sustainability and cost prediction. A quantitative approach was employed to analyse indicators from the Green Building Council Indonesia, VE, BLC, and new building cost performance. Data collection was conducted through distributed questionnaires and analysed using quantitative descriptive methods. Respondents were selected through snowball sampling, targeting experts and practitioners in green building concepts in Jakarta. The Content Validity Index (CVI) was used to assess the relevance of instrument items.

Keywords:

Building Life Cycle
Prediction Model;
SEM;
Sustainability.

1 Introduction

Regulation of the Minister of Public Works and Public Housing of the Republic of Indonesia Number 21 of 2021 mandates that the assessment of green building performance be a prerequisite for obtaining Building Construction Approval (PBG) and a Certificate of Functional Worthiness (SLF). This regulation reflects the government's commitment to promoting sustainable development and minimizing the construction environmental impact construction sector's environmental impact. Green buildings, designed to optimize resource use and reduce carbon emissions, are increasingly seen as crucial in addressing climate change and enhancing urban resilience [1, 2, 3].

However, despite the recognized benefits of green buildings, stakeholders in the construction industry often perceive them as costly investments. Concerns about high initial expenses, limited familiarity with green building practices, and uncertainty regarding long-term financial returns contribute to this perception. These challenges have led to resistance from developers and property owners in Indonesia, slowing the widespread adoption of green building principles as required by the regulation [4, 5].

Recent studies indicate that green buildings can deliver substantial long-term cost savings through reduced energy and water usage, improved operational efficiency, and enhanced occupant productivity. Two key cost-reduction methods, value engineering and building life cycle, are often employed to achieve these savings. The green building approach fosters sustainability by integrating resource-efficient practices throughout a building's lifecycle, from conception and design to operation and deconstruction [6]. These methods aim to develop a comprehensive cost model that balances upfront investment with long-term savings [7, 8, 9].

While existing research has primarily focused on the technical and environmental aspects of green buildings, there is a growing need to develop cost models that integrate financial performance with regulatory compliance. This study analyzes factors influencing green building life cycle costs using SEM-SD, combining statistical analysis with dynamic simulation. Their survey in China reveals how initial costs, operational savings, and policy incentives interact over time, highlighting the long-term financial benefits of green buildings despite high upfront expenses [10]. Furthermore, there is limited research on the interaction between conventional building practices, green building principles, and cost performance within Indonesia's regulatory framework. This study addresses that gap by proposing a detailed cost model tailored to the specific needs of the Indonesian construction industry [11, 12].

The proposed cost model integrates five key variables: conventional building practices, green building principles, value engineering, life cycle cost analysis, and cost performance. These variables are further broken down into 26 dimensions and 92 indicators derived from the conventional building framework, the Indonesian green building certification system (GREENSHIP), value engineering stages, life cycle cost stages, and cost performance assessments. The study introduces a novel approach that enhances the model's predictive accuracy and practical applicability by utilizing Structural Equation Modelling (SEM) with Smart-PLS software to analyse relationships among these variables [13, 14].

The primary goal of this study is to develop a cost-effective framework that addresses stakeholders' concerns regarding the high initial costs of green buildings. By illustrating the financial feasibility and long-term economic benefits of green building investments, the study aims to support the implementation of Regulation Number 21 of 2021 and facilitate the broader adoption of sustainable construction practices. Ultimately, the study seeks to demonstrate that a well-designed cost model can alleviate financial concerns, promote compliance with green building regulations, and advance sustainable development within Indonesia's construction sector [15, 16, 17].

2 Literature Review

2.1 Green Building

Green buildings adhere to technical building standards while optimizing energy, water, and resource conservation. This performance is achieved by integrating green building principles throughout the design, construction, and operational phases. In the design phase, emphasis is placed on energy and water efficiency by selecting high-performance materials and systems. Waste management practices are prioritized during construction and operation to encourage material recycling and reuse [18].

In Indonesia, the GREENSHIP certification system, developed by the Green Building Council Indonesia (GBCI), promotes the creation of environmentally friendly, energy-efficient, and sustainable buildings. GREENSHIP evaluates buildings across various categories to reduce environmental impact, improve energy efficiency, and enhance occupant well-being [16, 19].

The GREENSHIP framework comprises six assessment categories: Appropriate Site Development, Energy Efficiency and Conservation, Water Conservation, Material Resources and Cycles, Indoor Health and Comfort, and Building Environment and Management. It includes eight prerequisite criteria: Basic Green Area, Electrical Sub-Metering, OTTV Calculation, Water Metering, Fundamental Refrigerant Management, Outdoor Air Introduction, and Basic Waste Management. Additionally, there are 50 credit criteria, covering areas like Site Selection, Community Accessibility, Public Transportation, Bicycle Facility, Site Landscaping, Micro Climate, Stormwater Management, Energy Efficiency Measures, Natural Lighting, Ventilation, Climate Change Impact, Water Use Reduction, Water Fixtures, Water Recycling, Alternative Water Resources, Rainwater Harvesting, Water Efficiency Landscaping, Building and Material Reuse, Environmentally Friendly Material, Non-ODS Usage, Certified Wood, Prefab Material, Regional Material, CO_2 Monitoring, Environmental Tobacco Smoke Control, Chemical Pollutant, Outside View, Visual Comfort, Thermal Comfort, Acoustic Level, GP as a Member of Project Team, Pollution of Construction Activity, Advanced Waste Management, Proper Commissioning, Green Building Submission Data, Fit Out Agreement, and Occupant Survey. One bonus criterion, On-Site Renewable Energy, can further enhance a building's certification score. These criteria assess a building's environmental performance and contribute to its GREENSHIP certification ranking [20].

2.2 Regulation Number 21 of 2021

Regulation No. 21 of 2021, issued by the Indonesian Ministry of Public Works and Housing (PUPR), outlines provisions for Building Approval (Persetujuan Bangunan Gedung, PBG) and the Certificate of Building Functionality (Sertifikat Laik Fungsi, SLF), with an emphasis on green building principles. This regulation mandates that buildings' planning, construction, and operation adhere to environmental sustainability standards. [21].

The regulation requires compliance with technical building standards to obtain a PBG, including energy efficiency, water conservation, and the use of eco-friendly materials, in alignment with green building practices. Meanwhile, the SLF, granted post-construction, confirms that a building meets functionality, safety, and environmental criteria, ensuring its sustainable operation. These provisions aim to minimize environmental impact, encourage energy-efficient designs, and advance Indonesia’s commitment to sustainable and green development [22, 23].

2.3 Value Engineering

Value Engineering (VE) is a structured approach involving systematically evaluating projects, products, or processes by an independent, multi-disciplinary team to enhance performance, quality, and life cycle costs [24]. Within VE, Life Cycle Cost analysis focuses on maximizing value by identifying cost-effective alternatives with the lowest overall expenses [25].

VE aims to improve the value of goods, products, or services by optimizing the balance between performance and cost, with the dual objective of enhancing functionality or reducing expenditures. In modern construction practices, the application of VE plays a pivotal role in achieving project goals while minimizing costs. Countries worldwide have adopted VE for over five decades to address various construction challenges, ensuring high-value project delivery within set timeframes and budgets [26].

As an integrated management strategy, VE involves implementing problem-solving techniques, exploring alternative designs, making cost-focused decisions, and prioritizing performance-driven objectives through structured evaluation criteria. Both public institutions and private enterprises, particularly in the construction sector, have increasingly recognized VE's potential to improve efficiency and reduce costs. Since its introduction in the 1950s, VE has been widely adopted by governments, engineering firms, and contractors. According to Dell 'Isola, VE techniques can achieve multiple project objectives, including cost reduction, time optimization, and performance improvement [27].

The green building requirements outlined in GREENSHIP are categorized into six main areas, comprising eight prerequisites and 50 credit criteria. These criteria are further grouped into five classifications: prerequisites, passive design, given design, create design, and energy optimization. As illustrated in the FAST diagram in Fig. 1, this classification aims to achieve effective cost performance [28].

2.4 Building Life Cycle

Building Life Cycle (BLC) is an optimization approach to identify solutions that yield the highest economic returns over their lifespan or incur the lowest life cycle costs. These costs form the core of technical and financial analyses [29].

Lifecycle costs represent the total estimated expenses from a project's initiation to its disposal, determined by thoroughly examining all costs incurred throughout its lifespan. The primary goal of Life Cycle Cost (LCC) analysis is to select the most cost-effective option from various alternatives, ensuring the lowest long-term ownership cost. According to Kelly and Male (1993), their book "Value Management in Design and Construction": The Economic Management of Projects. London: E & FN Spon as the publisher. In this book, Life Cycle Costing is an economic evaluation method that considers all relevant costs over the investor's time horizon, factoring in the time value of money.

A comprehensive LCC includes all costs associated with an item, from its design and development phases to its eventual disposal [30]. The LCC formula is typically expressed as:

LCC = Initial Cost + Cost of Usage + Cost of Care and Replacement.

In green buildings, the additional expenses incurred in transitioning from conventional to green buildings are minimal or negligible compared to other life cycle costs

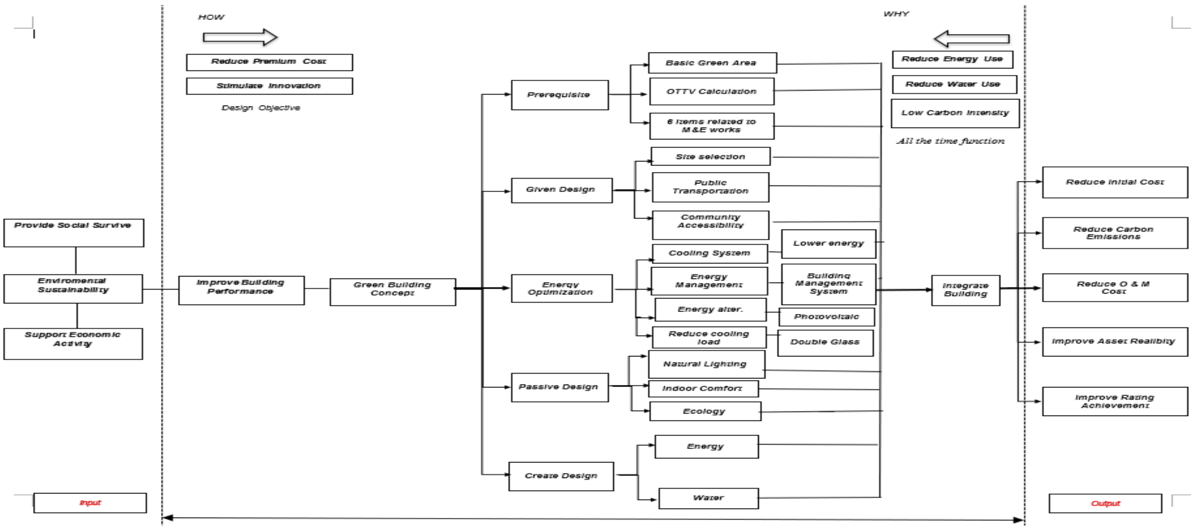

Fig. 1: FAST Diagram Green Building GREENSHIP.

Life Cycle Cost Analysis (LCCA) is a crucial approach for assessing the total cost of ownership by accounting for financial implications throughout an asset's lifespan. LCCA comprises multiple cost components, each playing a distinct role in the overall cost structure. Initial investment costs, including construction, materials, and installation, represent approximately 30–50% of the total life cycle cost, making them the most substantial upfront expenditure. Operation and maintenance (O&M) costs, covering expenses related to energy consumption, repairs, and routine inspections, typically range between 20–40%, with material quality and energy efficiency significantly influencing these costs [31].

Furthermore, replacement costs associated with component upgrades and refurbishments generally account for 10–20% of total expenditures. The residual or salvage value, which reflects the recoverable worth of an asset at the end of its useful life, varies between -5% and -15%, depending on factors such as asset type and recycling potential. Lastly, end-of-life or disposal costs, including demolition, decommissioning, and waste management, contribute 5–10%, with variations influenced by environmental regulations and sustainability policies. A clear understanding of these cost distributions enables more informed decision-making, fostering economic sustainability and efficient resource allocation in infrastructure and construction projects. [31]. In Indonesia, the initial construction costs are approximately 39% for architectural expenses, 25% for structural work, and the remainder for mechanical and electrical works. As shown in Fig. 2, ongoing building operations account for only a portion of the total building expenses.

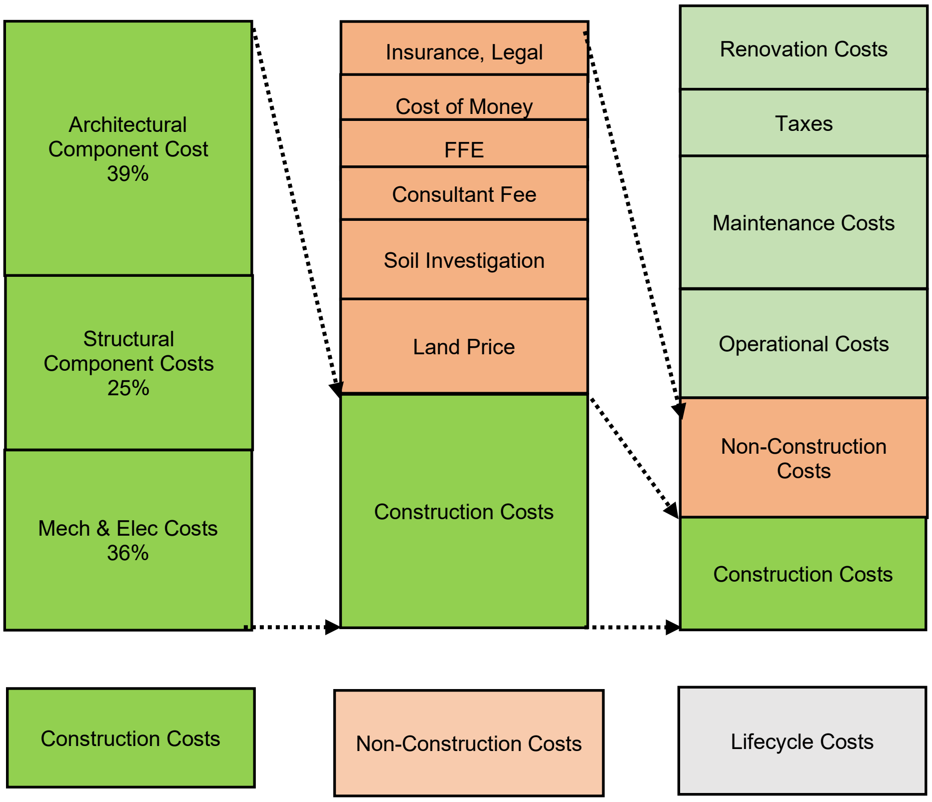

Fig. 2: Building Life Cycle [32].

3 Research Method

This study utilized a quantitative approach to examine indicators from the Green Building Council Indonesia, value engineering, lifecycle cost analysis, and the cost performance of new buildings in Indonesia. Data collection was conducted through distributed questionnaires and analyzed using quantitative descriptive methods.

Structural Equation Modelling (SEM) was applied using PLS software version 3.0 for the analysis. Key factors such as sample size, data distribution, missing values, and measurement scales were considered to ensure that the sample size met the requirements of the SEM-PLS model. The minimum sample size was determined based on a path coefficient (p Min) difference level and an 80% statistical power test, as recommended by previous studies.

Respondents were selected through a snowball sampling technique, a method effective for identifying, selecting, and sampling participants via a continuous network of relationships. This approach proved efficient in obtaining data from respondents addressing specific research problems.

The study population included experts and practitioners with knowledge and experience in green building concepts and practices in Jakarta. The Content Validity Index (CVI) was used to ensure content validity, evaluating the relevance of each instrument item to the construct being measured and reflecting the level of expert agreement.

The research model established a minimum sample size requirement of 69, based on a path coefficient value of 0.25, an 80% statistical power test, and a 5% significance level. One hundred fifteen questionnaires were distributed to selected respondents with educational backgrounds ranging from undergraduate to doctoral degrees, as in Fig. 3a and 5 to 30 years of experience in green building, as in Fig. 3b. Jakarta is Indonesia's central hub for high-rise and green building developments, making it a relevant and representative location for studying cost-effective models in sustainable construction. Given that Jakarta has the highest concentration of green-certified buildings. As a benchmark for national green building policies, insights from experienced professionals in this region provide valuable practical implications. Of these, 102 responses were received, comprising 88 men and 14 women, resulting in an 88.69% response rate.

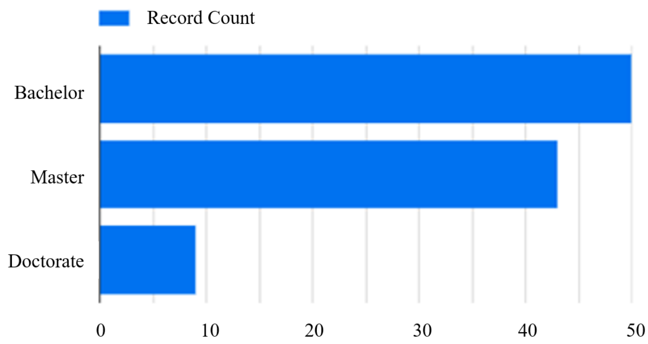

Fig. 3a: Respondent's Education Level.

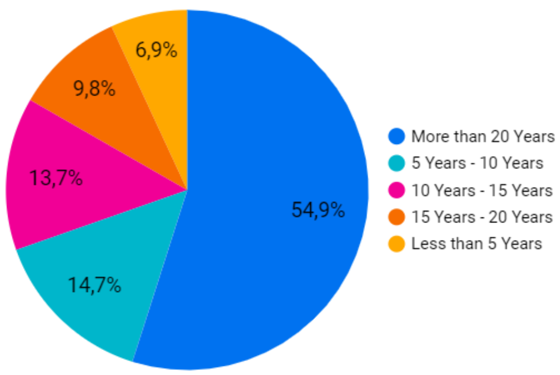

Fig. 3b: Respondent's Experience Level.

4 Results and Discussion

Questionnaire data obtained via Google Forms by researchers as part of this research will be processed and analyzed using structural equation modeling (SEM). This research consists of 5 variables divided into 4 endogenous and 1 exogenous variable. The endogenous variables include conventional buildings, green buildings, value engineering, and lifecycle cost analysis. The exogenous variable is effective cost performance. 25 Categories and 80 indicators.

Table 1 illustrates that all indicators effectively represent their respective variables. Specifically:

Conventional Building (X1) comprises two dimensions; Project Management and Contract Management, and encompasses 10 indicators: Project Organization, Risk Management, Monitoring and controlling, Project Manager Performance, Communication and coordination, Bill of Quantity, Technical Drawings, Technical Specifications, Work Schedule, and Regulation and terms.

Green Building (X2) consists of six dimensions: Appropriate Site Development, Energy Efficiency & Conservation, Water Conservation, Material Resources & Cycles, Indoor Health & Comfort, and Building Environment & Management, with 58 indicators, including Basic Green Area, Electrical Sub Metering, OTTV Calculation, Water Metering, Water Calculation, Fundamental Refrigerant, Outdoor Air Introduction, Basic Waste Management, Site Selection, Community Accessibility, Public Transportation, Bicycle Facility, Site Landscaping, Micro Climate, Stormwater Management, Energy Efficiency Measures, Natural Lighting, Ventilation, Climate Change Impact, Water Use Reduction, Water Fixtures, Water Recycling, Alternative Water Resources, Rainwater Harvesting, Water Efficiency Landscaping, Building & Material Reuse, Environmentally Friendly Material, Non-ODS Usage, Certified Wood, Prefab Material, Regional Material, CO_2 Monitoring, Environmental Tobacco Smoke Control, Chemical Pollutant, Outside View, Visual Comfort, Thermal Comfort, Acoustic Level, GP as a Member of Project Team, Pollution from Construction Activity, Advanced Waste Management, Proper Commissioning, Green Building Submission Data, Fit Out Agreement, and Occupant Survey. A bonus indicator, On-Site Renewable Energy, also assesses green building rankings.

Value Engineering (X3) comprises eight dimensions; Information, Function, Creativity, Evaluation, Development, Presentation, and Value Engineering Practice; with 17 indicators, such as Top Management Commitment Attitude, Data Analysis, Information & Communication, Policies & Regulations, Improved Project Quality, Function Analysis, Selection of Work Methods, Material Selection, Analyzing Value Engineering, Results from Idea Evaluations for Alternatives, Reduction of Material Costs, Seeking Alternative Materials, Implementation of Solutions, Resource Optimization, and the Positive Impact of Value Engineering on Cost Performance in Building Construction.

Life Cycle Cost Analysis (X4) includes five dimensions; cost Breakdown Structure, LCCA, Appropriateness, Risks, and Decision-Making; comprising 12 indicators: Initial Costs, Operational and maintenance Costs, Final Score, Payback Period Analysis, Payback Period Percentage, Sensitivity Analysis, Internal Rate of Return, Net Present Value, Exchange Rate, Inflation, Interest Rate, and the Role of LCCA in Green Building Investment Decisions.

Cost Performance (Y) consists of a single dimension; internal and external factors, and six indicators: Material Costs, Labor Costs, Equipment Costs, Shipping Costs, Material Price Fluctuation Costs, and Environmental Costs.

The researcher used SEM SMART-PLS version 3.0 software. Research variables from this study are presented in Table 1.

Table 1: Research variables, categories, and indicators.

CODE	VARIABLE/CATEGORY/INDICATOR		REFERENCES
GK	**CONVENTIONAL BUILDING**		
KP	**1.1 Project Management**		
KP01	1	Project Organization	[33], [5],[34]
KP02	2	Risk Management	[33], [5],[34]
KP03	3	Monitoring & controlling	[33], [5],[34]
KP04	4	Project Manager Performance	[33], [5],[34]
KP05	5	Communication & Coordination	[33], [5],[34]
KC	**1.2 Contract Management**		
KC01	1	Bill of Quantity (BoQ)	[33], [35], [36], [37]
KC02	2	Technical Drawings	[33], [35], [36], [37]
KC03	3	Technical Specifications	[33], [35],[36], [37]
KC04	4	Work Schedule	[33],[35], [36], [37]
KC05	5	Requisition and Terms	[33], [35],[36],[37]
GB	**GREEN BUILDING (GB)**		
GS	**2.1 Green Building Certification**		
GS01	1	In applying for PBG, green building certification is required	[20], [13], [21]
GS02	2	In applying for SLF green building certification is required	[20], [13], [21]
GS03	3	In applying for an SLF extension, GB certification is required	[20], [13], [21]
GC	**2.2 Green Building Construction Costs**		
GC01	1	GB construction is more expensive than conventional costs	[20], [38], [39]
GC02	2	The costs are smaller than the benefits of green building	[20], [38], [39]
GM	**2.3 Green building operational and maintenance costs**		
GM01	1	GB operational&maintenance are lower than conventional costs	[20], [38], [39]
GT	**2.4 Appropriate Site Development**		
GT01	1	Basic Green Area	[20], [40],
GT02	2	Site Selection	[20], [40],
GT03	3	Community Accessibility	[20], [40],
GT04	4	Public Transportation	[20], [40],
GT05	5	Bicycle Facility	[20], [40],
GT06	6	Site Landscaping	[20], [40],
GT07	7	Microclimate	[20], [40],

CODE		VARIABLE/CATEGORY/INDICATOR	REFERENCES
GT08	8	Stormwater Management	[20], [40],
GE	**2.5 Energy Efficiency and Conversation**		
GE01	1	Electrical Sub Metering	[20], [40],
GE02	2	OTTV Calculation	[20], [40],
GE03	3	Energy Efficiency Measures	[20], [40],
GE04	4	Natural Lighting	[20], [40],
GE05	5	Ventilation	[20], [40],
GE06	6	Climate Change Impact	[20], [40],
GE07	7	On-Site Renewable Energy	[20], [40],
GA	**2.6 Water Conservation**		
GA01	1	Water Metering	[20], [40],
GA02	2	Water Calculation	[20], [40],
GA03	3	Water Use Reduction	[20], [40],
GA04	4	Water Fixtures	[20], [40],
GA05	5	Water Recycling	[20], [40],
GA06	6	Alternative Water Resources	[20], [40],
GA07	7	Rainwater Harvesting	[20], [40],
GA08	8	Water Efficiency Landscaping	[20], [40],
GS	**2.7 Material Resources and Cycle**		
GS01	1	Fundamental Refrigerant	[20], [40],
GS02	2	Building and Material Reuse	[20], [40],
GS03	3	Environmentally Friendly Material	[20], [40],
GS04	4	Non-ODS Usage	[20], [40],
GS05	5	Certified Wood	[20], [40],
GS06	6	Prefab Material	[20], [40],
GS07	7	Regional Material	[20], [40],
GK	**2.8 Indoor Health and Comfort**		
GK01	1	Outdoor Air Introduction	[20], [40],
GK02	2	CO_2 Monitoring	[20], [40],
GK03	3	Environmental Tobacco Smoke Control	[20], [40],
GK04	4	Chemical Pollutant	[20], [40],
GK05	5	Outside View	[20], [40],
GK06	6	Visual Comfort	[20], [40],
GK07	7	Acoustic Level	[20], [40],
GL	**2.9 Building Environment and Management**		
GL01	1	Basic Waste Management	[20], [40],
GL02	2	GP as a Member of the Project Team	[20], [40],
GL03	3	Pollution of Construction Activity	[20], [40],
GL04	4	Advanced Waste Management	[20], [40],
GL05	5	Proper Commissioning	[20], [40],
GL06	6	Green Building Submission Data	[20], [40],
GL07	7	Fit Out Agreement	[20], [40],
GL08	8	Occupant Survey	[20], [40],
VE	**VALUE ENGINEERING**		
VI	**3.1 Information Phase**		
VI01	1	Top Management Commitment Attitude	[41],[25],[42], [26]
VI02	2	Data analysis	[41],[25],[42], [26]
VI03	3	Information and communication	[41],[25],[42], [26]
VI04	4	Policies and regulations	[41],[25],[42], [26]
VF	**3.2 Function Analysis Phase**		
VF01	1	Improved project quality	[41],[25],[42], [26]
VF02	2	Function analysis	[41],[25],[42], [26]
VK	**3.3 Creativity Phase**		
VK01	1	Selection of work methods	[41],[25],[42], [26]
VK02	2	Material selection	[41],[25],[42], [26]
VE	**3.4 Evaluation Phase**		
VE01	1	Analyzing Value Engineering	[41],[25],[42], [26]
VE02	2	Results from ideas and evaluations for alternatives	[41],[25],[42], [26]
VD	**3.5 Development Phase**		
VD01	1	Reduction of material costs	[41],[25],[42], [26]
VD02	2	Looking for alternative materials	[41],[25],[42], [26]
VP	**3.6 Presentation Phase**		
VP01	1	Implementation of the settlement	[41],[25],[42], [26]
VP02	2	Resource	[41],[25],[42], [26]
VM01	**3.7 Implementation Phase**		
VM01	1	Improved project quality	[41],[25],[42], [26]
VM02	2	Function analysis	[41],[25],[42], [26]
VN	**3.8 Value Engineering (VE) Practice**		

CODE	VARIABLE/CATEGORY/INDICATOR		REFERENCES
VN01	1	VE has a positive effect on cost performance	[41],[25],[42], [26]
VN02	2	*VE is often used in building construction*	[41],[25],[42], [26]
LA		***BUILDING LIFECYCLE / Lifecycle Cost Analysis***	
LC		4.1 Cost Breakdown Structure	
LC01	1	Initial Costs	[7],[43], [21]
LC02	2	Operational & Maintenance Costs	[7],[43], [21]
LC03	3	Final score	[7],[43], [21]
LL		**4.2 LCCA**	
LL01	1	Payback Period Analysis	[7],[43], [21]
LL02	2	Payback Period Percentage	[7],[43], [21]
LK		**4.3 Appropriateness**	
LK01	1	Sensitivity Analysis	[7],[43], [21]
LK02	2	*Internal Rate of Return* (IRR)	[7],[43], [21]
LK03	3	Net Present Value (NPV)	[7],[43], [21]
LR		**4.4 Risks**	
LR01	1	Exchange rate	[44]
LR02	2	Inflation	[38
LR03	3	Interest rate	[38
LP		**4.5 Decision**	
LP01	1	LCCA plays a big role in making GB investment decisions	[45]
KB		**COST PERFORMANCE**	
KY		5.1 Internal and External Factors	
KY01	1	Material Costs	[7], [38]
KY02	2	Labor Costs	[7], [38]
KY03	3	Equipment Cost	[7], [38]
KY04	4	Shipping Costs	[7], [38]
KY05	5	Material Price Fluctuation Costs	[7], [38]
KY06	6	Environment Costs	[7], [38]

Evaluation of the Measurement Model

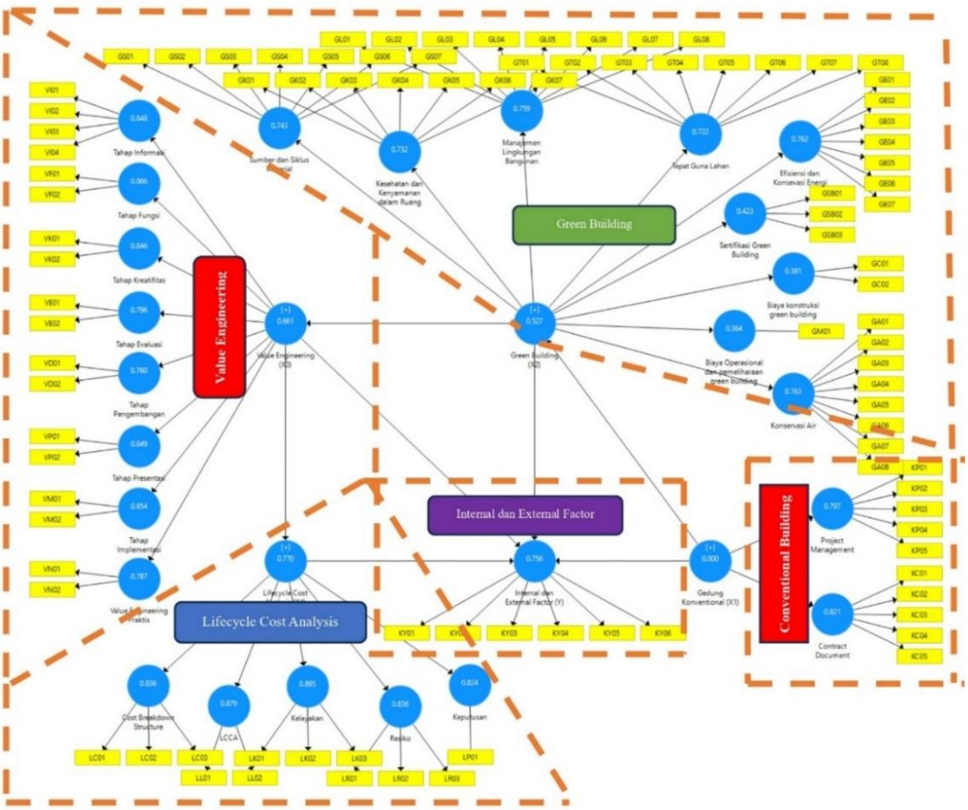

Fig. 4: Model with SEM-PLS.

Figure 4 illustrates that the blue elements represent latent variables, while the yellow elements represent indicators. The figure shows that all indicators reflect their corresponding variables, as detailed below:

1. Conventional Building (X1)
2. Green Building (X2)

3. Value Engineering (X3)
4. Lifecycle cost Analysis (X4)
5. Cost Performance (Y)

Discriminant validity testing confirms that each indicator has the highest loading factor on its corresponding construct, rather than on any other construct. The results of this validity test are shown in Table 2.

Table 2: Composite Reliability, Cronbach's Alpha, and AVE Values.

Construct / Variable	Average Variance Extracted (AVE) [>0.5]	Composite Reliability [> 0.7]	Cronbach Alpha [>0.7]
Conventional Building (X1)	0.979	0.976	0.979
Green Building (X2)	0.971	0.992	0.992
Value Engineering (X3)	0.979	0.989	0.988
Lifecycle Cost Analysis (X4)	0.992	0.986	0.987
Internal dan External Factor (Y)	0.987	0.971	0.964

R-Square (R^2) and Q-Square (Q^2) tests are commonly used to assess the Goodness of Fit of structural models. R^2 indicates the proportion of variance in the dependent latent variable explained by the independent latent variable, with values ranging from 0 to 1. Typically, R^2 values of 0.75, 0.50, and 0.25 are interpreted as strong, moderate, and weak models, respectively. Chin classifies R^2 values into three categories: strong (0.67), medium (0.33), and weak (0.19). The R^2 and Q^2 test results for each variable are presented in Table 3.

Table 3: R-Square & Q-Square Values.

Variable	[R Square]	[Q Square]
Green Building (X2)	0.757	0.527
Internal dan External Factor (Y)	0.908	0.756
Lifecycle Cost Analysis (X4)	0.906	0.770
Value Engineering (X3)	0.807	0.661

The R-squared (R^2) value represents the proportion of variance in the dependent variable explained by the independent variable. For example, an R^2 value of 0.908 for Y = cost indicates that the latent variables and the median account for 90.8% of the variance in price.

Path coefficients are measured to evaluate the significance and strength of relationships between constructs and test hypotheses. These coefficients range from -1 to +1, where values closer to +1 indicate a stronger positive relationship between constructs, and values below 0 represent a negative relationship.

The Bootstrapping procedure analyzes structural models (inner loading) and relationships between constructs (latent variables). The interpretation of path coefficients is based on bootstrapping results, path analysis, or structural models. A path is deemed significant if the T-statistic exceeds 1.96 and the p-value is below 0.05. Table 4 demonstrates that the analysis results are substantial, with T-statistic values greater than 1.96 and p-values less than 0.05.

Table 4: Path Coefficient Values.

Correlations	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values
Conventional Building(X1) -> Green Building (X2)	0.870	0.865	0.041	21.187	0.000
Conventional Building (X1) -> Internal and External Factor (Y)	0.756	0.751	0.066	11.383	0.000
Conventional Building (X1) -> Lifecycle Cost Analysis (X4)	0.744	0.738	0.066	11.239	0.000
Conventional Building (X1) -> Value Engineering (X3)	0.782	0.776	0.061	12.818	0.000
Green Building (X2) -> Internal and External Factor (Y)	0.850	0.845	0.078	10.904	0.000
Green Building (X2) -> Lifecycle Cost Analysis (X4)	0.855	0.851	0.042	20.139	0.000
Green Building (X2) -> Value Engineering (X3)	0.899	0.896	0.035	25.556	0.000
Lifecycle Cost Analysis (X4) -> Internal and External Factor (Y)	0.683	0.692	0.105	6.489	0.000
Value Engineering (X3) -> Internal and External Factor (Y)	0.743	0.747	0.098	7.611	0.000
Value Engineering (X3) -> Lifecycle Cost Analysis (X4)	0.952	0.949	0.016	59.212	0.000

To evaluate the significance of the prediction model in testing the structural model, refer to the T-statistic values for the relationship between the independent and dependent variables in the Path Coefficient table provided in the Smart-PLS output shown in Table 5.

The model is considered a good fit based on the SRMR value of 0.050, below the threshold of 0.08. However, it does not meet the fit criteria based on the RMS Theta (Root Mean Square Theta) value of 0.147, which exceeds the threshold of 0.10. Therefore, despite one of the fit criteria being satisfied, the model generally fits the data based on the assessment.

Table 5: Reflective Loading of Variables Based on Category.

Indicator	original sample estimate	mean of subsamples	Standard deviation	T-Statistic
Conventional Building (X1) -> Internal and External Factor (Y)	0.016	0.019	0.080	0.202
Green Building (X2) -> Internal and External Factor (Y)	0.182	0.174	0.118	1.551
Lifecycle Cost Analysis (X4) -> Internal and External Factor (Y)	0.683	0.692	0.105	6.489
Value Engineering (X3) -> Internal and External Factor (Y)	0.093	0.090	0.136	0.689

Obtained cost-effective model equation "$\mathbf{Y = 0.016X_1 + 0.182X_2 + 0.093X_3 + 0.683X_4}$"

The Smart PLS results highlight that lifecycle costs play the most significant role in determining the financial feasibility of green buildings. To provide a practical interpretation of these findings, developers can adopt several cost-reduction strategies throughout a building's lifecycle. One key approach is using Value Engineering (VE) during the design phase, allowing developers to optimize material selection, reduce waste through modular construction, and balance initial investment with long-term savings through comprehensive life cycle cost (LCC) assessments.

Additionally, energy-efficient technologies play a crucial role in reducing operational costs. Implementing solar panels, high-performance insulation, and intelligent building automation can significantly reduce energy expenses. Passive design strategies, such as natural ventilation and daylighting, further contribute to cost savings. Beyond construction and design, strategic maintenance and operational planning also influence lifecycle costs. Predictive maintenance using IoT sensors and water-saving technologies like rainwater harvesting and greywater recycling ensures long-term financial efficiency.

Furthermore, developers can leverage government incentives, tax reductions, and green financing schemes to offset upfront costs. Achieving green building certifications improves property value and aligns with regulatory requirements, such as Indonesia's Regulation No. 21/2021, which mandates sustainable construction practices. By integrating these strategies, developers can effectively manage lifecycle costs, ensuring that green buildings remain financially viable while supporting long-term sustainability goals.

Table 6: Fit Summary & RMS Tetha.

Fit Summary	Saturated Model	Estimated Model
SRMR	0.045	0.050
d_ULS	35.859	45.164

RMS Theta	0.147

The SRMR and RMS Tetha values are shown in the table 6. The model is Fit based on the SRMR value of 0.050, less than 0.08. Meanwhile, it does not fit based on the RMS Theta or Root Mean Square Theta value of 0.147 > 0.10. So based on the model assessment, one of the models meets the model fit criteria so it can be concluded that the model fits the data.

The contradiction between SRMR (good fit) and RMS Theta (poor fit) highlights potential model limitations that need further discussion. SRMR, which measures the difference between observed and predicted correlations, suggests that the model aligns well with the data. However, RMS Theta, which assesses residual covariances, indicates possible model misspecifications. This discrepancy suggests that while the model explains observed relationships, it may still omit key structural components, leading to unexplained residual variances.

In the next research, we will explore potential causes, such as model complexity, sample size effects, and measurement issues, to address this. Additionally, we will examine other fit indices like CFI and TLI to provide a more comprehensive assessment. Clarifying these inconsistencies will strengthen the model's reliability and improve the interpretation of findings.

Discussion

The cost-effective model equation Y=0.016X1+0.182X2+0.093X3+0.683X4 was applied to calculate cost performance for two types of buildings in Indonesia: government buildings and commercial office buildings.

In Indonesia, the inflation rate for the property industry is approximately 5% per year. The actual data collected includes initial investment costs, additional costs for converting conventional buildings to green buildings, and costs associated with value engineering, management, maintenance, electricity, and water. According to the Regulation of the Minister of Public Works and Public Housing No. 45/PRT/M/2007, the service life of a building is set at 50 years.

The previous research provides a valuable framework for evaluating public procurement through a life cycle cost perspective, highlighting its role in enhancing long-term economic and environmental sustainability [46].

First Case: Government Building

The first building analyzed is a government facility that began operations in 2012. This building operates consistently from Monday to Friday, with working hours from 8 AM to 4 PM and no overtime. The building covers a total area of 25,990 m².

Table 7 shows the actual cost data for this building from 2013 to 2020, covering expenses from initial investment to water usage costs. The total effective cost was recorded at IDR 25,042,088,877 in 2013 and increased to IDR 124,563,911,892 by 2020.

Table 8 calculates the predicted effective costs based on a 5% annual inflation rate, accounting for management, maintenance, electricity, and water costs. The expected costs are IDR 25,042,088,877 in 2013 and IDR 123,283,481,564 in 2020.

The difference between the predicted and actual costs is minimal, with only a 1% variance.

Second Case: Commercial Building

The second building is a commercial office that began operating as a green building in 2014. Unlike the government building, its operating hours vary according to tenant needs. They run from Monday to Saturday, with extended hours from 8 AM to approximately 7 PM. The building covers a total area of 100,980 m². Table 9 presents accurate cost data for the commercial building from 2015 to 2022, covering initial investment in water usage costs. The total actual effective cost was recorded at IDR 78,998,842,909 in 2015, increasing to IDR 426,637,164,798 by 2022, and to Table 10 IDR 437,233,525,659 by 2022.

The difference between the predicted and actual costs is minimal, with only a 2% variance.

Table 7: Cost-Effective Model for Actual of Government-owned Green Building.

Year	Cost-Effective Actual	Conventional Building Cost	Green Building Cost	Lifecycle Cost	Initial Cost PUPR Reg.	Cumulative Management & Maintenance Fee	Cumulative Elec.+ Water Fee
2013	25,042,088,877	361,816,967,582	39,799,866,000	17,583,370,108	8,032,336,672	6,364,101,876	3,186,931,560
2014	37,981,172,220	361,816,967,582	39,799,866,000	36,527,855,237	16,064,673,344	14,137,972,003	6,325,209,890
2015	51,958,323,665	361,816,967,582	39,799,866,000	56,992,205,816	24,097,010,016	23,054,560,283	9,840,635,517
2016	65,991,630,917	361,816,967,582	39,799,866,000	77,538,775,731	32,129,346,688	32,357,167,083	13,052,261,960
2017	80,194,484,141	361,816,967,582	39,799,866,000	98,333,582,794	40,161,683,360	41,831,223,923	16,340,675,511
2018	94,598,485,115	361,816,967,582	39,799,866,000	119,422,896,078	48,194,020,032	51,478,578,196	19,750,297,851
2019	109,349,573,444	361,816,967,582	39,799,866,000	141,020,389,971	56,226,356,704	61,363,907,903	23,430,125,365
2020	124,563,911,892	361,816,967,582	39,799,866,000	163,296,141,725	64,258,693,376	71,743,504,095	27,293,944,255

Table 8: Cost-Effective Model for Prediction of Government-owned Green Building.

Year	Cost-Effective Predicted	Conventional Building Cost	Green Building Cost	Lifecycle Cost	Initial Cost PUPR Reg.	Cumulative Management & Maintenance Fee	Cumulative Elec. + Water Fee
2013	25,042,088,877	361,816,967,582	39,799,866,000	17,583,370,108	8,032,336,672	6,364,101,876	3,186,931,560
2014	37,981,172,220	361,816,967,582	39,799,866,000	36,527,855,237	16,064,673,344	14,137,972,003	6,325,209,890
2015	51,292,905,433	361,816,967,582	39,799,866,000	56,017,947,788	24,097,010,016	22,300,535,636	9,620,402,137
2016	64,894,886,881	361,816,967,582	39,799,866,000	75,933,001,153	32,129,346,688	30,871,227,451	12,932,427,014
2017	78,840,367,570	361,816,967,582	39,799,866,000	96,350,981,664	40,161,683,360	39,870,453,857	16,318,844,447
2018	93,204,148,662	361,816,967,582	39,799,866,000	117,381,407,861	48,194,020,032	49,319,641,583	19,867,746,246
2019	108,068,852,994	361,816,967,582	39,799,866,000	139,145,250,220	56,226,356,704	59,241,288,696	23,677,604,821
2020	123,283,481,564	361,816,967,582	39,799,866,000	161,421,426,750	64,258,693,376	69,659,018,164	27,503,715,211

Table 9: Cost-Effective Model for Actual of Commercial Office Green Building.

Year	Cost-Effective Actual	Conventional Building Cost	Green Building Cost	Lifecycle Cost	Initial Cost PUPR Reg.	Cumulative Management & Maintenance Fee	Cumulative Elec. + Water Fee
2015	78,998,841,909	1,309,184,052,282	91,642,883,660	60,575,244,870	28,016,538,719	21,602,715,000	10,955,991,151
2016	125,681,101,656	1,309,184,052,282	91,642,883,660	128,924,087,838	56,033,077,438	47,599,790,678	25,291,219,722
2017	173,742,513,132	1,309,184,052,282	91,642,883,660	199,292,186,631	84,049,616,157	74,406,503,507	40,836,066,967
2018	222,927,718,081	1,309,184,052,282	91,642,883,660	271,305,663,863	112,066,154,876	102,161,216,207	57,078,292,780
2019	272,486,887,981	1,309,184,052,282	91,642,883,660	343,866,673,966	140,082,693,595	129,944,216,207	73,839,764,164
2020	323,069,576,095	1,309,184,052,282	91,642,883,660	417,926,246,607	168,099,232,314	157,650,216,207	92,176,798,086
2021	374,057,065,607	1,309,184,052,282	91,642,883,660	492,578,500,651	196,115,771,033	185,357,194,748	111,105,534,870
2022	426,637,164,798	1,309,184,052,282	91,642,883,660	569,562,540,461	224,132,309,752	214,449,522,216	130,980,708,493

Table 10: Cost-Effective Model for Prediction of Commercial Office Green Building.

Year	Cost - Effective Predicted	Conventional Building Cost	Green Building Cost	Lifecycle Cost	Initial Cost PUPR Reg.	Cumulative Management & Maintenance Fee	Cumulative Elec. + Water Fee
2015	78,998,841,909	1,309,184,052,282	91,642,883,660	60,575,244,870	28,016,538,719	21,602,715,000	10,955,991,151
2016	125,681,101,656	1,309,184,052,282	91,642,883,660	128,924,087,838	56,033,077,438	47,599,790,678	25,291,219,722
2017	173,740,709,593	1,309,184,052,282	91,642,883,660	199,289,546,018	84,049,616,157	74,896,720,140	40,343,209,722
2018	223,246,533,130	1,309,184,052,282	91,642,883,660	271,772,450,172	112,066,154,876	103,558,496,075	56,147,799,221
2019	274,270,883,046	1,309,184,052,282	91,642,883,660	346,478,672,597	140,082,693,595	133,653,360,807	72,742,618,196
2020	326,889,685,662	1,309,184,052,282	91,642,883,660	423,519,379,208	168,099,232,314	165,252,968,775	90,167,178,119
2021	381,182,663,610	1,309,184,052,282	91,642,883,660	503,011,294,213	196,115,771,033	198,432,557,142	108,462,966,038
2022	437,233,525,659	1,309,184,052,282	91,642,883,660	585,076,978,032	224,132,309,752	233,271,124,927	127,673,543,354

5. Conclusion

Utilizing Value Engineering and Lifecycle Cost methods and SMART-PLS statistical analysis, we can develop an effective predictive model to optimize project sustainability and costs. Our findings indicate that lifecycle cost is the most influential variable in cost calculation. The resultant cost prediction model demonstrates remarkable accuracy, with deviations under 3% from actual costs, primarily attributed to fluctuations in exchange rates, or interest rate factors.

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