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Blockchain-BIM: reducing cost in green retrofitting for sustainable construction development

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Abstract
During the implementation process, the construction sector significantly affects the environment, leading to environmental pollution and the overconsumption of natural resources. This jeopardizes the sustainability of a healthy living environment, requiring a solid system to control development. A sustainable and environmentally friendly development system is crucial from architectural, construction, and economic perspectives. However, when applying the concept of Green Building to existing buildings, the cost of green retrofits has increased by about 10.77%. A case study was carried out on the existing BRIN (National Research and Innovation Agency) building to provide alternative solutions to reduce these green retrofitting costs, making sustainable construction the primary option in developing the construction sector. One way to address this cost increase is using the Blockchain-Building Information Modeling (BIM) application, an alternative method to determine the most economical cost based on input or a given model. BIM models contain non-geometric information, including materials for building components, quantities, prices, procedures, scales, and sizes. This allows for real-time data exchange and collaborative decision-making between stakeholders, improving visualization and modeling and lowering costs due to better construction outcomes and higher productivity probability. The implementation of Blockchain-BIM is expected to result in green retrofit cost savings of at least 3% on each green level according to the Ministry of Public Works and Housing (PUPR) of the Republic of Indonesia Technical Guidelines No. 01/SE/M/2022, namely Primary, Intermediate, and Main.

Keywords:
Blockchain-BIM;
Green retrofitting;
Sustainability;
Office building;

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INTRODUCTION

Construction projects play an essential role in preventing environmental damage. Another indication of environmental damage is the occurrence of phenomena caused by the effect of greenhouse gas warming and increased carbon dioxide. One reason the researchers attribute this to the construction and operation of the building itself. The Green Office is expected to become a significant need and challenge with this research. It aims to present a more efficient business space for energy utilization, lower operational costs, and provide convenience for its users.

The construction industry in developing countries is facing challenges due to its failure to mitigate its impact. The building sector accounts for more than 40% of worldwide energy usage and almost one-third of global emissions of greenhouse gases. Typically, the production, transportation, building, and dismantling stages of materials and maintenance processes account for 10-20% of energy use [1].

Based on the Intergovernmental Panel on Climate Change (IPCC), In 2022, building

construction accounted for 5% (3.3 GtCO2e) of global greenhouse gas emissions. Additionally, it indirectly contributed about 11% (6.4 GtCO2e) of energy consumption and emissions due to the buildings' operation, as shown in the following illustration Figure 1.

The construction industry commonly utilizes energy and natural resources [3]. As a result, it is responsible for 36% of CO2 emissions [4]. Green buildings are emerging as an alternative solution for architecture, engineering, and construction (AEC) to assist sustainable development [5].

The construction industry covers the execution and control of many projects. Good management during construction is essential to ensure the building is built with good quality. Green building development promotes building design, construction, and operation by optimizing resource use (energy, land, water, and materials), reducing carbon emissions, and increasing the use of renewable resources [6]. Considering the number of existing buildings in developing countries that keep increasing every year to reach 1.5% to 2%, implementing green retrofitting is one of the better sustainable development parameters to use. It can reduce economic, environmental, and social costs [7].

The cost of retrofitting (green construction) increased by 10.77% due to obstacles associated with implementing green concepts, such as Implementing energy-efficient systems, lighting, conservation, and water recycling [8]. Generally, green project design costs show considerably higher cost increases, up to 5% higher than conventional projects [9].

In addition to design costs, preparation-related costs, including management costs, human resources, ratings, and commissioning-related costs such as green ratings, may also potentially emerge.

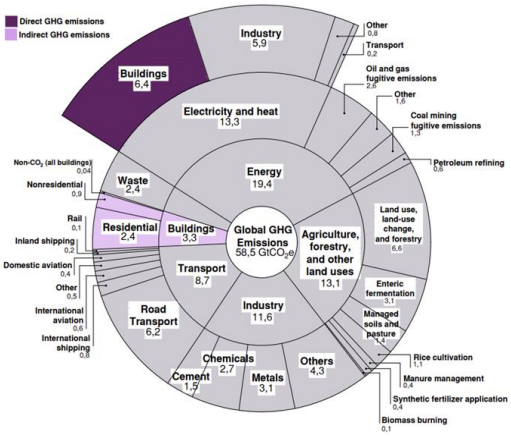

Figure 1. Contribution of Buildings to Global CO2 Emissions [2]

The costs are impacted by the lender's requirements, which include compliance with environmental and social management issues and the availability of expert resources. Green construction projects incur a cost performance that exceeds the budget by around 4.5% to 7% compared to conventional building projects. [10].

One way to decrease the cost of green building projects is to apply up-to-date technology applications, such as Building Information Modeling (BIM). In the development of the construction industry, implementing blockchain through the Building Information Modeling (BIM) approach can offer many advantages, especially in reducing costs and increasing project profits. Blockchain is a supervised and distributed peer-to-peer transaction database that records and stores a list of transactions, known as "blocks", verified through cryptography [11]. Efforts to address the rising costs caused by Green Retrofitting required the role of blockchain concepts and approaches that leverage Building Information Modeling methods (BIM). Using the BIM approach, potential issues and shortcomings in the initial project are found, which could serve as a solid foundation for a proposal for future design enhancements [12]. The study aims to analyze the results of applying Green Retrofit evaluation on office buildings using Blockchain-Building Information Modeling (BIM).

MATERIAL AND METHODS

Study Literature

Green buildings positively contribute to the environment and climate throughout their lifetime, from planning and construction to operation, maintenance, renovation, and demolition. Adopting green buildings in Indonesia presents several challenges, and this includes significant upfront expenses in comparison to conventional buildings, as well as a lack of public knowledge and awareness of green buildings and how eco-friendly products can be found on the market, and insufficient governmental provision of both financial and non-financial assistance. Worldwide, buildings can reduce carbon emissions by 35%, energy savings by 30-35%, water use by 40%, and solid waste by up to 70% [1]. Implementing green building regulations across countries is a viable approach to attaining global greenhouse gas emission targets in the construction sector. New buildings designed and built following green standards and existing buildings that have undergone green retrofitting will be awarded green building certification. Benefits can be felt by doing certification on green buildings, among other things:

a. Enhances the building's worth.

b. The building will be well insulated against external and internal heat.
c. water can be saved from both the rainfall and the recycling system.
d. Low electricity use.
e. The buildings will provide comfort.

Retrofitting involves modifying the effectiveness of buildings to comply with green building standards [13]. Green retrofitting solutions can enhance building functionality and energy efficiency [7]. Green retrofitting involves implementing energy-efficient equipment, sophisticated air conditioning and heating systems, and renewable technologies to improve the sustainability of buildings. Building retrofitting seeks to maximize energy efficiency and decrease the time it takes to recover the initial investment [14]. The green retrofitting building has enhanced maintenance quality while reducing energy consumption and cost efficiency, leading to financial gains for the owners [15]. Green buildings offer significant advantages, such as reducing water use by 30–50% and conserving energy by 20–30%. The intangible advantages are improved natural lighting, air purity, residents' comfort, health, and general well-being [16].

Research in Malaysia found that the overage of most green buildings falls between 0% and 10%. The return on investment is derived from reduced electricity costs and increased staff productivity [17]. Research in Switzerland evaluated retrofit solutions, considering efficiency in terms of cost and environmental consequences. The assessment examined the building envelope's retrofit and the heating system's effectiveness. The study found that the best cost-effective approach was to combine heat pumps with roof insulation, as the heater performed significantly more efficiently than the building envelope [18]. Green building upgrades can increase the cost of an existing structure by 10.77% [8].

Research results indicate that the blockchain-BIM method can save 8.3% of the total construction cost in housing construction, with a standard deviation of 1,26% [19]. Sustainable interior design is essential in creating the best solution to reduce energy consumption. This can be achieved by integrating energy-efficient lighting systems such as L.E.D. or C.F.L. lamps and applying passive solar designs to reduce the need for artificial lighting [20]. To successfully implement a green retrofitting system in office buildings, several guidelines must be followed to enhance cost-effectiveness and ensure financial viability. Green retrofit can improve operating cost performance using Blockchain-Building Information Modeling (BIM) methods. Utilizing Building Information Modelling (BIM) in building projects can offer team members efficient collaborative procedures [21][22]. In order to automate design processes, the construction sector today uses a lot of Building Information Modeling [23]. Due to bilateral subscription, stakeholders such as clients (owners), structural planners and architects (designers), supervisory consultants (construction management), and contractors can collaborate in data transactions related to construction business processes more quickly, safely, and confidently. The personal address generated by the system gives each user the ability to interact with the blockchain. The system's use is protected because this IP address does not reveal the original user's identity.

The initial Blockchain-BIM design was based on three technical principles;

a. Decentralization: transaction evidence and other primary data are kept on the blockchain dashboard. Secondary data, on the other hand, details regarding BIM protocol management are kept in decentralized file storage systems known as vaults or folders. The systems provide an encrypted peer-to-peer connection in which nodes store partially encrypted data, offering consumers increased speed, privacy, and security.
b. Confidentiality: encryption techniques safeguard the blockchain ecosystem. The Blockchain system offers a unique combination of open accessibility and data owner protection because it stores only cryptographic proofs, not data.
c. Personal data protection: Blockchain-BIM records proof of transactions or data occurrences; it does not broadcast all data to the blockchain. Identity and personal information are kept private and safe in designated areas known as role members and are only shared with project partners.

Utilizing blockchain-BIM can address interference in BIM for environmentally friendly construction design and project management throughout the construction's life cycle. These risks encompass technical, administrative, environmental, monetary, and legal aspects, as well as cybercrime and property rights concerns. Additionally, they involve delineating responsibilities among members of various project teams and formulating detailed and transparent plans for reusing and adopting BIM models. An encrypted BIM data blockchain consisting of sequentially validated transactions is called a BIM blockchain [24].

In order to ensure that any node that gets information distributes it to all of its counterparts, blockchain-BIM is a peer-to-peer system consisting of nodes that establish connections, maintain connections that already exist, and distribute encrypted information. In the collaborative BIM workflow, this resolves the issue of system failure or shutdown.

Suppose blockchain is used as a tool for data management and protection. Some problems arising during the BIM project can be overcome because blockchain guarantees a secure and controlled collaborative ecosystem. Since the blockchain guarantees neutrality on any changes made to the model, no party is in a favorable position over the other since it is designed as a distributed database. The blockchain is a secure source when system participants exchange module information in intelligent contracts [25]. With the blockchain, we can leave an irrevocable record of all the changes made to each BIM object [26]. Any changes will be automatically linked to the creator. This way, information will be reflected and replicated on all systems and servers (network nodes) with access to the model. In this way, problems may occur when finding the model editor. Thus, the model itself will not be manipulated. It is still in its early stages that developers of blockchain technology have the potential to improve and optimize the majority of today's design and development practices. It will benefit companies, individuals, industries, customers, and society. BIM materials and procedures have been established to increase profitability and change projects. It enables more professional handling of data collected and maintained throughout the building's life cycle. Financial sector advancements in blockchain technology have increased investors, deployed more recent blockchain applications, and technological advancements such as Smart Contracts, which are automatically executable [27][28]. The use of blockchain can increase efficiency, transform industrial culture, and promote future technologies [19]:

a. Cryptography employs several cryptographic methods, such as one-sided hashing procedures and the infrastructure of public keys.
b. Peer-to-peer (P2P) networks: online communities that facilitate peer-to-peer data exchange and discovery.
c. Consensus mechanism: an algorithm that establishes the order of transactions, given that not all participants are truthful
d. Ledger: a collection of transactions grouped into cryptographically connected "blocks."
e. Validity rules refer to a collection of overarching guidelines governing the network, such as accepting transactions and updating the ledger.

The Architecture, Engineering, and Construction (AEC) industry has been encouraged to develop new workflows and network dynamics without linear communication barriers [29]. Therefore, the benefits of BIM implementation in terms of collaboration and participation of the stakeholders involved in the project lifecycle have become essential [30]. Figure 2 shows the implementation of blockchain in the construction project cycle with various stakeholders involved.

In the construction industry, the project owner or the developer serves as the primary customer of the main contractor. In cases where a main contractor company uses a subcontractor, the direct customer of this subcontracting company is the main contractor, and the developer is the next direct customer. Supervisory consultants and planner consultants help developers. Main contractors pay subcontractors, and project owners pay vendors. It is a complex money flow system. Money is not the only element in the transaction. Transaction charges are charges incurred when conducting an economic exchange or doing business.

At the same time, contracts involve transactions, agreements result from many transactions, and collaborations result. Figure 3 shows another similar relationship. The transaction cost follows a black arrow, representing a relationship of cooperation between trade, heavily reliant on trust.

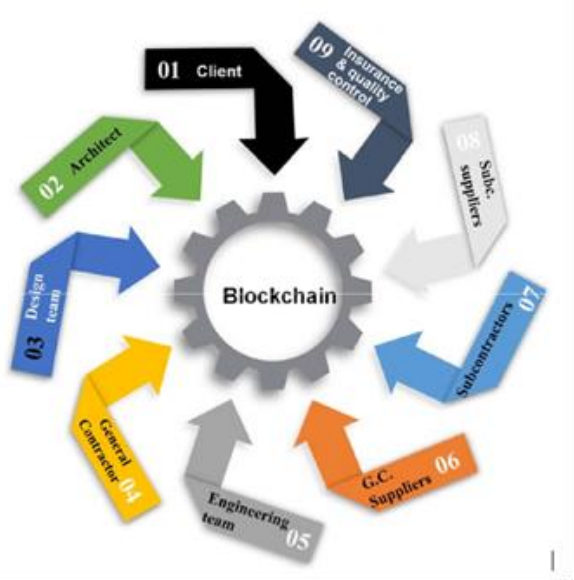

Figure 2. Construction-Based Blockchain [19]

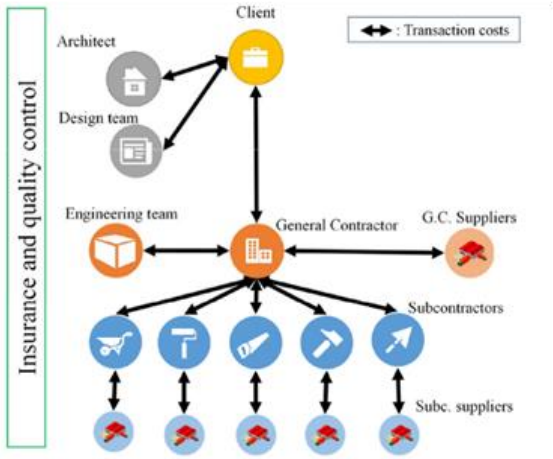

Figure 3. The Blockchain Cost Transactions [19]

Method

In previous studies, much literature has analyzed the factors determining the success of constructing green buildings and retrofitting existing buildings. However, research has yet to be carried out on green retrofitting office buildings that follow the latest Indonesian green building regulations, namely the Ministry of Public Works and Housing (PUPR) the Republic of Indonesia of Technical Guidelines No. 01/SE/M/2022.

Green Building Guideline of The Minister's Regulation PUPR No. 01/SE/M/2022

According to the Republic of Indonesia's Regulation of Public Works and Public Housing Minister (PUPR) No. 01/SE/M/2022, retrofitting is a method of modifying buildings' performance to comply with green building standards and decrease carbon dioxide emissions and energy usage. Green retrofitting enhances the efficiency of air conditioning, lighting, and ventilation systems [14].

A rating system is an instrument that includes information about an evaluation component known as a rating, where each assessment element is assigned a specific value or score point. Each successful assessment element will earn one value point. If the total number of points collected reaches a specific number, the building can be certified for a certain level of certification. However, a building inspection is carried out before reaching the rating stage to ensure the building meets the initial assessment requirements.

A green building is a construction that complies with the building criteria and has a considerably measured achievement of saving water, energy consumption, and other commodities.

The principles of constructing a green building are applied to every operation stage and classified according to its function [31]. One hundred sixty-five points will be required in the Green Building Guidelines under the Ministerial Technical Guideline PUPR No. 01/SE/M/2022, consisting of several sub-sections described in Table 1. The ranking according to the Minister of PUPR's Technical Guidelines No. 01/SE/M/2022 is as follows:

- Primary Green Building/Bronze Medal with a score of 45% to 65% (74–107 points).
- Intermediate Green Building/Silver Medal with a score of 65% to 80% (108–132 points).
- Main Green Building/Gold Medal with a score of 80% to 100% (133–165 points).

Blockchain-BIM

An innovation in this study is applying the Blockchain-BIM method to reduce the costs arising from green retrofitting of office buildings. Currently, many existing office building conditions owned by private and government entities still need to implement the concept of green buildings. It is expected that this research will produce innovative research as the best alternative recommendations in terms of cost performance for commercial and government office buildings as a place of business activity that will benefit companies have many economic, environmental, and social benefits, as well as reduce operational and maintenance costs of buildings. This will be one of the references in the construction industry in law enforcement. This research will produce green retrofit modeling innovations of office buildings using Blockchain-Building Information Modeling (BIM) methods to obtain cost efficiency.

Green retrofit activities can produce an additional cost effect of about 10.77% [32]. The blockchain-BIM approach will be used to determine the ideal retrofitting cost. This should lower the retrofit cost by at least 3% [33]. The framework is shown in Figure 4.

Table 1. Green Building Assessment

No.	Performance Assessment	Point
1	Site management	38
2	Energy efficiency	46
3	Water efficiency	22
4	Indoor air quality	19
5	Eco-friendly materials	21
6	Waste management	7
7	Waste water management	12
	Total	165

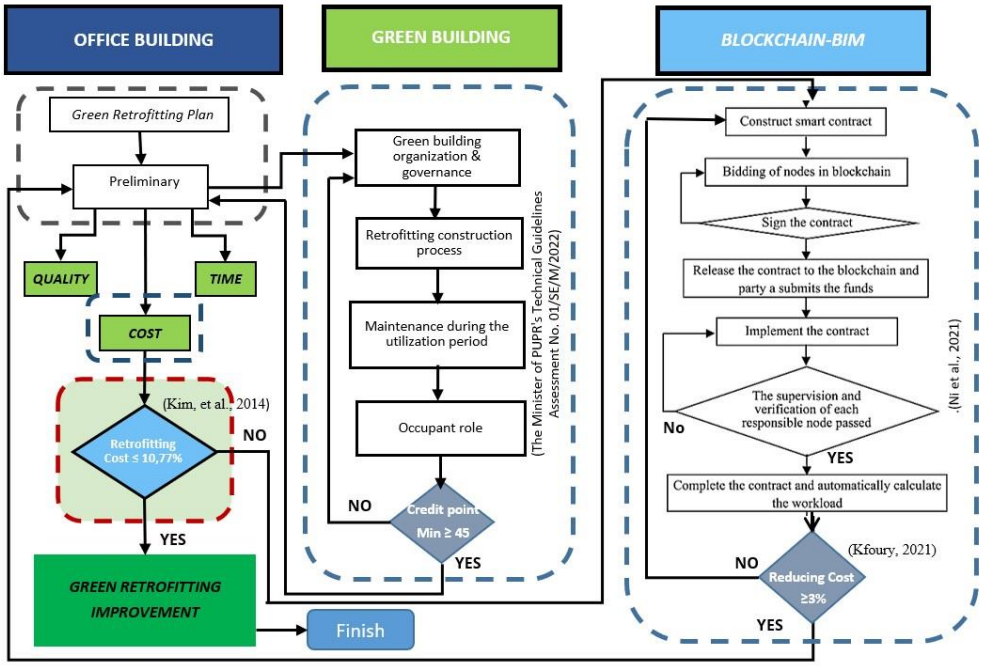

Figure 4. Research Framework

With Blockchain-BIM technology, stakeholders such as clients, owners, structural planners, architects, construction management consultants, and contractors can collaborate in data transactions on construction business processes more quickly, reliably, transparently, and securely because they are peer-to-peer- inscribed. Any user can interact with the blockchain through the personal address the system created. Since this address does not indicate the original identity of the system user, the privacy of the user in the system usage becomes awake. Each user has an account ID and password as the initial request at the time of login in this application, as shown in Figure 5.

The blockchain must support autonomous changes, ensure tracking modifications and information ownership, and integrate with smart contracts for protection and control based on established guidelines. This will help maintain the security and privacy of confidential project data, considering legal contract commitments binding some or all of the construction workers.

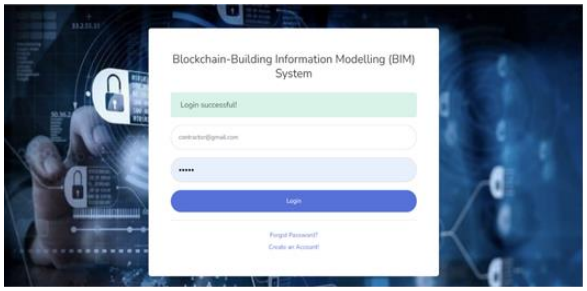

Figure 5. Blockchain-BIM Log In

All network users came to an agreement prior to the blockchain's implementation, which ensured that the distributed ledger would remain unaltered for the duration of its existence. After agreement on consensus mechanisms, role members run consensual protocols to validate transactions and create blocks and chains of hashes. Identity personal data is stored securely in a dedicated and isolated space called a role member and is only disclosed to stakeholders who share the same project. This member can only be customized by the head of management, who can also be called an admin. However, determining participation and authority remains in the joint corridor agreement stipulated in the smart contract. The existence of this role member can be seen in Figure 6.

When entering the main page (dashboard), the concept of integrated blockchain and anyone who is a member of this console, consisting of stakeholders who can access and agree in the blockchain, the dashboard page as in Figure 7.

Figure 6. Role Members Involved in The Blockchain Network

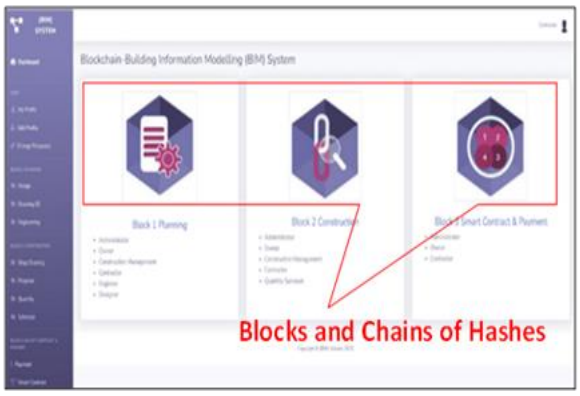

Figure 7. Blockchain-BIM dashboard

Blockchain makes records and transaction history permanent in this context, which means that when data is recorded in the blockchain, it will be challenging to change or delete it. If one wants to change it, one must first obtain the approval of most network users on the blockchain to change information and be incentivized not to change the data [34]. The recorded data preference is permanently described in the form of a hash. Hash is the part the blockchain uses to own, created by an algorithm that generates short strings of extensive data sets that follow mathematical rules. The hash is unique; therefore, some of its intrinsic critical properties are deterministic, impact-resistant, and pseudorandom. The hash must be a one-way function that cannot be changed. Permanent transactions of documents using history that no one can change are seen in Figure 8.

A smart contract is a set of coded instructions that can be automatically executed upon fulfilling certain conditions [11]. Smart contract systems driven by blockchain at the user level can also help improve BIM systems in sustainable building processes.

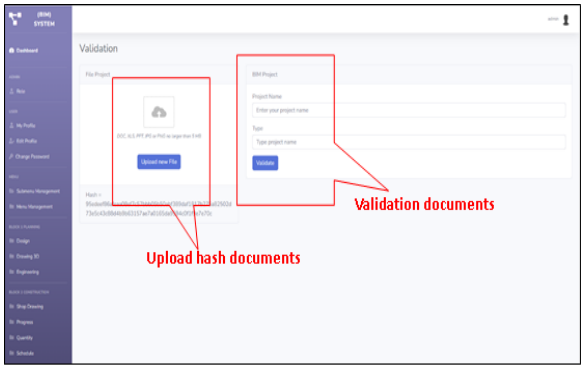

Figure 8. Validation and Transaction of Documents in Hash Form

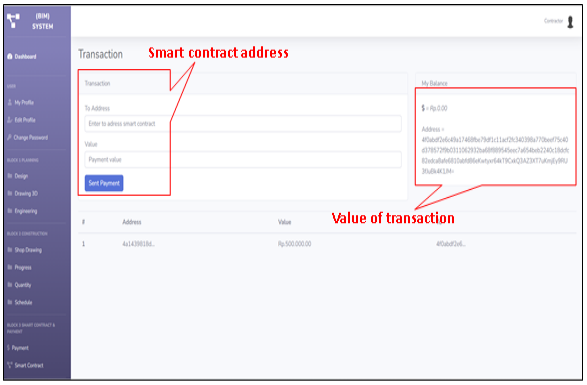

Figure 9. Payment Transaction Page

Payments made with smart contracts on a distributed blockchain enable consistent execution and reduce transaction costs, which enables process automation [35].

By combining the integration of Blockchain and BIM technology, unauthorized changes and inconsistencies can be detected, and project documents can become more reliable and safe from hacking. It suggests that historically stored data on performance, compliance, and certification will be more reliable, reducing the industry's fraud and corruption rate. It provides an opportunity to design a system that allows the control of modification rights on the BIM model, which limits any unauthorized modification from the outset. Specifically, it will add how intelligent contracts running on the blockchain will benefit this function by giving contractors, subcontractors, and various parties involved in the project payment assurance. Examples of payments/transactions carried out in this blockchain-BIM platform are shown in Figure 9.

RESULTS AND DISCUSSION

The office market is showing signs of improvement in early 2023 due to the rising demand for workspace. Various industries, including pharmaceutical manufacturing, law firms, consultancies, software developers, and telecommunications providers, are actively seeking office space. Renewable energy and renewable technology sectors include financial technology (Fintech), information technology (I.T.), and data centers, which are the most active sectors in the office rental market [36]. Due to changing resident preferences, investors rethink value and emphasize governance, social, and environmental aspects, leading to higher regulatory demands and operational expenses. When choosing office space, it is essential to consider building sustainability and high environmental standards, especially for multinationals.

Workplace safety has become an essential part of policy around the world.

Most residents will be attracted to high-quality office buildings that are well-located and have facilities that enhance employee well-being and engagement. In addition, companies will have a competitive advantage if they take sustainable action consistent with the company's social and environmental goals.

Adding green spaces to office buildings improves sustainable development. The goal of the sustainable building concept is to provide ecologically friendly building materials at every development level—from design to execution to deployment. The development of new green buildings, building retrofits, green infrastructure, green industries, and other green concepts are a few examples of current green implementations worldwide.

In this study, the author conducted the research at the National Research and Innovation Agency (BRIN) building on Pasir Putih Road No. 1, Ancol, North Jakarta, Indonesia, as shown in Figure 10.

Green Building Assessment Technical Guidelines According to The Minister's Regulation PUPR No. 01/SE/M/2022

Many previous studies have investigated aspects that determine the success of implementing a green building or retrofitting an existing building.

However, no research has been carried out on the green retrofit of office buildings that follow Indonesia's latest green building regulations, the Minister's Regulation PUPR No. 01/SE/M/2022. One innovation in this research is applying the Blockchain-BIM method to reduce the costs incurred by building renovations. It will be one of the examples of the construction industry supporting sustainable resource management.

Figure 10. Geographical Location of the National Research and Innovation Agency (BRIN) Building

By applying green building principles according to purpose and categorization in every step of its maintenance, green buildings will have significantly measured performance in saving water, energy, and other resources [37]. The BRIN office building was assessed according to green building performance requirements. The total points were calculated during the building utilization phase, along with the expected target after retrofitting, as displayed in Table 2.

Performing a simulation improvement plan that will enhance the green performance of existing buildings following a review of the current circumstances can help achieve points. The next phase is to improve the building's functions to increase the points earned for the green building category under the Technical Guidelines for the Evaluation of Green Buildings Ministerial Regulation PUPR No. 01/SE/M/2022. In order to get to the anticipated point and qualify for the green building category, the building must be retrofitted, as shown in the following Table 3.

With this research, the Green Office is expected to be a more efficient business place regarding energy use, operating costs, and customer satisfaction. Things like this will be a need and a challenge in the future.

Blockchain-BIM on Cost Performance

Cost-cutting measures will eventually need to cover the increased cost impact of retrofitting. BIM has much promise to boost sustainability, reduce waste in the building industry, and increase efficiency. Through modeling, BIM can help some aspects of sustainable design.

This modeling was produced by the author using the Revit 2021 program. The modeling stage follows and calls for a qualified quantity take-off-based BIM operator for work on office building construction. Autodesk Revit includes environment simulation, weather forecasting, energy analysis, building energy modeling, and structural analysis.

Applying the BIM quantity take-off method obtained more accurate quantity calculations than traditional methods; Table 4 shows the deviation of each item of work against the two methods of calculation.

Table 2. Assessment of Existing Building and Target Achievement of Green Retrofitting Points

No.	Item	Green Assessment Base on the Minister of PUPR's Technical Guidelines No. 01/SE/M/2022		
		Primary	Intermediate	Main
1	Standard Criteria	74-107	108-132	133-165
2	Assessment Result	67	67	67
3	**Target Achievement**	**100**	**118**	**137**
4	Points Deviation	33	51	70

Table 3. Retrofitting Requirements Towards Green Building

No	Retrofitting Requirements	Retrofitting plan for each category		
		Primary	Intermediate	Main
1	Bicycle parking and shelter bus	-	-	√
2	Establishment of designated smoking zones outside buildings and parks	√	√	√
3	Photovoltaic panels	√	√	√
4	Provisional waste management	√	√	√
5	Machine for composting organic waste	-	√	√
6	Machine for recycling inorganic trash	-	-	√
7	Sewage Treatment Plan (STP)	√	√	√
8	Constructing vertical drainage and infiltration systems	√	√	√
9	Solar-powered streetlights and garden lights	√	√	√
10	Energy-efficient lighting in structures	√	√	√
11	Installation of water-efficient plumbing fittings	√	√	√

Table 4. Comparison of Traditional Method Quantity Calculation with Quantity Take-Off (BIM) Method

No	Work Material Item	Unit	Traditional Method Quantity	Quantity Take-off (BIM) Method	Quantity Difference	Deviation (%)
1	Shelter bus and bicycle parking					
	- Steel	kg	1,517.76	1,449.63	68.13	4.49
	- UPVC for roofs and walls	m2	21.82	21.17	0.66	3.01
2	Temporary garbage disposal					
	- Lightweight brick wall	m2	13.45	12.78	0.66	4.94
	- Plaster	m2	27.09	25.61	1.49	5.48
	- UPVC roof	m2	11.90	11.45	0.45	3.75
3	Organic waste composter machine					
	- Lightweight brick wall	m2	5.36	5.22	0.14	2.63
	- Plaster	m2	10.83	10.44	0.39	3.57
	- UPVC roof	m2	4.28	4.14	0.14	3.38
4	Inorganic waste recycling machine					
	- Lightweight brick wall	m2	5.36	5.22	0.14	2.63
	- Plaster	m2	10.83	10.44	0.39	3.57
	- UPVC roof	m2	4.28	4.14	0.14	3.38
5	Sewage Treatment Plan (STP)					
	- Excavated soil	m3	246.81	230.02	16.79	6.80
	- Sand layer	m3	13.43	12.80	0.63	4.67
	- Lean concrete	m3	4.81	4.62	0.19	4.03
	- Ready mix concrete	m3	31.76	30.22	1.54	4.85
	- Reinforcing steel	kg	5,282.14	4,973.77	308.37	5.84
	- Formwork	m2	187.96	181.25	6.71	3.57

The renovation and addition of functions of this building is an attempt to make the green building following the target assessment points based on the Technical Guidelines for Green Building Assessment of the Minister of PUPR's Technical Guidelines Assessment No. 01/SE/M/2022 so that the office building is in the categories of Primary Rank, Intermediate Rank, and Main Rank.

This retrofitting activity will result in additional cost impact, which must be managed through savings. BIM can optimize efficiency,

reduce construction waste, and promote sustainable development. BIM can help with some aspects of sustainable design [38]:

- decreasing energy usage by adjusting building orientation,
- enhancing building functions,
- analyzing daylighting,
- decreasing water usage,
- evaluating renewable energy possibilities to lower energy demand,
- using recycled materials,
- reducing waste and carbon dioxide environmental impacts through site management, transportation, and distribution.

Figure 11 below shows the condition of the existing building before the green retrofitting. It is visible in front of the building, which does not yet have solar panels, shelter buses, and bicycle parking spaces, which are a requirement for building green level upgrades.

The figures below are examples of activity modeling and quantitative calculations based on BIM at some stage of the retrofit work.

Providing bus stops and bicycle parking as support facilities to reduce the potential emissions of motor vehicle exhaust gases is an effort to control carbon dioxide (CO2) and carbon monoxide (CO), as shown in Figure 12. Figure 13 shows solar panels converting sunlight into electricity, directly using photovoltaic or indirectly using concentrated solar energy to generate renewable electricity [39][40]. Figure 14 shows the provision of a Sewage Treatment Plant (STP), which serves waste processors to make environmentally friendly and wastewater outputs reusable.

Figure 11. The Front View of The Existing BRIN Building

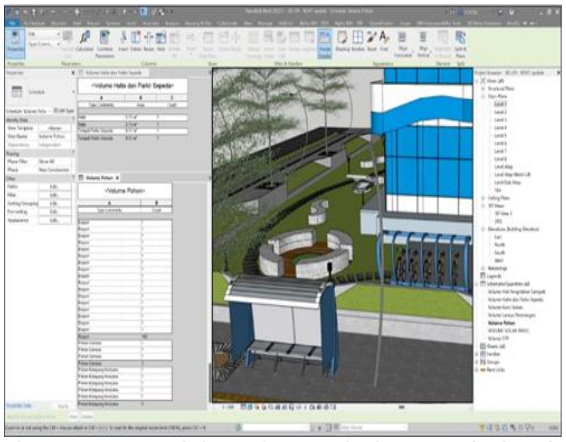

Figure 12. Provision of Bus Shelters and Bicycle Parking

Figure 15 shows the construction of waste disposal sites, provision of organic waste composting machines, and organic waste recycling machines. BIM tools can contribute positively to the management of sustainable projects seeking green building certification. The implementation of the Blockchain-BIM application will be reduced cost, as seen in Table 5.

In the literature studies that have been carried out, more research still needs to be done on reducing green retrofitting costs. The novelty of this research is reducing green retrofitting costs for sustainable construction, which is the first research conducted in the world.

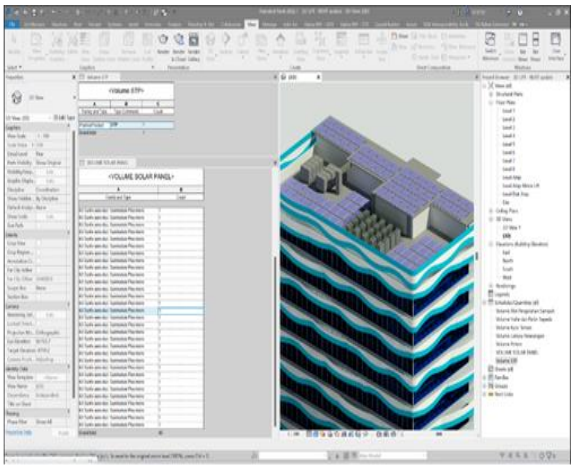

Figure 13. Construction of Solar Panels

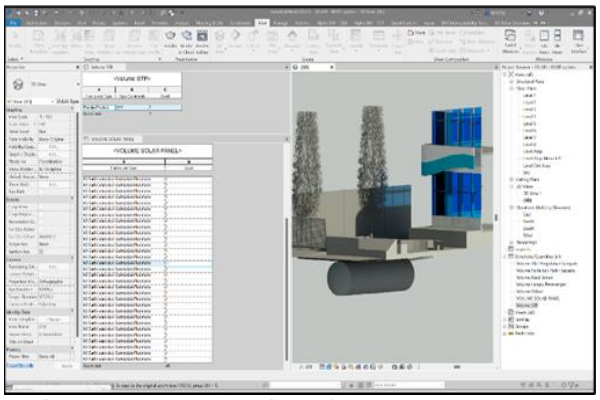

Figure 14. Construction of Sewage Treatment Plan (STP)

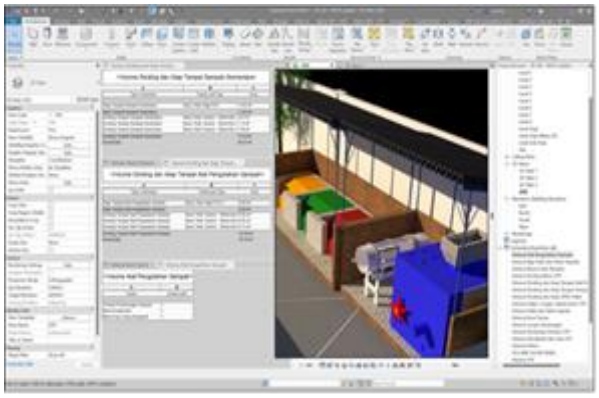

Figure 15. Waste Disposal Sites and their Treatment

CONCLUSION

Green retrofitting of buildings, particularly office buildings, enhances property value, improves thermal comfort, conserves water through rainwater and recycling systems, and has the potential to decrease electricity consumption. It will offer comfort within the structure. Based on the results of this study, it can be concluded that the application of Blockchain-Building Information Modelling (BIM) can reduce the cost of green retrofitting in high-rise office buildings by 4.10% for the Primary rank, while the Intermediate rank by 3.92% and the Main rank by 3.80%.

Governments must take the initiative to provide appropriate regulations, guidelines, and financial incentives to promote the development of green buildings in order to support sustainable construction in Indonesia. Plans for converting existing buildings into Green Retrofitting buildings must be customized to the requirements and functions of the buildings in order to achieve the Green Building classification objectives while maintaining the building's primary function and cost-effectiveness.

Future research can be done on the financial implications of green building investments using Blockchain-BIM to determine the payback period of green retrofitting costs that have been incurred.

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Table 5. Reduction Cost Based on Green Retrofitting Assessment with the Implementation of Blockchain-BIM Method

No.	Work Improvement Based on the Minister of PUPR's Technical Guidelines Assessment No. 01/SE/M/2022	Budget Cost Become Green Retrofitting Region (IDR)			Budget Cost With Blockchain-BIM Method Implementation (IDR)		
		Primary	Intermediate	Main	Primary	Intermediate	Main
1	Provision of standard operating procedures and green building governance	171,000,000	171,000,000	171,000,000	171,000,000	171,000,000	171,000,000
2	Customization planning works	128,250,000	128,250,000	128,250,000	128,250,000	128,250,000	128,250,000
3	Provision of shelter bus and bicycle parking	-	-	66,518,750	-	-	61,339,492
4	Provision of smoking areas outside buildings and parks	36,000,000	36,000,000	36,000,000	34,560,818	34,560,818	34,560,818
5	Solar panel construction	3,513,966,000	3,513,966,000	3,513,966,000	3,342,966,000	3,342,966,000	3,342,966,000
6	Construction of temporary waste storage	41,731,997	41,731,997	41,731,997	39,600,941	39,600,941	39,600,941
7	Procurement of organic waste composter machine	-	71,317,607	71,317,607	-	66,993,910	66,993,910
8	Inorganic waste recycling machine	-	-	134,909,266	-	-	127,680,910
9	Sewage Treatment Plan (STP)	838,886,000	838,886,000	838,886,000	805,332,510	805,332,510	805,332,510
10	Construction of vertical drainage and infiltration	291,640,000	291,640,000	291,640,000	280,850,000	280,850,000	280,850,000
11	Replacement of solar cell lights for street and park lighting	170,400,000	170,400,000	170,400,000	170,400,000	170,400,000	170,400,000
12	Replacement of energy-efficient lighting in buildings	111,625,000	111,625,000	111,625,000	105,750,000	105,750,000	105,750,000
13	Replacement of water-saving sanitary fixtures	351,900,000	703,800,000	1,058,875,000	351,900,000	703,800,000	1,058,875,000
14	Maintenance work during the utilization period	317,418,750	335,053,125	352,687,500	288,562,500	304,593,750	320,625,000
15	Socialization and empowerment work for building occupants	213,750,000	213,750,000	213,750,000	213,750,000	213,750,000	213,750.000
	TOTAL (IDR)	6,186,567,747	6,627,419,729	7,201,557,120	5,932,922,770	6,367,847,930	6,927,974,581
	Reduction in Retrofitting Costs after applying Blockchain-BIM application (IDR)				253,644,977	259,571,799	273,582,539
	Deviation (%)				4.10%	3.92%	3.80%