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THE EFFECT OF IMPLEMENTING GREEN CONSTRUCTION ON PROJECT PERFORMANCE: A COMPREHENSIVE STUDY USING STRUCTURAL EQUATION MODELS (SEM)

Abstract

This study uses the Structural Equation Model (SEM) 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 (OHS), 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 OHS 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;

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 NOx 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 NOx, 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.

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 [11], [12], 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. 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. [13] 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) [14], the use of environmentally friendly materials and sustainable methods [15], as well as the management of energy, water, and waste [16]; [10]. The concept of sustainability in construction generally includes three main pillars: economic, social, and environmental [17]; [18].

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 [19]; [20], 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. [21] 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 CO_2 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]; [22]. 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 [23], [25], [16]. This study also discusses green project management, focusing on Leadership in Energy and Environmental Design (LEED) certification as a sustainability performance assessment tool [24]; [15]. 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 [25], [26], [27], [26], [27]. Time performance is measured through time growth, delivery speed, and completion schedule [28]. Project quality is assessed through indicators such as turnover, system, equipment, customer satisfaction, and as-built system quality [25]; [29]; [30]; [31]. Several studies also discuss Occupational Health and Safety (OHS) performance in green construction, with indicators such as work accidents, injuries, fatigue, and unsafe conditions [16] [32].

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:

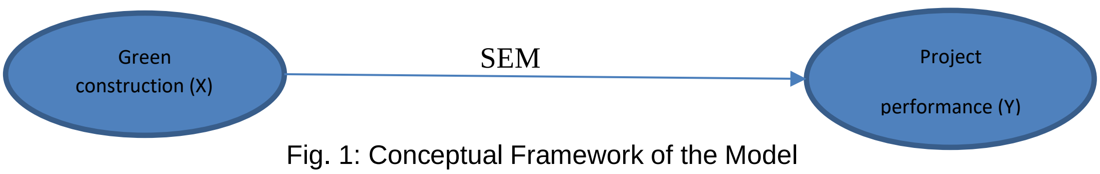

Fig. 1: Conceptual Framework of the Model

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 *as-built* 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	*Recordable injuries*	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

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. 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 [33]. So, the stages in modeling analysis with WarpPLS in this research are as follows:

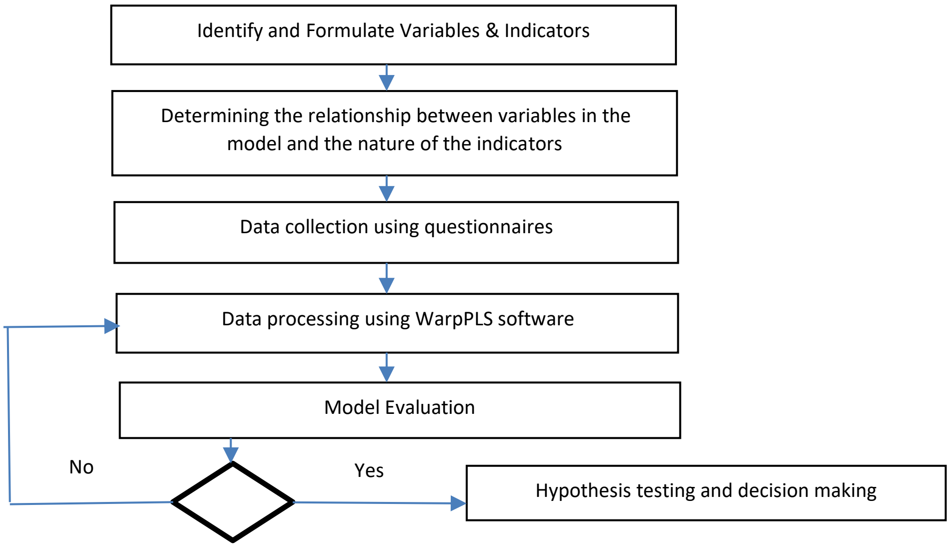

Fig. 2: SEM model analysis stages

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.

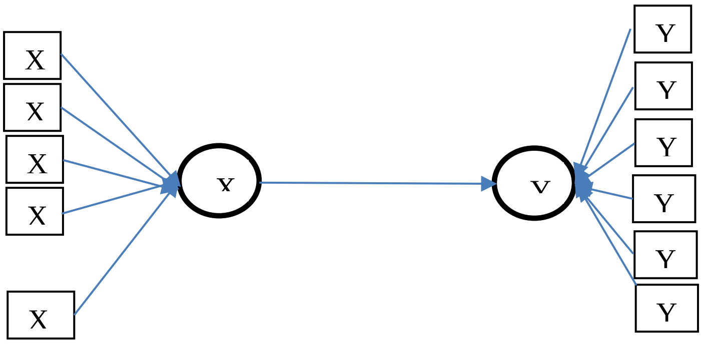

Fig.3: Model of relationships between variables in SEM

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
   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 ρ value is < 0.01 [34], 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 [35] and *Cronbach's alpha coefficients* > 0.6 [36]
2. *Inner model* testing
   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	*ρ<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: [37]

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 ρ value is <0.10 (alpha 10%), it can be considered *weakly significant.* Furthermore, if the ρ value < 0.05 (alpha 5%), then the variable is significant, and if the ρ value < 0.01 (alpha 1%), then the variable is declared *highly substantial.*

3 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 ρ 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 above, *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 X1 has the lowest AVE value (0.321), and Y2 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 with Table 3, all indicators meet the specified requirements. APC, ARS, and AARS showed statistical significance. AVIF and AFVIF are within the ideal range. GoF shows excellent effect. 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 ρ value is <0.10 (alpha 10%), it can be considered *weakly significant.* Furthermore, if the ρ value < 0.05 (alpha 5%), then the variable is important, and if the ρ value < 0.01 (alpha 1%), then the variable is declared *highly substantial.* The following is a model of hypothesis testing results:

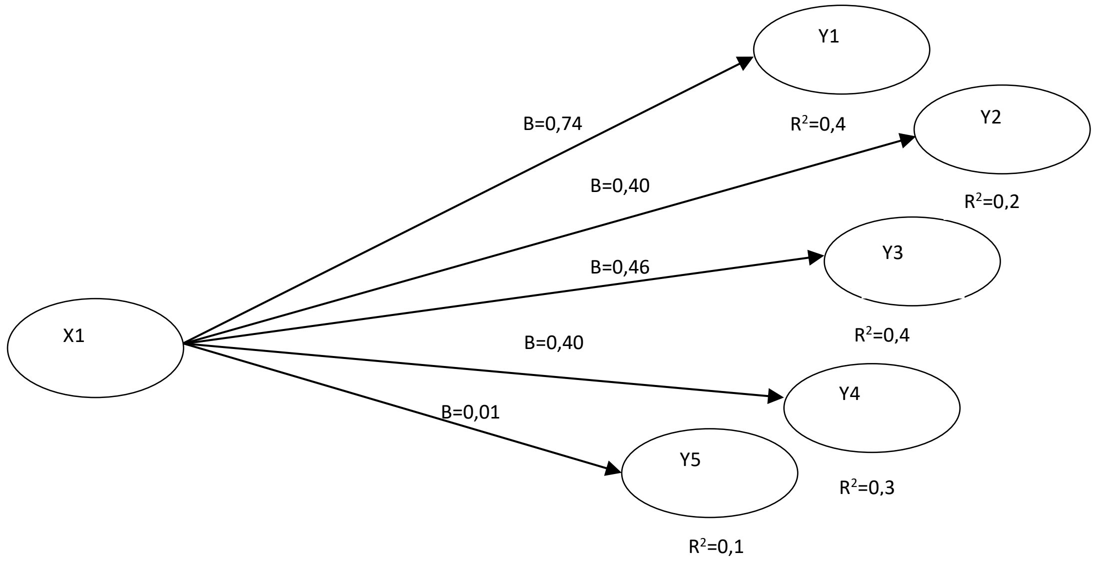

Fig. 4: SEM model of test results

Based on the SEM model shown in Fig. 4, there are two exogenous variables, namely the green construction variable (X) consisting of 20 indicators. Endogenous variables consist 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 [38], 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 [39], 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 [40]. 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:

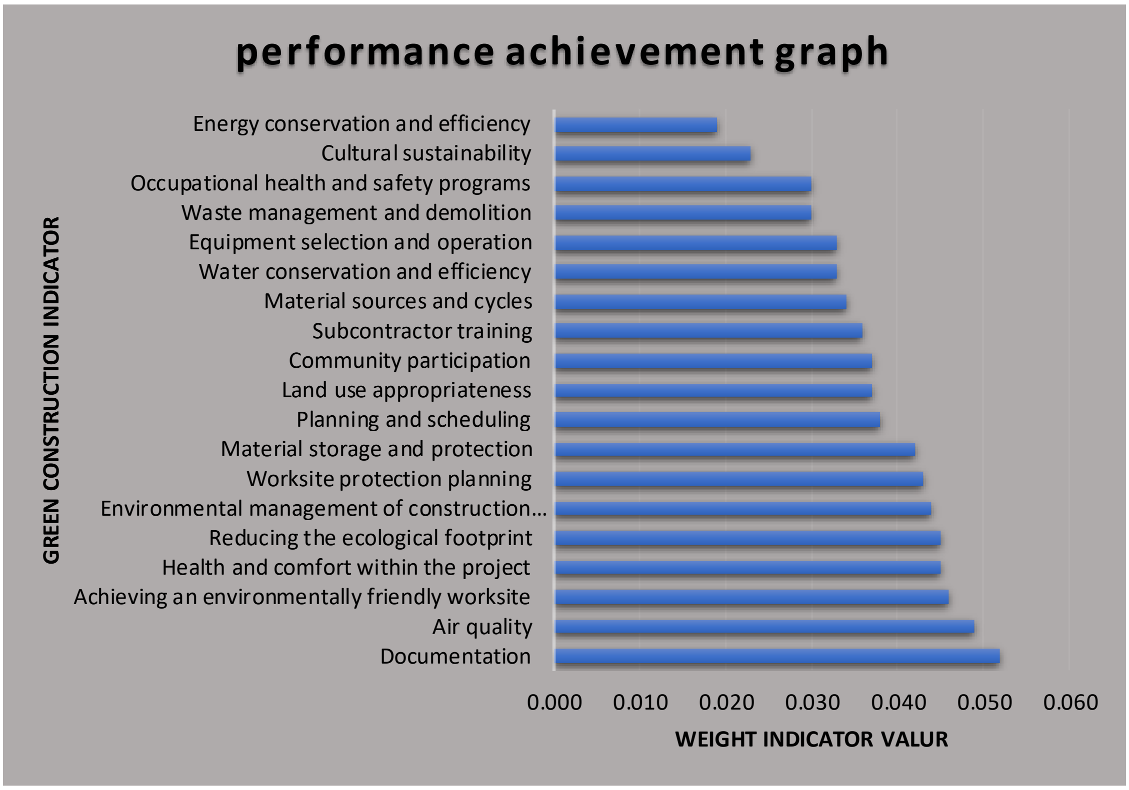

Fig.5: Performance achievement of green construction variable graph

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 the following graph:

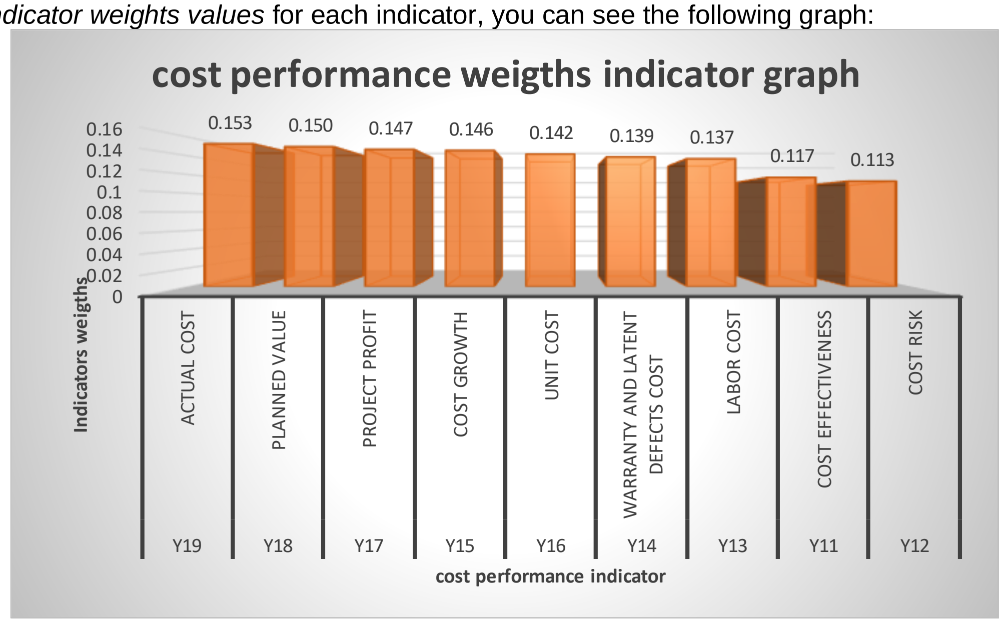

Fig. 6: Graph of the level of influence of cost performance

The graph 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 [41] 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.

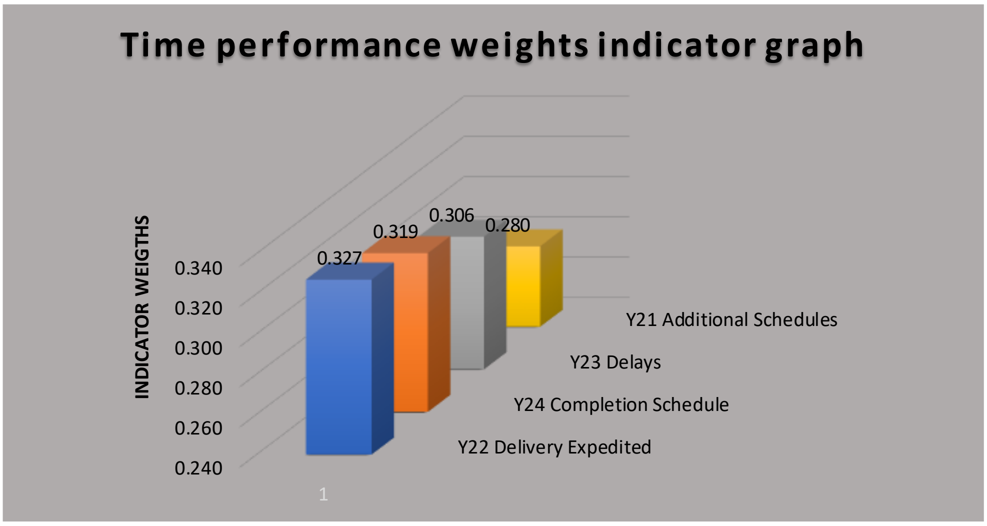

Fig. 7: Graph of the level of influence of time performance

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.

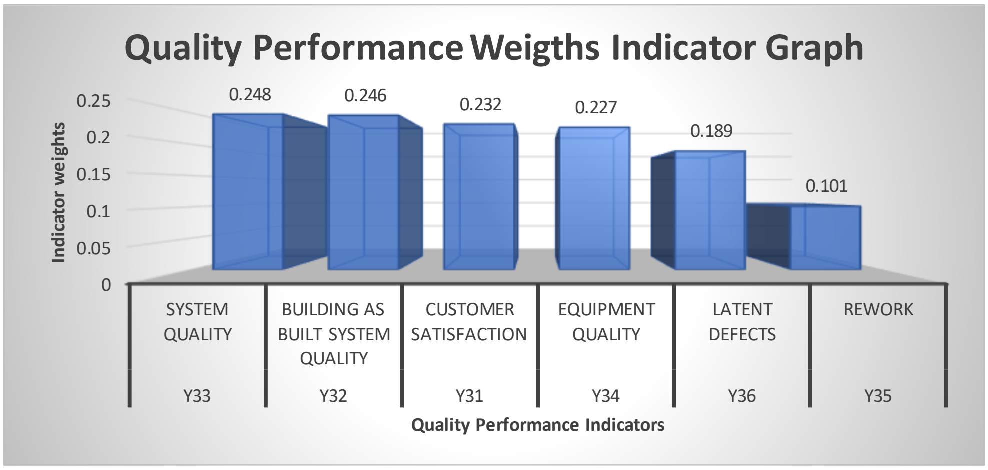

Fig. 8: Graph of the level of influence of quality performance

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 [42] 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.

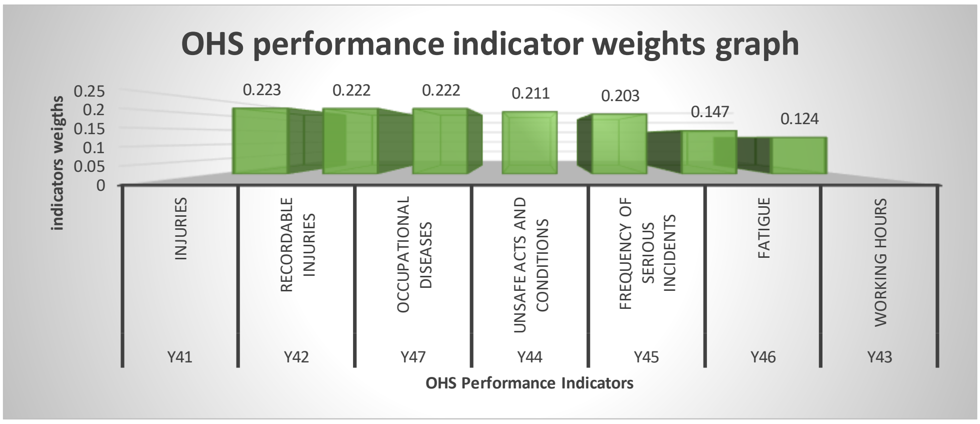

Fig. 9: Graph of the level of influence of OHS performance

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, [23] 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 8 6% 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

This research shows that implementing green construction significantly impacts various aspects of project performance, with the most substantial impact on cost performance. Project documentation was identified as the most influential green construction indicator, while energy conservation and efficiency had the lowest influence. In the context of project performance, actual and budget costs, accelerated delivery, system quality, and injuries and recordable injuries emerge as critical factors in each performance aspect. Another interesting finding is that applying 86% green indicators is optimal for Green Building Performance, indicating a balance between sustainability and project efficiency. Based on these results, it is recommended that construction companies and project managers pay special attention to documentation systems, cost management, project acceleration strategies, system quality improvement, and injury prevention programs. Targeting around 86% of green indicators as an optimal point is also essential. 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.

Acknowledgment

I want to thank my promoter, Dr. Eng. Ir. Yulvi Zaika, M.T., and co-promoters Ir. Kartika Puspa Negara, S.T., M.T., Ph.D, Dr. Ir. Solimun, MS, and Prof. Dr. M. Agung Wibowo, M.M., M.Sc., Ph.D, who has guided me in writing this journal. I would also like to thank my husband Ir. IGN Bagus Nurlastama, S.T), who has given me moral and material support. My daughters, Sagung Istri Pramitari Wima Devi, S.T., M.T., and Sagung Mirah Aishwarya Priyanka Devi, have always offered support and love while I was writing this journal. Finally, I extend my gratitude to my beautiful little *Angel who,* without me realizing it, always provides a way and solution from Heaven. Thank you so much.

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{Bibliography

2. HASIL REVIEW ARTIKEL

I Wayan Muka **<wayanmuka@unhi.ac.id>**

Aug 22, 2024, 5:57 AM

to CEE

To: CEE Editor
Greetings,
The results of the review of the article with the title "THE EFFECT OF IMPLEMENTING GREEN CONSTRUCTION ON PROJECT PERFORMANCE" were presented: A COMPREHENSIVE STUDY USING STRUCTURAL EQUATION MODELS (SEM).
Thank you

Best regards,
I Wayan Muka

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REVIEWER'S REPORT

The attached article has been submitted for publication.

Would you please review it, complete the checklist, and add your comments?

When you are done with the Reviewer's Report, please send it to the editor.

Once your Report is submitted you are not able to change it anymore.

The reviewed sheets will be then sent anonymously to the authors.

Title: THE EFFECT OF IMPLEMENTING GREEN CONSTRUCTION ON PROJECT PERFORMANCE: A COMPREHENSIVE STUDY USING STRUCTURAL EQUATION MODELS (SEM)

A: Checklist

1. Is the manuscript of high scientific quality? (How high is the scientific quality of the manuscript?)
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2. Is the topic suitable for given journal's scope of interest? (How suitable is the theme for given journal's scope of interest?)
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B: Recommendation (Please choose appropriate option)

☐ Publish as is;
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☐ Publish after mandatory minor revision;
☐ Publish after mandatory major revision;
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C: Remarks

This article can be published with several minor revisions:

1. In the background section it is necessary to add the novelty of this research, and the implications of this research for the development of science
2. In the literature review, it is necessary to add PUPR No. 21 of 2021 concerning Green Building Performance Assessment Criteria (Permen PUPR No.21 Tahun 2021 Tentang Kriteria Penilaian Bangunan Gedung Hijau)
3. Addition to the bibliography, at least 80% of reputable primary libraries/international journals)

D: Additional comment

Reviewer's name:	**Dr. I Wayan Muka, ST., MT**
Reviewer's affiliate:	**Hindu Indonesia University**
Date:	**16.08.202**

3. REVIEW ARTIKEL DITERIMA EDITOR

CEE
to me

Oct 7, 2024, 2:42 PM (16 hours ago)

Dear Dr. I Wayan Muka, ST., MT,
Thank you very much. Please find the review certificate attached.

Kind regards,
Dr. Jakub Kraľovanec
Associate Editor

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From: I Wayan Muka <wayanmuka@unhi.ac.id>
Sent: Saturday, October 5, 2024 5:07 AM
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REVIEW CONFIRMATION CERTIFICATE
We are pleased to confirm that
Dr. I Wayan Muka, ST., MT
has reviewed article
THE EFFECT OF IMPLEMENTING GREEN CONSTRUCTION ON PROJECT PERFORMANCE: A COMPREHENSIVE STUDY USING STRUCTURAL EQUATION MODELS (SEM)
for the journal *Civil and Environmental Engineering* ISSN 2199-6512.
Žilina, Slovakia, October 2024

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A. PERMOHONAN REVIEW ARTIKEL DARI EDITOR

Universitas Hindu Indonesia Mail – Article Review Request

UNIVERSITAS HINDU INDONESIA

I Wayan Muka <wayanmuka@unhi.ac.id>

Article Review Reqquest: Article JIPD-6205

1 message

Yvonne Hyde <yvonne.hyde@ep-pub.net> Aug 7, 2023 at 8:25 AM

To: I Wayan Muka <wayanmuka@unhi.ac.id>

Dr. I Wayan Muka:

I believe that you would serve as an excellent reviewer of the manuscript, "Safety risk management for construction workers in dredging andreclamation work of industrial port development projects" which has been submitted to Journal of Infrastructure, Policy and Development. The submission's abstract is inserted below, and I hope that you will consider undertaking this important task for us. Please log into the journal web site by 2023-08-14 to indicate whether you will undertake the review or not, as well as to access the submission and to record your review and recommendation. The web site is https://systems.enpress-publisher.com/index.php/jipd

The review itself is due 2023-08-26. Thank

you for considering this request.

Best wishes,
Ms. Yvonne Hyde Assistant
Editor
Email: yvone.hyde@ep-pub.net

Safety risk management for construction workers in dredging andreclamation work of industrial port development projects

Abstract

Dredging and reclamation operations are pivotal aspects of coastal engineering and land development. Within these tasks lie potential hazards for personnel operating dredging machinery and working within reclamation zones. Due to the specialized nature of the work environment, which deviates from conventional workplace settings, the risk of workplace accidents is significantly heightened. The aim of this study is to conduct a comprehensive riskanalysis of the safety aspects related to dredging and reclamation activities, with the goal of enhancing safety and minimizing the frequency and severity of potential dangers. This research comprises a thorough risk analysis, integrating meticulous hazard identification from sample projects and literature reviews. It involves risk assessment by gathering insights from experts with direct working experience and aims to assess potential risks. The study focuses on definingeffective risk management strategies, exemplified through a case study of a nearshore construction project in Thailand. The study identified numerous high and very high-risk factors in the assessment and analysis of occupational safety in dredging and reclamation work. Consequently, a targeted response was implemented to control and mitigate these risks to an acceptable level. The outcome of this study will provide a significant contribution to the advancement of guidelines and best practices for improving the safety of dredging andreclamation operations.

Keywords**:** dredging and reclamation work; construction hazard; safety risk assessment

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Keywords: dredging and reclamation work; construction hazard; safety risk assessment

1. Introduction

2.1 Safety risks and project implications

The construction industry, in general, is fraught with numerous safety risks due to the complex and ever-changing nature of construction sites. According to Rory (2003), these risks are exacerbated by a lack of information, which increases the potential for harm. These risks pose significant threats not only to the health and well-being of workers but also to the overall success and efficiency of construction projects.Safety hazards can range from falls injuries caused by machinery and improper use of equipment, each of which has the potential to cause serious injury or death. The existence of these risks necessitates strict safety measures and regulations to mitigate potential dangers. The impact of safety risks extends beyond injury or loss of life to workers. Accidents and incidents at construction sites can cause project delays, increased costs, and legal liabilities. When safety procedures are violated, projects may face work stoppages imposed by regulatory agencies, disrupting timelines and inflating budgets.Financial ramifications also include higher insurance premiums and potential compensation claims, which can strain project resources. In addition to direct costs, safety incidents can damage a construction company’s reputation, affecting confidence in its ability to perform. A company’s perceived commitment to safety is increasingly becoming a key factor in project owners’ contractor selection decision-making processes. Therefore, prioritizing safety is not only a financial obligation but also a strategic imperative. It is essential for maintaining competitive advantage, operational continuity, and fulfilling moral and legal responsibilities. Addressing construction safety risks is critical to protecting workers from injury or loss of life and ensuring successful project implementation. The interplay between safety and project efficiency emphasizes the need for serious and systematic risk management. By prioritizing safety and implementing comprehensive risk management strategies, construction companies cannot only protect their employees but also achieve sustainable project success and long-term viability in the construction industry.

2.2 Safety risk in dredging and reclamation

Dredging and reclamation works are important for the development of port construction projects in maritime transportation (Marsha, 2005). Maritime activities enable the global transfer of commodities, fostering efficient and cost-effective transportation with reliability and environmental benefits (Fratila et al., 2021) asking it a significant contributor to economic growth and development (Jouili, 2016). Dredging and reclamation operations involve extracting sediments from aquatic environments to create land, protect coastal structures, and enhance infrastructure (Nicky and Marsha, 2010). The prominent project examples are the Hong Kong International Airport, the Jurong and Tuas Expansions in Singapore, and Dubai's Palm and World Islands (Rene, 2012). Dredging and reclamation operations necessitate safety attention regarding the exposure of personnel to hazards. These hazards encompass the operations of heavy machinery, potential structural failures, risks associated with underwater conditions, and exposure to hazardous substances (HSE, 2021). Due to the significance and severity of accidents, injuries, and possible loss of human lives. It is imperative to undertake a thorough risk assessment in order to identify, evaluate, and mitigate the potential safety hazards involved. Through a comprehensive investigation of the potential hazards and the use of efficient risk management tactics, project stakeholders possess the ability to actively augment safety measures and alleviate unfavorable outcomes. The Health and Safety Executive (HSE) is the authoritative body responsible for overseeing workplace health and safety in the United Kingdom. Its technical documents have provided data on various types of accidents and the severity of injuries from 2012 to 2021 in the context of dredging and reclamation work. They identified possible accidents such as contact with moving machinery, struck by moving objects, strike against something fixed or stationary, injuries while handling, slips or falls on the same level, and falls from a height. Understanding these common types of accidents is crucial for instituting effective risk mitigation strategies.

Several studies have examined factors related to safety risks in dredging and reclamation operations. In dredging, Daniel (2011) delved into safety management for dredging work in a Nigerian port, providing insights into risk factors in sea dredging. Bugg et al. (2018) assessed the efficacy of RFID tag technology in monitoring personnel safety on dredgers, aiming to enhance safety and diminish fatalities. Rizki (2018) analyzed safety risks in river dredging in Surabaya, Indonesia, with a focus on reducing boat accidents. In reclamation work, Ma et al. (2020) presented safety management guidelines for engineering artificial islands, while Sevryugina and Apatenko (2020) developed a risk assessment model for vehicles used. Zhen et al. (2021) studied risk factors in sea reclamation, emphasizing risk reduction. Within the marine work, Cruickshank and Cork (2005) provided safety guidelines for coastal and marine construction. Valyani et al. (2019) identified key risks in marine construction projects, Mahapatra and Kushwaha (2020) studied hazards in port construction with preventive measures. In general construction, Holle et al. (2005) proposed safety and lightning education guidelines, and Gunduz and Laitinen (2018) suggested risk assessment methods, providing practical strategies for a safer workplace, especially suitable for SMEs construction businesses.

Notably, these existing studies offer valuable guidance for dredging and land reclamation work. However, there remains a dearth of research that specifically focuses on conducting risk analyses for safety in dredging and land reclamation activities within construction projects. This research aims to address these gaps by conducting a comprehensive risk analysis, focusing specifically on safety in dredging and land reclamation activities in construction. The outcome from this study will support the guideline development to improve safety in this specialized field and contribute to the existing body of knowledge in construction safety. The objective of this study was to conduct a comprehensive analysis of safety risks associated with dredging and reclamation activities, with the goal of increasing safety and reducing the frequency and severity of potential hazards. Understanding theimportance of managing safety risks in dredging and reclamation work offers significant benefits. Construction companies involved in these activities can protect their employees and achieve sustainable project success by focusing on safety. The next section, which is the current risk management, details the research methodology. This includes a comprehensive risk analysis that integrates meticulous hazard identification from sample projects and literature reviews. The methodology involves gathering insights from experts with direct work experience to evaluate potential risks through a risk assessment process.

2.3 Dredging and reclamation safety risk management

This study employed the risk management technique outlined by the Project Management Institute (PMI, 2013). It is a systematic approach widely adopted in project management. This approach is not only reliable but also internationally

recognized in project risk management. Highlighting the framework's capacity to improve security, ensure project success, and foster ongoing enhancements in risk management practices. Accordingly, the research methodology was constructed (see

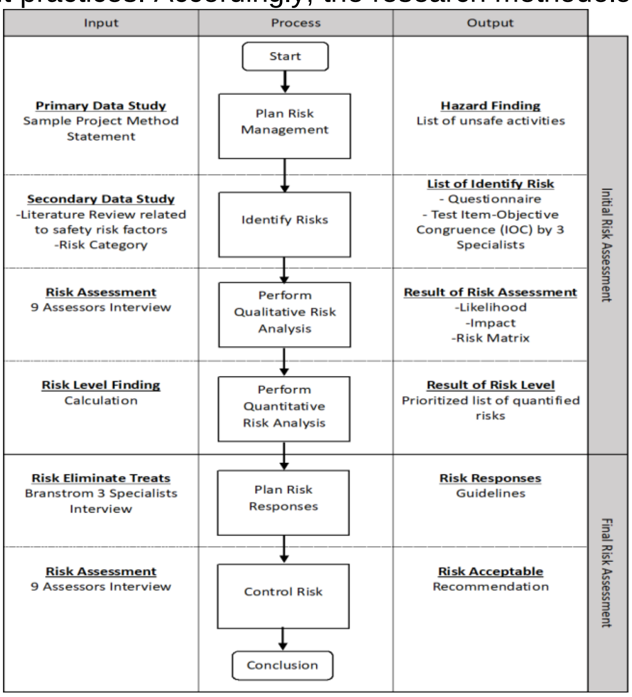

Figure 1. Research methodology.

Figure 1) demonstrating the input, process, and output in each analysis process.

In this research, two groups of people will assist in completing the study: a group of specialists and a group of assessors performing risk assessments.

Specialist Group:

- Number of Participants: 3
- Experience: More than 10 years of direct experience working in dredging and reclamation.
- Role: This group will help check the risk assessment checklist in the "Identify Risks" step and provide opinions on responses to risks in the "Plan Risk Responses" step. This information is shown in **Table 1**.

Table 1. Specialist group demographic information.

Position	**Frequency**	**% of Total**
Senior Manager	1	33.33
Senior Engineer	1	33.33
Project Manager	1	33.33
Discipline	Frequency	% of Total
Civil Engineering	3	100
Total Work Experience	Frequency	% of Total
35 or more	1	33.33
30–35	1	33.33
25–29	1	33.33
Dredging and Reclamation Work Experience	Frequency	% of Total
25 or more	1	33.33
20–24	1	33.33
15–19	1	33.33
Education level	Frequency	% of Total
Postgraduate	2	66.67
Undergraduate	1	33.33

Table 2. Risk assessor group demographic information.

Position	**Frequency**	**% of Total**
Manager	4	44.44
Project Engineer	3	33.33
Inspector	2	22.22
Discipline	Frequency	% of Total
Civil Engineering	7	77.78
occupational health and safety	2	22.22
Total Work Experience	Frequency	% of Total
30 or more	3	33.33
20–29	4	44.44
10–19	2	22.22
Dredging and Reclamation Work	Frequency	% of Total

Experience		
10 or more	3	33.33
6–9	4	44.44
3–5	2	22.22
Education level	Frequency	% of Total
Postgraduate	2	77.78
Undergraduate	7	22.22

Risk Assessor Group:

- Number of Participants: 9.
- Experience: More than 5 years of direct experience working in dredging and reclamation.
- Role: This group will help evaluate the risk in each factor in the "Perform Qualitative Risk Analysis" step and the "Control Risks" step, which is the final step in the risk assessment process. This information is shown in **Table2.**

The following will explain in detail the study of each step of safety risk management in dredging and reclamation work.

2.4 Plan risk management

First of all, it is worth mentioning that this paper applied risk management to thecase study of the Map Ta Phut Industrial Port Phase 3 Development Project, situated in Rayong province, Thailand. The methodology steps began with a plan for risk management and the development of a systematic risk categorization. This step involved a primary data collection of the method statement of the case study project from the field investigation and observation to preliminarily identify hazardous activities and compile the list of unsafe practices. Concurrently, the secondary data was gathered from a comprehensive literature review to pinpoint and delineate the various risks inherent in dredging and reclamation work. The findings from these twosteps were subsequently utilized in the development of a semi-structured interview questionnaire for assessor opinions evaluation on risk identification.

2.5 Identify risks

Subsequently, an examination of secondary data pertaining to safety in dredgingand reclamation work was conducted, as illustrated in **Table 3**. This comprehensive review delineates specific risk factors such as noise, crashes, pipe movement, lifting falls, diving, slips, and uncertain sea conditions within the context of dredging and reclamation operations, offering valuable insights into potential safety challenges.

Table 3. Summary of dredging and land reclamation safety risk factors.

Past study	Safety risk factor
Cruickshank and Cork (2005)	Noise, crash, pipe moving, lifting fall, diving, slip, and uncertain sea.
Holle et al. (2005)	Lightning.
Daniel (2011)	Heavy machine, fire, and diving.
Bugg et al. (2018)	Hazard during remove dredging sand.
Gunduz and Laitinen (2018)	Fall from scaffolding, work lighting, fire, and noise.
Rizki (2018)	Ship collision, and workers fall into the sea.
Ma et al. (2020)	Noise from the dredger machine disturbs.
Mahapatra and Kushwaha (2020)	Collision, falling, lifting fall, lighting, noise, and toppling.

Table 4 presents the identification of risk factors, organized into 7 categories and 22 sub-factors. These categories encompass a range of risks, including as:

- Contact with moving machinery, poses a significant risk due to the continuous operation of dredging machinery, increasing the likelihood of operator injury or harm.
- Struck by moving objects is heightened in areas with water and land traffic, particularly in temporary traffic zones, increasing the risk of accidents.
- Strike against something fixed or stationary underscores the potential damage to stationary objects when adequate protection measures are lacking.
- Injuries while handling, lifting, or carrying often result from inadequate knowledge or understanding of proper work practices, leading to frequent accidents.
- Slips, trips, or falls on the same level underscores the unfamiliar working environment, contributing to frequent accidents.
- Falls from height presents a significant risk due to the differences in working surfaces and poses a considerable threat to worker safety.
- Weather hazards, highlight the potential hazards posed by natural disasters, which can escalate if work continues unabated.

This categorization derives from a synthesis of findings in both primary and secondary data studies, forming the framework for a semi-structured interview questionnaire designed to assessor's opinions on risk identification. The subsequent evaluation of the index of item objective congruence by 3 specialists ensures alignment with research objectives, enhancing the robustness of the questionnaire. The unanimous evaluation results affirm the accuracy of the questionnaire in risk identification.

Table 4. Risk factors identification.

Item	**Risk Identification**
Contact with Moving Machinery	
(1)	The operator was injured in contact with the running dredger.
(2)	Noise from the dredger machine disturbs operator.
Struck by Moving Objects	
(1)	Dredger collides with cargo/fishing boat.
(2)	Vehicle of reclamation crashed by the driver's negligence.
(3)	Vehicle of reclamation crashed by the breaker's imperfection.
(4)	Dredging sand overlaps the workers.
(5)	Dredging sand conveying pipe fall on worker while connecting.
Strike against Something Fixed or Stationary	
(1)	Dredger collides with a pier or embankment.
(2)	Fire on dredger.
(3)	Diver was tied up by curtain cable.
(4)	Insufficient working light.
Injuries while Handling, Lifting, or Carrying	
(1)	Crane is unstable and fall on the workers.
(2)	Failure of lifting gear leading to heavy loads fall on workers.

Slips, Trips, or Falls on Same Level	
(1)	Operators slip on the dredger.
(2)	Worker were sedimented by quicksand at the silt pond.
Falls from Height	
(1)	Dredger operators fall into the sea.
(2)	General workers fall into the sea.
(3)	Operator/worker fall from temporary scaffolding.
(4)	Operators fall from dredger's ladder.
(5)	Vehicle of reclamation falls into the sea.
Weather hazards	
(1)	Storm, strong wind blows dredger.
(2)	Lightning in land reclamation open space.

2.6 Perform qualitative risk analysis

In this step, face-to-face interviews were conducted with 9 experts. After the identification of risks in the preceding phase, a structured questionnaire was developedto involve experts in the risk assessment process. Both the likelihood and impact of each risk were classified into 5 score levels. To ensure the reliability of subjective evaluations among the experts, the risk measurement and assessment index were initially established based on procedure outlines the risk management of Nanyang Technological University (2023), as illustrated in **Table 5**.

Table 5. Risk assessment index.

Score level	1: Very Low	2: Low	3: Moderate	4: High	5: Very High
Likelihood	One per ten years	One per five years	One per three years	One per year	Likely to occur many times per year
Impact	No injury	Injury at least 3 days of hospitalization	Injury at least 10 days of hospitalization	Injury at least 30 days of hospitalization	Fatality

Table 6. Initial risk assessment

Item	Likelihood	Impact
A		
(1)	4	4
(2)	4	4
B		
(1)	4	4
(2)	3	3
(3)	3	3
(4)	3	3
(5)	3	3
C		
(1)	3	3
(2)	3	3
(3)	2	2
(4)	3	3

D		
(1)	3	5
(2)	4	4
E		
(1)	4	3
(2)	2	4
F		
(1)	3	5
(2)	3	5
(3)	3	4
(4)	3	4
(5)	2	5
G		
(1)	4	5
(2)	2	5

The subjective evaluation on the likelihood of incidents and the severity of the impact among all 9 assessors were gathered and averaged. Then, the results of initial risk assessment representing the likelihood, the impact, and the risk exposure level were concluded in **Table 6**. The scores presented in the table, ranging from 1 to 5, indicate the frequency of likelihood in the second column and denote the level of impact in the third column of the table.

ISO 31000 (PECB, 2018) recommends using a risk matrix as a tool for assessing and prioritizing risks based on their likelihood and impact. This tool helps visualize the severity of each risk, assisting in the decision-making process for risk management. By prioritization risks into different levels, it becomes easier to identify which risks require immediate attention and which can be monitored over time.

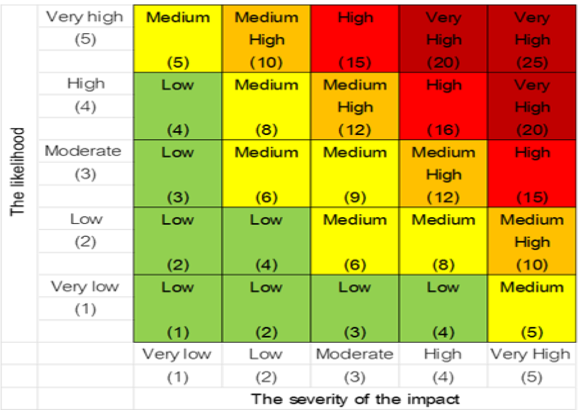

Figure 3. Risk matrix (Modified from Lehner, 2021).

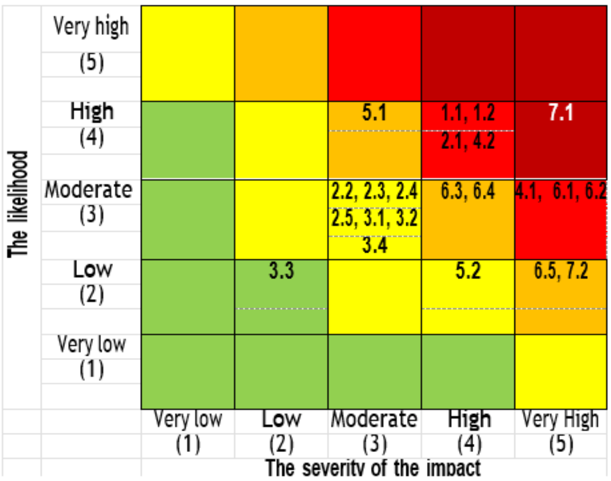

Figure 4. Initial risk assessment matrix.

In this research, the scale under ISO 31000, as shown in **Figure 3**, was applied to propose a risk matrix and scoring system for risk prioritization based on the likelihood and impact scores. Risk levels were arranged into five categories as follows: Low, Moderate Medium, Medium High, High, and Very High.

Based on the results of the qualitative risk analysis, values for both the Likelihood and Impact of various risks were obtained. These values have been plotted onto a risk matrix, which visually represents the risk level for each identified risk factor. The risk levels are prioritized and displayed in **Figure 4**.

2.7 Perform quantitative risk analysis

In this quantitative risk analysis process, a prioritized list of quantified risks based on the numerical analysis conducted is presented. The likelihood and impact values from the previous steps were multiplied to obtain the risk priority values. These values help in determining which risks need immediate attention and which can be monitored over time. The calculation items and the resulting prioritized list are detailed in **Table 7**. This table enables stakeholders to focus on the most critical risks first, ensuring efficient allocation of resources for risk mitigation and management.

Table 7. Prioritized list of quantified risks.

Item	Likelihood Value	Impact Value	Risk Priority Value (Likelihood × Impact)	Priority Level
A				
(1)	4	4	16	High
(2)	4	4	16	High
B				
(1)	4	4	16	High
(2)	3	3	9	Medium
(3)	3	3	9	Medium
(4)	3	3	9	Medium
(5)	3	3	9	Medium
C				
(1)	3	3	9	Medium
(2)	3	3	6	Medium
(3)	2	2	4	Low
(4)	3	3	9	Medium
D				

(1)	3	5	15	High
(2)	4	4	16	High
E				
(1)	4	3	12	Medium High
(2)	2	4	8	Medium
F				
(1)	3	5	15	High
(2)	3	5	15	High
(3)	3	4	12	Medium High
(4)	3	4	12	Medium High
(5)	2	5	10	Medium High
G				
(1)	4	5	20	Very High
(2)	2	5	10	Medium High

2.8 Plan risk responses

The risk response is planned based on the identified risks and assessments to develop appropriate risk management strategies. The strategies are proposed on the prevention, mitigation, and control measures to minimize or eliminate safety risks. A panel discussion was conducted through a brainstorming session involving interviews with 3 specialists. The aim was to exchange ideas and collaboratively analyze the causes of risk events in each factor. The outcome of this discussion was the establishment of a comprehensive guideline designed to avoid, mitigate, and reduce risk levels. The primary focus of this guideline is to effectively control operational safety risks in dredging and reclamation operations.

This phase constitutes an essential risk response strategy aimed at mitigating potential hazards in the workplace. To this end, specialists were interviewed using a series of brainstorming questions designed to elicit insights and recommendations for addressing each identified risk factor. Through this collaborative process, measures toreduce or avoid risks were explored and documented, resulting in the creation of a comprehensive work manual. **Table 8** delineates the responses to safety risks in dredging and reclamation work, showcasing the concerted efforts to enhance workplace safety and minimize potential incidents.

Table 8. Proposed guidelines.

Item	Risk Rating Level	Risk Response	Guidelines for Risk Control
A			
(1)	High	Avoid & mitigate	Before repairing, the machine must be stopped and must have protective equipment and safetyguard.
(2)	High	Avoid & mitigate	Provide operators with suitable hearing protection such as earmuffs or earplugs and controls toreduce noise levels at the source.
B			
(1)	High	Avoid	Equip the dredger and cargo/fishing boats with advanced navigation aids and technologies, suchas radar, VHF radios, GPS, and AIS.
(2)	Medium	Avoid & mitigate	Enforce speed limits, safe driving practices and implement a system for monitoring driverbehavior.

(3)	Medium	Avoid	Conduct post-operation inspections of breakers to assess their condition before and after use.
(4)	Medium	Avoid	Designate exclusion zones around the dredging area to keep workers at a safe distance from the sand discharge and implement warning signals.
(5)	Medium	Avoid & mitigate	Establish control zones around the area where the sand conveying pipe is being connected and Require workers to wear safety fall protection equipment.
C			
(1)	Medium	Avoid & mitigate	Install collision avoidance systems on the dredger to detect and alert the crew of potential collisions with piers or embankments.
(2)	Medium	Avoid & mitigate	Install effective fire detection and alarm systems on the dredger to provide early warning in case of a fire outbreak and install fire extinguishers.
(3)	Low	Avoid	Equip the curtain cables with an emergency release mechanism that can be activated immediately in case a diver becomes entangled.
(4)	Medium	Avoid & mitigate	Install backup lighting systems, such as battery-powered emergency lights or backup generators.
D			
(1)	High	Avoid	Assess and ensure that the ground where the crane is positioned is stable and capable of supporting the crane’s weight and the loads it lifts.
(2)	High	Avoid	Ensure that all materials to be lifted are properly rigged and securely attached to the crane’s hook or lifting device.
E			
(1)	Medium High	Avoid	Ensure that the dredger’s decks have non-slip surfaces or anti-skid coatings and require operators to wear appropriate footwear with slip-resistant soles.
(2)	Medium	Avoid & mitigate	Establish safe work perimeters around the silt pond and clearly mark them with warning signs and provide workers with appropriate life vests.
F			
(1)	High	Avoid & mitigate	Provide dredger operators with appropriate personal protective equipment, including life jackets or personal floatation devices (PFDs).
(2)	High	Avoid & mitigate	Install safety lanyards and tethers on vessels or work platforms to secure general workers when working near the water’s edge and provide worker’s life jackets.
(3)	Medium High	Avoid & mitigate	Proper scaffolding design and provide operators and workers with appropriate personal fall protection equipment, such as harnesses and lanyards.
(4)	Medium High	Avoid & mitigate	Equip the ladder with non-slip steps or rungs to enhance grip and prevent slipping and provide operators with safety harnesses.
(5)	Medium High	Avoid	Implement a traffic management plan that includes clear instructions on vehicle routes and areas where vehicles need to slow down and install guardrails/barriers.
G			
(1)	Very High	Avoid	Implement an early warning system to alert personnel of potential storms or strong winds include provisions for securing and evacuating the dredger if necessary.
(2)	Medium High	Avoid	Instruct workers to stay away from tall objects, metal structures, avoid using electronic, and stop working and enter a safe area during lightning storms.

2.9 Control risk

The final step involves controlling risks through a comprehensive final assessment, which includes conducting interviews with 9 assessors to tackle the identified risks. This process aims to verify the guidelines for reducing risk levels effectively. To ensure the validity of the findings, a follow-up questionnaire was conducted with the same nine assessors who participated in the initial survey. This phase includeda thorough final risk assessment to verify the effectiveness of the deployed risk response methods in minimizing risks. As a result, the overall risk levels were reducedto a level deemed acceptable. **Table 9** presents an exhaustive evaluation of the identified risks and their respective levels, both prior to and after the implementation of risk response methods.

While **Figure 5** depicts the risk matrix obtained from this phase. The outcomes derived from the final column in table indicate that the risk assessment was at a low level. This implies that it falls within an acceptable risk range.

Table 9. Final risk assessment.

Item	Initial Risk Rating			Final Risk Rating		
	Risk Assessment		Risk Assessment	Risk Assessment		Risk Assessment
	Likelihood	Impact		Likelihood	Impact	
A						
(1)	4	3	High	1	1	Low
(2)	4	3	High	2	1	Low
B						
(1)	4	5	High	2	2	Low
(2)	3	5	Medium	1	1	Low
(3)	3	5	Medium	1	1	Low
(4)	3	4	Medium	2	1	Low
(5)	3	3	Medium	1	1	Low
C						
(1)	3	4	Medium	1	1	Low
(2)	3	5	Medium	1	2	Low
(3)	2	5	Low	1	1	Low
(4)	3	3	Medium	1	1	Low
D						
(1)	3	5	High	1	2	Low
(2)	4	4	High	2	2	Low
E						
(1)	4	3	Medium High	1	1	Low
(2)	2	4	Medium	1	1	Low
F						
(1)	3	5	High	1	1	Low
(2)	3	5	High	1	1	Low
(3)	3	4	Medium High	1	2	Low
(4)	3	4	Medium High	1	1	Low
(5)	2	5	Medium High	1	2	Low
G						
(1)	4	5	Very High	2	1	Low

(2)	2	5	Medium High	1	1	Low

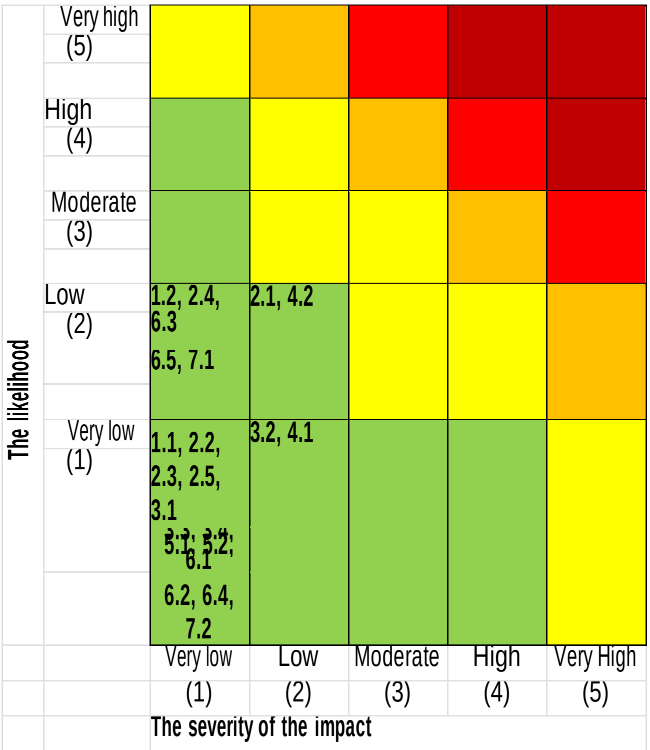

Figure 5. Final risk assessment matrix.

3. Discussion

When comparing the results of this study with past research, several consistent themes emerge, indicating the ongoing relevance and importance of addressing safety risks in dredging and reclamation work as. Contact with moving machinery, previous studies by Cruickshank and Cork (2005) and Daniel (2011) have also emphasized the dangers associated with heavy machinery in dredging operations, aligning with the findings of this study. Struck by moving objects, similar to Bugg et al. (2018) and Rizki (2018), this study highlights the risk of collisions involving dredgers and other vehicles during material handling, reinforcing the importance of safety protocols in such environments.

Strike against something fixed or stationary. consistent with past research by Cruickshank and Cork (2005), this study identifies the risk of collisions with fixed structures, such as piers or embankments, as well as fires on dredgers, underscoring the persistent hazards in these operations.

Injuries while handling, lifting, or carrying, findings from Holle et al. (2005) and Mahapatra and Kushwaha (2020) align with this study's identification of risks associated with unstable cranes and lifting gear failure, highlighting ongoing challenges in ensuring safe lifting practices.

Slips, trips, or falls on the same level, the concerns raised by Daniel (2011) regarding slip and fall incidents are consistent with the findings of this study, emphasizing the need for vigilance in preventing accidents on slippery surfaces.

Falls from height, similar to Holle et al. (2005), this study identifies the risk of falls from elevated surfaces, including into the sea, underscoring the continued importance of fall protection measures.

Weather hazards, the identification of weather-related hazards, such as storms and lightning during land reclamation, corresponds with past research by Cruickshank and Cork (2005), highlighting the ongoing challenges posed by adverse weather conditions.

However, while past research has addressed certain risk factors, this study acknowledges its limitations in comprehensively covering all inherent risks in dredging and reclamation work. By identifying and compiling new risk factors and evaluating the reliability of the questionnaire, this study aims to bridge this gap and provide a more comprehensive understanding of safety risks in these operations. The proactive measures formulated in response to the identified risks, along with subsequent assessments indicating risk mitigation to acceptable levels, contribute valuable insights and guidelines for future work in this reducing the potential for safetyrisks in dredging and reclamation work.

The risk assessment methodology employed involved several key steps, including qualitative and quantitative analyses, to ensure effective risk management.
Methodology Overview:

Qualitative analysis

- Risk Identification: Risks were identified through sample project method statement study and literature review related to safety risk factors.
- Likelihood and Impact Assessment: Likelihood and impact values were assigned to each identified risk and subsequently plotted on a risk matrix.

Risk matrix utilization

- The use of a risk matrix was instrumental in visualizing and prioritizing risksbased on their likelihood and impact. This approach facilitated the identification of the most critical risks requiring immediate attention.

Quantitative analysis

- Risk Priority Value Calculation: Likelihood and impact values were multiplied to obtain a risk priority value for each risk. This quantitative measure further aided in the prioritization process.

Risk response development

- Specialist Brainstorming: A brainstorming session with specialists was conducted to develop guidelines aimed at reducing identified risks.
- By conducting this comprehensive final assessment and mitigation process, it was ensured that the proposed strategies were both practical and effective in minimizing risks. This robust approach not only validated the effectiveness of the riskresponse methods but also provided a clear path for future risk management improvements in other dredging and reclamation work. Including construction in othermarine infrastructure project.

While this research provides valuable insights, it is essential to acknowledge its limitations. The study's focus on specific projects introduces potential constraints stemming from variations in topography, weather conditions, and design specifics, as well as differences in dredging and reclamation technologies. The findings, therefore, may not universally apply to all contexts within these domains. To address this limitation, future studies could adopt a more extensive approach, encompassing a diverse range of projects and locations. Such an inclusive strategy, involving rigorousdata collection, risk analysis, and assessment, could contribute to the creation of a substantial database. This, in turn, would facilitate the development of advanced technologies in risk management, promising heightened accuracy in risk assessments and significantly benefiting occupational health and safety practices.

The results of this study highlight the critical importance of addressing safety risks in dredging and reclamation. By following a detailed risk management process aligned with the guidelines of the Project Management Institute (PMI), which is an internationally recognized authority in project management, and incorporating insights from sample projects and personnel with direct experience in this field, this study provides comprehensive guidelines for managing safety risks in dredging and reclamation. Construction companies engaged in dredging and reclamation can applythe findings of this study to enhance their safety protocols. Implementing the recommended measures will not only protect workers but also contribute to the sustainable success and long-term viability of construction projects in the marine construction sector. The research offers further guidance on effective risk managementpractices, which will enable the industry to achieve higher safety standards and promote a culture of continuous improvement in workplace safety.

4.Conclusion

Aligned with Project Management Institute (PMI) guidelines, this study meticulously follows a structured risk management process, plan risk management andidentification stages. The risk identify covers seven main categories and twenty-two sub-risk factors through qualitative and quantitative assessments. Expert evaluations identify safety risks in dredging and reclamation as notably high and very high, leading to proactive risk response strategies, validated by industry experts. Emphasizing adherence to safety protocols and international standards, the study concludes with a final expert assessment, indicating low or acceptable risk levels. Serving as a crucial reference for decision-makers, the study underscores the significance of proactive riskawareness in ensuring the sustainable progress of dredging and reclamation projects. This research study stands as a valuable guide for proactive safety control practices in dredging and reclamation work, providing a comprehensive overview of potential risks and hazards inherent in the job. The study not only identifies these risksbut also offers clear guidelines for their mitigation, thereby reducing overall risk. Its exemplary nature makes it a valuable resource for decision-makers involved inmanaging safety in similar types of work. The insights gained from this study can be directly applied to enhance safety measures, making it an instrumental tool for fostering a secure work environment in dredging and reclamation projects.

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2. HASIL REVIEW ARTIKEL

Journal: Journal of Infrastructure, Policy and Development

Manuscript ID: # 6205

Title: Safety risk management for construction workers in dredging and reclamation work of industrial port development projects

Reviewer: I Wayan Muka

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1. How do you rate the significance of the research (in a scale of 1 to 5 with 5 being the most significant)?
   I would rate the research significance as 5.

2. How do you rate the originality (in a scale of 1 to 5 with 5 being the highest)? I would rate the manuscript's originality as 4

3. How do you rate the experimental design and quality of data (in a scale of 1 to 5 with 5 being the highest)?
   I would rate the experiment design and data quality as 4.

4. Is the organization of the article appropriate?
   The Article organized well

5. Did you find any language problem?
   No, I did not find any language problem

6. Your decision for this manuscript: **minor revision**

7. Comments to the Author:
   General comment: This research topic is very important and useful for knowing work safety risks in dredging and reclamation operations projects which are important aspects in coastal engineering and land development. Hazard identification, priority risk assessment and risk maps have been carried out.

8. Particular comments:
   a. Arrange the article according to the template in the journal.
   b. The abstract contains a general description, research objectives, research methods, data analysis techniques and research results. Keywords maximum 5 words.
   c. In the Literature review add the HIRACH analysis method. complete the risk assessment process.
   d. Add priority risk management strategies to the research results.
   e. Primary literature (80%) plus reputable international journals/Proceedings/article reports

9. Common:
   a. Please add the limitation of this study
   b. In the discussion the writer must adapt to the research problem formulation: hazard identification, risk assessment, determining priority risks, risk management. This section is discussed clearly, tables and figures are equipped with explanations.
   c. In the closing section: conclusions are made concise and clear, according to the results of the analysis and discussion.

10. Comments to the Editor (Confidential):
    This article is interesting regarding assessing the risk of work accidents on construction projects. I suggest adding the HIRARC method to be used to analyze work safety risks so that they can be analyzed more comprehensively. This research only uses conventional risk assessment methods. However, this research is very important and useful for assessing work safety risks, especially on construction projects. This article is worth publishing.

3. REVIEW DITERIMA EDITOR

Universitas Hindu Indonesia Mail – Article ID: JIPD-6205 – Article Review Acknowledgement

UNIVERSITAS HINDU INDONESIA

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Article ID: JIPD-6205 – Article Review Acknomledgement

1 message

Yvonne Hyde <yvonne.hyde@ep-pub.net> Aug 27, 2023 at 11:40 AM

To: I Wayan Muka <wayanmuka@unhi.ac.id>

Dr. I Wayan Muka:

Thank you for completing the review of the submission "Safety risk management for construction workers in dredging and reclamation work of industrial port development projects," for Journal of Infrastructure, Policy and Development.

Your insight comments should be valuable for authors to think about their study rigorously, and also provide us the significant reference to make the final decision. We appreciate your contribution to maintaining the quality of the work that we publish. You may forward this message to Publons to verify your review, the instructions can be found at http://webofscience.help.clarivate.com/en-us/Content/peer-review-in-wos-researcher-profile.html?Highlight=peer-review.

For well-prepared review reports submitted in a timely manner, we also provide 100 USD APC discount vouchers for publication in International Journal of Environmental Science and Development. The voucher is valid within one year.

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BTW, please complete your information in the OJS system, including your professional title and your research interests, so that we could call for your expertise in appropriate time.

JIPD is a journal which is indexed by SCOPUS, you are welcome to contribute your paper to the journal, please remember to inform me your paper ID once you submit it via the OJS system.

I hope we will be more active in working on together in the future.

Best wishes,
Ms. Yvonne Hyde
Assistant Editor
Email: yvone.hyde@ep-pub.net