Journal of Construction Project Management and Innovation, 12(1): 87-108, 2022
ISSN 2223-7852

Modus of tower cranes' efficient use on construction sites

Oluseye Olugboyega[1*], Godwin Ehis Oseghale[2], Clinton Aigbavboa[3]

[1&2]Faculty of Environmental Design and Management, Department of Building, Obafemi Awolowo University, Ile-Ife, Nigeria
[3]cidb Centre of Excellence, University of Johannesburg, South Africa

Email: oolugboyega@oauife.edu.ng*

ABSTRACT

The choice, mixes, and setups of tower cranes do not just mean knowing the size, load limit, and functional boundaries of the system. There are fundamental factors that must likewise be thought of. To fill this gap, this study examines the considerations, configurations, and combinations that guarantee the efficient use of tower cranes in Nigeria. The investigation utilises a positivist philosophical framework. The data was gathered principally from the site managers working on forty-five construction sites in Lagos State, Nigeria. The discoveries from the examination conducted on the elicited data from the respondents uncovered that tower cranes are predominantly utilised for short-term and high-rise building projects. Lifting activities straightforwardly affect the project schedule and indirectly impact the project duration. The study concludes that the effective utilisation of tower cranes begins with tower crane load and location contemplations. Considerations for locating tower cranes should adhere strictly to tower crane setups, load type, and load quantity. The principal standard to be considered is the site limitations. The study recommends that building height, operator cost, cost of support system, soil condition, breakdown cycle and repair time are parameters that must be thought of while choosing tower cranes for a project.

Keywords: tower crane, site management, efficient use of tower crane, selection of tower crane

1. INTRODUCTION

Tower cranes are cranes that are typically fixed to the ground by either a concrete slab or by securing the crane to another kind of structure. Tower cranes are characterised both by their height and lifting capacity. The base is fixed to the mast of the tower, which decides the most extreme usable height and permits the crane to pivot since it is secured to the rotation unit. Tower cranes are important for the lifting and moving of heavy loads and are totally central to each construction site that requires working at height or having to move construction materials that would otherwise be immovable. Tower cranes are utilised on construction sites to lift heavy materials like steel and concrete. Large items are also moved by utilising tower cranes. Since tower cranes are slim compared with high-rise buildings, their lifting capacity can be effectively underrated based on appearance. Likewise, mishaps, including tower cranes, can bring about serious injuries, fatalities, and expensive harm to buildings and materials. Moreover, it will likewise prompt huge time and financial costs. This means that the utilisation of tower cranes should be informed by their configurations (Al Hattab et al., 2017). Loads could tumble from tower cranes because of operator incompetency, slipping, mechanical disappointment, and overloading (Sadeghi et al., 2021). While at least two tower cranes could be combined to forestall overloading, the selection of a tower crane genuinely should conform to their functional limits. Any other way, they will be exposed to structural stresses and irreversible damage.

As significant as the selection, blends, and configurations of tower cranes are to their utilization; studies have been quiet with regards to them. The focal point of researchers has been on models or algorithms for locating tower cranes (Nadoushani et al., 2018; Li et al., 2018; Abdelmegid et al., 2015; Kaveh and Vazirinia, 2017; Dasovi´c et al., 2019), tower crane accident and risk factors (Shin, 2015; Lingard et al., 2021; Kim and Kim, 2020; Jiang et al., 2021), and decision support for tower crane selection (Nayal et al., 2020; Al Hattab et al., 2017; Daniel et al., 2021; Shapira and Ben-David, 2017). These investigations have basically centered on optimizing the location of tower cranes.

Parameters influencing tower crane choice and productive use as far as designs and blends have not been completely represented. The choice, mixes, and setups of tower cranes do not just mean knowing the size, load limit, and functional boundaries of the system. There are fundamental factors that must likewise be thought of (Wang et al., 2021). To fill this gap and guarantee proficient utilisation of tower cranes, this study examines the (i) types of loads that tower cranes are considered for in Nigeria, (ii) significant considerations for deciding the most appropriate tower cranes in Nigeria, (iii) tower cranes' configurations and combinations on construction sites in Nigeria, and (iv) significant considerations for deciding the optimal location of tower cranes in Nigeria.

2. LITERATURE REVIEW

Many investigations have been conducted on tower crane locations. A portion of these examinations takes care of location optimization of tower cranes and assignment of material supply points in a construction site considering operating and rental costs (Nadoushani et al., 2018) and optimization algorithms to recognise the optimal type and location of an attached tower crane with the appropriate location of a material supply point (Li et al., 2018). The concentrate by Abdelmegid et al. (2015) fostered an optimization model to tackle tower crane location issues in construction sites utilising a Genetic Algorithm. The target of the study was to minimise the total transportation time. Kaveh and Vazirinia (2017) attempted to optimise tower crane location and material quantity between supply and demand points, while Dasovi c et al. (2019) proposed a working BIM method to optimise work facilities and tower crane locations on construction sites with monotonous tasks.

Having examined the optimal location for tower cranes, Kaveh and Vazirinia (2020) built on their previous work to propose a redesigned sine cosine algorithm for tower crane selection and layout problems. As for mutual interference, Briskorn and Dienstknecht (2018) proposed a mixed-integer programming model for tower crane selection and positioning. The study by Jeong et al. (2021) talked about another idea, the "lifting limit axis" concept, which was applied to develop an automatic arrangement (optimal arrangement) algorithm of the tower crane. Explicit investigations by Huang et al. (2019), Wu and Soto (2020), and Carlos and Mohamed (2017) have been seriously uncovered. Huang et al. (2019) proposed a cost-based selection and location optimization model for the tower crane to uncover the connection between the prefabrication ratio and the optimal selection and location of the tower crane. Results from the study exhibited that when the necessary prefabrication proportion is not under 30%, choosing a prefabricated beam is the most efficient for the construction project. When the number arrives at 50%, the mix of prefabricated columns and beams is the most prudent. The most minimal expense of the tower crane will be acquired when the supply point is situated at the midpoint of the long side of the construction project.

Wu and Soto (2020) proposed spatiotemporal modelling of lifting task scheduling for tower cranes, which comprises a lifting task scheduling optimization model with a tabu search and a lifting task scheduling display method with 4-D simulation. According to the study's findings, the average total time of the optimised lifting task scheduling, material preparation, and transfer times at the supply and demand points can be reduced by 25.82%. In addition, it was uncovered that the component data and relationship of lifting tasks can be plainly given utilising the proposed display method with 4-D simulation. Carlos and Mohamed (2017) introduced a modified ant colony optimization approach (MACA) and its application to the tower crane allocation problem. A comparison was conducted between the performances of Ant Colony Optimisation (ACO) and MACA in solving the tower crane allocation problem. The outcomes showed that MACA outperforms ACO and offers critical computing capabilities that can be utilised for other optimization problems. Regardless of how in-depth these investigations appear to be, they all emphasise the importance of tower crane positioning in relation to overall safety and cost, rather than efficiency.

A few investigations have zeroed in on factors adding to tower crane mishaps. The focal points of these investigations can be ordered as accident factors or risk factors. For instance, Shin (2015) explored the elements that contribute to accidents during tower crane installation and dismantling in Korea. The study uncovered that the competence of the workers, roles of stakeholders such as principal contractors in the tasks, deterioration of tower crane components, and working conditions for conducting the tasks are antagonistically influencing the safety of the tower crane installation and dismantling. Lingard et al. (2021) investigated causal and contributing variables to crane safety incidents in the Australian construction industry. A total of 77 causal and contributing variables were distinguished in the examination, which was found to work at numerous levels inside the working framework connected with the utilisation of cranes in the construction industry. The investigation likewise uncovered that these variables communicate with one another in complex ways inside and between levels of the work system. Kim and Kim (2020) inferred the significance ranking of accident factors of cab-control tower cranes by AHP analysis. The effects of the AHP examination uncovered that the highest-level component of the cab-control tower crane's accident was erection work. The study presumed that the inferred variables ought to be made due, and the necessary measures taken to diminish the tower crane accidents as per the positioning of accident factors. The study by Jiang et al., (2021) zeroed in on the system hazard analysis of tower cranes in various stages of a construction site.

Regarding risk factors, Jiang (2020) concentrated on the safety risk analysis and control of the tower crane. Through the subjective investigation of the accident tree, the minimum cut (diameter) set is gotten, on this premise, the primary significance of all fundamental occasions is arranged, and the principal factors influencing the safety accident of the tower crane are determined. Discoveries from the study give a premise to forestalling tower crane accidents and controlling tower crane risks. Zhou et al., (2018) analyzed tower crane safety from a complex sociotechnical framework viewpoint by carrying out both subjective and quantitative examination techniques. Through the principal component analysis, nine principal aspects of the tower crane safety system were recognized. They are: (i) tower crane equipment quality and dependability, (ii) tower crane safety management and upkeep, (iii) the tower crane safety program, (iv) workers' safety practice, (v) working environment, (vi) on-site working conditions for tower crane operation, (vii) supervisors' safety practice, (viii) auxiliary safety equipment, and (ix) government safety supervision.

The concentrate by Salihu et al., (2020) assessed safety risk factors during the installation and dismantling of tower cranes in construction sites in Nigeria. Results showed that abrasion (wear and tear of components such as bolts, nuts, or pins) is the most plausible element with a mean value of 3.63. It was observed that the fracture of a wire rope during dismantling had the highest degree of impact with a mean value of 4.63. The examiner reasoned that fracture of a wire rope during dismantling and abrasion (wear and tear of components such as bolts, nuts, or pins) are exceptionally influencing factors on safety during installation and dismantling. The study reasoned that the reception of a preventive maintenance strategy or routine check on the tower crane parts and components could assist with limiting the likelihood of occurrence and effect of the safety risk factors on-site.

Studies on the utilisation of tower cranes have been concerned about decision support for tower crane selection, overlapping work zones, and tower crane activities. Outstanding investigations in these classifications incorporate Nayal et al., (2020), Marzouk and Abubakr (2015), Al Hattab et al., (2017), Al Hattab et al., (2014), Daniel et al., (2021), and Shapira and Ben-David (2017). Nayal et al. (2020) explored the choice of tower crane utilising multi-rule decision-making techniques. The study also proposed a system of selection of tower cranes at the site using a multi-criteria decision-making (MCDM) model for the same. Marzouk and Abubakr (2015) introduced a system for the selection of tower crane types and locations at construction sites. The framework considered a decision-making model to select the tower crane type; an optimization model for the selection of the ideal number and location of tower cranes; and a 4D simulation model to simulate tower crane tasks.

Al Hattab et al. (2017) explored the effect of overlapping cranes, used on high-rise buildings, on functional adaptability, which is the harmony between schedule duration, crane utilization, and safety. The study showed that the outcomes of the balancing will depend on a few intensified factors, for example, the experience of planners and crane operators; the sequencing of basic versus non-basic exercises; and the general exertion and care taken when arranging tasks of overlapping cranes. It was deduced in the study that increasing overlap size can be gainful or troublesome depending on how appropriately planners assign overlapping cranes to workload demand, remembering that there are sure compromises while accomplishing functional adaptability. Al Hattab et al. (2014) optimised the use of two tower cranes by simulating the scheduling of tasks in the overlapping work zones to accomplish shorter operation durations and higher crane utilisation rates. An optimization model dependent on parametric variation was produced for studying two cranes by using, as input, the construction schedule detailed down to daily operations through look-ahead planning. The study guaranteed that the model provides a decent workload schedule for both cranes and accomplishes the best utilisation rates while diminishing inactive times to eventually support the production of the cranes while reducing project duration and cost. Daniel et al. (2021) proposed a philosophy to gauge the productivity of a construction site through the investigation of tower crane data. In the exploration, the activity of the tower crane was estimated by separating effective lifting operations using the load signal essentially.

The study by Shapira and Ben-David (2017) described equipment planning for multi-crane building construction sites. Different examinations in this area are a light-weight design of tower crane boom structure dependent on multi-objective optimization (Jia and Wan, 2015), seismic responses and dynamic attributes of boom tower cranes (Yao et al., 2018, 2019), payload swing control of a tower crane utilising a neural network-based input shaper (Fasih et al., 2020), and evaluation of the safe use of tower cranes on construction sites (Bamfo-Agyei and Atepor, 2018). There is adequate data in the above examinations to recommend that choosing the appropriate type, number, and locations of cranes is reliant upon the site's layout and logistics, expected workload demand, and project surroundings such as traffic and adjoining buildings. It was additionally clarified that tower crane layout design and planning within construction sites is a typical construction technical issue. Cranes must be chosen and their on-site locations have to be determined so that each demand area is associated with its supply area.

Specifically, studies on location optimization have shown that deciding the location of the tower crane is a fundamental task of layout planning. As indicated by these examinations, the optimization of tower crane location relies upon many interrelated variables, including shape and size of the buildings; type and quantity of required materials; crane configurations; crane type; and construction site layout. These elements differ starting with one project to the next, coming about due to muddled site layout strategies and approaches. Notwithstanding, tower cranes are basic equipment that should be appropriately planned and matched with construction work on-site so that operations can be performed proficiently, securely, and accurately. Additionally, in the event that the crane's essential qualities don't match the work's necessities, then it might prompt huge impacts as far as significant cost, potential postponements, and dangerous work conditions. The utilisation and choice of tower cranes requires more than location optimization and making arrangements for safety on the grounds that their structures, foundations, and presence on the site are generally for as long as the heavy construction phases continue. In choosing a tower crane, the characteristics, configurations, and potential mixes of different tower cranes available should be considered against the prerequisites forced by the loads to be taken care of and the environmental factors wherein the tower crane will operate. Assuming this isn't done, effective utilisation of the tower crane is not ensured (Abdelmegid et al., 2015).

3. METHODOLOGY

In exploring the considerations, configurations, and combinations underlying the efficient use of tower cranes on construction sites; this study utilized a positivism philosophical framework. The examination depended on the research framework in Figure 1. The framework clarifies that:

- The efficiency of tower cranes generally relies upon their type, number, location, and load consideration. As the number of work assignments and the demand for tower cranes increases, planners might encounter troubles in settling on a fitting choice with regard to the location of tower cranes. A poor decision, notwithstanding, is probably going to have critical adverse consequences, which will prompt extra expenses and potential postponements. The load considered for the tower crane will advise the type of tower crane to be selected, its configurations, and the plausibility of joining at least two tower cranes.
- To decide the appropriate tower crane type and reasonable positions, many variables should be thought about. These impressive variables incorporate tower crane data, construction project data, construction site data, and construction materials data. Tower crane data incorporate the heaviest lift and the largest lifting radius.
- The mounting, structures and jib of a tower crane should be considered to decide the most reasonable tower crane configurations.
- A single tower crane could be utilized or joined as a double or multiple tower crane contingent upon the load necessity.

Figure 1 illustrates the proposed factors, configurations, and potential mixes that would guarantee the productive utilisation of tower cranes. Construction site managers overseeing ongoing sites with tower cranes were purposively selected as the study populace. This was hinged on the fact that the actual and detailed plan of tower cranes was prepared by the construction site managers. The site manager readies the subtleties included in the Construction Method Plan contingent upon the actual project scope, status, and type of cranes available. Furthermore, the site manager prepares the Tower Crane Assignment Schedule, which is an important document for planning the productive use of the tower crane(s). A pilot study to identify ongoing sites with tower cranes was conducted in Lagos State, Nigeria. The choice of Lagos State as the study area was informed by its status as the hub of construction activities in Nigeria. At the end of the pilot study, an aggregate of 45 ongoing sites with tower cranes was identified and used to decide the target population for the study. A full enumeration of the distinguished 45 construction sites was embraced.

Data was gathered principally from the site managers working on the identified construction sites. The questionnaire utilised for the survey evoked information on respondents' company profiles, contemplations for deciding the most proper tower cranes, contemplations for deciding the ideal location of tower cranes, techniques guiding the location of tower cranes, sorts of load that tower cranes are considered for, and tower cranes' configurations and combinations on construction sites. Table 1 shows the profile of the construction organisations that the surveyed site managers were working for. The majority of site managers (40%) work for companies whose primary business is building and civil construction. Most (33.3%) of the site managers indicated that their companies have 50 employees and 101-150 employees. A few (20%) of the companies have existed for over 21 years, while most (40%) of the companies operate at the national level.

The data collected were analysed using the mean score, z-score, Analysis of Variance, and Tukey HSD Post Hoc test. For the mean score analysis, the significance level of the scores was determined as follows: very low (1.00 – 1.80), low (1.81 – 2.60), medium (2.61 – 3.20), high (3.21 – 4.20), and very high (4.21 – 5.00). The z-score analysis supplements and permits the correlation of mean scores by normalising the dispersion. It was calculated according to the formula given by Abdi (2007). In deciding the significance level of the z-scores, a variable was viewed as significant if its z-score was positive and insignificant if the z-score was negative.

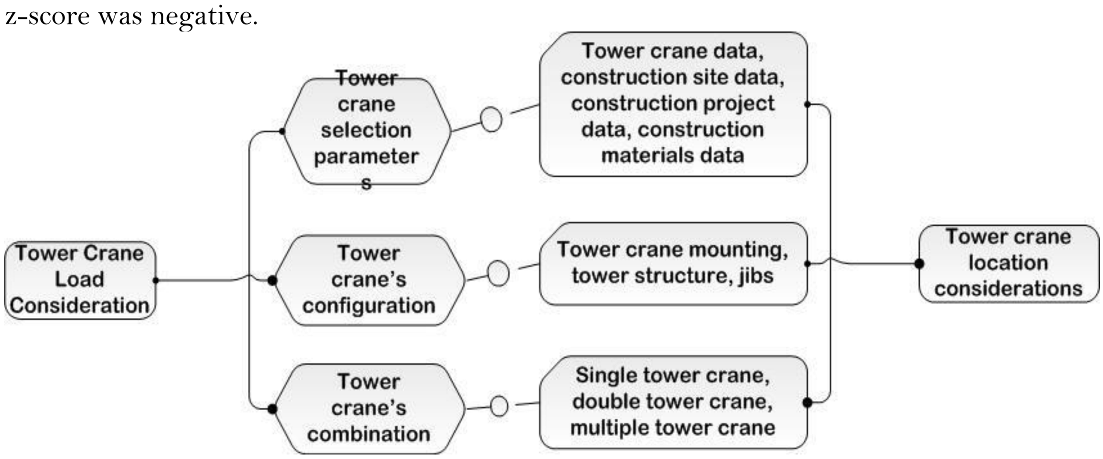

Figure 1: research framework

Table 1: Respondents' company profile

Section	Options	Frequency	Percent
Area of operation	Building construction	12	26.7
	Industrial construction	6	13.3
	Civil construction	6	13.3
	Building & civil construction	18	40.0
	Special construction	3	6.7
	Total	45	100.0
Company size	< 50 employees	15	33.3
	51-100 employees	12	26.7
	101-150 employees	15	33.3
	>151 employees	3	6.7
	Total	45	100.0
Years of experience of respondents	6-10	6	13.3
	11-15	5	11.1
	16-20	10	22.2
	21 years & above	24	53.3
	Total	45	100.0
Company age	6-10	12	26.7
	11-15	12	26.7
	16-20	12	26.7
	21 years & above	9	20.0
	Total	45	100.0

Region of operation	Local-level	6	13.3
	State-level	6	13.3
	Interstate	9	20.0
	National level	18	40.0
	International level	6	13.3
	Total	45	100.0

4. RESULTS

4.1 Tower cranes load considerations

The tower crane load configuration on construction sites was researched by eliciting information on the use of tower cranes for various kinds of loads and projects. Utilizing a 5-point Likert scale, the site managers were approached to demonstrate their level of understanding (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) with the kinds of loads and projects that tower cranes were considered for on construction sites. The data collected were analysed using the mean score and z-score (see Table 2). The outcomes from the mean score analysis uncovered that 16 unique kinds of loads were exceptionally considered for lifting by tower cranes on construction sites. Only precast materials were very highly considered for lifting by tower cranes. On the basis of this finding, Huang et al. (2019) have connected prefabrication with the utilisation of a tower crane. This recommends that the tower crane is a significant consideration for load lifting in assembly and erection processes involving precast and prefab materials.

The mean score investigation further showed that tower cranes were not generally utilised for lifting workers to work stations, machinery and equipment, roof covering and accessories, roof trusses, and plumbing fixtures. Plumbing apparatuses and roof coverings may not really be weighty and, in this way, may not need lifting by a tower crane. Notwithstanding, roof trusses, because of their size and weight, should be lifted by the tower crane. This outcome appears to be astonishing. The main clarification for the non-lifting of roof trusses with tower cranes on construction sites could be that the surveyed sites were, for the most part, high-rise buildings and, in this manner, didn't need the utilisation of roof trusses. In an alternate manner, it may be the case that the trusses were lifted into position utilising different strategies like the pulley system because of the tight timetable of the tower crane.

The non-lifting of work and machinery with tower cranes could be because of the requirement for safety. The safe use of the tower crane doesn't uphold the lifting of live loads like workers (Lingard et al., 2021; Kim and Kim, 2020). The aftereffect of the Z-score analysis gave an elective translation of the degree of significance of the loads considered for the tower crane. As displayed in Table 2, the outcomes revealed that tower cranes are principally utilised for lifting purlins, plumbing fixtures, workers to work stations, precast materials, formwork, curtain wall, precast façade elements, reinforcement, concrete, and blocks. The results of the Z-score analysis for the most part upheld the discoveries from the mean score analysis. In any case, plumbing fixtures and workers were uncovered by Z-score analysis as critical loads lifted by tower cranes on construction sites. These loads recorded medium-level significance in mean score analysis. Considering the two outcomes, it may very well be surmised that plumbing fixtures and workers were lifted using tower cranes on some construction sites. The sort of plumbing fixtures lifted using the tower crane might contrast with the construction sites. Nonetheless, the lifting of workers with a tower crane is a safety risk factor, as verified by Jiang (2020) and Zhou et al. (2018).

Likewise, Table 2 showed the mean and Z-score analysis of the use of tower cranes for various kinds of projects. The results of the mean score analysis uncovered that tower cranes were profoundly considered for short-term projects, medium-sized and large projects, and high-rise building projects. This helps the non-thought-of tower cranes for lifting roof trusses, as indicated by the respondents. Roof trusses are not common with high-rise buildings and could, without much of a stretch, be lifted into position utilising other non-tower crane strategies for medium-sized projects. The consequences of the Z-score analysis uncovered that tower cranes are, for the most part, utilised for short-term projects and high-rise building projects. The two outcomes complemented one another and immovably settled the utilisation of tower cranes for short-time and high-rise building projects.

Table 2: Load considered for lifting by tower cranes

Usage of Tower Crane for different types of projects					
Usage of tower crane for different types of loads	Mean score	The significance level for the mean score	Standard deviation	z-score	The significance level for z-score
Project in restricted locations	2.4667	Low	.89443	-0.29	Insignificant
Wall ties	2.9333	Medium	83.39348	-0.00	Insignificant
Electrical fixtures	3.0667	High	1.19469	-0.46	Insignificant
Roof trusses	3.0667	Medium	1.19469	-0.46	Insignificant
Plumbing fixtures	3.0667	Medium	1.35512	0.38	Significant
Roof covering and accessories	3.1333	Medium	1.15994	-0.42	Insignificant
Balustrade	3.1333	Medium	1.32459	-0.36	Insignificant
Machinery and equipment	3.1333	Medium	1.15994	-0.42	Insignificant
Workers to work station	3.2000	Medium	1.12006	0.31	Significant
HVAC fixtures	3.2667	Medium	1.13618	-0.31	Insignificant
Floor wall	3.2667	High	1.19469	-0.29	Insignificant
Steel materials	3.3333	High	1.20605	-0.23	Insignificant
Furniture and fixture	3.4000	High	1.37179	-0.15	Insignificant
Scaffolding	3.4000	High	1.37179	-0.15	Insignificant
Motor	3.4000	High	1.37179	-0.15	Insignificant
Doors and window frames	3.4000	High	1.15601	-0.81	Insignificant
Installation of prefab arrangements	3.4000	High	1.15601	-0.81	Insignificant
Painting and interior decoration materials	3.4667	High	1.27208	-0.16	Insignificant
Medium & large project	3.4667	High	1.15994	-0.13	Insignificant
Formwork	3.6667	High	1.14812	0.04	Significant
Curtain wall	3.6667	High	.95346	0.05	Significant
Precast facade elements	3.6667	High	1.02247	0.05	Significant
Reinforcement	3.7333	High	1.13618	0.08	Significant
Short time project	3.7333	High	1.13618	0.11	Significant
Concrete	3.8000	High	1.17937	0.18	Significant
High-rise building project	3.9333	High	.78044	0.41	Significant
Purlins	4.0000	High	2.15322	0.18	Significant
Precast materials	4.4000	Very high	13.1640	0.06	Significant
Block/bricks	4.8667	High	4.77017	0.26	Significant

4.2 Tower crane selection parameters

Data on the criteria considered in choosing tower cranes on construction sites was evoked from the surveyed site managers. The criteria were arranged into four groups: construction materials data, construction project data, construction site data, and tower crane data. Mean score analysis was used to examine the level of significance of the criteria, while Z-score analysis was used to confirm the mean score examination and set up extremely large rules. As introduced in Table 3, the mean score analysis uncovered that the height of a building is profoundly considered as construction project data and soil condition is exceptionally considered as construction site data. For tower crane data, transportation cost, disassembly cost, maintenance and depreciation, operators' cost, the capacity of crane required, and cost of support system are exceptionally thought to be in choosing tower cranes on construction sites. The breakdown cycle and repair time are very highly considered.

The outcomes from the Z-score analysis upheld the mean score analysis. As displayed in Table 3, the height of the building (construction project data), operator cost, cost of support system, and breakdown cycle and repair time (tower crane data) are the primary criteria considered in choosing tower cranes on construction sites. Soil conditions are fundamental for the stability of the tower crane (Yao et al., 2018). This explains why it was the main construction site data profoundly considered in the tower crane choice. Shin (2015) featured the significance of tower crane installation and dismantling. This current study likewise observed tower crane installation and dis-assembly as a feature of the exceptionally considered tower crane data.

Table 3: Criteria affecting the selection of Tower Crane on construction sites

Criteria	Mean score	The significance level for the mean score	Standard deviation	Z-score	The significance level for z-score
Construction materials data					
Weight & size of materials	2.6000	Low	1.09545	-0.92	Insignificant
Types of material required on site	3.0667	Medium	1.00905	-0.55	Insignificant
Construction project data					
Project duration & size	2.3333	Low	1.14812	-1.14	Insignificant
Availability of expertise	2.3333	Low	1.08711	-1.19	Insignificant
Productivity target	2.6667	Medium	1.20605	-0.79	Insignificant
Construction methodology and programme	2.6667	Medium	1.08711	-0.87	Insignificant
Height of building	4.0000	High	7.32989	0.05	Significant
Construction site data					
Site layout plan	2.3333	Low	1.14812	-1.12	Insignificant
Site constraint	2.6667	Medium	1.20605	-0.79	Insignificant
Noise and dust	2.8667	Medium	1.21730	-0.62	Insignificant
Site neighborhood	3.1333	Medium	1.09959	-0.44	Insignificant
Soil condition	3.4667	High	1.15994	-0.13	Insignificant
Tower crane data					
Weather condition	2.5333	Low	1.21730	-0.89	Insignificant
Space requirement	2.6667	Medium	1.08711	-0.87	Insignificant
Availability of spare parts	2.8667	Medium	.96766	-0.78	Insignificant
Availability of parts	3.0000	Medium	1.10782	-0.55	Insignificant
Installation cost	3.2000	Medium	1.34164	-0.31	Insignificant
Rental cost	3.2000	Medium	1.28982	-0.30	Insignificant
Transportation cost	3.2667	High	1.35512	-0.26	Insignificant
The capacity of the crane required	3.2667	High	1.19469	-0.29	Insignificant
Disassemble cost	3.3333	High	2.35488	-0.12	Insignificant
Maintenance and depreciation	3.4667	High	1.15994	-0.13	Insignificant
Operators cost	3.6000	High	1.21356	0.00	Significant
Cost of support system	3.9333	High	12.50891	0.03	Significant
Breakdown cycle & repair time	4.0000	Very high	.90453	0.43	Significant

4.3 Tower cranes' configurations and combinations on construction sites

Table 4 shows the results of the mean score and Z-score investigations of the tower crane designs and mixes as indicated by the respondents. The consequences of the mean score analysis uncovered that the telescope tower is the most exceptionally utilised tower structure on construction sites. The exceptionally utilised jibs incorporate fixed radius jibs, horizontal trolley jibs, and articulated jibs. The mean score analysis did not give a reasonable outcome on the type of tower crane mounting. This suggests an absence of emphasis on tower crane setups among the site managers.

The Z-score analysis revealed that horizontal trolley jibs were the most extensively used jib. Combining the outcomes from the Z-score and mean score examinations, it may very well be deduced that site managers just connected significance to jibs as the fundamental tower crane components. Concerning mixes of tower cranes on construction sites, the mean score analysis and Z-score analysis uncovered that double tower cranes are dominatingly utilised on construction sites. This proposes that site managers are productively using tower cranes on construction sites by combining them in twos.

Table 4: Tower crane configurations and combination

Tower Crane mounting on construction sites	Mean score	The significance level for the mean score	Standard deviation	Z-score	The significance level for z-score
Static base	2.8000	Medium	1.05744	-0.77	Insignificant
Rail	3.0000	Medium	.90453	-0.67	Insignificant
Crawler	3.0667	Medium	1.00905	-0.55	Insignificant
Truck	3.1333	Medium	.72614	-0.69	Insignificant
Tower structures on construction sites					
Mono tower	2.9333	Medium	.68755	-1.00	Insignificant
Inner & outer tower	2.9333	Medium	1.00905	-0.68	Insignificant
Telescope tower	3.4667	High	.89443	-0.17	Insignificant
Jibs on construction sites					
Rear pivoted luffing jib	2.9333	Medium	1.25045	-0.54	Insignificant
Fixed radius jib	3.4000	High	1.15601	-0.18	Insignificant
Articulated jibs	3.5333	High	1.03573	-0.08	Insignificant
Horizontal trolley jibs	4.2000	High	5.23797	0.11	Significant
Combinations of a tower crane on construction sites					
Multiple tower crane	2.5333	Low	.62523	-1.74	Insignificant
Single tower crane	3.0667	Medium	1.07450	-0.51	Insignificant
Double tower crane	3.4000	High	.71985	0.00	Significant

4.4 Considerations for determining the optimal location of tower cranes

Two questions were used to investigate the factors that should be considered when determining the best location for tower cranes. First and foremost, site managers were asked to respond to questions on criteria considered in locating tower cranes on construction sites using a 5-point Likert scale. The mean score and Z-score analysis of the reactions are presented in Table 5. Second, the site managers were approached to show their level of concurrence with the techniques guiding the location of the tower crane on construction sites. Table 6 gives the mean score and Z-score analysis conducted on the responses. The mean score examination revealed that site constraint, type and quantity of required material, crane configuration and type, as well as hook movement and height, are the primary measures influencing tower crane location, as shown in Table 5. The Z-score analysis just upheld site constraints as the fundamental basis influencing tower crane location. This implies that any remaining variables are influenced by site constraints. For instance, safety, jib length, crane capacity, tower crane configuration and type, as well as the size and shape of buildings, are associated with the site constraints. Site limitations will unquestionably influence the attributes of buildings and tower cranes.

Table 6 shows that every one of the recognised procedures should be followed as a direction for locating the tower crane. Only the determination of the weight of loads to be lifted and optimising lifting motion for the tower crane were not shown as fundamental techniques by the respondents. Both mean score and Z-score examinations settled on the significance of the identified procedures. It is obvious from the outcomes that load consideration, tower crane configurations, and planning of tower crane activities are fundamental in locating tower cranes. Tables 7 and 8 show the results of the descriptive statistics, the Analysis of Variance (ANOVA), and the Tukey post hoc tests that were conducted to determine if there are statistical differences between the mean item scores for the ratings indicated by the respondents. The ANOVA results revealed that the F-ratio value is 1.54544 and the p-value is.219703. The result is not significant at p.05, indicating that no statistically significant difference between groups was found using ANOVA. The Tukey post hoc test also revealed that there was no significant difference between the various pairs of means.

Table 5: Criteria affecting the location of Tower Crane on construction sites

Criteria	Mean score	The significance level for the mean score	Standard deviation	Z-score
Safety	2.3333	Low	.87905	-1.47
Shape and size of the building	3.0667	Medium	1.25045	-0.44
Jib length	3.0667	Medium	1.25045	-0.44
Crane capacity	3.1333	Medium	1.15994	-0.42
Hosting movement	3.2000	Medium	.99087	-0.41
Hook movement &height	3.2667	High	1.30384	-0.27
Crane configuration & type	3.4000	High	1.37179	-0.15
Type & quantity of required material	3.4667	High	1.15994	-0.13
Site constraint	3.5333	High	1.42382	0.01

Table 6: Procedures guiding the location of Tower Crane on construction sites

Procedures	Mean score	The significance level for the mean score	Standard deviation	Z-score	The significance level for z-score
Determination of the weight of loads to be lifted	2.8667	Medium	1.09959	-8.33	Insignificant
Optimizing lifting motion for the tower crane	3.0667	Medium	1.25045	-0.44	Insignificant
Identifying feasible tower crane location	3.1333	Medium	1.03573	-0.47	Insignificant
Identifying obstacles and work zones on construction site	3.4000	High	1.09545	-0.19	Insignificant
Selecting appropriate jibs	3.5333	High	1.21730	-0.07	Insignificant
Determination of the coverage area for the tower crane	3.6000	High	1.21356	-0.01	Insignificant
Calculating safe working loads for the tower crane	3.6000	High	.96295	-0.01	Insignificant
Listing out load to be lifted	3.6667	High	1.26131	0.04	Significant
Creating a safety zone around the tower crane coverage area	3.6667	High	1.14812	0.04	Significant
Preparing tower crane task schedule	3.7333	High	1.25045	0.09	Significant
Selecting appropriate sling angle and factor	3.7333	High	1.13618	0.08	Significant
Selection of appropriate rigging method	3.8667	High	1.15994	0.22	Significant
Selection of appropriate demand and supply points for the loads	4.0000	High	1.16775	0.34	Significant
Analyzing the working spaces required for the tower crane	4.0667	High	.86340	0.52	Significant

Table 7: One-way ANOVA for non-homogeneity of variance

Result Details				
Source	***SS***	***df***	***MS***	
Between-treatments	0.5828	4	0.1457	F = 1.54544
Within-treatments	2.357	25	0.0943	
Total	2.9398	29		

Table 8: Post Hoc Tukey HSD

Pairwise Comparisons		$HSD_{.05}$ = 0.5206 $HSD_{.01}$ = 0.6448	$Q_{.05}$ = 4.1534 $Q_{.01}$ = 5.1439
T_1:T_2	M_1 = 3.24 M_2 = 3.22	0.02	Q = 0.18 (p = .99994)
T_1:T_3	M_1 = 3.24 M_3 = 3.32	0.08	Q = 0.62 (p = .99185)
T_1:T_4	M_1 = 3.24 M_4 = 3.59	0.34	Q = 2.75 (p = .32206)
T_1:T_5	M_1 = 3.24 M_5 = 3.47	0.22	Q = 1.77 (p = .72092)
T_2:T_3	M_2 = 3.22 M_3 = 3.32	0.10	Q = 0.80 (p = .97907)
T_2:T_4	M_2 = 3.22 M_4 = 3.59	0.37	Q = 2.93 (p = .26457)
T_2:T_5	M_2 = 3.22 M_5 = 3.47	0.24	Q = 1.95 (p = .64597)
T_3:T_4	M_3 = 3.32 M_4 = 3.59	0.27	Q = 2.13 (p = .56922)
T_3:T_5	M_3 = 3.32 M_5 = 3.47	0.14	Q = 1.15 (p = .92349)
T_4:T_5	M_4 = 3.59 M_5 = 3.47	0.12	Q = 0.97 (p = .95696)

5. DISCUSSION OF FINDINGS

Proper planning of tower crane utilisation is basic to their effective use. Numerous scientists have conceived that optimising the location of tower cranes will ensure their effective use. According to the current study, the productive utilisation of tower cranes is dependent on determining the most appropriate tower crane, determining the ideal location of the tower crane, using the tower crane for the appropriate load, and determining the ideal tower crane configurations and combinations. These contentions were operationalized by surveying site managers overseeing ongoing construction sites with tower cranes in Lagos State, Nigeria. The discoveries from the examination conducted on the elicited data from the respondents uncovered that tower cranes are principally considered for lifting heavy and cumbersome materials; the lifting of light materials with tower cranes is not conservative and effective; and the lifting of live loads with tower cranes is not safe.

The investigation likewise discovered that tower cranes are predominantly utilised for short-term projects and high-rise building projects. Lifting activities straightforwardly affect the project schedule and have an indirect impact on project duration. Consequently, the use of tower cranes in high-rise buildings where there are lots of lifting operations could be because of the need to decrease the project time and cost. The safety and thoroughness of pouring concrete in ongoing upper floor levels may suggest that tower cranes be used for high-rise buildings. It was amazing to observe that the tower crane was not being utilised for projects in confined areas. This could be because of the absence of specialised ability with respect to the site managers or safety requirements in the location. It may be the case that tower cranes are predominantly utilised for short-term projects in view of the cost-saving measures and the risk of leaving tower cranes for a longer period on sites.

It was found in this research that construction materials and construction site data were not viewed as significant while choosing tower cranes on construction sites. Among the construction project data, only the height of the building was typically considered as a significant element in the choice of tower cranes. This could be on the grounds that tower cranes are chiefly utilised for high-rise building projects. The operator's cost, cost of support system, and breakdown cycle and repair time were the criteria that were indicated as influencing the choice of tower cranes. This suggests that tower crane planning only accentuates the cost of operating tower cranes. Other important factors such as available space, climate, and crane capacity were not considered. This could be connected to the contractor's quest to boost profit to the detriment of safety and productivity. Daniel et al. (2021) had previously affirmed that productivity is the main criteria in analysing tower crane data. The discoveries of this current study are demonstrated in any case.

Studies, for example, Jiang et al., (2021), Lingard et al., (2021), and Jiang (2020), have accentuated the need to focus on tower crane configurations for safety and efficiency. This current study inspected tower crane configuration designs in practice. Moreover, Shapira and Ben-David (2017) and Bamfo-Agyei and Atepor (2018) have exhibited the potential outcomes of combining tower cranes on sites. This current study went above and beyond to explore the occurrence of tower crane mixes on sites. The discoveries recommend that telescope towers and horizontal trolley jibs are the normal parts of tower crane configurations on construction sites. This could be on the grounds that the telescope tower is the most adaptable tower structure and represents the norm by which other tower structures are measured. The telescope tower gives utility, adaptability, and the means to lift weighty loads. The telescope tower has the highest reach and allows for height adjustment as needed. It could likewise be clarified that the site managers opt for horizontal trolley jibs since they give adaptability and support the lifting of weighty loads. The discoveries implied that the mission to accomplish higher tower crane utilisation rates has prompted the common use of double tower cranes on construction sites. The utilisation of two-story tower cranes is related to fewer on-site problems and deferrals.

It arose out of the discovery that site constraints are the main criterion influencing tower crane location. The emphasis on cost and safety as criteria in tower crane location is predominant in the literature (Huang et al., 2019; Al Hattab et al., 2017). The discoveries of this study uncovered that there are more significant contemplations in tower crane locations. The main criterion was viewed as site constraints. This finding conflicts with the convention and focal point of location optimization studies. Those examinations have stressed safety. The results of this current study propose that the focus of location optimization ought to be site constraint. This is on the grounds that tower crane safety will be dictated by the accessible space on site. At the point when the site constraints have been calculated into the tower crane location, the safety issue would have been provided for. Scarcely any researchers have glanced at site constraints as the significant standard to be considered in tower crane location.

Discoveries on the techniques guiding the location of tower cranes on construction sites revealed that the main advance is dissecting the working spaces required for the tower crane. These further stresses the significance of site constraints as the main basis for tower crane location. Site constraints are usually considered in the tower crane working space analysis.

5.1 Practical implications

The discoveries of this study have wide-reaching implications for site management training and skill development, tower crane assignment schedules, and planning of double tower cranes. To start with, there is a requirement for a code of practise on directing the utilisation and planning of tower cranes on Nigerian construction sites. The code will support consistency and ethics in the utilisation of tower cranes. It will help site managers deal with planning dilemmas related to tower crane location and selection. It will likewise serve as a significant reference for upgrading safety and optimising the tower crane assignment schedule. The code ought to broadly dissect the tower crane selection and location criteria and procedures. The usage of tower cranes in accordance with its setups should likewise be stressed in the code.

Second, training on the effective utilisation of tower cranes ought to be part of the site management training for the experts. It is appropriate for site managers to comprehend that a tower crane is a more reasonable method for addressing the lifting needs of any construction project. Meeting the lifting needs should be done effectively and economically. For instance, focusing on the utilisation of tower cranes for tall building construction and focusing on the utilisation of tower cranes for lifting heavy loads. With the information on the proficient utilisation of tower cranes, site managers will actually be able to achieve a quicker speed of construction, manpower reduction, reduced concrete wastage, and timely completion of projects.

As far as site management and site layout skills are concerned, site managers will find this study helpful in knowing how to choose tower cranes during the design and construction phases of a project. Their insightful abilities will be improved to cover the utility of the selected tower cranes. They will actually want to decide if the tower crane can meet the construction programme in terms of capacity and production rates. The effect of the selected tower cranes on the structural and architectural design, and lastly, the expense of operating the selected tower cranes. Third, the productive utilisation of tower cranes may once in a while require the utilisation of double tower cranes. Subsequently, site managers ought to not exclusively know about this reality but ought to look into the framework and related to the utilisation of double tower cranes. An illustration of such a precautionary measure is the overlapping work zones that result from the utilisation of double tower cranes.

5.2 Limitations and future studies

The study is restricted as far as setting and strategy. Relevantly, the discoveries in this study might be summed up as the Nigerian construction sector dependent on the significance of Lagos state to the country. Be that as it may, the discoveries are restricted to Nigeria and ought to be stretched out warily to different climes. Methodically, predispositions related to the quantitative examination might influence the dependability of the discoveries made by this exploration. Future investigations are urged to use a mixed method case study to develop this exploration. It would likewise be intriguing if future examinations would research and foster a balanced workload schedule for double tower cranes. Factors affecting tower crane relocation as well as evacuation strategies and issues related to the expulsion of tower cranes are significant regions that should be considered in later examinations.

6. CONCLUSION

Beyond tower crane location optimization, this study has set up that the effective utilisation of tower cranes begins with tower crane load and location contemplation. Basically, precast materials like blocks, bricks, precast façade, and concrete are to be considered as loads to be lifted with tower cranes. Other significant materials, like HVAC installations and formworks, ought to be lifted with tower cranes. Considerations for locating tower cranes should adhere strictly to tower crane setups, load type, and load quantity. Be that as it may, the principal standard to be considered is the site limitations. Without this thought, the tower crane location will become risky. As the functioning spaces are needed for the tower crane, the creation of a tower crane safety zone and determination of the tower crane coverage area will be hard to accomplish.

This study has additionally established that between tower crane load and location contemplations, selection parameters, configurations, and combinations of tower cranes should be focused on. Building height, operators' cost, cost of support system, soil condition, breakdown cycle and repair time are parameters that must be thought of while choosing tower cranes for a project. The significance of tower crane setups has not been linked, despite the fact that the safe and optimal utilisation of the tower crane is dependent on its design. In light of the discoveries made in this study, it is additionally reasoned that a double tower crane ought to be thought of while making arrangements for the effective utilisation of tower cranes.

This study has added to knowledge by introducing the techniques guiding the location of tower cranes on construction sites. The study found site constraints as the significant concentration in tower crane locations. This gives a more profound understanding of tower crane location and clarifies why safety and cost ought not to be the focal point of tower crane location optimization. Moreover, this study has featured the various kinds of loads and projects for which tower cranes ought to be considered. Knowledge of tower crane choice boundaries has been significantly enhanced by this study.

REFERENCES

Abdelmegid, M. A., Shawki, K. M., and Abdel-Khalek, H. (2015). GA optimization model for solving tower crane location problem in construction sites. Alexandria Engineering Journal, 54(3), 519-526.

Abdi, H. (2007). Z-scores. Encyclopedia of measurement and statistics, 3, 1055-1058.

Al Hattab, M., Zankoul, E., and Hamzeh, F. (2014). Optimizing joint operation of two tower cranes through look-ahead planning and process simulation. In Proceedings 22nd Annual Conference of the International Group for Lean Construction.

Al Hattab, M., Zankoul, E., and Hamzeh, F. R. (2017). Near-real-time optimization of overlapping tower crane operations: a model and case study. Journal of Computing in Civil Engineering, 31(4), 05017001.

Bamfo-Agyei, E., and Atepor, L. (2017, July). Assessing the Safety Use of Tower Cranes on Construction Sites in Central Region of Ghana. In International Conference on Applied Human Factors and Ergonomics (pp. 486-496). Springer, Cham.

Briskorn, D., and Dienstknecht, M. (2019). Mixed-integer programming models for tower crane selection and positioning with respect to mutual interference. European Journal of Operational Research, 273(1), 160-174.

Danel, T.; Lafhaj, Z.; Puppala, A.; Lienard, S.; Richard, P. Proposal for Tower Crane Productivity Indicators Based on Data Analysis in the Era of Construction 4.0. Buildings 2021, 11, 21. https://doi.org/10.3390/buildings11010021

Dasović, B., and Klanšek, U. (2021, December). Comparison of spreadsheet-based optimization tools applied to construction site layout problem. In IOP Conference Series: Materials Science and Engineering (Vol. 1209, No. 1, p. 012010). IOP Publishing.

Dasović, B., Galić, M., and Klanšek, U. (2019). Active BIM approach to optimize work facilities and tower crane locations on construction sites with repetitive operations. Buildings, 9(1), 21.

Dasović, B., Galić, M., and Klanšek, U. (2020). A survey on integration of optimization and project management tools for sustainable construction scheduling. Sustainability, 12(8), 3405.

Fasih, S. M., Mohamed, Z., Husain, A. R., Ramli, L., Abdullahi, A. M., and Anjum, W. (2020). Payload swing control of a tower crane using a neural network–based input shaper. Measurement and Control, 53(7-8), 1171-1182.

Huang, C., Li, R., Fu, Y., and Ireland, V. (2019). Optimal Selection and Location of Tower Crane for the Construction of Prefabricated Buildings with Different Prefabrication Ratios. Journal of Engineering Science and Technology Review, 12(6).

Hyun, H., Park, M., Lee, D., and Lee, J. (2021). Tower crane location optimization for heavy unit lifting in high-rise modular construction. Buildings, 11(3), 121.

Jeong, K., Yun, K., and Lee, D. (2021). Study on Automatic Arrangement Algorithm for Tower Cranes with Applying Lifting Limit Axis. Turkish Journal of Computer and Mathematics Education, 12(6), 418 - 412
Jia, J., and Wan, Y. (2016, March). Light-weight design of tower crane boom structure based on multi-objective optimization. In International Conference on Mechanical Science and Engineering. Qingdao: Atlantis Press (pp. 1-6).
Jiang, L., Zhao, T., Zhang, W., and Hu, J. (2021). System hazard analysis of tower crane in different phases on construction site. Advances in civil engineering, 2021.
Jiang, T. (2020, July). Safety risk analysis and control of tower crane. In IOP Conference Series: Earth and Environmental Science (Vol. 546, No. 4, p. 042070). IOP Publishing.
Kaveh, A., and Vazirinia, Y. (2018). Optimization of tower crane location and material quantity between supply and demand points: A comparative study. Periodica Polytechnica Civil Engineering, 62(3), 732-745.
Kaveh, A., and Vazirinia, Y. (2020). An upgraded sine cosine algorithm for tower crane selection and layout problem. Periodica Polytechnica Civil Engineering, 64(2), 325-343.
Kim, J. Y., and Kim, G. H. (2020). Importance Ranking of Accident Factors of Construction Tower Crane by AHP Technique. Journal of Building Construction and Planning Research, 8(4), 237-244.
Li, R., Fu, Y., Liu, G., Mao, C., and Xu, P. (2018). An algorithm for optimizing the location of attached tower crane and material supply point with BIM. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction (Vol. 35, pp. 1-8). IAARC Publications.
Lingard, H., Cooke, T., Zelic, G., and Harley, J. (2021). A qualitative analysis of crane safety incident causation in the Australian construction industry. Safety Science, 133, 105028.
Marzouk, M., and Abubakr, A. (2016). Decision support for tower crane selection with building information models and genetic algorithms. Automation in Construction, 61, 1-15.
Moussavi Nadoushani, Z. S., Hammad, A. W., and Akbarnezhad, A. (2018). Closure to "Location Optimization of Tower Crane and Allocation of Material Supply Points in a Construction Site Considering Operating and Rental Costs. Journal of Construction Engineering and Management, 144(11), 07018002.
Nayal, D., Paul, V. K, and Kumar, K. (2020). Selection of Tower Crane using Multi-Criteria Decision-Making Techniques. International Journal of Engineering Research and Technology (IJERT), 9(5), 31 – 35.
Sadeghi, S., Soltanmohammadlou, N., and Rahnamayiezekavat, P. (2021). A systematic review of scholarly works addressing crane safety requirements. Safety Science, 133, 105002.
Shapira, A., and Ben-David, A. (2017). Characteristics of equipment planning for multi-crane building construction sites. Buildings, 7(3), 81.
Shin, I. J. (2015). Factors that affect safety of tower crane installation/dismantling in construction industry. Safety science, 72, 379-390.
Trevino, C., and Abdel-Raheem, M. A (2017). Modified ant colony optimization method for solving the single tower crane allocation problem.
Wang, R. D., Zayed, T., Wei. P., Zheng, S., and Tariq, S. (2021). A system boundary-based critical review on crane selection in building construction. Automation in Construction, 123 (2021) 103520
Wu, K., and Garcia de Soto, B. (2020). Spatiotemporal Modeling of Lifting Task Scheduling for Tower Cranes with a Tabu Search and 4-D Simulation. Frontiers in Built Environment, 6, 79.
Yao, G., Li, H., Yang, Y., and Pu, W. (2019). Seismic responses and dynamic characteristics of boom tower crane basing on measured strong earthquake excitation. Journal of Vibroengineering, 21(1), 154-169.
Yao, G., Xu, C., Yang, Y., Wang, M., Zhang, M., and Thabeet, A. (2018). Working Mechanism of a High-performance Tower Crane Attached to Wall Joints. Journal of Engineering Science and Technology Review, 11(1).
Zhou, W., Zhao, T., Liu, W., and Tang, J. (2018). Tower crane safety on construction sites: A complex sociotechnical system perspective. Safety science, 109, 95-108.