

THE EFFECT OF IMPLEMENTING GREEN CONSTRUCTION ON PROJECT PERFORMANCE: A COMPREHENSIVE STUDY USING STRUCTURAL EQUATION MODELS (S.E.M.)

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Abstract

The construction industry plays a crucial role in development but also faces serious challenges related to environmental impact and occupational safety. The sector contributes significantly to producing solid waste, air, water, soil pollution and emissions of hazardous gases. In addition, high noise levels from construction activities can harm public health. Workplace accidents at construction sites are also a major problem, with impacts ranging from worker safety to project costs. Green construction offers a comprehensive solution to address these issues. By adopting sustainable practices such as efficient waste management, using environmentally friendly materials, and implementing modern construction technologies, projects can reduce their negative impact on the environment. This study uses the Structural Equation Model (S.E.M.) to analyze green construction implementation's effect on project performance. This study identifies 20 green construction indicators and evaluates their impact on five aspects of project performance: cost, time, quality, Occupational Health and Safety (O.H.S.), and Green Building performance. The analysis results show that green construction has a significant and robust effect on cost performance and a moderate impact on time, quality, and O.H.S. performance. Project documentation is identified as the most influential green construction indicator, while conservation and energy efficiency have the lowest effects. Another interesting finding is that implementing 86% of green indicators is optimal for Green Building Performance, indicating a balance between sustainability and project efficiency. This study provides valuable insights for practitioners and policymakers in optimizing sustainable construction practices and developing more effective regulations for the green construction industry.

Keywords:

Green construction;
Project performance;
Structural Equation Model;
Sustainability;
Green building.

1 Introduction

The construction industry is vital in infrastructure development and the global economy but also contributes significantly to environmental problems. In Indonesia, construction projects generate 20-30% of total solid waste; in some countries, this figure can reach 50% [1]; [2]. The environmental impact of construction activities is not limited to solid waste but also includes air, water, and land pollution. Research shows that the average construction project produces 12 tons of dust per hectare per year and contributes 10-25% of NO_x emissions in urban areas. Noise levels from construction activities can reach 90 dB, equivalent to the sound of a jet engine at close range, which can potentially cause health problems such as hearing loss, stress, and insomnia [3].

Construction project problems related to the environment are increasingly becoming a global concern. A study by [4] shows that during the construction period, a production plant can produce dust emissions of 33 tons and daily NO_x, CO, and THC of 5.35 kg, 3.7 kg, and 1.1 kg, respectively. In addition, research by [5] revealed that demolition and earthmoving work significantly contribute to emissions from construction equipment. Construction waste is also a severe problem, with production levels varying between 3,275 to 8,791 kg/m² [2]. These impacts are detrimental to the environment and can affect public health and overall project efficiency [6].

The construction industry is also known as one of the sectors with the highest risk of work accidents. Accidents on construction sites not only threaten the safety and health of workers but also have a significant impact on productivity, project costs, and company reputation. [6] reported that five major types of accidents accounted for 96% of fatal accidents on NYSDOT (New York State Department of Transportation) construction projects at nearly \$133.8 million. Meanwhile, [7] identified seven main factors causing construction accidents: worker actions, risk management, and direct supervision. In Asia, [8] found that health and safety management skills, employer values, and compliance with work safety laws influenced work accidents in small construction companies in Taiwan. A study by [9] in Indonesia shows that electrical accidents, falls from heights, and being hit by objects are the leading causes of construction accidents.

Facing these challenges, the green construction concept emerged as a potential solution to mitigate the negative impact of the construction industry on the environment. Green construction integrates environmentally friendly practices into the construction process, including using sustainable building materials, efficient energy management, good waste management, and stormwater management. Previous research has shown that implementing green construction can positively influence project performance. [9] Green construction practices can affect the economic performance of projects by meeting environmental performance standards. Meanwhile, [10] confirmed that implementing environmentally friendly construction practices significantly improves the environmental performance of construction projects.

Cost, time, and quality performance in the green building P.D.S. process raise greater sensitivity to the inherent nature of green buildings. If poor quality performance occurs at the design stage, it will result in changes at the construction stage. It will impact the productivity of construction staff because overall progress is less [11]. Green construction practices also affect other performance achievements, such as environmental performance and OHS. Environmental performance is the best solution to combat ongoing pollution and negative impacts of development [12]. According to [13], green construction can significantly benefit energy and CO₂ reduction, cost savings, and improved health conditions for building users. In addition to the above project performance, green project management that applies green construction indicators in its implementation has a sustainability goal. According to [14], sustainable construction is becoming more common and may become mandatory in assessing sustainability or green project performance. Thus, measuring the ability of the P.D.S. method by including green building performance assessments according to the owner's needs is important.

Although previous research has demonstrated the positive potential of green construction, there is a gap in a comprehensive understanding of the critical factors that influence project performance in the context of green construction. Most studies focus on specific aspects such as economic or environmental performance. Still, no systematic review has integrated various dimensions of project performance and identified key factors contributing to the successful implementation of green construction. The long-term implications of implementing green construction in the sustainable construction industry have not been fully explored.

Based on these research gaps, this study aims to answer two main research questions: (1) How does the implementation of green construction affect construction project performance? and (2) What factors most influence project performance in green construction? This research analyzes the effect of implementing green construction on construction project performance. Additionally, this study seeks to identify the most significant project performance factors in green construction to provide insights for practitioners and decision-makers in the sustainable construction industry.

The implications of this research are expected to significantly contribute to a better understanding of the benefits of green construction in improving project performance. The results of this study can help construction companies optimize their sustainable practices, encourage innovation in environmentally friendly technologies, and provide a basis for policymakers to develop regulations that support green construction in the future. Thus, this research contributes to the academic literature on green construction and has the potential to shape industry practice and public policy toward more sustainable construction.

2 Literature Review

Construction is a complex and multidimensional concept influenced by various factors and indicators. Several primary sources such as [15], [16], PT Pembangunan Perumahan (Indonesian government contractor), Green Building Council Indonesia (GBCI), and the Ministry of Public Works and Housing (Kementerian Pekerjaan Umum dan Perumahan Rakyat; abbreviated as Kemen PUPR) through PUPR Ministerial Regulation No. 2/PRT/M/2021 have identified various construction indicators green. Green construction indicators based on the Regulation consist of the following parameters: site management, energy use efficiency, water use efficiency, water use quality, indoor air quality, use of environmentally friendly materials, waste management, and wastewater management. Despite differences in emphasis and classification, several common themes emerge among the sources, including energy and water efficiency, waste management, use of environmentally friendly materials, air quality, and occupational health. [17] has synthesized these various sources, producing 17 comprehensive green construction indicators. These differences in perceptions regarding green construction indicators from multiple sources show that this concept is still developing and can be adapted to specific contexts and needs. However, the ultimate goal remains the same, namely to create a more sustainable and environmentally friendly construction process. Literature studies show that green construction and sustainability in the construction industry have developed significantly and cover various aspects. Previous studies have examined multiple indicators of green construction, including the use of technologies such as Virtual Design and Construction (VDC) [18], the use of environmentally friendly materials and sustainable methods [19], as well as the management of energy, water, and waste [20]; [10]. The concept of sustainability in construction generally includes three main pillars: economic, social, and environmental [21]; [22].

The paper [23] states that resource optimization has a strong positive relationship with economic, social, and environmental sustainability. This shows that optimizing resource use can improve construction companies' economic, social, and environmental outcomes. The three dimensions of sustainability (economic, social, and environmental) are positively correlated, indicating that they are interrelated and mutually reinforcing in the context of sustainable construction. This study highlights the importance of a holistic approach to sustainability in the construction industry, simultaneously considering economic, social, and environmental aspects. Meanwhile, the study [24] identified one of the main components that influence the implementation of green buildings as social factors, which include lack of knowledge/awareness, lack of skilled workers, lack of market demand, training and technology, and risk and uncertainty. This study also adds three critical parameters in sustainable construction that align with global sustainability indicators, which is a gap from previous research. Community participation, an essential aspect of SDG 16 (Peace, Justice, and Strong Institutions) and SDG 11 (Sustainable Cities and Communities), is considered necessary in various stages of development. In Indonesia, this is guaranteed by the constitution (article 28 C paragraph (3) of the 1945 Constitution). Gender equality, which is SDG 5, has become a global focus [25]; [26], and the Indonesian government is implementing this Gender Mainstreaming (Pengarusutamaan Gender; abbreviated as PUG) strategy through Presidential Regulation No. 18 of 2020 (PUPR, 2020). Cultural sustainability, although not explicitly mentioned as a separate SDG, is closely related to SDG 11, which includes the protection of cultural heritage. [27] emphasize the importance of cultural sustainability as a central component in sustainable development. In Indonesia, several regions have implemented regulations regarding building architecture that reflect regional characteristics, such as Yogyakarta Regional Regulation No. 1 of 2017, Bali Provincial Regulation No. 5 of 2005, and Banjarbaru City Regional Regulation No. 1 of 2022. This literature study shows that the concept of green and sustainable construction continues to develop by including broader social and cultural aspects, in addition to considerations of environment and economy. This reflects a more holistic understanding of sustainability in the context of development and construction, which aligns with the Sustainable Development Goals (SDGs) and global sustainability principles.

The impact of green construction practices on various aspects of project performance, including environmental performance and Occupational Health and Safety (OHS). Research shows that green construction can significantly reduce energy and CO₂ emissions and improve the health of building users (Balaban, 2016). Several studies reveal that energy management, rainwater management, and sanitation are the green construction practices influencing environmental performance [10]; [28]. However, there are mixed results regarding the impact of green construction practices on OHS, with some studies reporting positive effects and others reporting negative consequences [29], [25], [20]. This study also discusses green project management, focusing on Leadership in Energy and Environmental

Design (LEED) certification as a sustainability performance assessment tool [14]; [19]. This study emphasizes the complexity and multidimensionality of green construction practices and the importance of an integrated approach in achieving sustainability goals in the construction industry. In Indonesia, sustainability performance is categorized into three levels: Main Green Buildings, Middle Green Buildings, and Primary Green Buildings.

Project performance indicators commonly discussed include cost, time, and quality. For cost performance, the indicators used include building cost effectiveness, cost risk, cost growth, and unit costs [30], [26], [27], [31], [32]. Time performance is measured through time growth, delivery speed, and completion schedule [33]. Project quality is assessed through indicators such as turnover, system, equipment, customer satisfaction, and as-built system quality [30]; [34]; [35]; [36]. Several studies also discuss Occupational Health and Safety (OHS) performance in green construction, with indicators such as work accidents, injuries, fatigue, and unsafe conditions [20] [37]. The project performance indicators were not studied comprehensively, so in this study it can be concluded that the identified green construction indicators and project performance that will be studied comprehensively in this study are as shown in Table 1 and Table 2 below:

Table 1 Green construction variables studied.

No	Green construction variables	Symbol
1	Planning and scheduling	X1
2	Worksite protection planning	X2
3	Material sources and cycles	X3
4	Water conservation and efficiency	X4
5	Energy conservation and efficiency	X5
6	Appropriate use of land	X6
7	Waste management and demolition	X7
8	Occupational health and safety program	X8
9	Environmental management of construction projects	X9
10	Creating an environmentally friendly work location	X10
11	Equipment selection and operation	X11
12	Air quality	X12
13	Health and comfort in the project	X13
14	Material storage and protection	X14
15	Documentation	X15
16	Subcontractor training	X16
17	Reduce ecological footprint	X17
18	Society Participation	X18
19	Gender equality	X19
20	Cultural Sustainability	X20

Table 2 Project performance variables

No	Cost performance indicators	Symbol
1	Building cost-effectiveness	Y11
2	Cost risk	Y12
3	Labor costs	Y13
4	Warranty costs	Y14
5	Cost growth	Y15
6	Unit cost	Y16
7	Project profits	Y17
8	Actual cost (AC)	Y18
9	Planned value (PV)	Y19

No	Time performance indicators	
1	Added schedule	Y21
2	Accelerated delivery	Y22
3	Completion schedule	Y23
4	Lateness	Y24
No	Quality performance indicators	
1	Customer (owner) satisfaction	Y31
2	Quality of the <i>as-built</i> building system	Y32
3	System quality	Y33
4	Equipment Quality	Y34
5	Rework	Y35
6	Latent defects	Y36
No	OHS performance variables	
1	Injury	Y41
2	<i>Recordable injuries</i>	Y42
3	Working hours	Y45
4	Unsafe actions and conditions	Y46
5	Frequency of serious incidents (work accidents)	Y47
6	Fatigue	Y48
7	Occupational illness	Y49
No	Green Building Performance variable	
1	Main Green Building	Y51
2	Middle Green Building	Y52
3	Primary Green Building	Y53

3 Methodology

This research aims to analyze the influence of independent variables (green construction indicators) on dependent variables (project performance indicators). The conceptual framework of the analysis model for the impact of green construction variables on project performance can be described as follows:



Fig. 1: Conceptual Framework of the Model

In this stage, the research is focused on determining the influence of various indicators on the independent variable and the indicators on the dependent variable. This analysis will evaluate the influence between variables directly or indirectly. The direct influence referred to here is the influence of green construction variables on project performance achievement. In contrast, the indirect influence is the influence of PDS features on the relationship between green construction and project performance achievement. However, this study does not discuss the indirect influence. This analysis uses Structural Equation Models (SEM) with the WarpPLS Approach. Based on the SEM method in general, the main characteristic of this method is the simultaneous solution of a system of equations formed based on the problem whose solution is to be sought. The WarpPLS method approach uses three estimates of parameters: the *outer model*, the *inner model*, and hypothesis testing [38]. So, the stages in modeling analysis with WarpPLS in this research are as follows:

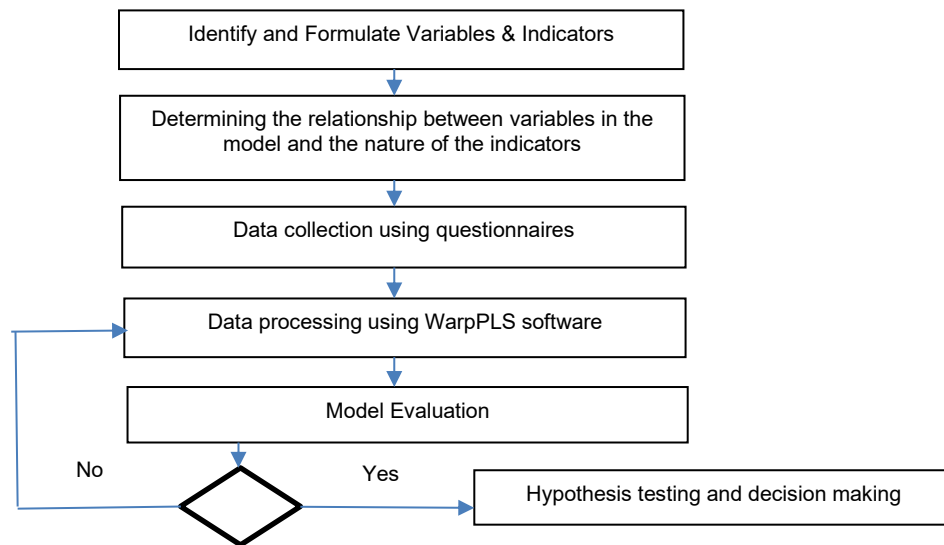


Fig. 2: SEM model analysis stages

In SEM, designing relationships between variables is very important in building models. Variables in SEM are latent variables that cannot be measured directly, and it is essential to identify whether the latent variable is endogenous or exogenous. For this reason, each variable must be measured through indicators. In SEM with WarpPLS, the nature of this indicator, whether reflective or formative, is crucial for building the model. One modeling framework, the outer model, determines reflective or formative indicators. There are two types of indicators, namely reflective indicators and formative indicators. According to this, the reflective indicator model was developed, assuming that latent variables form indicators, showing the causality of the latent variables to the indicators. Furthermore, for formative indicators, there is no need for correlation between indicators, so they do not have common *factors*. Therefore, there is no need for internal reliability for formative indicators, which is indicated by *Cronbach's alpha value*. Additionally, latent variables with characteristics such as attitude, personality, or behavior represent something reflected or reflected and can be categorized as reflective indicators. In contrast, variables whose characteristics are composed or formed from several indicators are called variables with formative indicators.

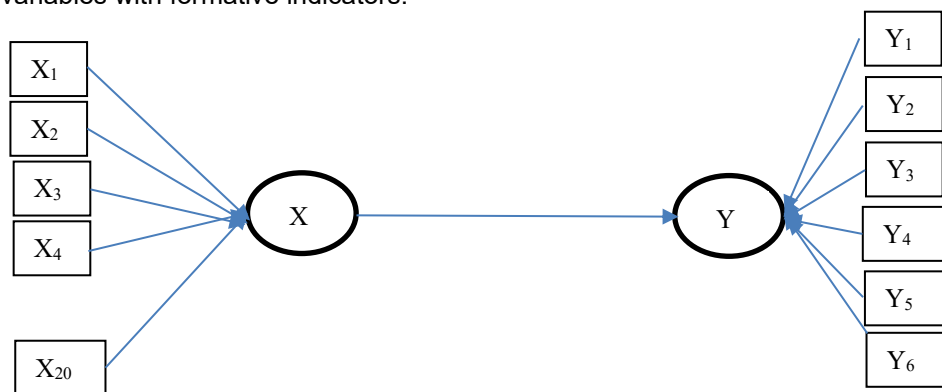


Fig.3: Model of relationships between variables in SEM

The survey results were tabulated and analyzed using WarpPLS v.8.0 student software. Model evaluation or testing includes three stages, namely:

- 1) Outer model testing
- 2) This testing includes validity and reliability tests. The validity test itself consists of convergent validity and discriminant validity. The conditions for convergent validity are met if the factor loading value is > 0.3 and the p value is < 0.01 [39], which shows its significance. Discriminant validity is measured from the root value of the average variance extracted (AVE), compared with the correlation

between the latent variables. Meanwhile, reliability is measured from composite reliability coefficients ≥ 0.7 [40] and Cronbach's alpha coefficients > 0.6 [41]

3) Inner model testing

4) The Goodness of Fit Model test determines whether the built model is significantly good and can be used to make conclusions. The parameters evaluated are presented in Table 3. The values in the table are obtained from the WarpPLS output results.

Table 3 Model Fit and Indicators

Indicator	Ideal
Average path coefficient	$\rho < 0.05$
Average R-squared	$P < 0.05$
Average adjusted R-squared	$P < 0.05$
Average block VIF	≤ 5
Average full collinearity VIF	≤ 5
Tenenhaus GoF small ≥ 0.1 , medium ≥ 0.25 , large ≥ 0.36	Big
Sympson's paradox ratio	1
R-squared contribution ratio	≥ 0.9
Statistical suppression ratio	≥ 0.7
Nonlinear bivariate causality direction ratio	≥ 0.7

Source: [42]

3. Next, hypothesis testing was carried out using the t-test as in the WarpPLS analysis, using the *resampling method*, and carried out with the t-test. Determining decisions on influential variables is based on stipulating that if the p value is < 0.10 (alpha 10%), it can be considered *weakly significant*. Furthermore, if the p value < 0.05 (alpha 5%), then the variable is significant, and if the p value < 0.01 (alpha 1%), then the variable is declared *highly substantial*.

4 Result and Discussion

Before testing the hypothesis, test *the outer model* and *inner model* first. *Outer model* testing includes validity and reliability tests. This test was carried out at the trial stage on all statements in the research instrument, and the results were valid and reliable. In the SEM test results, you can also see the results of the validity and reliability tests and the responses from the SEM analysis respondents. The validity test itself consists of convergent validity and discriminant validity. The conditions for convergent validity are met if the *factor loading value* is > 0.3 and the p value is < 0.01 , which indicates significance. Discriminant validity is measured from the root value of *the average variance extracted* (AVE), compared with the correlation between the latent variables. Meanwhile, reliability is measured from *composite reliability coefficients* ≥ 0.7 and *Cronbach's alpha coefficients* > 0.6 . The following table shows the results of validity tests and reliability tests from SEM analysis.

Table 4 *Outer model* test results

	X_1	Y_1	Y_2	Y_3	Y_4	Y_5	X_2
Composite reliability	0.961	0.940	0.885	0.898	0.882	0.791	0.924
Cronbach's alpha	0.957	0.928	0.825	0.857	0.842	0.602	0.906
Avg. var. Extract.	0.321	0.639	0.658	0.61	0.527	0.562	0.577

Source: Analysis Result

From the Table 4, *the composite reliable value* for the green construction and project performance variables is ≥ 0.7 , meaning all variables meet the requirements (values range from 0.791 to 0.961) and *Cronbach's alpha value* > 0.6 , meaning all statements are declared reliable (values range from 0.602 to 0.957). Likewise, the *average variance extracted* (AVE) value ranges from 0.321 to 0.658, where X_1 has the lowest AVE value (0.321), and Y_2 has the highest AVE value (0.658) > 0.3 , meaning the statement is declared valid with all variables meeting *composite reliability requirements* and almost all meeting *Cronbach's alpha requirements*.

Inner model testing is carried out to determine whether the model built is significantly good and can be used to make decisions. This test is known as *the Goodness of Fit Model*. The parameters evaluated are presented in Table 3. The results obtained from the WarpPLS *output* are as follows:

Average path coefficient (APC)=0.344, $P < 0.001$
 Average R-squared (ARS)=0.333, $P < 0.001$
 Average adjusted R-squared (AARS)=0.320, $P < 0.001$
 Average block VIF (AVIF)=1.263, acceptable if ≤ 5 , ideally ≤ 3.3
 Average full collinearity VIF (AFVIF)=2.394, acceptable if ≤ 5 , ideally ≤ 3.3
 Tenenhaus GoF (GoF)=0.451, small ≥ 0.1 , medium ≥ 0.25 , large ≥ 0.36
 Simpson's paradox ratio (SPR)=0.800, acceptable if ≥ 0.7 , ideal = 1
 R-squared contribution ratio (RSCR)=0.979, acceptable if ≥ 0.9 , ideally = 1
 Statistical suppression ratio (SSR)=1,000, acceptable if ≥ 0.7
 Nonlinear bivariate causality direction ratio (NLBCDR)=0.800, acceptable if ≥ 0.7

When compared to Table 3, all indicators meet the specified requirements. APC, ARS, and AARS showed statistical significance. AVIF and AFVIF are within the ideal range. GoF (Goodness of Fit) shows excellent effect. GoF measures how well a model can explain the data. The better the model fit, the more valid the inferences drawn from the model. SPR, RSCR, SSR, and NLBCDR all meet or exceed acceptable values. These results indicate that the model fits well and meets the established evaluation criteria. This model shows excellent performance in all indicators. It has high predictive power and low multicollinearity and is essentially free from statistical problems such as Simpson's paradox and suppression effects. The relationships in the model generally support the proposed causal hypothesis, and the contribution of the independent variables to the dependent variable is significant. The model appears robust and reliable based on the given evaluation criteria.

Next, hypothesis testing was carried out using the t-test as in the WarpPLS analysis, using the *resampling method* and carried out with *the t-test*. Determining decisions on influential variables is based on stipulating that if the p value is < 0.10 (alpha 10%), it can be considered *weakly significant*. Furthermore, if the p value < 0.05 (alpha 5%), then the variable is important, and if the p value < 0.01 (alpha 1%), then the variable is declared *highly substantial*. The following is a model of hypothesis testing results:

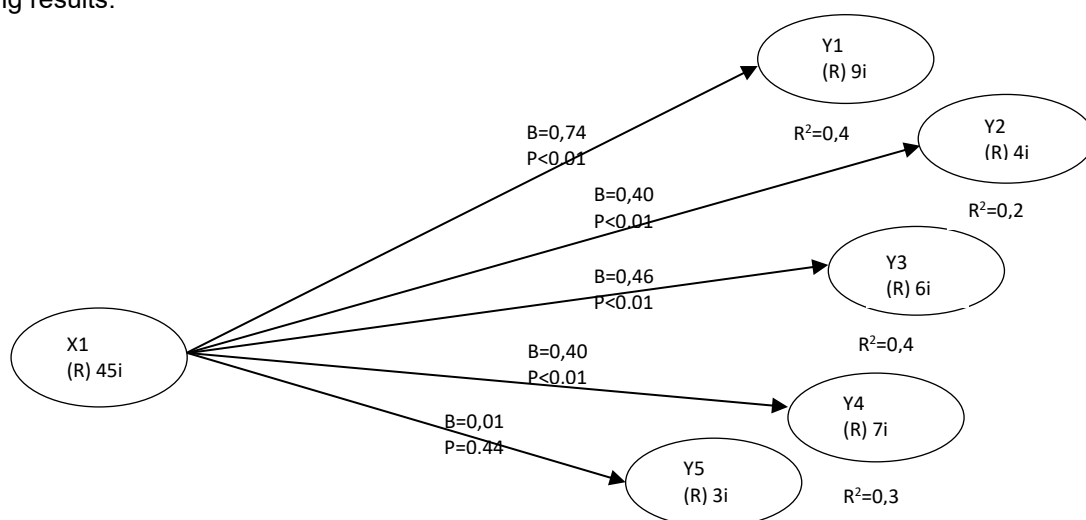


Fig. 4: SEM model of test r $R^2=0,1$

Based on the SEM model shown in Fig. 4, . There are 2 variables studied: the exogenous variable, namely the green construction variable (X) consisting of 20 indicators, and the endogenous variable, namely project performance variables. The project performance variables consist of 5 indicators, namely cost performance (Y1), time performance (Y2), quality performance (Y3), OHS performance (Y4) and green building performance (Y5). Each of these project performance indicators consists of Y1 (9 indicators) value $R^2 = 0.48$, Y2 (4 indicators) $R^2 = 0.28$, Y3 (6 indicators) $R^2 = 0.40$, Y4 (7 indicators) $R^2 = 0.31$ and Y5 (3 indicators) $R^2 = 0.19$. From the value of *the path coefficients* (β), the most vital and most significant relationship between variables (the influence of X on Y1) is the relationship between green construction and cost performance (Y1: $\beta = 0.74$ ($P < 0.01$) - significant and robust. These results align with [43], which shows that green cost premiums range from 5% to 10%, and cost performance

often exceeds budget, ranging from 4.5% to 7%. The application of green construction in project management has the most decisive influence on cost performance, meaning that implementing green construction in project management affects cost performance indicators, which are one of the project limitations, namely the appropriate relationship between construction variables green on-time performance (Y2: $\beta = 0.40$ ($P < 0.01$), quality Y3: $\beta = 0.46$ ($P < 0.01$) and K3 Y4: $\beta = 0.40$ ($P < 0.01$) were declared significant and moderate. Based on the results of [44], Chan's research also states that cost and schedule performance have a positive relationship, and cost performance positively affects economic sustainability. A time performance study shows that green building projects take an average of 8% longer to complete than traditional projects of similar size and characteristics. In addition, these projects are, on average, 4.8% behind schedule [45]. The application of green construction can further improve quality performance compared to time and OHS performance. Meanwhile, the achievement of Green Building Performance Y5: $\beta = -0.01$ ($P = 0.44$) is insignificant, meaning it is not influenced by the implementation of green construction in the field. This is because there is a classification of levels of application of green construction in the field with percentages, namely Primary Green Building (56%), Middle Green Building (86%), and Main Green Building (100%), meaning that just by implementing 56% of green construction it has been declared a green building. Green with the Primary Green Building title, so construction service actors have not entirely (100%) implemented green construction as the project's final goal. Overall, it can be concluded that X (green construction) significantly and strongly influences Y1 (cost performance). X (green construction) has a significant and moderate influence on Y2 (time performance), Y3 (quality performance), and Y4 (OHS performance).

Fig. 5 shows the identified green construction indicators starting from the strongest (dominant) influence to the weakest (subordinate) on performance achievement. The indicators with the strongest (dominant) influence are documentation indicators, while those with the lowest (subordinate) influence are energy conservation and efficiency indicators. Meanwhile, the results of [9] Omatule's research stated that energy management influences economic performance the most. The strength and weakness of this influence is determined by the size of the weight indicator (IW) value in Fig. 5 below:

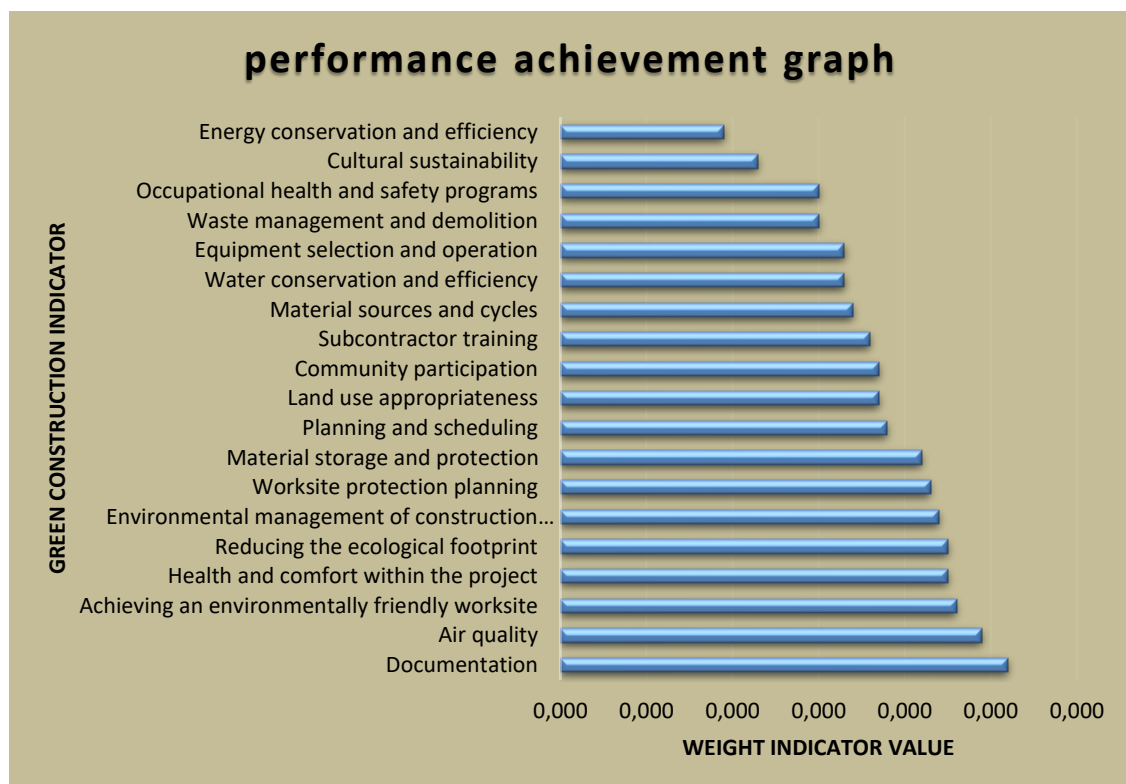


Fig.5: Performance achievement of green construction variable graph

The SEM test results found that the project performance indicators, except for green building performance, were positive, which means that all these indicators were influenced by applying green construction variables in their achievements in the field. To see the project performance that is strong (dominant) and weakest (subordinate) from the implementation of green construction in the field based on the *indicator weights values* for each indicator, you can see in the Figure 6

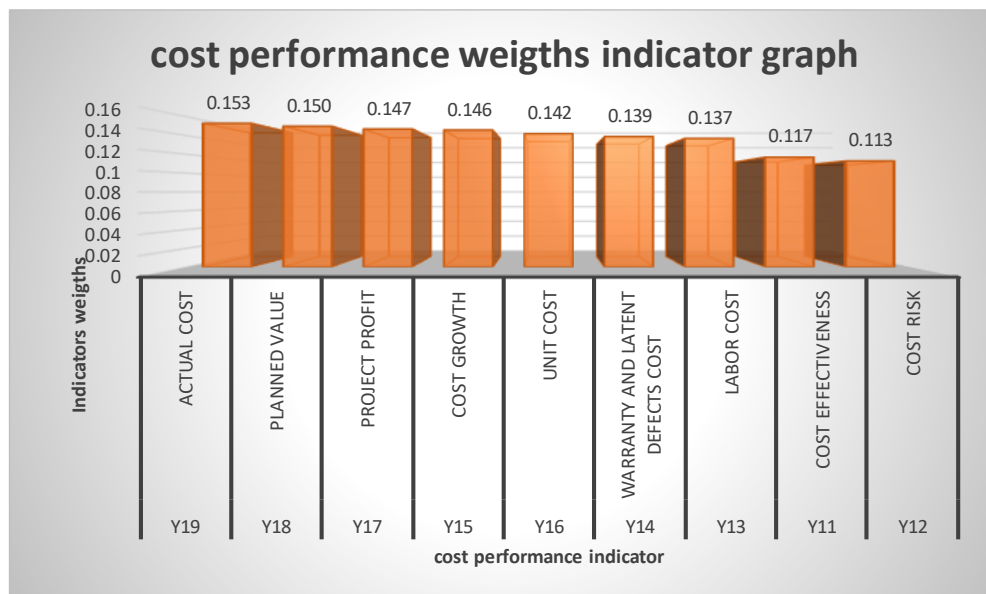


Fig. 6: Graph of the level of influence of cost performance

The graph in Table 6 shows the indicator weights for various aspects of cost performance, ordered from highest to lowest. The indicator with the highest weight is Y19: Actual costs incurred (0.153) and Y18: Planned value with indicator weights 0.150. Meanwhile, in [46] Noor's research, it was stated that the factor that had the most influence on cost performance was the high initial cost of developing green buildings. The indicator with the lowest weight is Y12: The risk of costs occurring is minimal (0.113), and Y11: Cost-effectiveness (0.117). Other indicators have t-weights between 0.137 and 0.147, indicating a reasonably even contribution. The range of indicator weights ranges from 0.113 to 0.153, indicating relatively small variations between indicators. All indicators have a positive weight, suggesting they contribute positively to cost performance. No indicator is dominant or significant because the weight difference between indicators is relatively tiny. This graph shows that various factors have a reasonably balanced contribution in assessing cost performance with a slightly greater emphasis on total actual costs and budget costs. Green project management must consider these indicators to optimize overall cost performance.

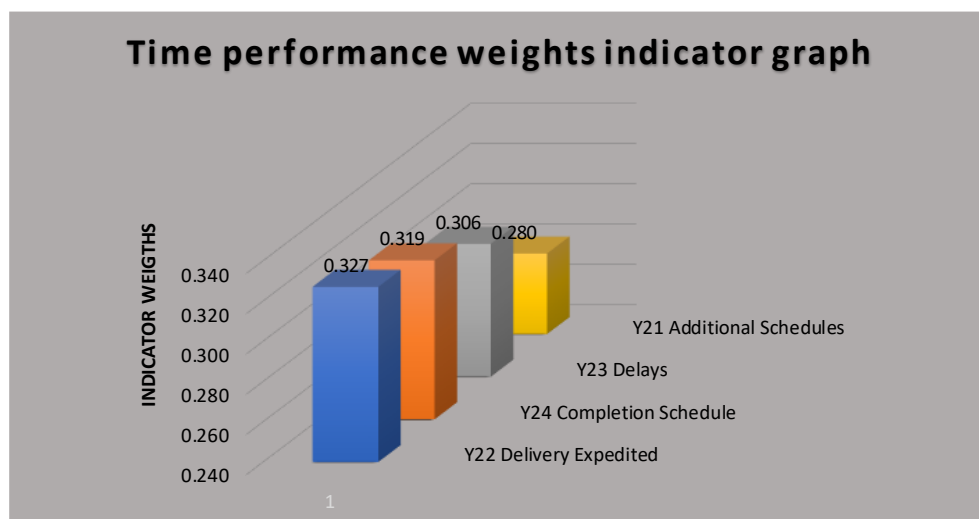


Fig. 7: Graph of the level of influence of time performance

Fig. 7 above shows the indicator weights for four aspects of time performance in a project. These indicators are Y22 (Delivery expedited), Y24 (Completion schedule), Y23 (Delay), and Y21 (Addition to schedule). This result aligns with Noor's research, stating that green building project delivery is difficult and hurts project schedule performance. Order of indicator weights from highest to lowest: Y22 with a weight of 0.327, Y24 with a weight of 0.319, Y23 with a weight of 0.306, and Y21 with a weight of 0.280.

The indicator weights range from 0.280 to 0.327, indicating relatively small variations between indicators. All indicators have significant weights (above 0.280), suggesting they contribute to project time performance. The indicator with the highest weight (Y22) focuses on the timeliness of product delivery, while the indicator with the lowest weight (Y21) relates to differences in overall project completion time. Overall, it can be concluded that this graph shows that in assessing project time performance, the four aspects measured have a relatively balanced level of importance. However, there is a slightly greater emphasis on the on-time delivery of products and compliance with planned schedules. Project management in green project management needs to pay attention to all these indicators to optimize overall time performance, particularly to aspects with a higher weight.

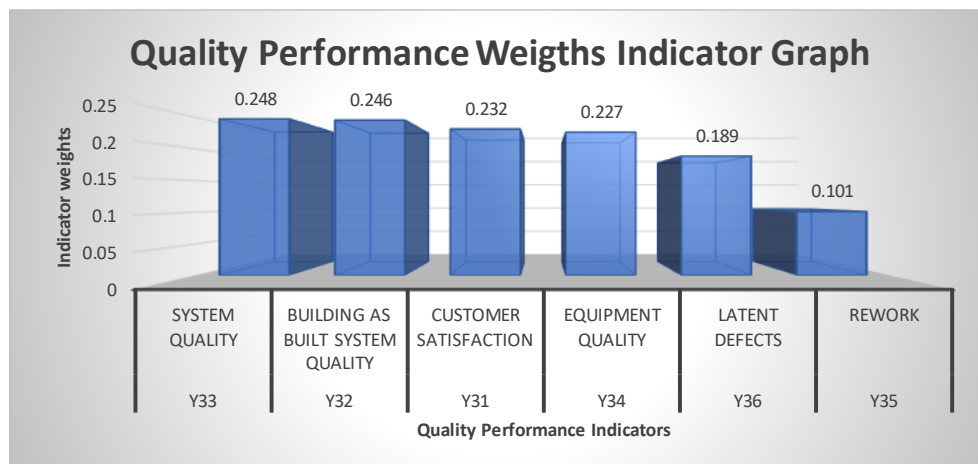


Fig. 8: Graph of the level of influence of quality performance

Fig. 8 shows the indicator weights for six quality performance aspects in a project. These indicators are Y33: System quality Y32: Quality of *as-built* building system Y31: Customer satisfaction Y34: Equipment quality Y36: Latent defects Y35: Rework Order of indicator weights from highest to lowest: Y33 with a weight of 0.248, Y32 with a weight of 0.246, Y31 with a weight of 0.232, Y34 with a weight of 0.227, Y36 with a weight of 0.189, Y35 with a weight of 0.101 The range of indicator weights ranges from 0.101 to 0.248, showing quite significant variations between indicators. The top four indicators (Y33, Y32, Y31, Y34) have relatively equal weights, ranging from 0.227 to 0.248. The last two indicators (Y36 and Y35) have a lower weight than the other four indicators, with Y35 having a much lower weight. The conclusion obtained by this graph shows that in assessing project quality performance, aspects such as suitability of implementation methods, building suitability, physical results performance, and equipment suitability have a relatively balanced and high level of importance. This result is in line with [47] Omatule's research, which states that green construction practices significantly positively affect customer satisfaction, where OHS is said to mediate the relationship between GCPs and CS partially. Meanwhile, aspects related to defective work and corrective actions have a lower weight. Project management in green project management needs to pay greater attention to the top four indicators to ensure optimal project quality, but still not ignore the last two indicators even though their weight is lower.

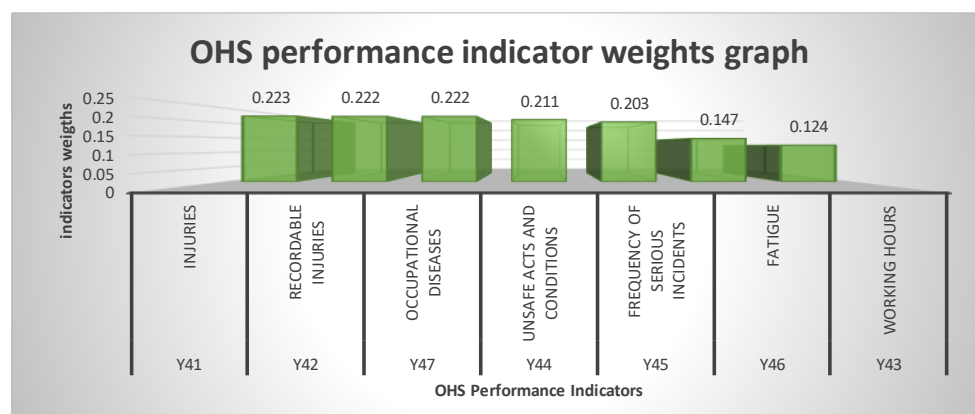


Fig. 9: Graph of the level of influence of OHS performance

Fig. 9 above shows the indicator weights for seven aspects of a project's OHS (Occupational Health and Safety) performance. These indicators are Y41: Injuries Y42: Recordable injuries Y47: Occupational diseases Y44: Unsafe actions and conditions Y45: Frequency of serious incidents Y46: Fatigue Y43: Working hours. Order of indicator weights from highest to lowest: Y41 with a weight of 0.223, Y42 with a weight of 0.222, Y47 with a weight of 0.222, Y44 with a weight of 0.211, Y45 with a weight of 0.203, Y46 with a weight of 0.147, Y43 with a weight of 0.124. The range of indicator weights ranges from 0.124 to 0.223, showing quite significant variations between indicators. The top five indicators (Y41, Y42, Y47, Y44, Y45) have relatively equal weights, ranging from 0.203 to 0.223. The last two indicators (Y46 and Y43) have a lower weight than the other five indicators. Overall, this graph shows that worker compliance with safety regulations and a project implementation process free from hazards are relatively balanced and highly important in assessing project OHS performance. Meanwhile, factors related to the number of workers and other indicators have a lower weight. Project management in green project management needs to pay greater attention to the top five indicators to ensure optimal Occupational Health and Safety (OHS), but still not ignore the last two indicators even though their weight is lower. Meanwhile, [29] Karakhan's research results state that no statistical evidence supports the hypothesis that green construction is associated with lower injury rates.

Table 5 Indicator Weights for Green Building Performance

No	Symbol	Indicator	KBGH
1	Y52	Implemented 86% green indicators in project implementation	0.512
2	Y53	Implemented 56% green indicators in project implementation	0.436
3	Y51	Implemented 100% green indicators in project implementation	0.374

Table 5 above shows the value and weight of the Green Building Performance indicator (Y5); the indicators measured consist of Y51: Implementation of 100 % green indicators, Y52: Implementation of 86% green indicators, and Y53: Implementation of 56 % green indicators. Indicator weight: Y52 has the highest weight: 0.512; Y53 is in second place: 0.436, and Y51 has the lowest weight: 0.374. The application of 86% green indicators is considered the most optimal, with the highest weight. The implementation of 56% green indicators is still considered quite significant. The application of 100% green indicators has the lowest weight. An interesting pattern: the highest weight is not for full implementation (100%) but rather for most implementation (86%). Significant weight loss exists between 86% and 56% of implementations. There are trade-offs between the full implementation of green indicators and other aspects of the project (such as cost or time). Implementation of 86% is considered the optimal point between sustainability and project efficiency. The conclusion obtained in the context of green building performance is that applying the majority (86%) of green indicators is considered the most optimal. This suggests a desirable balance between green building principles and other practical considerations in implementing green projects. Full implementation (100%) of green indicators has the lowest weighting, reflecting the challenges or trade-offs that arise when trying to achieve the highest green standards. These findings can provide valuable guidance for project managers in setting realistic and practical sustainability targets.

4 Conclusion

Based on the problems and analysis results above, the following two things can be concluded:

1) The implementation of Green Construction significantly influences various aspects of construction project performance. The strongest and most significant impact is seen in cost performance ($\beta = 0.74$, $P < 0.01$), indicating that green construction practices greatly affect the financial aspects of the project. Moderate but still significant influences are also seen in time performance ($\beta = 0.40$), quality ($\beta = 0.46$), and Occupational Safety and Health (OHS) ($\beta = 0.40$), indicating that Green Construction has a positive impact on time efficiency, quality of results, and worker safety. Interestingly, the implementation of Green Construction does not have a significant influence on the achievement of Green Building performance, with the finding that the implementation of 86% of green indicators is considered the most optimal, indicating a balance between sustainability and project efficiency.

2) Several key factors that influence project performance have been identified in the context of Green Construction. Project documentation appears to be the most influential Green Construction indicator, while conservation and energy efficiency have the lowest influence. For specific performance aspects, actual costs and planned values are the most important factors in cost performance. In time

performance, delivery acceleration and completion schedule have the highest weight. System quality and as-built building system quality are the main indicators for quality performance. As for OHS performance, injuries and recordable injuries are the factors with the highest weight. These findings provide valuable insights for practitioners and policymakers in optimizing sustainable construction practices and developing more effective strategies to improve project performance in the green construction industry.

Further research is needed to understand why the application of 100% green indicators has the lowest weight. Finally, these findings can provide valuable input for policymakers in developing more practical and realistic green construction regulations.

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