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Cost performance analysis of green chemical industrial buildings using blockchain-BIM

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ABSTRACT

Blockchain technologies have recently garnered substantial attention in research and industry sectors due to their potential advantages across various industries. Blockchain provides an effective solution to address challenges by offering distributed, secure, and permissioned transactional ledgers. This paper introduces an innovative conceptual framework that integrates blockchain technology with building information modeling, specifically designed for digital transactions and smart contracts in the retrofitting of green buildings within the chemical industry. The core objectives include enhancing cost efficiency, fortifying cybersecurity measures, improving information management and sharing, simplifying payment transactions, and promoting sustainability in this specific context. The research, conducted at a chemical facility in Cilegon, Banten, Indonesia, utilizes Structural Equation Modeling-Partial Least Squares (SEM-PLS) to analyze questionnaire data and identify influential factors. Results indicate that incorporating Blockchain-BIM leads to cost savings of 4.42%, 4.45%, and 4.40% for low-level, medium-level, and high-level retrofitting categories, respectively, highlighting the significant role of Blockchain-BIM in enhancing cost efficiency throughout the retrofitting process.

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KEYWORDS
Blockchain; BIM; cost performance, green building, smart contract

1. Introduction

Buildings' extensive energy consumption represents a grave environmental threat and stands as a primary contributor to the global climate crisis (Of, Potential, and Offices 2021). Considering the urgent challenge of global warming impacting both private sector institutions and governmental entities, societies globally need to develop fresh strategic initiatives that prioritize environmental problem-solving (H et al., Dao and Nguyen 2021). This entails substantial greenhouse gas emission reductions across all sectors of the economy, with the aim that all buildings achieve Net Zero Carbon Emission status by 2050 (B et al. 2021; Besana and Tirelli 2022). In the construction industry, energy and natural resource consumption are notably high. Globally, buildings account for 30% of total CO2 emissions (Le, Nguyen, and Do, n.d.). Consequently, the Green Building (GB) concept holds considerable promise for facilitating sustainable growth within the Architecture, Engineering, and Construction (AEC) sector (Fang et al. 2022). The Green Building concept brings forth numerous advantages encompassing economic, societal, and environmental dimensions. It embodies the principles of conserving sustainable resources like energy, water, land, and nature, emphasizing resource efficiency in terms of energy, water, land, and materials, and promoting resource sharing through the provision of public facilities for transportation and workspaces (Sutikno et al. 2023). These studies are guided by the Technical Guidelines of the Ministry of Public Works and Housing No. 1 of 2022, which furnishes the most recent directives for green building construction in Indonesia. This regulation introduces three rating levels: Green Building Main (80% – 100%), Middle (65% – 80%), and Primary (45% – 65%), with a maximum score of 165 points (PUPR 2022). Typically, retrofitting existing structures to meet Green Building standards tends to incur higher costs compared to integrating Green Building concepts into new constructions. The expense associated with upgrading existing buildings to Green Buildings can reach approximately 10.77% of the initial construction cost (Sun et al. 2019). Instead, it meets all its energy needs through renewable sources such as solar energy, often achieved by employing various design strategies to minimize the building's energy consumption (Dwaikat and Ali 2018). Solar energy represents a clean and cost-effective energy source with no adverse environmental effects (Nejad and Asadpour 2019). Hydroelectric power, exemplified by water turbine generators, is another rapidly expanding application of renewable energy (Pat and Recovery 2021;

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Rochman and Hermawan 2022). Renewable energy regulations prioritize energy efficiency enhancements and the utilization of renewable energy sources, aligning with the core principles of Green Building philosophy regarding energy utilization (Shayan and Najafi 2023). Blockchain, a decentralized system for transaction and data management, plays a crucial role in enabling secure and immutable information exchange among multiple participants (Aitsam and Chantaraskul 2021). It relies on highly secure encryption and operates as a distributed database system known as a "blockchain ledger" (Zheng et al. 2019). This ledger is shared across all participants (nodes) within the network, constituting the essence of distributed ledger technology (Wouda and Opdenakker 2019). The utilization of a Building Information Modeling (BIM) model, which simulates the actual appearance and details of a building's design and construction, can yield substantial information for users (Akmal et al. 2019). This experience has revealed valuable insights, notably that while BIM can enhance certain aspects of projects, it also entails increased project costs and extended project timelines (Dao and Nguyen 2021). This approach aims to comprehend and implement environmentally-friendly buildings with minimal ecological impact (Study et al. 2019).

The integration of BIM and Blockchain technology presents the prospect of a more private and secure corporate environment, offering extensive control over processes (Fialho, Codinhoto, and Fabricio 2020). The implementation of smart contracts on the Blockchain introduces a novel value proposition aimed at enhancing specific facets of sustainability within projects (Cheng, Chong, and Xu 2023). The initial implementation of Blockchain and BIM integration, focusing on enhancing productivity, has been tested at the research and technology development facility of the Spanish DELFOS project (Atabay, Pelin Gurgun, and Koc 2020; Mathews, Bowe, and Robles 2017). This amalgamation of BIM and Blockchain technologies holds the potential to create a progressively secure and confidential business environment, providing complete control over various processes (Zia et al. 2022). Blockchain technology introduces several valuable features, including proof of ownership, which addresses rights, and proof-of-provenance, facilitating record-keeping through a transparent and unchangeable ledger (Kfoury 2021). Additionally, it aids in reducing human errors and deviations. Smart contracts on the Blockchain have emerged as a novel value proposition for enhancing specific sustainability aspects within projects (Sreckovic et al. 2021).

The objective focus of this study is to investigate the impact of applying Green Building (GB) concepts on investment decisions for chemical industrial buildings. The assessment criteria align with the Technical Guidelines for the Minister of Public Works and Public Housing (PUPR) No. 1 of 2022, which encompasses performance evaluation standards for GB. These standards encompass the Planning Stage, where criteria related to the application of renewable energy, as outlined in Table 1. Table 2 outlines the variables for the GB Implementation stage, and Table 3 delineates the variables related to Blockchain-BIM. In addition to these, there are several other research variables, and all sub-factors will be analyzed to identify the factors influencing the implementation of GB in contemporary shopping center buildings. This study adopts an Action Research approach to transition the building's status into a green industry, aiming to mitigate environmental impacts associated with the chemical industry (Crawley et al. 2001). To achieve a comprehensive analysis of cost efficiency leveraging Blockchain-BIM in the context of green retrofitting in the chemical industry, a research framework was employed. This framework includes variables formulated for assessing resulting impacts. The collected data was then analyzed to derive preliminary insights, which were subsequently discussed and reviewed. The objective was to draw conclusions about the efficacy of payment processes and provide a descriptive account to enhance cost efficiency using Blockchain-BIM in the green retrofit-based industry.

2. Data and method

2.1. Data collection

In this research, we gathered primary data through an audit or verification process to assess the compliance of existing buildings with green building requirements (Al-Abbas et al. 2023). The primary data collected in this phase indicates the adherence to the Technical Guidelines (Juknis) outlined in the Ministry of Public Works and Housing Regulation No. 01 of 2022. To commence this process, we started by utilizing existing secondary data within the company, encompassing information like energy production and consumption data. Additionally, we incorporated secondary data from project documents such as planning drawings, Bill of Quantity, and operational data of the facility.

During the development of the questionnaire, we identified the most influential indicators. This questionnaire, designed for distribution among project stakeholders, encompasses those directly and indirectly involved. In terms of data analysis, we plan to employ Structural Equation Modeling (SEM) using the SMART PLS (Partial Least Squares) 3.0 software. Additionally, to gain a more profound understanding, interviews will be conducted. The aim is to employ this tool to identify the primary factors and predominant subfactors influencing the cost efficiency under examination. SMART PLS stands out as a widely recognized and frequently

Table 1. Point assessment of the planning stage in green buildings based on the Minister of PUPR's technical guidelines No.1 of 2022.

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 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 a 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

Source (PUPR 2022).,

employed software for scientific research data analysis (Sutikno, Husin, and Yuliati 2022).

2.2. Methodologycal

Initially, Structural Equation Modeling (SEM) – Version 3.0 of the Partial Least Squares (PLS) software was employed to ascertain the sample size and assess whether the data adheres to the prerequisites of the SEM-PLS model. Figure 1 illustrates the research flow adopted in this study, with guidance from prior research for the SEM-PLS testing. Factors to be taken into account encompass model characteristics, sample size, data distribution shape, handling of missing data, and measurement scale. The minimum required sample size is determined by the path factor (p-min) and the tolerance margin during the 80% statistical stress test (Ringle and Sarstedt, n.d.). In pursuit of the research objectives, the next phase for the researcher involves outlining a research plan for each stage to facilitate statistical analysis and the practical application of the research

Table 2. Point assessment of the implementation stage in green buildings based on the Minister of PUPR's technical guidelines No.1 of 2022.

No.	Criteria (Sub Factor)	Points	No.	Criteria (Sub Factor)	Points
1	Electricity usage of equipment	1	47	Project Innovation Improve	2
2	Equipment energy audit report	1	48	'Green' Improvement	2
3	Potential green suppliers	1	49	Efficient innovation	2
4	Identify the right material	1	50	Has integrated building data	2
5	Material supplier ≤200 km away	1	51	Improvement mechanism	2
6	Material wrapping packaging	1	52	Comprehensive work plan	2
7	Proper utilization of materials	1	53	Validated as-built drawings	2
8	Effective material warehousing	1	54	Equipment Operation Document	2
9	Effective material management	1	55	Main equip. warranty	2
10	ISO 14,001-certified material	1	56	Document of equipment training	2
11	No use of CFC materials	1	57	Documentation of test com	2
12	Domestic Component Level materials ≥40%.	1	58	Copy material approval list	2
13	Rewards for Green Culture	1	59	Optimal construction equipment	2
14	Environmental Management policy	1	60	Waste Water (WW) Recycling	2
15	No feeling during construction	1	61	WW Treatment to Outside	2
16	Impact of construction activities	1	62	Collect. Recording System	2
17	Control of the environment	1	63	Waste Manage. System	2
18	Decent worker canteen	1	64	Application of the 3R	2
19	Smoking area facilities	1	65	Rainwater Storage 50%	2
20	Worker barracks facilities	1	66	Hazardous Material Control	2
21	HSE Mechanism	1	67	Refrigerant Control	2
22	Work Method Document	1	68	CO2 and CO control	2
23	Dangerous Work Mechanism	1	69	Air quality	2
24	HSE Plan	1	70	Water-saving sanitary ware	2
25	Lighting & air cond. ≥30% usage	1	71	Water usage efficiency	2
26	Monitoring electricity usage	1	72	Water source efficiency	2
27	Gen-set operation feasibility test	1	73	Electrical energy efficiency	2
28	kWh meters on the panel board	1	74	Energy Efficiency Calculation	2
29	Project Electrical Procedures.	1	75	Building Transp. efficiency	2
30	Energy Conservation Rules	1	76	Lighting energy efficiency	2
31	Raw water source (State Water Company)	1	77	Environmentally Materials	2
32	Rainwater to clean water alternative	1	78	Ventilation energy efficiency	2
33	Rainwater Utilization	1	79	Construction tool monitoring	3
34	Building Orientation	1	80	Air-conditioning efficiency	3
35	Rainwater infiltration	2	81	Clarity of access in and out	3
36	3R (reduce, reuse, recycle)	2	82	Outdoor Lighting	3
37	Disposal type of waste type	2	83	Parking Lot	3
38	Facilities for hazardous waste	2	84	Basement Tread Management	3
39	Construction waste sorting	2	85	Provision of Pedestrian Path	3
40	Construction waste reduction	2	86	Private green space	3
41	Heavy equipment security	2	87	Hazardous waste Management	4
42	Material fall safety	2	88	Site & Access Management	4
43	SIO of heavy equipment	2	89	Plan & site management	5
44	SILO of heavy equipment	2	90	Site suitability implementation	6
45	Shop drawing for test com	2	91	Mutual check GB Implementation	8
46	Building Envelope Efficiency	2			
				Total	165

Source (PUPR 2022).

Table 3. Blockchain-BIM variables.

No.	Sub-factor	Source	No.	Sub-factor	Source
1	Project requirements	Pedroza (2019)	8	Blockchain Transactions	Pedroza 2019 Kfoury (2021)
2	Consistent data	Baig and Wang 2019; Pedroza (2019)	9	Blockchain data sources	Pedroza 2019 Kfoury (2021)
3	Professional role	Pedroza (2019)	10	Bitcoin Blockchain	Pedroza (2019)
4	Secure information	Akbarieh et al. 2021; Pedroza (2019)	11	Block chain-BIM Usage	Kfoury 2021 Sreckovic et al (2021)
5	Blockchain-BIM Specifications	Li et al. 2022; Pedroza (2019)	12	Block chain-BIM Adoption	Kfoury 2021 Sreckovic et al (2021)
6	Blockchain Verification	Pedroza (2019)	13	BIM Level on Blockchain	Pedroza (2019)
7	Blockchain Transparency	Kfoury 2021; Pedroza (2019)			

in the case studies. It's noteworthy that in one particular study, only half of the systematic reviews integrated flowcharts to elucidate the process of evaluating studies (Vu-Ngoc et al. 2018).

Secondly, during this initial phase, the evaluation must satisfy a minimum threshold of 74.25 for the Basic Rating. The research methodology is outlined in Figure 2, detailing the Research Flow for the GB Concept.

Thirdly, the incorporation of renewable energy sources involves identifying alternative sources within the research site, aligning with the assessment outcomes and the 2022 GB requirements outlined in the Minister of PUPR's Regulation. The researcher recommends implementing natural lighting and Solar PV systems at the research site, as depicted in Figure 3, the Identification Analysis for Renewable Energy Implementation. Modeling renewable energy through

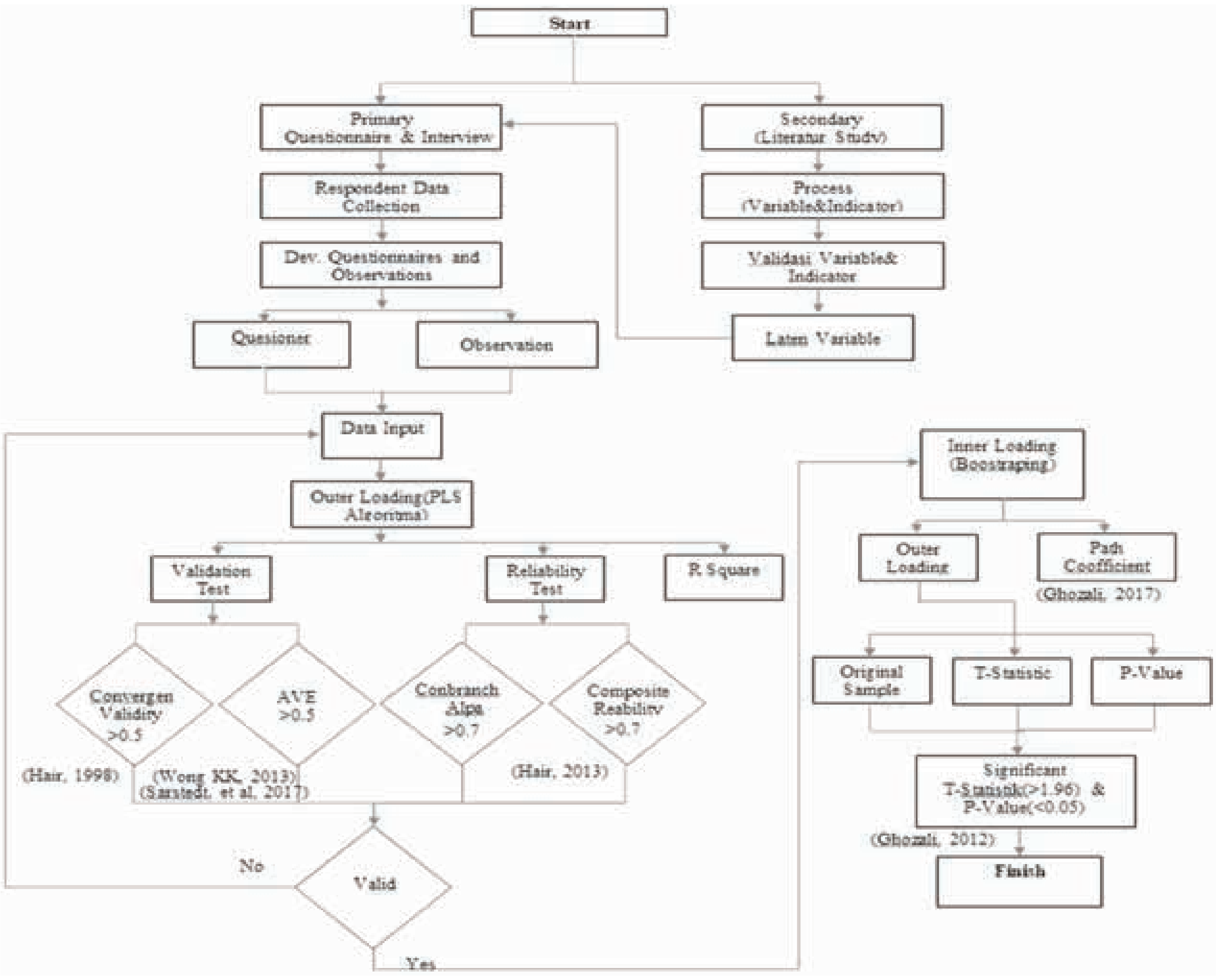

Figure 1. Data processing diagram.

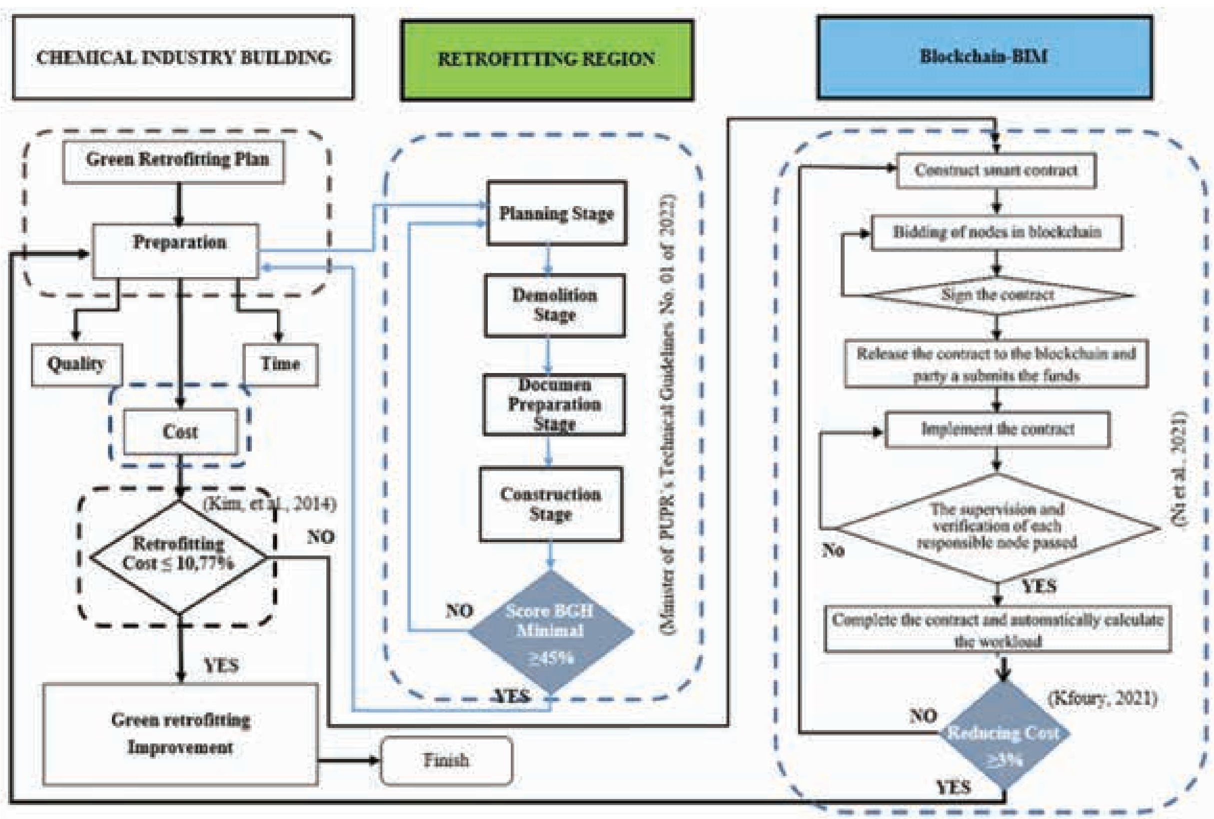

Figure 2. Research implementation of GB concept on chemical industrial buildings.

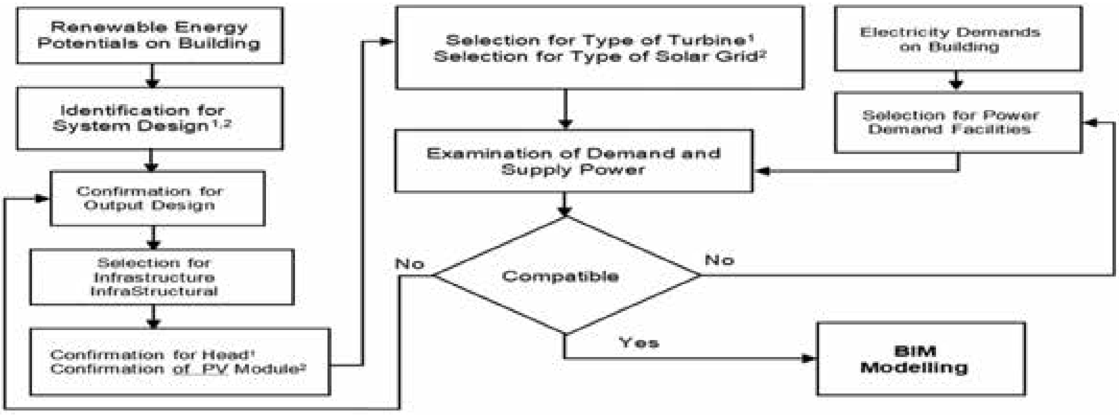

Figure 3. Identification analysis for renewable energy implementation.

BIM is considered crucial for assessing the cost components of the GB project.

3. Case study

The research was carried out at a chemical industry construction project situated in Cilegon – Banten, Indonesia. Regarding the assessment's planning stage, the obtained score was 62.3 points. This indicates that there are various aspects in the building planning phase that require enhancements to achieve the minimum Basic rating threshold of 74.25 points.

Using the method outlined previously, we have identified the potential for implementing green building (Figure 4) in this building for renewable energy utilization. Researchers have developed two models: The first model involves the installation of solar PV panels on the building's roof (Figure 5(a)) and street lighting (Figure 5(c)). This configuration covers a specific area and has the capacity to generate approximately 850 KWh of electrical energy. In the second model, researchers have designed natural lighting (Figure 5(b)) for the entire building and the sheltered warehouse installation. Although the electrical power generated in this model is less significant than the solar PV system due to limitations in water discharge and head in the building's irrigation canals, it is still sufficient to meet the required criteria for renewable energy implementation.

Others modeling related to the outcomes of the GB assessment has been conducted. This includes improvements to the chiller plant unit, enhancements to the sewage treatment plant (Figure 5(e)), the addition of water filtration systems in detention ponds (Figure 5(d)), the design of waste management facilities, and several other models. These models were developed to explore the cost aspects associated with green building requirements. However, due to paper limitations, these additional models are not presented here.

This modeling will be integrated into Smart Contracts and the Blockchain-BIM network (Riadi

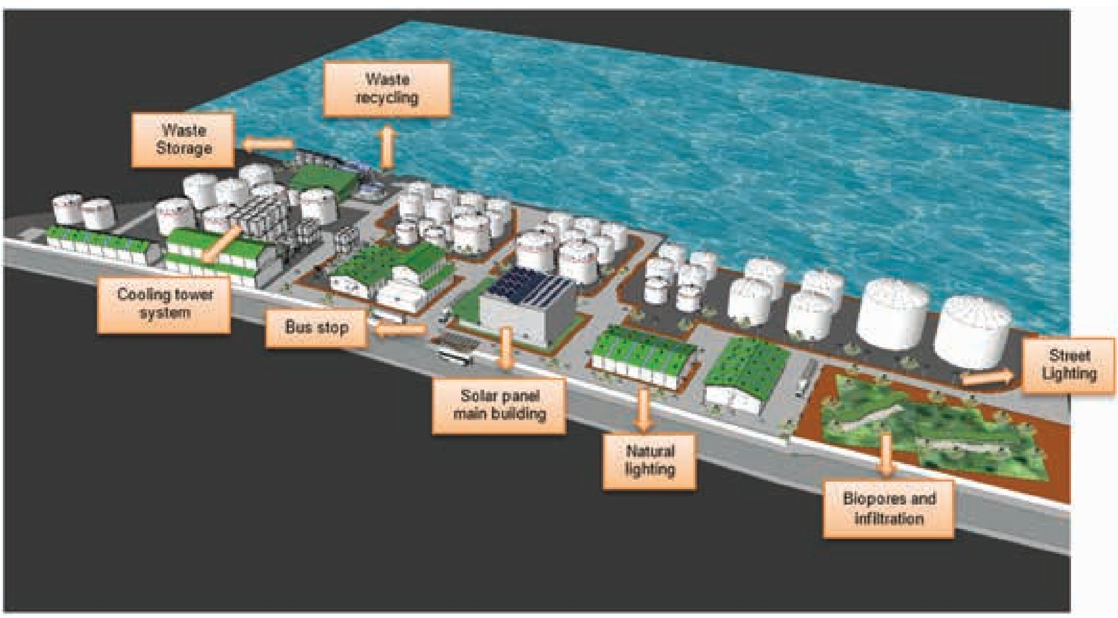

Figure 4. BIM modelling for renewable energy.

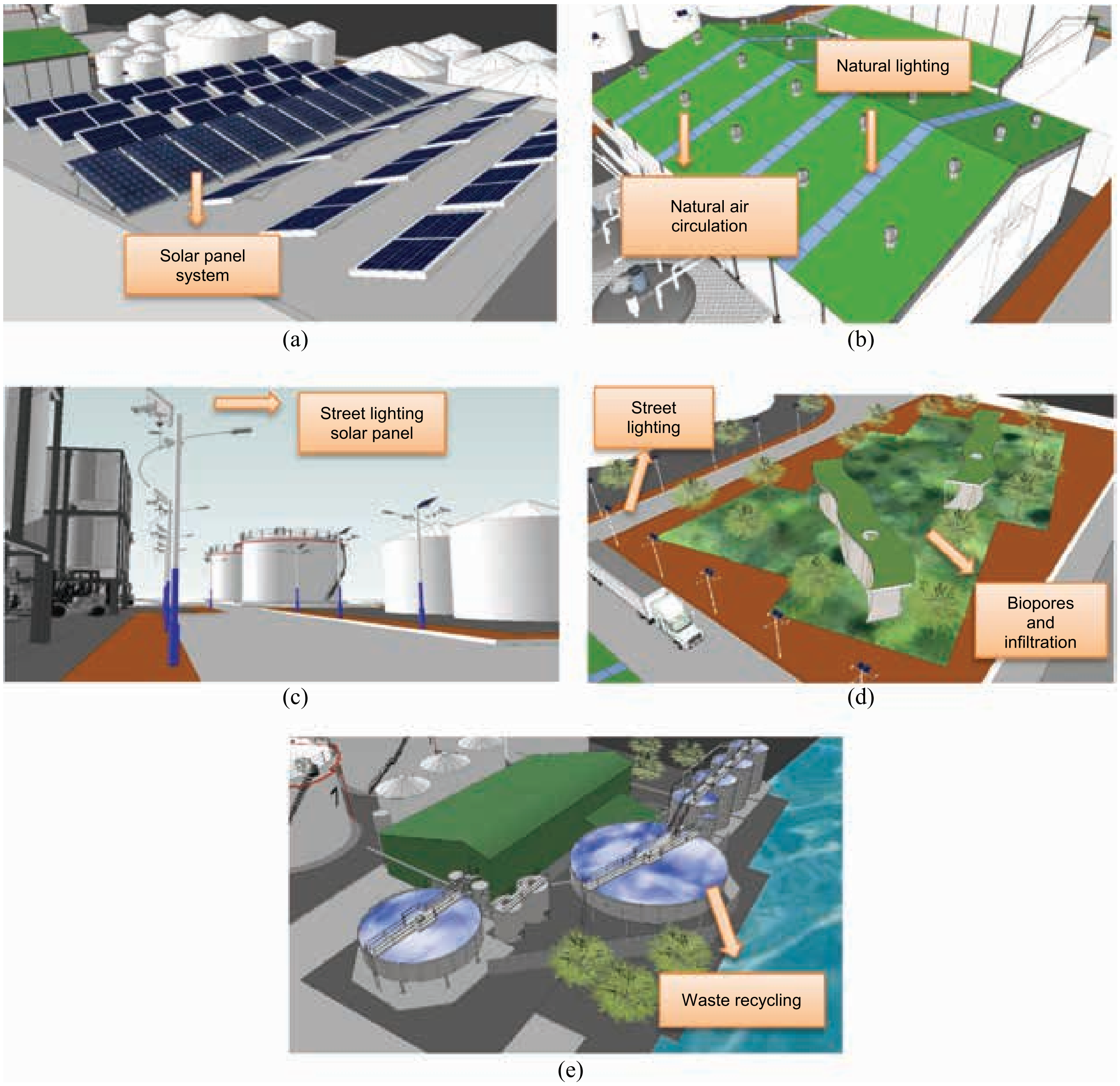

Figure 5. BIM modeling for renewable energy, (a) solar panels system; (b) natural lighting and HVAC; (c) street lighting solar panel; (d) biopores and infiltrasi; (e) west recycling.

et al. 2020). Thus, this research aims to explore the potential of applying Blockchain technology in the context of sustainable infrastructure development (Ouyang, Yuan, and Wang 2019). By utilizing this demo system, we can assess the effectiveness and reliability of the approach employed in implementing Blockchain-BIM. This enables us to test the interactions among participants in the blockchain network and observe how data and transactions can be securely and transparently managed using this technology

4. Results

4.1. Measurement model evaluation (outer loading – PLS algorithm)

A total of 120 research questionnaires were disseminated, satisfying the minimum requirement of 118 respondents for subsequent statistical analysis, as indicated in Figure 6, Figure 4. The respondent data encompasses the information gathered from these participants:

The initial phase includes running the SEM-PLS program for computations. Convergent Validity analysis evaluates the extent to which a measure correlates with other measures of the same construct (Al-Emran and Mezhuyev 2018). Composite Reliability and Cronbach's Alpha are the tools employed for this assessment. Composite reliability values falling within the range of 0.6–0.7 are indicative of good reliability (Sarstedt, Ringle, and Hair 2021). For all variables, reliability values exceeding 0.6 are determined for the overall scale used in the study (Miloševića et al. 2022). The validity test is deemed acceptable when the Average Variance Extracted (AVE) value surpasses 0.5. AVE values exceeding 0.5 signify that the latent variable

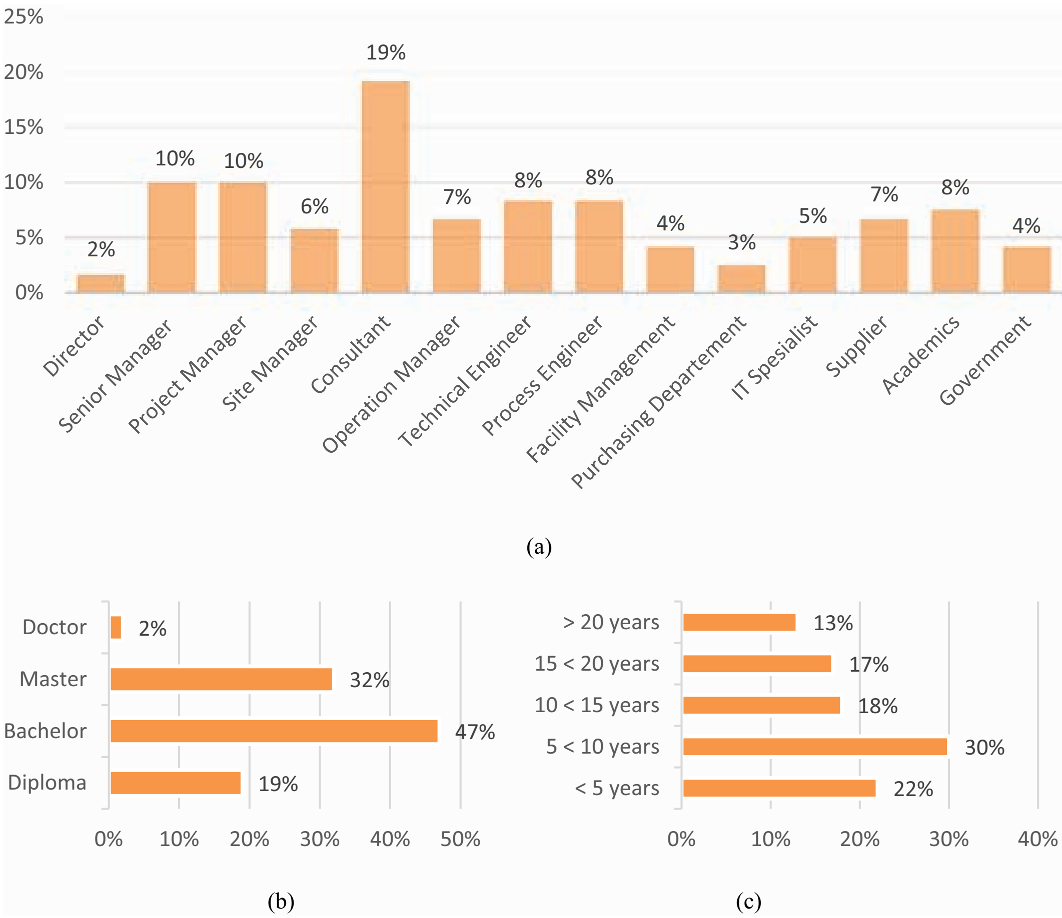

Figure 6. Respondent data, (a) positions, (b) educations, (c) work experiences.

construct explains more than half of the variance in the indicator (Bittencourt et al. 2020). All indicators with outer loading values greater than 0.5, as per outer loading validity criteria, confirm that all indicators possess convergent validity, as illustrated in Table 4 below.

In terms of reliability, variables are considered reliable if Cronbach's Alpha exceeds 0.7 and Composite Reliability is greater than 0.7, which are widely accepted standards for research instrument reliability (Ardiansyah and Ardiansyah 2024). Based on the values presented in the table, the following conclusions can be drawn:

- The AVE values for the latent and median variables are greater than 0.5, indicating that the convergent variables are valid and meet the required threshold.
- Both the Composite Reliability and Cronbach's alpha values exceed 0.7, signifying that the instrument is reliable and meets acceptable standards.

4.2. Evaluation of measurement models (inner loading – bootstrapping)

The analysis was carried out utilizing SEM SMART-PLS software version 3.0. Illustrated in Figure 7, the R-Square value, representing the cumulative influence on the Cost (Y) variable, stands at 0.825. Additionally, the adjusted R-Square value is 0.824. This indicates that

Table 4. 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

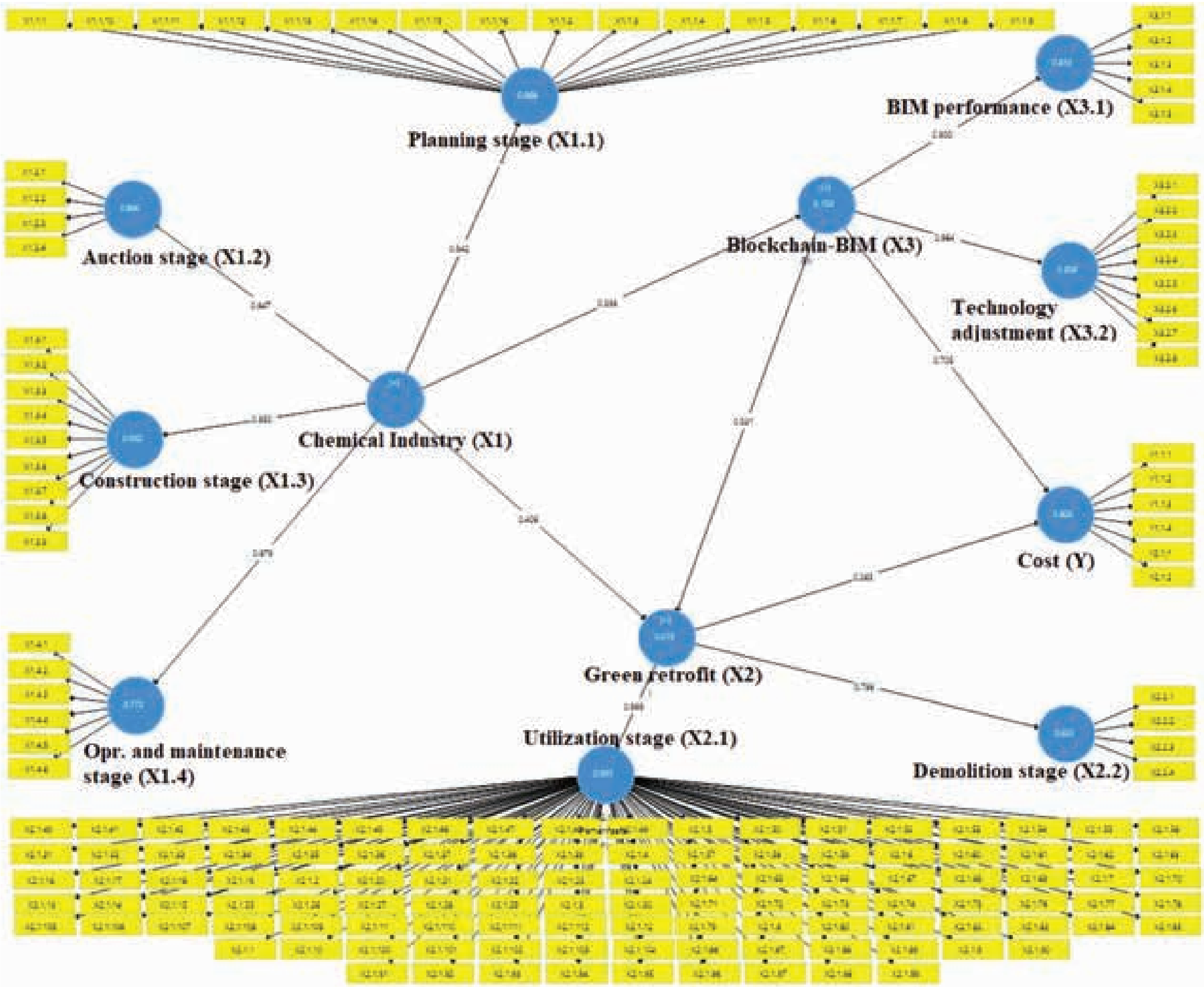

Figure 7. The diagram of p-values and partial coefficients.

Table 5. 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	0,998
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 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	
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	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	

all independent variables collectively contribute to influencing the Cost (Y) variable by 82.5%. Since the adjusted R-Square value exceeds 50%, it suggests that the impact of all independent variables on the Cost (Y) variable is significant.

From the analyzed questionnaire data, we can identify the most influential factors among the 304 sub-factors examined. Subsequently, various criteria such as the coefficient of determination (R2), cross-validation redundancy (Q2), effect size (f2), and path coefficients are employed (Ardiansyah and Ardiansyah 2024). Q2 > 0 signifies that the model exhibits strong predictive relevance, Q2 < 0 indicates a lack of predictive relevance in the model. The path coefficients' estimated values in the structural model are assessed for both strength and significance, with a P-value <5% and a T-Statistic >1.96 considered significant. Subsequently, a detailed analysis is conducted to examine the direct and indirect influences of individual factors using the calibrated SEM model (Barman and Bandyopadhyaya 2023). The 10 most influential factors have been ranked in descending order, with the most impactful factor being the validation of Green Building (GB), as illustrated in Table 5.

Energy efficiency standards for building envelopes serves as a guide for all parties involved in the design, construction, monitoring, and management of buildings, aiming to achieve energy efficiency. The meticulous design of a building's envelope is crucial in significantly reducing energy consumption. In the case of multi-purpose buildings, more than half of the energy demand is attributed to heat loss through the building envelope, an aspect often overlooked. This underscores the importance of optimizing the design of the building envelope, potentially resulting in substantial energy savings of around 50%. Additionally, the implementation of an automated HVAC (Heating, Ventilation, and Air Conditioning) control system has the potential to reduce up to 20% of a building's overall heating requirements (Ascione et al. 2019; Fan and Xia 2017). Beyond the efficiency gains related to HVAC systems, given the pressing concerns associated with global warming (Akram et al. 2022), the depletion of fossil fuels, and the escalating cost of energy, there is a growing imperative to reduce energy consumption in industrial wastewater treatment plants as well (Saghafi et al. 2020).

The execution of energy conservation involves several key components, such as strategizing for the adoption of cutting-edge, energy-efficient technologies, the careful selection of energy-efficient infrastructure and machinery, and the efficient operation of systems. In practice, energy savings initiatives typically encompass three primary actions: deactivating unused electrical devices or curtailing power consumption, unplugging devices that draw power when not in use, and fine-tuning air conditioning settings to align with collective efforts aimed at mitigating greenhouse gas emissions.

4.3. Relationship between renewable energy on green building and blockchain-BIM

The researchers attempted to replicate the utilization of Blockchain-BIM in line with the previously outlined procedure. During these simulations, the primary focus was placed on establishing the feasibility of the front-end network, particularly for the validation of smart contracts integrated into the Blockchain network.

Figure 8 illustrates the smart contract for payment transactions within the blockchain network. Within the blockchain network, smart contracts serve as the mechanisms for executing transactions contained within a block. When a smart contract method is initiated, the corresponding transaction is executed, leading to the creation of blocks. In this context, the Client is required to make payments to the contractor upon the completion of each process, utilizing the funds derived from the Bill of Quantity (BOQ). Notably, a single block within the blockchain network has the capacity to encompass multiple transactions, aligning with the logic of each action performed. Further elaboration on this topic will be provided in the subsequent chapter (Aithal and Aithal 2019). To facilitate interaction with the blockchain network, the SDK Owner is employed as a tool for connecting applications to the blockchain, particularly with regard to smart contracts. To enhance user-friendliness and systematic engagement with the blockchain network, we offer two web-based applications. Through the utilization of these applications, users can readily and efficiently communicate and interact with the blockchain network.

The evaluation of the integration of Blockchain-Building Information Modeling (BIM) in retrofitting activities, involving modeling and the input of unit price parameters, yielded the investment values for chemical industry retrofitting projects. The analysis,

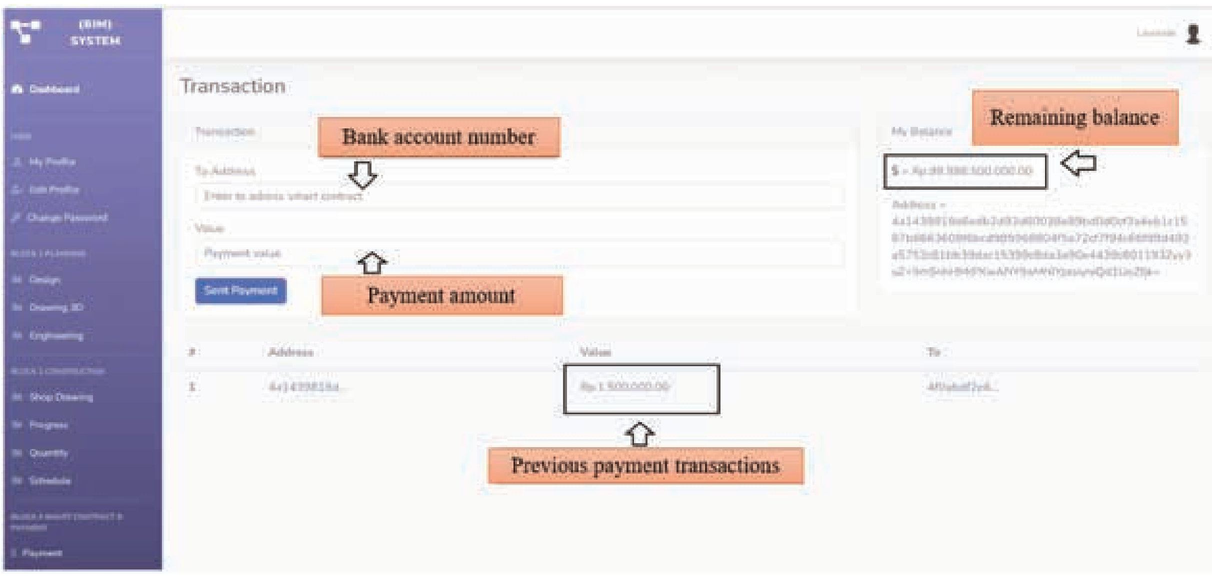

Figure 8. Block approval smart contract payment transaction.

Table 6. Reduction cost based on green retrofitting assessment with the implementation of blockchain-BIM method.

		Green Building Improvement Budget Plan (IDR)			Green Building Improvement Budget Plan Using Blockchain-BIM (IDR)		
No	Description	Primary	Middle	Main	Primary	Middle	Main
1	Bus stop and bicycle parking	-	385,000,000	385,000,000	-	367,290,000	367,290,000
2	Solar panels	8,586,070,577	8,586,070,577	8,586,070,577	8,191,111,330	8,191,111,330	8,191,111,330
3	Replacement of water-saving sanitary fixtures	-	445,769,222	445,769,222	-	425,263,837	425,263,837
4	Provision of smoking areas outside buildings and parks	-	-	175,000,000	-	-	166,950,000
5	Temporary landfill	2,026,061,613	2,026,061,613	2,026,061,613	1,932,862,779	1,932,862,779	1,932,862,779
6	Organic waste composter machine	-	-	397,612,378	-	-	379,322,209
7	Inorganic waste recycling machine	-	-	357,500,000	-	-	341,055,000
8	Provision of Biopores and Infiltration	489,750,000	489,750,000	489,750,000	467,221,500	467,221,500	467,221,500
9	Natural Lighting Fixtures inside the Building	995,766,611	995,766,611	995,766,611	949,961,347	949,961,347	949,961,347
10	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
11	Sewage Treatment Plant (STP)	-	2,391,214,509	2,391,214,509	-	2,281,218,642	2,281,218,642
12	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
Total (IDR)		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
Deviation (%)		10.46%	14.87%	15.92%	774,750,641	1,107,390,017	1,173,667,650
Percentage Reduction in Cost Deviation (%)					4.42%	4.45%	4.40%

as indicated in Table 6, revealed cost savings of 4.42% for the Primary stage, 4.45% for the Middle stage, and 4.40% for the Main stage.

5. Conclusions

In this research, the authors require assistance in initiating the development of smart contracts on the Blockchain network, as they have encountered technological constraints that hinder their progress. Multiple attempts to create blockchain-based applications have resulted in failures. Therefore, for future endeavors, collaboration and cooperation with blockchain practitioners are essential to streamline the method and facilitate its application effectively. Promoting the adoption of Blockchain-BIM to enhance the cost efficiency of Green Building (GB) construction should focus on equipping construction engineers with the necessary skills to extract value in various building projects. However, the effective utilization of Blockchain-BIM is contingent on users' ability to adapt to the technology and their understanding of encryption technology. Future research endeavors should delve deeper into the intricacies of GB and consider the diverse needs of stakeholders. The innovation in this study lies in the development of a comprehensive strategy that amalgamates Blockchain-BIM to bolster GB practices, particularly in conjunction with renewable energy. This strategy aims to enhance modeling proficiency in renewable energy integration within GB projects and bolster knowledge of digital software and Blockchain technology among stakeholders. The research findings indicate that the implementation of Blockchain-BIM in Green Industry can lead to cost savings of 4.42% for Primary-level buildings, 4.45% for Middle-level buildings, and 4.40% for Main-level Chemical Industry Buildings. These results confirm the hypothesis that the utilization of Blockchain-BIM can effectively enhance the cost efficiency of Chemical Industrial Buildings within the Green Industry sector.

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