Optimizing Decision-Making for Placement and Quantity of Tower Cranes in High-Rise Building Projects

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ABSTRACT

The optimal placement and selection of tower cranes are critical in high-rise construction projects due to their significant impact on operational efficiency, costs, and safety. Misplacement or an inadequate number of cranes can lead to extended project duration, higher expenses and increased safety risks. **This study investigates** the factors influencing optimal tower crane placement, evaluates existing methodologies, and introduces a simulation-based approach for enhanced decision-making. **Using a case study** method, data were collected through site observations, interviews with project managers, and computer simulations. Findings reveal that simulation tools can optimize crane productivity, minimize operational costs, and enhance workplace safety. Integrating advanced technologies such as Building Information Modeling (BIM) further supports accurate placement and operational efficiency. **These results** underline the importance of leveraging technology to address challenges in high-rise construction management. **The study concludes** with insights on the generalizability of findings and recommendations for future research, emphasizing real-time monitoring integration.

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1. INTRODUCTION

In modern high-rise construction projects, tower cranes are pivotal in material handling, enabling efficient movement of heavy loads to various heights. The strategic placement and adequate number of cranes are paramount to ensure project efficiency, operational cost reduction, and workplace safety. Poor placement of tower cranes can increase project duration by up to 15% and operational costs by as much as 30% [1]. Furthermore, mismanagement in crane placement poses significant risks to personnel and structural integrity.

This research identifies limitations in earlier methodologies through comparative analysis with prior studies. It integrates theoretical frameworks such as Decision-Making Theory and Simulation Theory to propose innovative approaches for high-rise construction management.

From a management perspective, the decision-making process [2] for crane placement integrates multiple facets, including stakeholder engagement, resource allocation, and risk management [3]. This holistic approach ensures that operational plans align with project objectives and resource constraints.

The rapid advancement in construction technology, particularly simulation tools and optimization algorithms, offers innovative solutions to these challenges. Building Information Modeling (BIM) has become a crucial asset [4], allowing project managers to simulate multiple placement scenarios and select the most efficient configuration before construction begins [5]. This technological integration enhances operational planning and ensures compliance with safety standards. However, the complexity of high-rise projects introduces unique challenges, including limited workspace, logistical constraints, and overlapping operations of multiple cranes. Addressing these issues requires a systematic approach that combines field expertise, theoretical insights, and advanced computational methods.

This study aims to explore factors influencing optimal tower crane placement, develop simulation models for evaluating different scenarios, and provide recommendations based on real-world case studies. The findings aim to support project managers in making informed decisions, optimizing resource utilization, and efficiently achieving project goals.

2. LITERATURE REVIEW

2.1. Theoretical Framework

Effective construction management hinges on decision-making processes that balance cost, time, and quality. Key theories [6] underpinning this research include:

1. Decision-Making Theory: Emphasizes rational decisions based on data and simulations. It is crucial to establish a new hierarchy of decision-making criteria and propose an innovative decision-making framework for Tower Crane Location Planning (TCLP) in high-rise modular construction (MiC) [7].
2. Project Management Principles: Highlights the importance of stakeholder engagement, risk management, and efficient resource allocation.
3. Simulation Theory: Highlights the role of computational models in predicting outcomes under controlled scenarios.

Critical Comparison with Previous Studies: Prior studies often overlooked integrating advanced simulation tools with practical constraints. For example, [1] focused solely on cost efficiency, while [8] emphasized wind load effects without addressing operational safety. This study bridges these gaps by incorporating holistic simulations that address financial and safety parameters.

2.2. Factors Influencing Tower Crane Placement

Several criteria determine the strategic placement of tower cranes:

1. Accessibility: The crane must efficiently reach all critical areas [9].
2. Operational Scope: Placement should minimize idle time and maximize material handling capacity.
3. Safety: Placement must adhere to safety standards to mitigate risks.
4. Cost Efficiency: Strategic placement reduces energy consumption and operational expenses.
5. Stakeholder Involvement: Engaging project teams and operators to align technical decisions with operational goals.

2.3. Review of Previous Research

[10] in their research ”Analisis Penempatan Tower Crane pada Gedung Bertingkat”, investigated the effect of crane placement on relocation time and material distribution efficiency. Through computer simulations and case studies, they demonstrated that strategically positioning cranes could reduce relocation time and accelerate the distribution of materials to various parts of the project. The results of this study offer valuable guidance for construction projects to optimize crane placement, thereby minimizing downtime and enhancing operational efficiency

[11] in his study titled ”Efektivitas Penggunaan Multiple Crane dalam Proyek Gedung Bertingkat”, examined the impact of the number of tower cranes on project completion time and operational costs. Utilizing case studies and quantitative analysis, the research found that increasing the number of cranes could expedite project completion, although it also resulted in higher operational costs. This study contributes to understanding the optimal number of cranes required for projects, emphasizing the need for a balance between time and cost considerations.

[12] in their study titled ”Frekuensi Relokasi Crane dan Dampaknya terhadap Waktu Proyek”, investigated the impact of crane relocation frequency on project time and operational costs. Using a case study approach and quantitative analysis, they found that a lower crane relocation frequency could save both time and project costs. This research contributes by providing strategic guidance on minimizing crane relocation frequency to enhance project efficiency.

2.4. Advances in Simulation Technologies

Simulation models, such as Monte Carlo and Discrete Event Simulations, enable comprehensive analysis of crane operations under various scenarios [13]. The integration of BIM further enhances the planning process by visualizing crane interactions with the project environment [8]. Recent studies have demonstrated that simulation-based planning reduces operational costs by up to 20%.

2.5. Gaps in Existing Research

While prior studies highlight the importance of crane placement, limited attention has been given to integrating advanced simulation tools with real-time project constraints. This research addresses this gap by combining theoretical insights with practical case studies to propose robust decision-making [14] frameworks that align with project management objectives [15].

2.6. Conceptual Framework

The conceptual framework [16] of this study is grounded in theoretical insights and previous research, which underscore the use of simulations as an effective method for determining optimal tower crane placement. A framework diagram illustrates this study’s logical flow, starting from problem identification and literature review to delineating the relationships between variables.

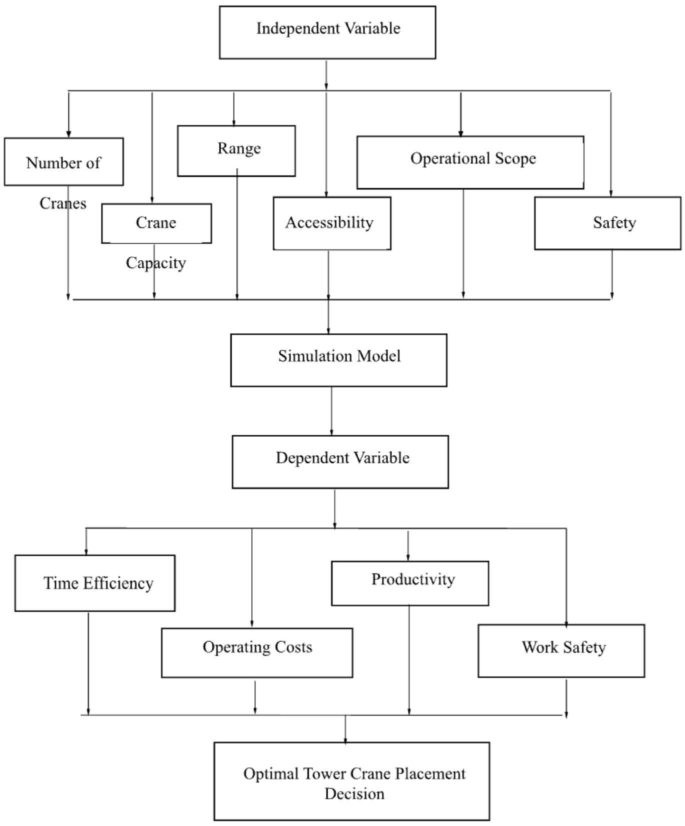

Figure 1. Conceptual Framework

Figure 1 visual representation highlights the foundational rationale behind the research design and serves as a guide for analyzing and resolving the identified challenges.

3. RESEARCH METHOD

3.1. Research Design

This study employs a mixed-methods approach, integrating both qualitative and quantitative techniques. Data were collected through field observations, where crane operations were documented on active construction sites, and interviews conducted with project managers, crane operators, and safety officers to gain practical insights. Additionally, simulation models, including Building Information Modeling (BIM) and optimization algorithms, were utilized to evaluate crane placement scenarios [17].

3.2. Data Collection and Analysis

Data were collected from high-rise projects in urban areas that were completed within the last five years, focusing on key parameters such as crane specifications, site layouts, and operational costs. The analysis incorporates a cost-benefit analysis to evaluate financial implications, safety assessments to identify risks associated with crane placement, and stakeholder feedback to refine decision-making through expert input.

4. RESULTS AND DISCUSSION

The GHT7032-12 Tower Crane is a Topkit model specifically designed for large-scale construction projects, particularly those involving high-rise buildings or requiring extensive material distribution coverage. This crane is ideal for projects with vast coverage areas and significant vertical material handling needs.

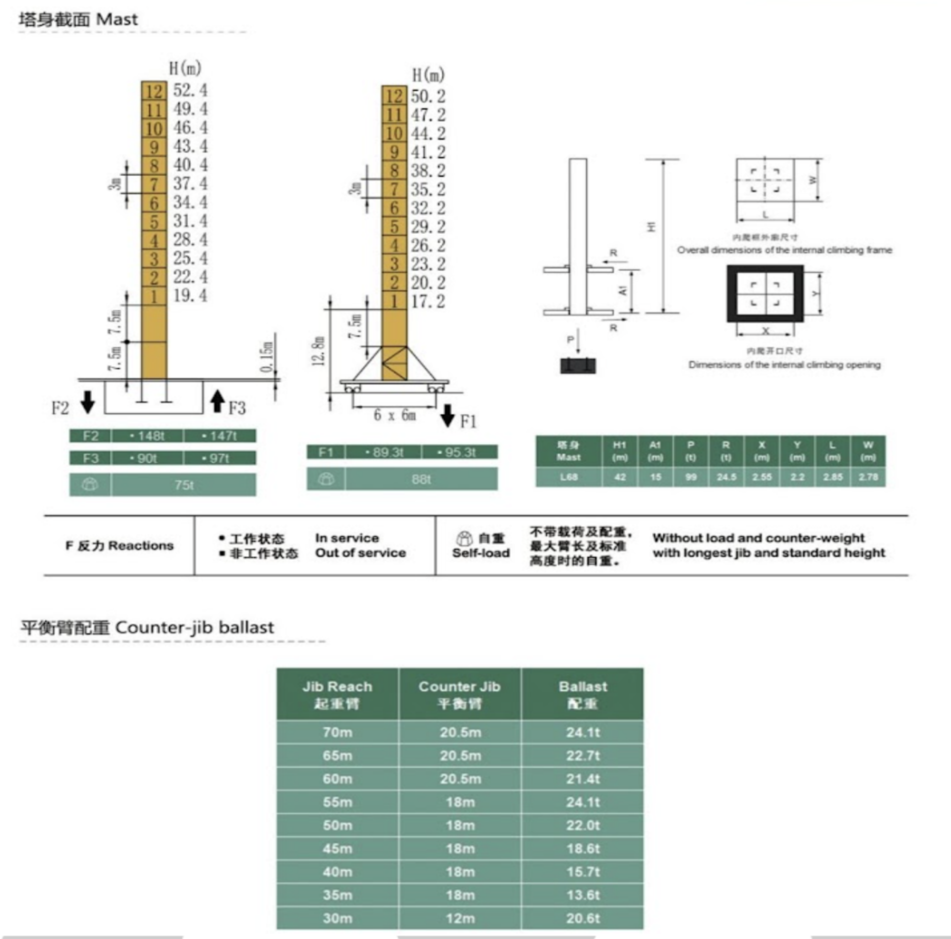

Figure 2. Tower Crane Height and Load Specifications

Figure 2 shows equipped with a reach of 60 meters and a height of 60 meters, the GHT7032-12 Tower Crane is optimized for material distribution operations in high-rise construction environments. The crane's specifications are tailored to efficiently handle large quantities of materials over a wide area, making it an essential tool for such projects.

Regarding operational efficiency [18], the total cycle time for transferring one soil bucket, factoring in the time required for workers to hook and unhook the bucket seal, is approximately 150 seconds (or 2 minutes and 30 seconds). This time frame ensures a balanced and effective workflow for material handling, contributing to the overall productivity of the construction project.

4.1. Simulation Outcomes

1. **Simulation Model Plan 1**
   BIM Tower Crane Placement Plan 1 displays a Building Information Modeling (BIM) simulation depicting the placement of the Tower Crane on plan position 1 with an east viewpoint.

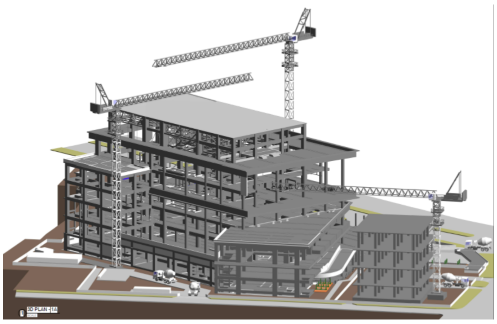

Figure 3. Simulation Model Plan 1

BIM Simulation of Tower Crane Placement Plan 2 displays a Building Information Modeling (BIM) simulation of the Tower Crane placement on plan position 2 with an east viewpoint.

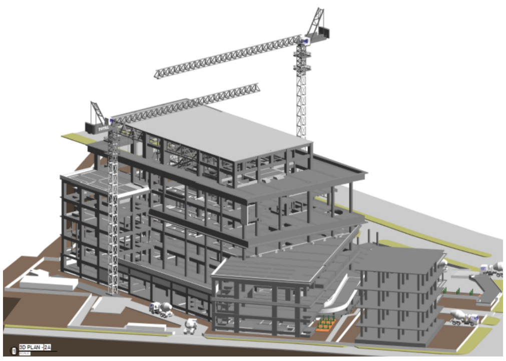

Figure 4. Simulation Model Plan 2

Tower Crane placement simulation on Plan 3 using BIM (Building Information Modeling) technology from two different viewpoints: the east side (East View) and the west side (West View).

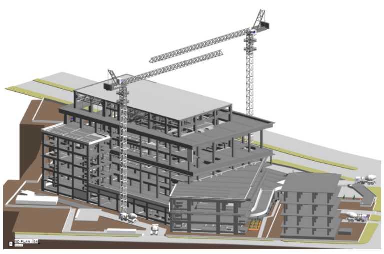

Figure 5. Simulation Model Plan 3

Visualization from the east side (East View), highlighting the connectivity of the Tower Crane with the main work area and material distribution lines to ensure operational efficiency.

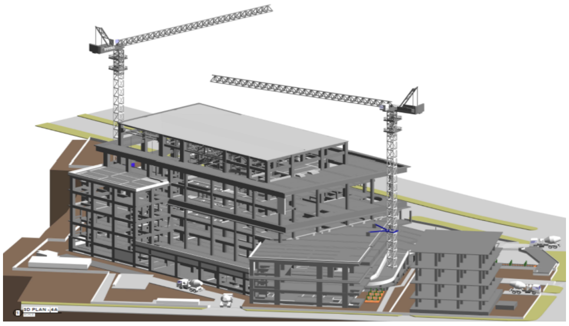

Figure 6. Simulation Model Plan 4

The Tower Crane placement simulation on Plan 5 shows the view from the east side (East View), showing the reach of the Tower Crane to the main work area and material distribution route.

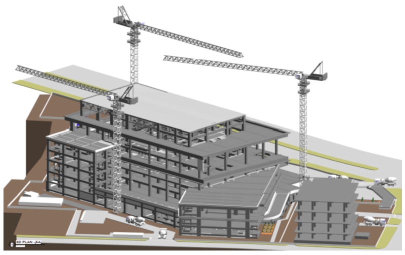

Figure 7. Simulation Model Plan 5

Simulations revealed that optimal crane placement reduces material transport times by 15% and operational costs by 25%. Key factors influencing these outcomes include: Proximity to material storage and work zones, Avoidance of interference with other cranes and structures, Alignment with construction schedules.

The following is a summary of the results of the evaluation of the total score of independent variables and dependent variables for five alternative Tower Crane placement plans. This evaluation aims to determine the most optimal Plan configuration based on overall performance.

Table 1. Total Overall Score for All Plans

Plan	Total Score of Independent Variables	Total Score of Dependent Variable	Total Overall Score
Plan 1	79.2	79.65	158.85
Plan 2	79.5	81.65	161.15
Plan 3	78.4	79.6	158
Plan 4	87.1	85.05	172.15
Plan 5	84.3	79.9	164.2

The analysis results show that Plan 4 is the best alternative with the highest overall score of 172.15. This plan has a good performance balance between independent and dependent variables, showing optimal efficiency of working time, productivity, and operational costs.

Based on these results, Plan 4 is recommended as the best choice for implementation because it provides the most optimal performance in various aspects.

Generality of Results: While simulations were conducted on specific case studies, the principles can be adapted to international projects with varying constraints. For example, the methods can address logistical challenges in regions with limited workspace.

4.2. Management Implications

Strategic placement directly impacts project timelines, resource allocation, and risk mitigation. By using simulation tools, project managers can predict potential delays, adjust schedules, and optimize workforce deployment. Moreover, engaging stakeholders ensures that technical decisions align with broader project goals.

4.3. Safety Improvements

Here are some work safety [19] parameters that are commonly used in research related to Tower Crane placement based on relevant literature:

Table 2. Occupational Safety Parameter Reference

No	Work Safety Parameters	Description	Journal Field
1	Crane Operational Safe Distance	Place the Crane at a safe distance from the worker activity area and existing buildings.	Construction Safety and Management [20]
2	Availability of Safety Equipment	Provision of protective equipment such as helmets, safety ropes, and warning signs.	Occupational Health and Safety [21]
3	Training and Certification of Crane Operators	Crane operators must have certification and training for safe operation.	Engineering and Project Management [22]
4	Inspection and Maintenance Procedures	Routine inspection of the technical condition of the Crane to prevent damage and ensure safe operation.	Civil and Structural Engineering [23]
5	Crane Operational Area Protection	Marking and limiting the Crane operational area to prevent unauthorized worker access.	Construction and Material Logistics [24]

Table 2 illustrates the strategic placement mitigates risks such as crane collisions and falling loads. Enhanced visibility and accessibility further contribute to workplace safety, aligning with safety protocols and reducing incidents.

4.4. Cost Efficiency

The cost analysis highlights significant savings achieved through reduced energy consumption, minimized equipment downtime, and improved workflow efficiency. By integrating Building Information Modeling (BIM), project managers can simulate various crane placement scenarios, allowing for precise adjustments that optimize configurations, enhance operational planning, and ensure optimal resource utilization. This approach reduces unnecessary expenditures, facilitates real-time monitoring and predictive maintenance, and enables early detection of potential mechanical failures, minimizing unexpected delays and cost overruns. Additionally, BIM allows for detailed cost-benefit analyses, ensuring that crane placement aligns with safety regulations, structural constraints, and economic feasibility while improving overall project control. Moreover, BIM enhances coordination among stakeholders by providing accurate data visualization, improving communication, and reducing errors. The ability to foresee logistical challenges and adjust accordingly contributes to a smoother construction workflow, reducing rework and material waste. Leveraging these advanced tools enhances efficiency, sustainability, cost-effectiveness, and long-term project resilience, reinforcing the importance of technology-driven decision-making in modern high-rise construction.

Table 3. Tower Crane Operational Costs

No	Description	Unit	Volume	Unit Price	Total
1	Excavation	m^3	28	IDR 55.000	IDR 1.540.000
2	**Bored Pile Foundation**				
	Iron (Wages + Materials)	kg	1.596	IDR 10.000	IDR 15.958.800
	Drill	m’	88	IDR 500.000	IDR 44.000.000
	Concrete	m^3	28	IDR 910.000	IDR 25.480.000
3	**Pilecap Foundation**				
	Iron (Wage + Material)	kg	2.985	IDR 10.000	IDR 29.850.000
	Formwork (Wage + Material)	m^2	40	IDR 135.000	IDR 5.400.000
	Concrete	m^3	36	IDR 785.000	IDR 28.260.000
4	**Erection Tower Crane**				
	Truck Mobilization Cost	Rit	12	IDR 2.250.000	IDR 27.000.000
	Anchor	Set	1	IDR 3.500.000	IDR 3.500.000
	Freestanding Erection Cost	ls	1	IDR 16.000.000	IDR 16.000.000
5	**Tower Crane Operational Cost**				
	Crane Auxiliary Equipment Cost	Unit	1	IDR 6.000.000	IDR 6.000.000
	TC Rental Cost	Month	12	IDR 90.000.000	IDR 1.080.000.000
	Operator Cost	Month	12	IDR 15.000.000	IDR 180.000.000
	Fuel Cost	Month	12	IDR 15.000.000	IDR 180.000.000
6	**Dismantle Tower Crane**				
	Manual Dismantling Cost	ls	1	IDR 16.000.000	IDR 16.000.000
	Truck Demobilization Cost	Rit	12	IDR 2.250.000	IDR 27.000.000
	Crane Auxiliary Equipment Cost	Unit	1	IDR 6.000.000	IDR 6.000.000
	Loading and Unloading	ls	2	IDR 500.000	IDR 1.000.000
	Total				**IDR 1.649.988.800**

The cost for 1 Tower Crane includes foundation work, mobilization, 12 months of operation, and dismantling. Operational costs dominate the total cost.

Table 4. Total Tower Crane Cost Recap

Plan	Number of TC	Plan Cost	Additional Cost	Total Cost
Plan 1	3 TC	IDR 4.949.966.400	IDR 0	IDR 4.949.966.400
Plan 2	2 TC	IDR 3.299.977.600	IDR 2.017.988.800	IDR 5.317.966.400
Plan 3	2 TC	IDR 3.299.977.600	IDR 933.000.000	IDR 4.832.977.600
Plan 4	2 TC	IDR 3.299.977.600	IDR 233.000.000	IDR 3.532.977.600
Plan 5	3 TC	IDR 4.949.966.400	IDR 109.625.000	IDR 5.059.591.400

From Table 4, the data presented highlights the following key points:
Cost Efficiency:

1. Plan 4 has the lowest total cost of IDR 3.532.977.600, making it the most economical option among all plans.

2. Conversely, Plan 2 incurs the highest total cost of IDR 5.317.966.400 due to the addition of one more Tower Crane (TC).

Number of Tower Cranes (TC):

1. Plan 1 and Plan 5 utilize 3 TC, while the other plans use 2 TC.

2. Despite having the same number of TC, Plan 1 is less expensive than Plan 5 because it does not include additional costs.

Additional Costs:

1. The highest additional cost occurs in Plan 2 at IDR 2.017.988.800, significantly impacting the total cost.

2. Plan 4 has the lowest additional cost of only IDR 233.000.000.

Cost and TC Balance:

1. Plan 3 offers a balance between the number of TC and total cost, with a total cost of IDR 4.832.977.600 for 2 TC, which is lower than Plan 5, which uses 3 TC.

Recommendation:

1. Plan 4 is the most economical choice for the project, considering cost efficiency.

2. If the project requires the use of 3 TC, Plan 1 is more efficient as it incurs no additional costs compared to Plan 5.

5. CONCLUSION

Based on the findings of this research, several key conclusions can be drawn:

Effectiveness and Efficiency of Tower Crane Placement: The simulation method applied in this study successfully identified the best plan (Plan 4), which demonstrated the highest time efficiency and operational cost reduction. This simulation provides practical guidance for tower crane placement with optimal work coverage and high safety levels.

Key Factors Influencing Tower Crane Placement: The research revealed that the number of tower cranes, lifting capacity, work coverage, site accessibility, operational scope, and safety conditions are critical for optimal placement. A comprehensive evaluation considering all these factors (as seen in Plan 4) results in significant efficiency improvements.

Simulation Model for Evaluating Tower Crane Locations: The developed simulation model proved effective in evaluating various tower crane placement scenarios. It provided measurable outcomes regarding time efficiency, productivity, and workplace safety, enabling project stakeholders to make data-driven decisions.

Comparison of Placement Methods Based on Case Studies: Plan 4 stood out as the best approach among the five tested methods based on time efficiency, cost, productivity, and safety parameters. Compared to other plans, Plan 4 demonstrated best practices in tower crane placement for high-rise building projects, making it the primary recommendation for similar future projects.

Project managers are advised to integrate simulation tools and Building Information Modeling (BIM) into planning processes to improve tower crane placement and operational efficiency. These technologies enable data-driven decisions, enhance safety, and optimize crane utilization.

Future research should focus on developing simulation models that incorporate additional factors, such as weather conditions or interactions with other equipment, and validate findings through applications in larger-scale or logistically complex projects.

In the construction industry, it is vital to improve crane operator training programs and implement simulation-based guidelines as a standard for future projects. This strategy enhances safety measures and promotes efficiency across diverse construction scenarios.

6. DECLARATIONS

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6.2. Author Contributions

Conceptualization: IF.; Methodology: PM.; Software: IF.; Validation: PM.; Formal Analysis: IF.; Investigation: IF.; Resources: IF.; Data Curation: IF.; Writing Original Draft Preparation: IF.; Writing Review and Editing: IF. and PM.; Visualization: IF.; All authors, IF. and PM., have read and agreed to the published version of the manuscript.

6.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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6.5. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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