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Cost Efficiency of Retrofitting Green Chemical Industrial Buildings

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Abstract

Climate change is a threat and crisis that hit the world today. The green industry is widely implemented in the manufacturing sector as an effort to reduce negative impacts on the environment. The implementation of the green industry is influenced by various factors. The Chemical Industry is one sector that faces challenges in implementing green industry practices. The objective of this paper is to create an innovative conceptual framework that combines blockchain technology and building information modeling. This research examines the concept of green retrofitting in the chemical industry using an assessment based on the Ministry of Public Works and Housing Regulation No. 21 of 2021. The study was conducted in a chemical industry located in Cilegon, Banten, Indonesia. The research method combines Blockchain-Building Information Modeling (BIM) to analyze the cost efficiency of green retrofitting and Structural Equation Modeling-Partial Least Squares (SEM-PLS) as a tool to process data from questionnaires and identify influential factors. The results indicate that the use of Blockchain-BIM can reduce retrofitting costs by 4.42% for low-level, 4.45% for medium-level, and 4.40% for high-level categories. This demonstrates that Blockchain-BIM has a significant impact on improving cost performance in the retrofitting process.

Keywords: Green Retrofit; Green Chemical Industry; Blockchain-BIM; SEM-PLS; Cost Efficiency.

1. Introduction

The awareness of the worldwide consequences of climate change, energy depletion, and the increase in greenhouse gas emissions has intensified public concern about the current trends in energy consumption [1–3]. Approximately 30% of the world's total CO2 emissions can be attributed to buildings [4–6]. The progression of climate change and increasing temperatures amplifies the occurrence and intensity of droughts. In arid and semi-arid areas, climate change has resulted in more frequent and severe droughts, diminishing the accessibility of water for diverse purposes [7]. As part of the Coordinated Regional Climate Downscaling Experiment, Ozturk et al. [8] conducted a study investigating the impact of climate change on the seasonal fluctuations of precipitation and temperature in an Asian region. The results indicated a notable warming trend in surface temperatures in the southeastern Pacific. Due to the significant challenge of global warming faced by the world, climate change is an important environmental issue [9], impacting both private sector institutions and governments. It has become essential for all communities to develop new business plans that prioritize finding environmental solutions. The construction industry plays an important role in various industrial impacts on the natural environment. The industry is characterized by high energy and resource consumption and high environmental pollution [10]. The construction sector bears responsibility for the excessive utilization of natural resources and energy consumption [11, 12]. The concept of Green Buildings offers several advantages in terms of economics, social aspects,

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and the environment, which incorporate principles of sustainable resource conservation (energy, water, land, and nature), resource efficiency (energy, water, land, and materials), and resource sharing (public facilities for transportation and work) [13]. The Technical Guidelines of the Ministry of Public Works and Housing No. 1 of 2022 provide the latest guidelines for green building construction in Indonesia. According to this regulation, there are three rating levels: Green Building Main (80%–100%), Middle (65%–80%), and Primary (45%–65%), with a maximum total score of 165 points [14]. Generally, retrofitting existing buildings tends to be more expensive compared to integrating Green Building concepts into new construction. The cost to upgrade existing buildings into Green Buildings can reach around 10.77% of the initial cost [15].

The green building chemical industry plays a crucial role in promoting the development of environmentally sustainable buildings through the integration of design strategies that minimize the adverse effects of buildings on the environment and their occupants [16]. The chemical industry catalyzes the development and progress of modern society [16]. The issue of global warming is a significant global concern that affects both private enterprises and governmental organizations, necessitating the need for everyone to devise innovative business plans that prioritize environmental solutions [17]. Draft Building Green has multiple advantages in terms of economics, social aspects, and the establishment of environmentally friendly structures through the utilization of sustainable conservation sources (energy, water, land, and nature), efficient power sources (such as geothermal energy and eco-friendly materials), and the ability to share resources (including general facilities, transportation, and workspace) [1, 18].

Identifying critical success factors (CSFs) is crucial for the successful implementation of a project and the attainment of specified objectives [19]. In the context of green concept development, understanding the CSFs is vital for ensuring optimal project performance, as suggested by the existing literature and proposed methodology [20]. Based on the reviewed literature, the three most significant factors are management support, financial capability, and design specifications [21]. Furthermore, the literature indicates that project cost is a more critical factor compared to project schedule and quality. Green buildings offer tangible benefits such as 30-50% water savings and 20-30% energy savings. Additionally, there are intangible benefits such as enhanced air quality, natural light, and improved health, comfort, and well-being for occupants [22].

Blockchain operates as a decentralized framework for handling transactions and information [23]. Blockchain is a technology that enables the secure and immutable exchange of information and transactions between two or more participants through complete encryption [24]. Blockchain technology relies on distributed ledger technology—a shared ledger among all participants in the network [25, 26]. Transfers do not require a centralized intermediary to identify and authenticate information but are distributed among multiple independent participants in the blockchain network (nodes) who register and validate it [27]. Each participant has an exact copy of the information, enabling traceable and tamper-proof transactions. This transparency can be extended to every change made to the project model [28]. The identification has been made that Blockchain possesses the capability to overcome obstacles hindering industries from embracing BIM for sustainable design [29].

Building Information Modeling (BIM) represents a paradigm shift that offers numerous benefits, not only for those involved in the construction industry but also for the wider community [30]. A superior building requires less energy, labor, and capital during its construction phase [31]. Through BIM models that create realistic prototypes of building design and construction, it generates sufficient information that meets the needs of users [25, 28, 31]. BIM provides all the necessary tools and automation to achieve end-to-end communication, data exchange, and information sharing among collaborators [32]. A Building Information Modeling (BIM) model, which serves as a prototype for the visual representation of genuine building design and construction, is capable of producing substantial information for users [33]. Lessons learned include the fact that, while BIM can provide certain benefits to a project, it also extends the project duration and increases project costs [34, 35]. The first integrated application of Blockchain and BIM aimed at productivity has been tested at the research and technology development site of the Spanish DELFOS project [36]. The integrated technology of BIM and Blockchain promises an increasingly secure and private environment for conducting business with full control over processes [37]. Blockchain enables features such as proof of ownership, for example, addressing rights; proof-of-provenance, for example, recording through a traceable and immutable ledger; and reduction of human errors and deviations [38]. Blockchain smart contracts have emerged as a new value proposition for enhancing specific sustainability aspects within projects [39].

This research utilizes an Action Research approach to transform the building's status into a green industry and address the environmental impacts generated by the chemical industry [40]. To obtain a better analysis of cost efficiency using Blockchain-BIM in the green retrofit-based chemical industry, a research framework was employed, consisting of variables formulated to compare the resulting impacts. The collected data was then analyzed to gather preliminary information. This initial information was subsequently discussed and reviewed to draw conclusions regarding the effective payment process and provide a descriptive account to enhance cost efficiency using Blockchain-BIM in the green retrofit-based industry.

2. Methodological Framework

2.1. Data Collection

In this study, primary data was collected through an audit or verification process to evaluate the compliance of existing buildings with green building requirements [41]. The primary data reflects the level of compliance with the Technical Guidelines of the Ministry of Public Works and Housing Regulation No. 01 of 2022. In this stage, the use of data begins with available secondary data within the company, such as energy production and consumption data. Additionally, secondary data in the form of project documents, such as planning drawings, Bill of Quantity, and operational data of the facility, will also be utilized. During the development of the questionnaire, the author sought indicators that had the most significant influence. When formulating the questionnaire, we referred to the indicators that had been identified and presented by previous researchers. This questionnaire will be distributed to project stakeholders, including those directly and indirectly involved. In analyzing the data, we will utilize a simulation tool called Structural Equation Modeling (SEM) using the SMART PLS (Partial Least Squares) 3.0 software. Additionally, we will conduct interviews to gain a deeper understanding. With the use of this tool, we aim to identify the main factors and dominant subfactors that influence the cost efficiency we are examining. SMART PLS is a widely used and renowned software for data analysis in scientific research.

2.2. Research Methodology

The objective of this research is to identify the significant factors influencing the implementation of cost efficiency in green retrofitting of the chemical industry based on Blockchain-Building Information Modeling (BIM). Below is a flowchart diagram (Figure 1) illustrating the process of discovering the most significant influencing factors. In the initial stage of this research, the identification of relevant factors and subfactors was conducted. Subsequently, data collection was carried out using the research instrument. These steps have been completed before the current discussion. The research involved a literature review to gather influential factors related to the Chemical Industry (X1), Green Retrofitting (X2), Blockchain-BIM (X3), and Cost Variable (Y).

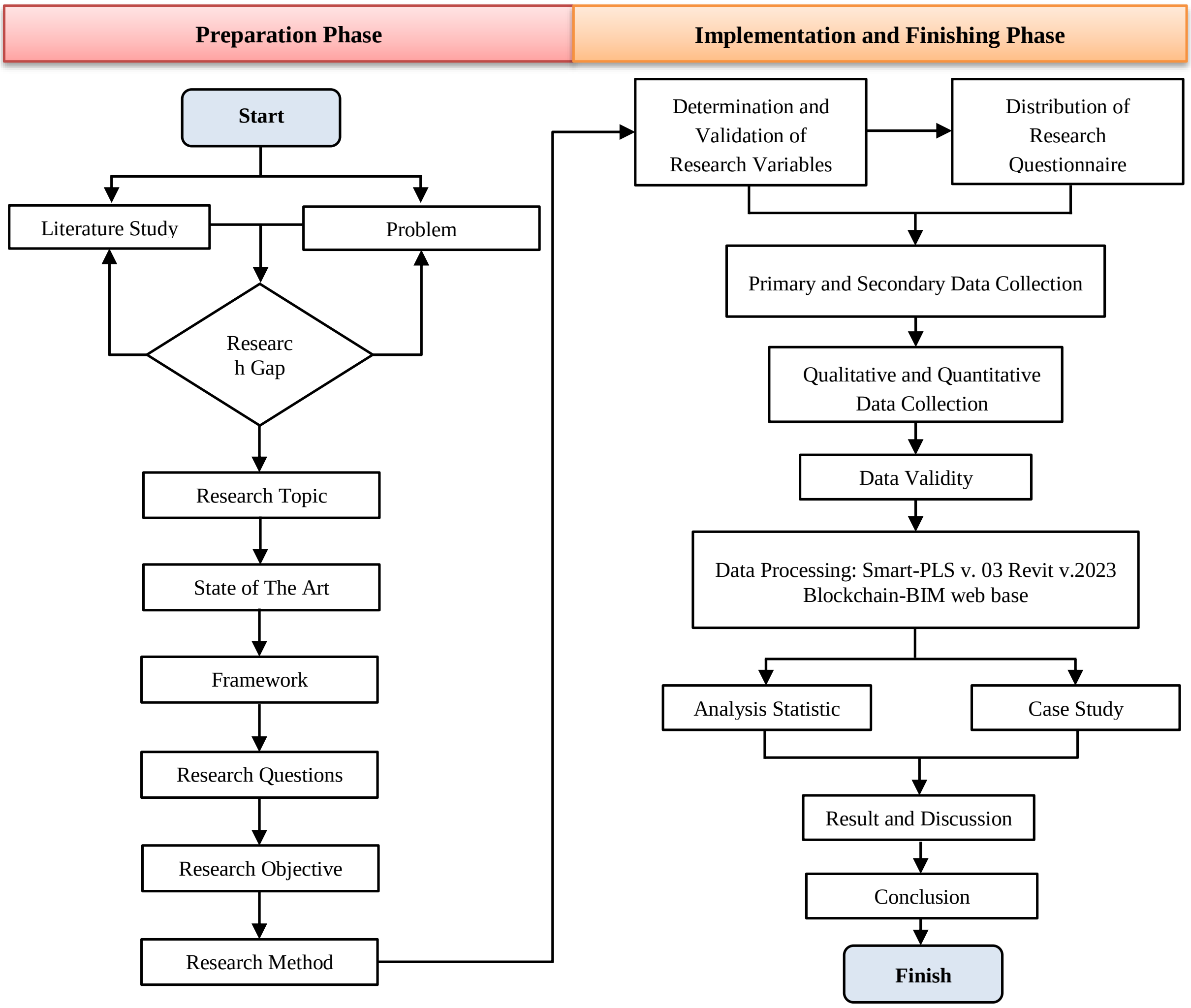


Figure 1. Research Framework [5, 42]

The questionnaire provided to selected respondents involves a rating scale from 1 to 6, where each answer choice represents a different criterion. The scale is designed in such a way that a score of 1 indicates the least expected answer, while a score of 6 indicates the most expected answer. The processed and tabulated data in Excel format will be securely stored as an archive. This is done to ensure that the data can serve as easily accessible evidence if needed. Following data collection, the data will be examined and categorized based on respondents' highest education level, position, and work experience. This process is crucial to ensure the targeted distribution of the questionnaire and to ensure the obtained data has good validity. The research instruments used, including the questionnaire, have been thoroughly prepared and are available in a comprehensive appendix that also includes a summary of respondent data.

The PLS (Partial Least Squares) method follows a three-stage approach, which includes the principal component approach, the projection or regression approach, and the measurement approach. In SEM-PLS analysis, several factors need to be considered when determining the appropriate sample size, such as missing values, data distribution, and measurement scales [43]. Researchers should pay attention to whether the data used meets the requirements for SEM-PLS modeling. Researchers should also consider the presence of incomplete observations (missing values) in their data. Additionally, it is advisable to use a better measurement scale than a nominal scale when measuring endogenous latent variables to ensure a well-identified model. In SEM-PLS testing, factors under consideration encompass model properties, sample size, the distribution shape of data, missing values, and the measurement scale. The determination of the minimum sample size arises from the path factor (p-min) and the variation observed during the 80% statistical stress test [44]. To accomplish the research objectives, the subsequent phase involves formulating a research plan for each step to obtain statistical analysis and outlining the steps for implementing the research in the case studies.

Revit is renowned across various engineering domains due to its versatility, exceptional precision, and rapidity. It functions as a Building Information Modeling (BIM) software, commonly referred to as Revit. The evolution of information modeling streamlines the storage of data, facts, and analyses. The results of the project will be amalgamated with a supportive framework to generate a realistic depiction. For enhanced accuracy in translation, additional details from the source text are necessary. Panels are present on both opposing sides. The assessment of project time and cost management principles, coupled with existing methodologies, aims to provide actionable suggestions.

According to Figure 2, the execution of the research involves 4 main variables, which are subsequently investigated and analyzed to ensure the precision of the research. Subsequently, the researcher details the stages involved in exploring, developing, and analyzing the key factors in the research process to attain the research objectives.

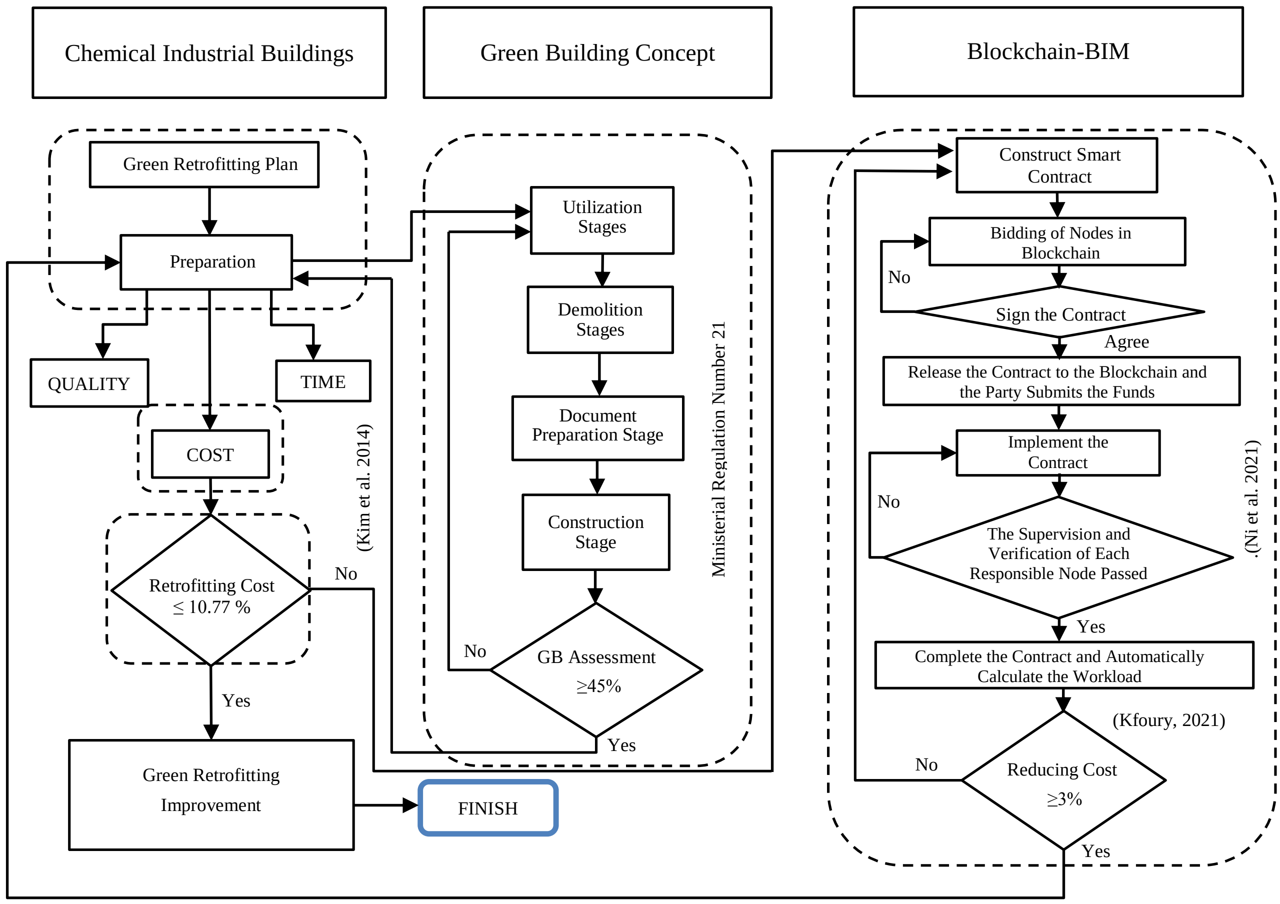


Figure 2. Research Implementation of GB Concept on Chemical Industrial Building, Configured of [42, 45, 46] and Flow Adoption of Yuliatti et al. (2022) [47]

3. Result and Discussion

3.1. Data Processing Result

The study was conducted at a Chemical Industry Building Project located in Cilegon-Banten, Indonesia. This project, spanning approximately ± 50,000 m^2, is intricate and aligns with all the stipulated parameters outlined in the Technical Guidelines for implementing the latest Green Building regulations mandated by the Indonesian government. Research questionnaires were distributed to 120 participants, which meets the minimum requirement of 118 respondents for statistical analysis (Figure 3). The respondent data consists of the information collected from the participants:

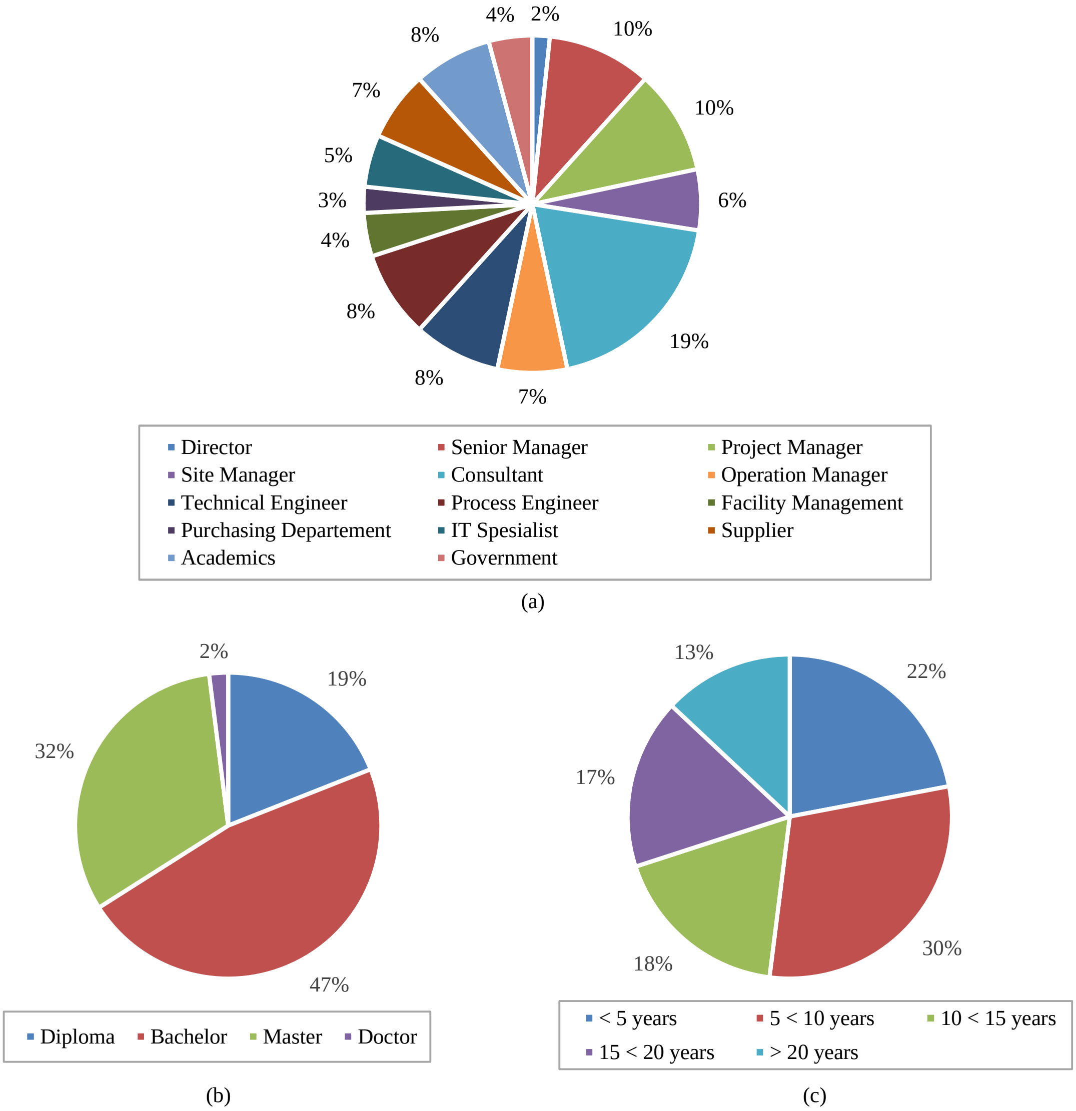


Figure 1. Respondent data, (a) position, (b) education, (c) work experience

To ensure that the data population is accurately targeted, determining the population is not solely based on the population size but also involves validation from experts. This is done to ensure that the targeted population aligns with the research objectives. After data collection, the gathered data is examined and grouped based on variables such as education, job position, and project experience. This is crucial to appropriately direct the questionnaire to relevant respondents, thereby obtaining valid data (Table 1). By the latest Green Building regulations established by the Indonesian government, it is mandatory for this building to meet the specified Green Building criteria. However, the evaluation results reveal a score of 62.3 points in the planning stage, indicating the need for improvements across various aspects to achieve a minimum Basic rating of 74.25 points. Of particular significance is the role of energy-related points in reaching this goal.

Table 1. Performance Assessment of Utilization Stage in Green Building based on Technical Guidelines of the Ministry of PUPR No.1 Year 2022 [14, 48]

No.	Criteria	Point	No.	Criteria	Point
1	Public Transportation	1	57	Do not use materials that affect health	2
2	Vehicle electric battery charging	1	58	Construction does not interfere with activities	2
3	Bicycle parking lots	1	59	Project innovation toward 'green' area improvement	2
4	Environmental Management Documents	1	60	Efficient construction equipment	1
5	Document on water-saving efforts	1	61	Safety against tool use	1
6	Document on energy-saving efforts	1	62	Management of construction waste piles	1
7	Area improvement effort document	1	63	Green construction process document	1
8	Document on waste management efforts	1	64	Work handover document	1
9	Document on waste management efforts	1	65	Government spatial plant drawing document	1
10	Opr. & Standard Operating Procedure (SOP) Document	1	66	Evaluation of waste management utilization	3
11	Master plan area	1	67	Evaluation of water consumption utilization	3
12	Performance management area	1	68	Evaluation of local material utilization	3
13	Inspection of area infrastructure and facilities	1	69	Evaluation of electricity consumption utilization	3
14	SOP emergency response	1	70	Evaluation of Outdoor Space Function Utilization	3
15	Maintenance manager training	2	71	Maintenance and care according to evaluation	4
16	Soft skills training	1	72	Improvements to increase tenant satisfaction	4
17	Local architecture design	2	73	Local architecture for building and area design	2
18	Preservation of heritage areas and buildings	2	74	Preservation of cultural heritage buildings	2
19	20% local raw materials (0-20 km radius)	3	75	20% local materials	2
20	Consumption plants (min. 10% of green space area)	1	76	Planting of consumption of crops min. 10%	2
21	Drainage with flood ≤ 30cm, receding ≤ 2 hours	1	77	Drainage reliability to manage water logging	2
22	Periodic blackout-free power grid	2	78	Regional power grid free of periodic blackouts	2
23	Information and communication networks.	2	79	Disruption-free information. and comm. networks	2
24	Facilities are in good condition.	2	80	Vehicle electric battery charging	2
25	Min. 10% of the area of the facility	1	81	Min. 10% of the area for MSEs	1
26	Maintenance of regional road facilities and infrastructure	1	82	There are road operations within the area	1
27	Green lanes on-road facilities and infrastructure	1	83	Green lanes on-road facilities and infrastructure as required	1
28	Path of Sharing in a Residential Environment	1	84	Roads in residential neighborhoods	1
29	Shared beneficial path	1	85	Sharing the road with speed bumps	1
30	Sharing road equipped with speed bumps	1	86	There are road signs	1
31	Road signs or markers	1	87	Min. 50 street trees per 10 meters	1
32	Min. 50% of road sections share trees	1	88	There is >30% green space from the total area of the whole area	3
33	Outdoor Space > 30% of the total area	3	89	Land area according to the Government Spatial Plan	2
34	Land by Government Spatial Plan	3	90	Not using productive land	1
35	Development of areas not on productive land	2	91	There is a soil pollution investigation	1
36	Area soil pollution investigation	1	92	Negative value land revitalization	2
37	Land revitalization is negative.	2	93	Min. 50% natural terrain	2
38	Retain min. 50% natural landforms.	2	94	Min. 30% infiltration surface area	1
39	Min. 30% of the area's surface for rainwater.	2	95	Min. 10% porous land cover	2
40	Min. 10% using porous covers	1	96	There is green vegetation with a canopy area of min. 20% of the area	2
41	Green vegetation min. 20% area	2	97	There is a use of alternative water sources of at least 10%.	1
42	Alternative water sources min. 10%	1	98	Note of work application	1
43	Whole area water meters	1	99	The entire area uses water meters	1
44	Min. 1% catchment area	1	100	Min. 1% water catchment area	1
45	Min. 1 communal wastewater treatment	1	101	There is a communal wastewater treatment plant	1

46	Min. 1 communal garbage	1	102	There is at least 1 communal waste disposal facility	1
47	Min. 1 communal waste composter	1	103	Min. 1 waste composter facility	1
48	Min. 1 waste collection device	1	104	There is at least 1 polling station	1
49	Min. 1 temporary waste storage	1	105	There is 1 waste recycling building	1
50	Min. 1 Waste recycling	1	106	There is an organization that manages the waste in the area	1
51	Waste management organization	1	107	There is the use of renewable electricity sources	2
52	Infrastructure lighting area	2	108	Project implementation record	1
53	Facility lighting area	1	109	If only 50% of the lights are illuminated, the score is 1 point.	2
54	Facilities and infrastructure meet the law	2	110	There is the use of renewable electrical energy sources	2
55	Reuse of used materials min. 10% of the total cost	2	111	Facilities and infrastructure comply with laws and regulations	2
56	Renewable materials min. 10% of material costs	2	112	Use of 10% reused materials	2

3.2. Implementation of SEM-PLS for Identifying the Dominant Factor of Influence

In this research project, the questionnaire data gathered by the researchers will undergo processing and analysis using "structural equation modeling" (SEM). The p-values of the loading factor and path coefficient, along with the diagram corresponding to Figure 4, can demonstrate the relationship between p-value and path coefficient. SEM allows for a thorough examination of latent variables, factors, and procedural issues, which can be analyzed as subfactors of observed or latent variables. The researchers utilized the SEM SMART-PLS software version 3.0 for this analysis. Figure 5 shows that the R-Square value of the collective influence on the Cost (Y) variable is 0.825, with an adjusted R-Square value of 0.824. This indicates that all independent variables collectively influence the Cost (Y) variable by 0.825, or 82.5%. Since the adjusted R-Square value of 82.5% is greater than 50%, it can be concluded that the influence of all independent variables on the Cost (Y) variable is considered strong.

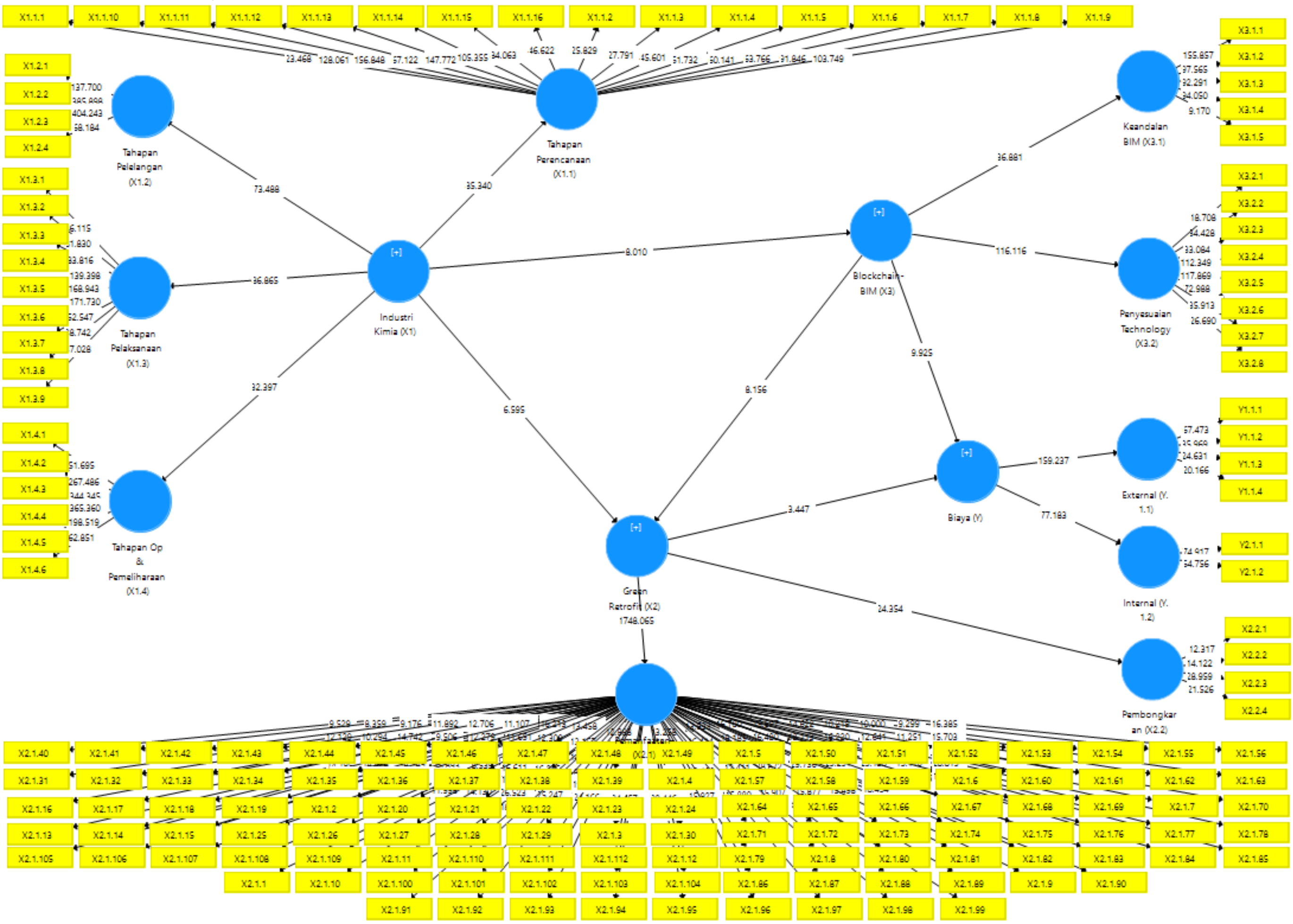


Figure 2. The Diagram of P-values and Partial Coefficients

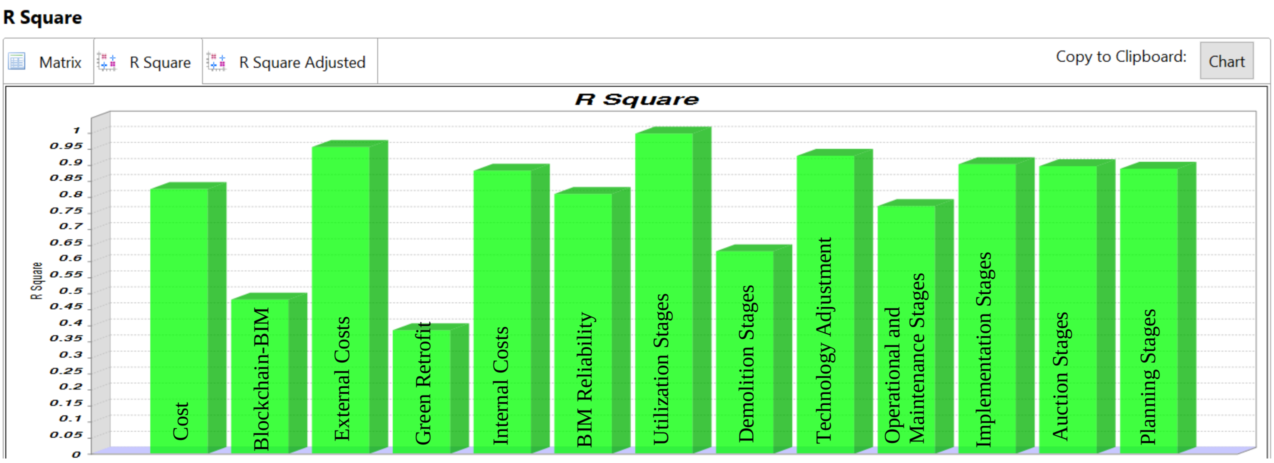


Figure 3. The diagram of R-Square values

Based on the analysis conducted on 170 factors, it was found that there are 10 factors in Table 2, that have the most significant influence in improving the cost performance of Green Building retrofit in Industrial Buildings using Blockchain-BIM Table 3. The most influential factor, in descending order, is the evaluation of electricity consumption utilization Table 4.

Table 1. The Most Influential Main Factor

No	Factor	R Square
1	Utilization Stages (X2.1)	0.998
2	External Costs (Y1.1)	0.956
3	Technology Adjustment (X3.2)	0.928
4	Implementation Stages (X1.3)	0.902
5	Auction Stages (X1.2)	0.896
6	Planning Stages (X1.1)	0.888
7	Internal Costs (Y2.1)	0.882
8	BIM Reliability (X3.1)	0.810
9	Operational and Maintenance Stages (X1.4)	0.772
10	Demolition Stages (X2.2)	0.631

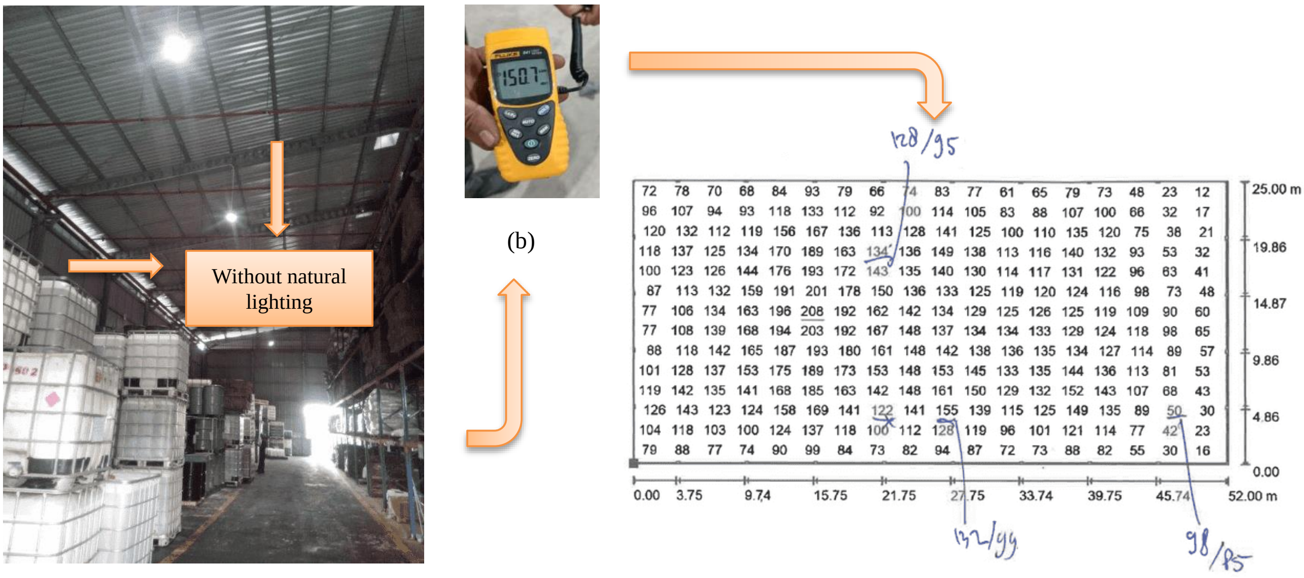
Table 2. Results of Construct Reliability Examination based on Convergent Validity

Main Factor	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
Green Retrofit (X2)	0.992	0.992	0.992	0.514
Chemical Industry (X1)	0.993	0.993	0.993	0.807
External Costs (Y2)	0.900	0.904	0.952	0.909
Internal Costs (Y1)	0.901	0.904	0.931	0.773
Costs (Y)	0.935	0.940	0.949	0.757
Blockchain-BIM (X3)	0.973	0.974	0.976	0.760
BIM Reliability (X3.1)	0.949	0.950	0.964	0.844
Auction Stage (X1.2)	0.992	0.992	0.994	0.977
Implementation Stages (X1.3)	0.992	0.992	0.993	0.938
Utilization Stages (X2.1)	0.991	0.992	0.992	0.517
Demolition Stages (X2.2)	0.871	0.883	0.912	0.721
Technology Adjustment (X3.2)	0.979	0.980	0.983	0.876
Planning Stages (X1.1)	0.991	0.992	0.992	0.887
Operational and Maintenance Stages (X1.4)	0.995	0.995	0.996	0.977

Table 3. The Most Influential Sub Factor (Significant)

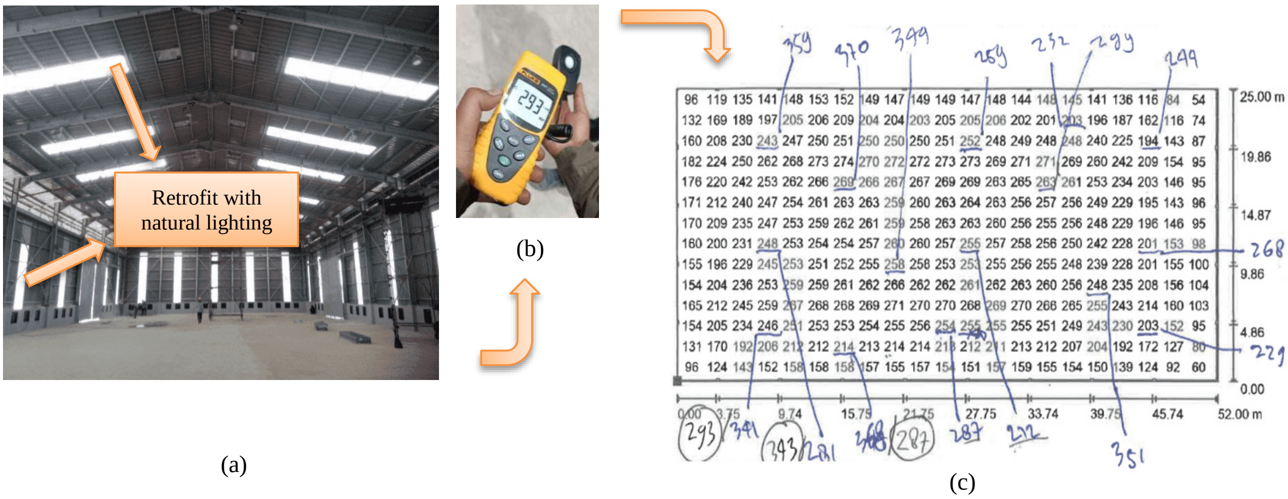
No	Sub Factor		Original Sample Value	Mean	t. statistic > 1.96 (p < 0.05)	R Square
1	Waste management	X2.1.66	0.831	0.831	32.617	
2	Blockchain Transactions	X3.2.3	0.920	0.920	32.344	
3	Demolition Material Disposal Locations	X2.2.3	0.866	0.865	27.238	
4	Planting consumption crops min. 10% of the industrial open space area	X2.1.76	0.815	0.815	27.612	
5	Min. 30% of the surface area absorbs rainwater	X2.1.94	0.812	0.811	25.279	
6	Documents efforts to save energy	X2.1.6	0.686	0.686	12.958	0.998
7	The reliability of the drainage network manages stagnant water	X2.1.77	0.715	0.717	15.756	
8	The use of renewable sources of electrical energy for lighting industrial facilities	X2.1.108	0.709	0.709	12.599	
9	Evaluation of water consumption utilization	X2.1.67	0.680	0.681	12.571	
10	Evaluation of the utilization of electricity consumption	X2.1.69	0.653	0.653	9.735	

The suggested optimization and decision support techniques are subjected to simulation for validation purposes. All simulations were and 12 GB of RAM, using BIM Revit 2023. The results of the retrofit simulation conducted with the addition of natural lighting in the warehouse building have proven to be very successful. From the lighting lux measurement results, before the retrofit, it was below 200 lux Figure 6, and after the retrofit, the luminance value increased to above 200 lux Figure 7.



(a) (b) (c)

Figure 4. Lumination check before retrofitting, (a) building condition without natural lighting, (b) lux meter measurement value, (c) values chart in lux



(a) (b) (c)

Figure 5. Lumination check after retrofitting, (a) building condition with natural lighting, (b) lux meter measurement value, (c) values chart in lux

Utilizing BIM enabled the creation of highly efficient building models for overseeing low-carbon construction initiatives. This approach ensures a thorough analysis of the entire lifecycle, encompassing service life planning and the optimization of building design and usage throughout its lifecycle. Before the retrofitting of the existing building, the monthly electricity consumption can be observed in Table 5, and the electricity consumption versus the kWh meter graph is shown in Figure 8.

Table 4. Monthly electricity consumption of case study, 2023

Month	KWh			Cost/KWh (IDR)	Total Cost (IDR)
	LWBP	WBP	Total		
Jan-22	625,350	130,950	756,300	IDR 1,035.78	IDR 783,360,414
Feb-22	625,460	130,810	756,270	IDR 1,035.78	IDR 783,329,341
Mar-22	624,300	131,990	756,290	IDR 1,035.78	IDR 783,350,056
Apr-22	628,890	127,360	756,250	IDR 1,035.78	IDR 783,308,625
May-22	624,980	130,860	755,840	IDR 1,035.78	IDR 782,883,955
Jun-22	624,340	132,020	756,360	IDR 1,035.78	IDR 783,422,561
Jul-22	626,450	129,900	756,350	IDR 1,035.78	IDR 783,412,203
Aug-22	624,580	131,780	756,360	IDR 1,035.78	IDR 783,422,561
Sep-22	624,390	131,940	756,330	IDR 1,035.78	IDR 783,391,487
Oct-22	622,990	133,350	756,340	IDR 1,035.78	IDR 783,401,845
Nov-22	624,640	131,670	756,310	IDR 1,035.78	IDR 783,370,772
Dec-22	625,680	130,670	756,350	IDR 1,035.78	IDR 783,412,203
Total (IDR)	**7,502,050**	**1,573,300**	**9,075,350**	**IDR 12,429.36**	**IDR9,400,066,023**

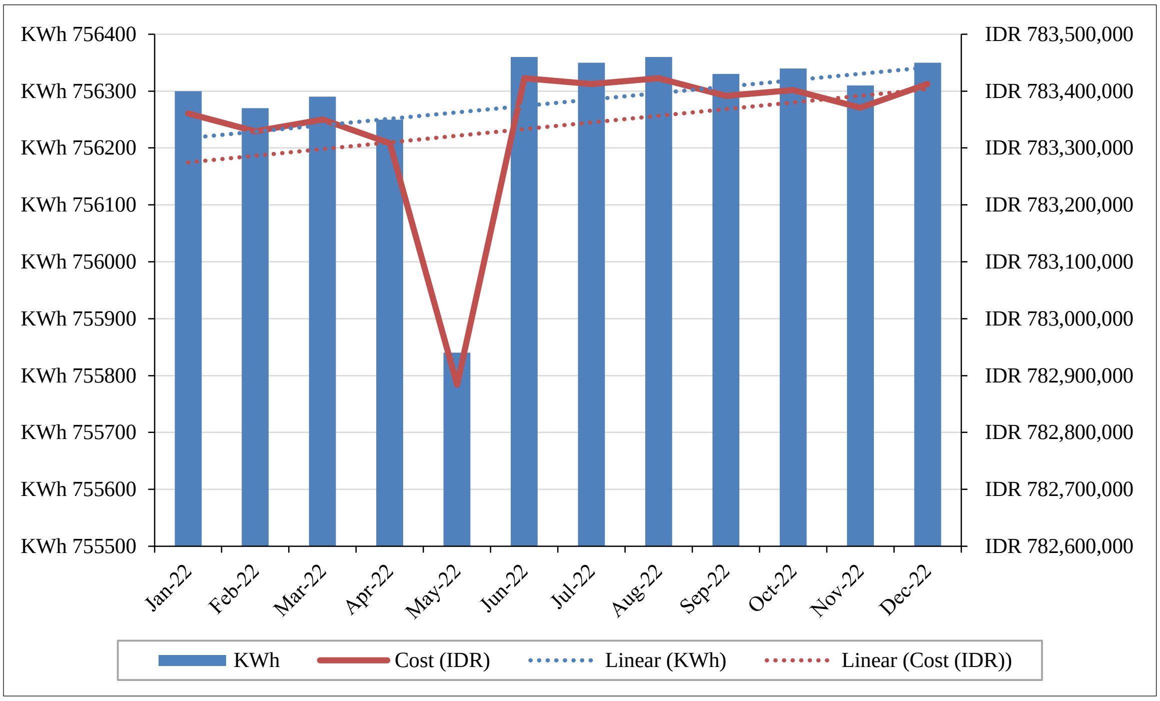


Figure 6. Monthly electricity consumption of case study, 2023

Table 6 and Figure 9 below illustrate the reduction in electricity consumption measured in kWh meters, resulting in reduced electricity usage costs from March 2024 to August 2024 after the green retrofitting of the chemical industry building.

Table 5. Monthly electricity consumption of case study, 2024

Month	KWh			Cost/KWh (IDR)	Total Cost (IDR)
	LWBP	WBP	Total		
Jan-23	625,456	130,975	756,431	IDR 1,035.78	IDR 783,496,101
Feb-23	625,468	130,828	756,296	IDR 1,035.78	IDR 783,356,271
Mar-23	622,200	126,990	749,190	IDR 1,035.78	IDR 775,996,018
Apr-23	621,890	126,360	748,250	IDR 1,035.78	IDR 775,022,385
May-23	620,980	125,860	746,840	IDR 1,035.78	IDR 773,561,935
Jun-23	620,340	125,020	745,360	IDR 1,035.78	IDR 772,028,981
Jul-23	619,850	124,900	744,750	IDR 1,035.78	IDR 771,397,155
Aug-23	620,180	125,180	745,360	IDR 1,035.78	IDR 772,028,981
Total (IDR)	**4,976,364**	**1,016,113**	**5,992,477**	**IDR 8,286.24**	**IDR6,206,887,827**

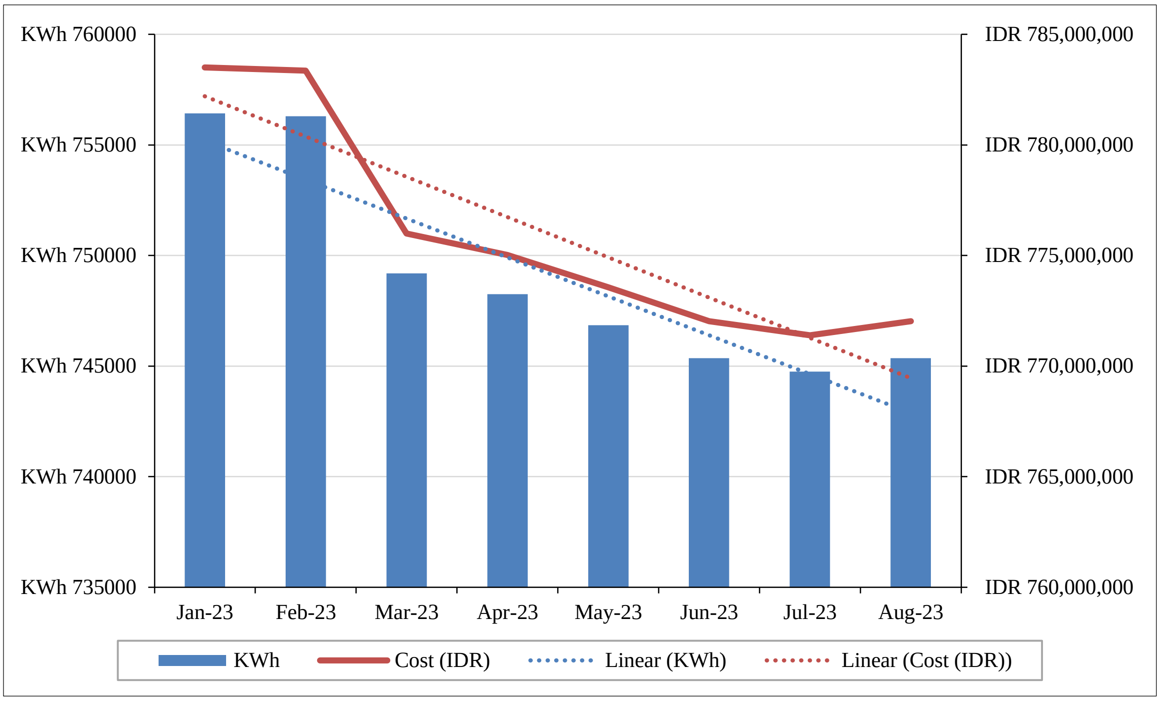


Figure 7. Monthly electricity consumption of case study, 2024

The analysis of the implementation of Blockchain-Building Information Modeling (BIM) on retrofitting works through modeling and input of unit price parameters resulted in the investment value of chemical industry retrofitting works and the analysis results as shown in Table 7, cost savings of 4.42% for Primary, 4.45% for Middle, and 4.40% for Main were obtained.

Table 6. Budget Plan for Green Retrofitting with Blockchain-BIM

NO	DESCRIPTION	Initial Budget Plan	Green Building Improvement Budget Plan			Green Building Improvement Budget Plan Using Blockchain-BIM		
			PRIMARY	MIDDLE	MAIN	PRIMARY	MIDDLE	MAIN
1	**Preliminary, Legal, and Safety Work**	4,539,606,575	4,539,606,575	4,539,606,575	4,539,606,575	4,539,606,575	4,539,606,575	4,539,606,575
2	**Structure Office Building**	19,395,000,000	19,395,000,000	19,395,000,000	19,395,000,000	19,395,000,000	19,395,000,000	19,395,000,000
3	**Laboratory Building**	1,320,763,000	1,320,763,000	1,320,763,000	1,320,763,000	1,320,763,000	1,320,763,000	1,320,763,000
4	**Utility Facility**	24,937,500,000	24,937,500,000	24,937,500,000	24,937,500,000	24,937,500,000	24,937,500,000	24,937,500,000
5	**Plant Production Facility**	106,816,000,000	106,816,000,000	106,816,000,000	106,816,000,000	106,816,000,000	106,816,000,000	106,816,000,000
6	**Infrastructure Facility**	10,500,000,000	10,500,000,000	10,500,000,000	10,500,000,000	10,500,000,000	10,500,000,000	10,500,000,000
7	**Provision of Green Building Handbook (BGH) SOP & Governance Documents.**		260,000,000	364,000,000	572,000,000	260,000,000	364,000,000	572,000,000
8	**Planning for Renovation Work**		416,000,000	468,000,000	577,200,000	416,000,000	468,000,000	577,200,000
9	**Retrofitting Works**							
	- Bus Stop		-	385,000,000	385,000,000	-	367,290,000	367,290,000
	- Solar panel		8,586,070,577	8,586,070,577	8,586,070,577	8,191,111,330	8,191,111,330	8,191,111,330
	- Replacement of Water-Efficient Sanitary Fixtures		-	445,769,222	445,769,222	-	425,263,837	425,263,837
	- Provision of Outdoor Smoking Area Outside the Building		-	-	175,000,000	-	-	166,950,000
	- Temporary Waste Storage Area		2,026,061,613	2,026,061,613	2,026,061,613	1,932,862,779	1,932,862,779	1,932,862,779
	- Organic Waste Composting Machine		-	-	397,612,378	-	-	379,322,209
	- Inorganic Waste Recycling Machine		-	-	357,500,000	-	-	341,055,000
	- Provision of Biopores and Infiltration		489,750,000	489,750,000	489,750,000	467,221,500	467,221,500	467,221,500
	- Natural Lighting Fixtures inside the Building		995,766,611	995,766,611	995,766,611	949,961,347	949,961,347	949,961,347
	- Public Street Lighting and Garden Lamps Using Solar Cells		-	3,668,836,563	3,668,836,563	-	3,500,070,081	3,500,070,081
	- Sewage Treatment Plant (STP)		-	2,391,214,509	2,391,214,509	-	2,281,218,642	2,281,218,642
	- Improvement cooling tower system		2,928,913,800	2,928,913,800	2,928,913,800	2,794,183,765	2,794,183,765	2,794,183,765
10	**Maintenance Work During Utilization Period**		1,361,881,973	1,702,352,466	2,213,058,205	1,299,235,402	1,624,044,252	2,111,257,528
11	**Socialization and Empowerment Work for Green Building Occupants/Users**		453,960,658	453,960,658	453,960,658	433,078,467	433,078,467	433,078,467
	TOTAL (IDR)	**167,508,869,575**	**185,027,274,806**	**192,414,565,592**	**194,172,583,710**	**184,252,524,165**	**191,307,175,575**	**192,998,916,060**
	Difference between Non-Green Building Cost Estimate (RAB) and Green Building Improvement Cost Estimate (RAB) (IDR)		**17,518,405,231**	**24,905,696,017**	**26,663,714,135**	**16,743,654,590**	**23,798,306,000**	**25,490,046,485**
	Difference (%)		**10.46%**	**14.87%**	**15.92%**	**774,750,641**	**1,107,390,017**	**1,173,667,650**
	Percentage Reduction in Cost Difference					**4.42%**	**4.45%**	**4.40%**

4. Conclusion

The implementation of green initiatives like energy-efficient systems, improved lighting, water conservation, and recycling results in a 10.77% increase in green construction costs, often referred to as retrofitting costs. Considering that all assessment results indicate a rating exceeding 10.77%, it implies the need for retrofitting. To mitigate these retrofitting expenses, the blockchain-BIM approach can be employed. The flow diagram for implementing cost efficiency in Green Industrial Buildings using Blockchain-BIM has proven to be effective in improving the cost efficiency of Green buildings. The research results showed cost savings of 4.42% at the Primary level, 4.45% at the Middle level, and 4.40% at the Main level for Chemical Industry Buildings with Blockchain-BIM implementation. Based on the analysis results, the hypothesis was confirmed that the Blockchain-BIM method in the Green Industry can effectively improve the cost efficiency of Chemical Industrial Buildings.

In this research, assistance is required for initiating the development of intelligent smart contracts on the Blockchain network due to limitations that impact the technological aspect of the study. The researchers have encountered setbacks multiple times while attempting to create applications based on Blockchain. Consequently, future studies should involve collaborative efforts with Blockchain practitioners to streamline and facilitate the implementation of this method. The associated expenses, conversely, will be in direct correlation with the electrical energy generated, depending on the stakeholders in question. Evaluating the profitability of a technology necessitates considering both its cost and energy demands. Moreover, governmental policies, regulations, and incentives are pivotal and can drive the widespread adoption of the Green Building (GB) concept, particularly in retail structures. This strategy is crucial for attaining the objectives of sustainable development in Indonesia.

5. Declarations

5.1. Author Contributions

Conceptualization, L.S., A.E.H., and B.D.K.; methodology, L.S., A.E.H., K., and E.J.A.; software, L.S. and K.; validation, L.S., A.E.H., and B.D.K.; formal analysis, L.S.; investigation, L.S.; resources, L.S., A.E.H., and B.D.K.; data curation, A.E.H. and M.A.; writing—original draft preparation, L.S.; writing—review and editing, L.S. and A.E.H.; visualization, L.S. and B.D.K.; supervision, A.E.H. and M.A.; project administration, L.S.; funding acquisition, L.S., K., E.J.A., W.T.A., and B.D.K. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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