CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Optimum Selection of Communication Tower Structures Based on Wind Loads & lifecycle cost analysis

Yasmin Elhakim¹,²*, Tawfik Ismail³,⁴ and Irene Fahim¹

Abstract: Communication towers are vital assets in our daily lives as they transfer signals between cell phones facilitating communication and commerce among people and businesses all around the world. Wind loads are crucial in the communication towers design since they are tall and slender. With climate change bringing more storms and higher wind speeds, it is more crucial to research the finest tower structure that withstands such conditions with the least life cycle cost. Therefore, in this paper, a comparative case study is performed between 45 m height lattice tower and monopole tower in Egypt. Two locations were considered, the first is inside the city and the second is an open terrain. In addition, two load scenarios were investigated. The comparison parameters are the behavior under critical wind loads taking into account three wind speeds which are 100 km/hr, 130 km/hr and 140 km/hr, and life cycle cost analysis. It was found that the lattice tower behaves...
better under critical wind loads with a maximum tilting equal to 0.4784 degrees at location 1, load 2, and a wind speed of 140 km/hr compared to 0.5806 in the case of the monopole tower. Similarly, the lattice tower behaves better at the second location as well. However, the monopole tower has less life cycle cost with a total life cycle cost of 3,201,846.80 EGP compared to 4,380,419.91 EGP in case of lattice tower. Therefore, based on the location, wind speed, and available land area, and life cycle cost assessment, the optimum tower structure could be selected.

Subjects: Engineering project management; Structural engineering; telecommunications; engineering economics; building services engineering

Keywords: communication towers; lattice tower; monopole tower; life cycle cost analysis; hazard repair cost; structural analysis

1. Background

1.1. Introduction
With the rapid advancement in communications worldwide, the selection of signal-transmitting towers has become critical. These towers have to be chosen such that they perform their intended functions in the most cost-effective manner possible. Antennas and microwaves are carried by these towers to send and receive telecommunications and information waves (Sudjianto et al., 2021). Communication towers are becoming taller and lighter to satisfy social demands; therefore, they are more sensitive to wind loads. Wind load is considered the most crucial natural disaster that may affect communication towers because it happens frequently and influences wide areas. (Tian et al., 2020). These towers can be built in a variety of structures, the most common of which are lattice self-supporting, monopole, and guyed towers. The lattice self-supporting tower is a truss-like structure that can be 4-legged or 3-legged that is only supported at the foundations. The guyed tower is supported by cables at different heights that are anchored to the ground. The monopole tower consists of one pillar that is supported on the ground. The most suitable tower structure is determined by the location, the available land area, and the maximum structure height. As a result of government rules, there are often height restrictions in particular areas. Furthermore, land can be expensive, particularly in urban areas, and therefore, the selection of the towers should consider all these factors (Sudjianto et al., 2021).

Lattice communication towers are often utilized for heights of 50 meters, and they are easy to erect. Guyed towers, on the other hand, are best for towers that are higher than 50 meters and are located in open locations to allow for wire installation. The monopole tower takes up the least amount of space and can be reduced in height to 20 or 30 meters; nevertheless, it requires specific handling and construction and is relatively expensive (Majeed et al., 2017). Therefore, the cost is a crucial parameter, besides behavior under wind loads, when selecting the optimum tower structure for a specific site. However, that cost should include not only the initial cost but also the life cycle cost.

Life cycle cost is “the sum of all expenses associated with a product or a project, including acquisition, installation, operation, maintenance, refurbishment, discarding and disposal cost” Australian/New Zealand Standard 1999 as cited in Kara (2014). Acquisition cost includes costs for land purchase, material procurement, and construction costs. The remaining costs are classified as “ownership costs” which include costs related to future costs after the facility is constructed such as operating, maintenance, and disposal costs. Deciding between several alternatives based on life cycle cost early in the design stage could result in expenses savings and revenue increase during the facility’s usage and end life. The basic steps to perform life cycle cost analysis are to do cost breakdown structure and present value cost estimating, discounting and inflation. The cost breakdown structure is used to identify all the cost elements in the project to avoid any cost
omissions or double counting. Present value cost estimating is used to be able to compare different alternatives that include future costs (Kara, 2014). According to Gregory, J and CShub research team, 2017, a new parameter should be added to the life cycle cost factors in buildings, which is hazard repair cost. This parameter would add the environmental benefits of resilient construction to the selection criteria between alternatives. The hazard repair cost will give an overview of a structural response to hazard occurrence or “its resilience”, as it combines the probability that a hazard will take place with the damage associated with that hazard for different alternatives. Therefore, this parameter is a crucial one in selecting the optimum tower structure that could sustain wind loads with the best performance and least repair cost. Considering this parameter would be fundamental to long-term building sustainability, as the impacts that the construction industry imposes on society, environment, development, and economy are the main pillars of sustainable buildings. In addition, the evident change in climate leading to an increase in temperatures would make natural disasters more frequent and less predictable. It was found that if the wind speed increased from 40 m/s to 45 m/s, the damage incidents would escalate by a factor of five (Spence et al., 1998 as cited in Yau & Hasbi, 2012). In addition, if the wind speeds increased by 6% in England, for example, that would lead to a cost of repair of about £1-2 billion in buildings (Graves & Philipson, 2000 as cited in Yau & Hasbi, 2012). Therefore, the hazard repair cost becomes critical to be assessed (Sang-Guk et al., 2020).

There are around 22,666 communication towers in Egypt. Vodafone Company owns the largest number of communication towers in Egypt with a total of 8500 towers. Then comes Orange with a total of 6166, after that, Etisalat with a total of 6000 towers and finally telecom Egypt owns 2000 towers. Two third of communication towers in Egypt are ground-based towers, while one-third are rooftop ones. 90% of the sites in Cairo are rooftops (Khera, 2020). In 2021, Egypt represented by the communication authority signed an agreement with IHS towers to construct and lease telecom towers in an initiative to enhance the services and reduce the burden of constructing and operating the asset among the providers. However, the communication providers still have the right to build their own towers if they choose to do so (Masrawy, 2021).

Therefore, in this paper, a comparison is done between lattice self-supporting towers and monopole towers in terms of their behavior under wind loads and their life cycle cost analysis. Accordingly, two case studies of 45 m tower height for both towers are selected in Egypt. Different loading conditions, wind speeds and locations will be used to judge performance under wind loads. Then, the life cycle cost analysis is performed to judge which is the lowest option without jeopardizing quality and function.

1.2. Communication towers
Several aspects of communication towers were investigated in previous searches. Sharma et al. (2015) did a comparison between different tower heights with different bracing systems under wind and seismic loads for different zones in India. STAAD Pro is used for the analysis. They concluded that the displacement increase between different wind zones is minimum for the K bracing type and maximum for the W bracing type. In addition, there is an increase in stresses with the increase in wind speed, it reaches its maximum for k bracing and minimum for XX bracing. For the seismic loads, they concluded that the displacement increase is maximum for W bracing and minimum for K bracing. They also found that the V bracing towers were having the maximum weights, while K bracing towers had the minimum weights for the same height. They concluded that wind is the dominant load in the tower analysis more than seismic forces; however, seismic should be studied as well.

Raju et al. (2017) did a study to compare different bracing systems for a 4-legged 24 m high communication tower under 6 different wind speeds for different zones in India. They used STAAD Pro for the analysis, and they concluded that angular cross-section with K bracings was the most effective and economical choice among the other options.
Al-jassani Azhar et al. (2018) performed a general comparison between lattice towers and monopole towers 36 m high in Budapest city (Hungary) where they found that in general, the monopole is better in terms of the aesthetic side, while the lattice tower is better regarding cost and statistical limit. Then, they compared 3-legged and 4-legged lattice towers—having different member cross-sections where CHS members are used in the 3-legged tower, while angle members are used in the 4-legged tower—in terms of their behavior to wind loads and buckling capacity. They concluded that the 3-legged lattice tower with CHS members is better as they require less material and foundations, yet they are still strong and can sustain equal loads to the 4-legged tower. In addition, 3-legged towers with CHS sections have aerodynamic effects and have no weak axis for buckling dissimilar to angle cross-sections. Therefore, a 3-legged tower is preferred.

According to Gao et al. (2018), failure of monopole towers or guyed mostly usually happens because of guys rupture or overall turning. However, for the case of the lattice tower, a progressive collapse analysis under design and accidental loads should be carried out, as it is more complicated to determine the causes of failure. In their study, they conducted progressive collapse analysis for latticed communication towers under wind loads with different wind directions. This analysis was conducted on two different configurations of 50 m latticed towers, namely, standard tripod tower and standard angle tower (as defined by the Chinese government standard drawing collection of a telecommunication steel tower, DCTST 2014) using ABAQUS software. According to their findings, in order to minimize the telecommunication towers and collapse probability due to wind loads, first unfavorable wind direction should be avoided through proper design. Second, critical leg member that tend to trigger collapse should be protected. Third, anti-collapse design should be done using an alternative load path or bridge-over method to protect the tower against collapse.

According to Tian et al. (2020), communication towers are becoming taller and lighter to satisfy social demands; therefore, they are more sensitive to wind loads. Wind load is considered the most crucial natural disaster that may affect communication towers because they are more frequent and influence wider areas. Although communication tower designs consider wind loads, numerous collapse incidents of the towers are due to wind disasters. They investigated the collapse analysis of a lattice communication tower with a height of 53 m and a lightning rod of 7 m subjected to wind loads. The Finite element model was built using ABAQUS software. They used the Tian-Mo-Qu material model to study the wind-induced response considering member buckling. Incremental dynamic analysis is used to simulate the tower collapse with different wind attack angles. In addition, collapse fragility analysis was performed to account for the randomness and fluctuations of wind loads and their impact. From their study, the main reason for the collapse was the buckling of main members, leading to progressive collapse due to wind loads.

1.3. Transmission towers
Because transmission towers have similar structures as communication towers, such as monopole steel tubes and latticed steel towers, the research done in this track was also studied to reveal the themes searched in this sector. Most of the search done in this area is to analyze the performance of transmission towers under different structure alternatives. Syamsir et al. (2022) analyzed the performance of full assembly glass fiber-reinforced polymer composite cross arm in transmission towers. They concluded that the GFRP composites were capable of withstanding loads of five to three times the working load of normal and broken wire conditions. Amir et al. (2020) proposed a composite filled sandwich structure for the existing cross arms in transmission towers, which are susceptible to environmental factors that affect their performance. Asyraf et al. (2020) investigated the development of a creep test rig design for a cross-arm structure and mechanical simulation of the product. They used four different bracing configurations for the analysis. They concluded that the hybrid-bracing configuration improved the mechanical and safety properties of the baseline model. Jeromin et al. (2009) investigated the life cycle cost analysis of transmission and distribution systems. They performed a life cycle analysis for a 110 kV overhead transmission grid with air-insulated substations. They highlighted the primary cost-driving elements of the system. Accordingly, they investigated the different maintenance strategies and
compared different network topologies and equipment types. They emphasized the importance of life cycle assessment in deciding on appropriate actions to reduce costs and maintain the assets.

1.4. Life cycle assessment
Based on a study done by Stanford University (2005), the present value of the maintenance and operation cost could be nearly as great as the initial cost, therefore, taking into consideration maintenance and operating costs when designing new buildings could lead to significant savings. Accordingly, the objective of life cycle cost analysis is to determine the cost-effective options for the building to be efficient during its lifetime. The suitable time to perform this analysis is during schematic design and design development when the project team would compare different building system options and their costs to choose the optimum design. According to Fuller 2016, the simplest and easiest-to-understand measure of economic evaluation is the lowest life-cycle cost (LCC), which helps in determining the lowest overall ownership cost that does not jeopardize quality and function.

Y Sang-Guk et al. (2020) studied the relationship between maintenance cost and natural hazards based on 11 years of data from 2007 to 2017 of international chain hotel claim payouts to study the relationship between the maintenance costs and damage and the intensity of natural disasters. They proposed an assessment method for life cycle cost that includes not only expected costs related to maintenance and operation but also exceptional ones related to natural hazards.

1.5. Research objectives
From the literature reviewed, various studies have been conducted to analyze different parameters in the lattice tower; however, there is limited research that compares the lattice and monopole towers in detail. In addition, up to the researcher's knowledge, no research considered the life cycle cost analysis for communication towers or the hazard repair cost for judging the optimal tower selection. Therefore, this paper aims to compare the behavior of lattice and monopole towers under wind loads with different loading conditions and different geographical zones and to investigate the differences in life cycle cost and hazard repair cost. Subsequently, the following are the upcoming sections of this paper: Section 2: Case Study where behavior under wind loads and life cycle cost assessment are studied in detail, Section 3: Analysis and comparative analysis where the results obtained from the case study are analyzed and compared, and Section 4: Conclusions where the main conclusions of this search are explained.

2. Case study
A self-supporting lattice tower and a Monopole tower, both having a height of 45 meters, are compared in this research. This research is being carried out to gain a comprehensive understanding of the conditions under which each type of tower is best suited. Figure Figure 1 summarizes this search methodology. The behavior of a self-supporting lattice tower and a monopole tower is compared in terms of behavior under wind loads and life cycle cost in two different locations. As a result, the most appropriate structural type is selected based on the same criteria.

2.1. Behavior under wind loads
In order to judge the performance of lattice telecommunication towers and monopole towers under wind loads, a case study for each tower is considered. Then, the performance is judged according to the maximum deflection and tilting.

Lattice communication tower: A case study of a lattice telecom tower with a height of 45 m is studied under 2 different wind loads. The tower is a 4-legged tower with equal angle steel sections with different sizes for the legs and diagonals of the tower. The tower base face width is 4.5 m, and the uppermost width is 1.25 m. The tower is divided into sections with heights of 5 meters. Bracing types change from one section to another to best withstand wind loads. The first two sections have a bracing type of double K1, the following four sections have a double K type bracing and the last
three sections have an X brace type. The tower leg material is Steel 52, and the diagonals and bracing material is Steel 37. Connections used galvanized A325 bolts, nuts, and locking devices.

Monopole: A case study of a monopole tower with a height of 45 m is studied under the same wind loads. The tower is a tapered pole with a diameter of 1259 mm at the bottom of the tower and 650 mm at the uppermost of the tower. The pole grade is Steel 37. Connections use galvanized A325 bolts, nuts, and locking devices. Tower members are hot-dipped galvanized following ASTM A123 and ASTM A153 Standards.

Figure C2 and C3 show the geometric properties of the lattice and monopole towers.

In order to analyze the behavior of the two towers under wind loads, the (Ansi-tia-222-G, 2005) code, which is the structural standard for antenna supporting structures and antennas, is selected for the analysis. This is a well-established communication tower code that is widely recognized by professionals both locally and internationally. Then, two design wind speeds are selected based on two different locations in Egypt according to the defined speeds in the Egyptian code.

(a) Location 1: inside the city, representing Exposure category B, which resembles “closely spaced obstructions having the size of a single-family dwelling or larger and surrounds the structure in all direction” (Ansi-tia-222-G, 2005). Design wind speed = 100, 130 &140 Km/hr are considered

(b) Location 2: representing Exposure category C, which resembles “open terrain with scattered obstructions. This includes flat, open country, grasslands, and shorelines in hurricane-prone regions” (Ansi-tia-222-G, 2005). Design wind speed = 100, 130 &140 Km/hr are considered

For each location, two loading conditions are studied, which are

(a) Load 1: 6 antennas, 2 microwaves, 5 RRU/antenna
(b) Load 2: 6 antennas, 4 microwaves, 5 RRU/antenna

The analysis is performed using TNX tower software, which is a software package that is designed for the analysis of communication towers and allows the user to select the code governing the analysis and design to automatically generate the loads accordingly.

2.2. Life cycle cost assessment
In order to analyze the life cycle cost assessment for the towers in consideration, the following parameters are considered:

**Initial Cost:** this includes the initial cost of constructing the telecom tower including the material, labor, and equipment costs representing the direct cost of the project. The indirect cost includes costs incurred indirectly to the project such as head office expenses. Total cost would be the sum of the direct and indirect costs.

(a) Material cost represents the cost of steel used in the tower and bolts for the tower structure, in addition to the concrete cost for the foundations. Plates used in monopole towers are more expensive and need precise quality control. On the contrary, angle sections in lattice towers are easy to fabricate and have a quick factory setup. The galvanization needed for monopole sections is usually more difficult than that of lattice tower angle sections (Fabrimet, 2022)

(b) Labor cost includes supervising engineers for the project and skilled and unskilled labor.

(c) Equipment cost includes equipment used for transporting the material from the producing company to the location site, in addition to the cost of equipment used in the installation. For
angle sections of lattice towers, they are usually easier to be transported. Lattice tower angle sections are less in size and weight than monopole tower tubular sections (Fabrimet, 2022)

**Operating Cost:** This represents the lifetime cost that is used to operate communication towers. This includes utilities and fuel, insurance, property management, ground leases and property taxes. According to Vertical consultants (2022), property management and property taxes represent 35% and 25%, respectively, which are the largest percentages of operating costs. Then, ground lease percentages could reach 20%. After that, utilities and fuel represent 15%. Finally, insurance represents 5%. These percentages may have a slight variance according to the location and countries’ laws.

Therefore, property management represents the highest percentage of towers’ operating costs. Property management includes activities related to managing the property after its construction. These activities include day-to-day operations including any repairs or maintenance required, property security, maintaining the site landscape, and removal of any accumulated snow (Investopedia, 2021).

Security cost: This includes ensuring the safety of the site and the asset itself against any act of vandalism or theft. As many of the towers are located in remote areas, they are prime targets for such vandalism acts. The main targets for theft are usually copper wires and batteries. Such acts not only charge the tower owners the cost of replacing the stolen properties but also the cost of interrupted service. There are several copper sources in the communication towers such as “ground wires, copper grounding bus bars, and waveguides”. As for battery theft, it is stated by Northstar battery that around 20% of failures in batteries in the tower industry are attributed to theft or vandalism. Diesel fuel is another asset that faces the theft risk in the communication towers industry. Around the globe, diesel theft is as high as 30%. Administrative diesel theft can reach up to 50% of such thefts. The staff or the contractors responsible for the supplies of diesel on tower sites are held liable for such thefts committed through fraud. This might happen if the trucks are not properly filled at the gas station or if some of the diesel fuel is replaced with another liquid to match the needed quantity in the bills, which could harm the generator if the fuel is mixed with water (Asentria Corporation, 2019).

Land Rental: This depends on several factors, which are location, land elevation, distance to adjacent towers, the density of population in the proposed location, and zoning, if sublease is included. Therefore, according to the location prices and whether there are already multiple towers in a certain location, the rental price for the tower will be affected. In addition, if the site is already elevated, this location will be preferred as the tower performance will be more efficient. Communication towers should not be adjacent to each other, and therefore, this should be considered while selecting the location. If the tower will be subleased, the original owner may ask for a percentage that ranges from 10 to 30 % of such an arrangement (Macerick, 2021). In the US, the average annual leasing cost for cell towers is around $ 45,000 and the lowest leasing cost could reach $ 100. This cost range depends on the aforementioned factors in addition to network needs and the construction limitations of the site (Vertical consultants, 2022).

For the same load applied, the monopole tower has a base width of 1.53 m, while the lattice tower has a base width of 4.5 m. Therefore, the area needed for a lattice tower will be larger than the area needed for a monopole tower. Therefore, the lattice tower will cost higher related to lease prices (Vertical consultants, 2022).

Energy costs: This could reach up to around 25% of total operating costs in communication towers. Typically, towers demand electrical power that ranges from 1 kW to 8.5 kW. Therefore, to ensure the availability of more than 99.95% of the required power, the electrical grid is backed up with a combination of batteries and a diesel generator. In India, the telecom tower industry is considered the second-largest diesel consumer in the country as it consumes over 2.5 liters of
diesel every year. In addition to the expensive costs of such consumption, it hurts the environment as it causes the emission of 6.6 million metric tons of CO2 annually (Telecomlead, 2012).

3. Maintenance cost
According to the (ANSI-Tia-222 G code, 2005), the maintenance maximum intervals for self-supporting towers should be five-year intervals. Also, maintenance should be performed after severe weather conditions or severe wind or ice storms. However, a shorter inspection interval should be done for towers in coastal regions, for class III structures, for towers located in corrosive environments, and in areas subjected to high risk of theft and vandalism.

**Hazard repair cost**: The probability and impact of a certain natural hazard is studied, and its projected costs associated with needed repairs are estimated. The wind hazard is the hazard in consideration in this research because it is critical for tower performance (Gregory, and CSHubMIT, 2017). The information related to the probability of hazard occurrence and its severity impact is not available in Egypt. However, overall performance and hazard could be detected based on the behavior under wind loads in addition to the wind atlas maps. In a study made in Egypt by Mortensen et al. (2006) in a collaboration between a new and renewable energy authority in Egypt and Riso National Laboratory in Denmark, results based on a thorough view of an 8-year assessment program for wind resources in Egypt are presented. They aimed to have reliable and accurate wind data in order to evaluate the potential of generating electricity through wind turbine installations. This database can be utilized with elevation maps generated from the space shuttle topography mission to estimate wind resources simply. From this database, it was captured that there are high wind resources in the Gulf area of Suez and Aqaba, in addition to the Western Desert. The result of this study is published as a wind atlas for Egypt (Mortensen et al., 2006). From these data, locations, where wind speed is highest, would be considered the critical places to install communication towers. According to the data obtained and the land topography in Egypt, areas located at the Red sea beaches, specifically Ras Gahreb, Nuweiba, and Gulf of Suez, are considered places with the highest mean wind speed (Mortensen et al., 2006). Special considerations should be adopted while constructing these areas. At these locations, the severity of the hazard will be maximum because of combined parameters, which are high wind speed, open terrain, and places adjacent to the sea.

4. Analysis and comparative study

4.1. Analysis under wind loads
TNX tower software is used for the analysis. Wind loads are considered every 45 degrees. The analysis is done based on different locations, wind speeds, and loads as illustrated in the methodology.

Table A1 in appendix (a) summarizes the data obtained from the analysis of both towers.

The envelope of maximum deflections vs tower height in the highest wind speed of 140 km/hr and the lowest wind speed of 100 km/hr is highlighted in Figure 4(44–4) where

(a) Figure 4(a) presents deflection at location 1, wind speed 140 km/hr, load 1
(b) Figure 4(b) presents deflection at location 1, wind speed 140 km/hr, load 2
(c) Figure 4(c) present deflection at location 2, wind speed 100 km/hr, load 1
(d) Figure 4(d) presents deflection at location 2, wind speed 100 km/hr, load 2

From the data obtained, it is observed that the deflection in the case of monopole tower is higher than the lattice tower by 17.2% to 18.5% based on wind speeds. Therefore, it is evident that the lattice tower behaves better at higher wind speeds than the monopole towers as also concluded by (Kumar et al., 2017). The higher the load applied to the tower, the more the deflection, similarly,
the higher the wind speed, the higher the deflection. In addition, when the monopole is located in open terrain (location 2) with higher loads, the tilting exceeds the allowable 0.5 degrees determined by the (Ansi-Tia-222 G, 2005) standard. Therefore, the tower design should be revised. However, in the lattice tower, it can sustain the wind in open areas with a minor deviation from 0.5 degrees defined by the standard. Accordingly, it is recommended to use the monopole tower inside cities where the wind is not as critical as in open terrains and to use the lattice tower when wind speeds are expected to be high and in open terrains.

4.2. Life cycle cost analysis
For the towers in consideration, the monopole tower weight is 9.51 ton of steel, while the lattice tower is 4.68 ton of steel. The steel used for the monopole tower is Steel 37, while the steel used in lattice legs is Steel 52. Steel prices in Egypt range from 1000 to 1200 $/ton. The footprint area for the lattice tower is higher than that of the monopole tower as the base width of the lattice tower is 4.5 m, while in the monopole tower is 1.259 m as also stated by Ali et al. (2018). Energy costs are assumed to be the same as both towers are having the same numbers and specifications of appurtenances. Based on this information, in addition to an interest rate of 10% and a lifetime of 30 years, the following findings are obtained.

Table B1 in appendix (b) illustrates the main costs incurred in both towers in Egyptian pounds based on data obtained from experts in the industry. Table B2 in appendix (b) shows the total present value for all costs for the monopole and lattice tower on flat terrain. Table B3 in appendix (b) illustrates the main costs incurred in both towers in Egyptian pounds based on data obtained from experts in the industry. Table B4 in appendix (b) shows the total present value for all costs for the monopole and lattice tower at a crest (an elevated terrain).

As for the hazard repair cost, Mahfouz et al. (2020) observed an increasing trend in the mean annual wind speed at a rate of 0.12 kt/year, which is approximately equivalent to 0.22224 m/s yearly while analyzing meteorological conditions over the western harbor of Alexandria. Not only in Egypt but also in the US, it was found that in less than a decade, the wind speed global average has increased by 0.4 mph, which is approximately equivalent to 0.178816 m/s (Harvey, 2019). Therefore, there is an increase in wind speeds in various places around the globe. Such an increase may cause hazards especially if the structure designs did not account for that. It was observed that if the wind speed increased from 40 m/s to 45 m/s, the damage incidents would escalate by a factor of five (Spence et al., 1998 as cited in Yau & Hasbi, 2012). Therefore, taking into consideration the case of Egypt and the lifetime of the communication tower as 30 years, if the wind speed increases by 0.22224 m/s per year, the increase in wind speed by the end of 30 years will be approximately 6.7 m/s.

Therefore, if the wind speed increased by 6.7 m/s at the end of the 30 years than the design speed, the repair cost would represent not only the tower repair cost itself but also the surrounding buildings that may be affected by the damage that happened in the tower. These damages could result from the failure of some members of the tower or the total collapse of the tower itself.

Table B5 and Table B6 in appendix (b) show the hazard repair costs for the lattice tower and the monopole tower in general topography and at a crest.

4.3. Major findings
Although the lattice tower had less initial cost based on material, transportation and installation costs as also stated by Al-jassani Azhar et al. (2022), it has a higher life cycle cost when all operating and maintenance costs are considered as well. These calculations emphasize the importance of performing a life cycle cost analysis at the beginning of the project to better assess the optimum option for the project in consideration. If the towers are located at a crest, the overall costs would be higher to account for higher wind actions, higher transportation costs, and higher maintenance and operation.
As already proved, the lattice tower behaves better in wind than the monopole tower. Therefore, in the case of hazardous wind, the impact and cost of repair would be more severe in the case of the monopole tower.

Accordingly, if the tower is to be placed in a location where the wind is expected to be critical with high speeds, then a lattice tower is recommended for use as also recommended by (Kumar et al. (2017)). However, inside cities, it is recommended to use a monopole tower as its life cycle cost is less than that of the lattice tower and the wind is less critical than that in open terrain.

5. Conclusions
Communication towers are strategic assets that transfer signals between cell phones making communications easier and faster. Consequently, selecting the optimum structure type that withstands the surrounding environment with the optimum cost is a crucial task. Most of the literature review focused on structural aspects of the towers without examining the life cycle assessment and hazard repair cost; consequently, this is the novelty of this paper. Therefore, in this paper, a case study of lattice tower and monopole towers was investigated in Egypt. Their behavior under wind speeds is studied and their life cycle cost analysis. From the findings, it was found that lattice tower behaves better under high wind speeds with less deflection and tilting to 0.4784 degrees at location 1, load 2, and wind speed 140 km/hr compared to a maximum tilting of monopole tower equal to 0.5806 at the same location. Taking into account the life cycle cost analysis, the monopole tower is cheaper although it has a high initial cost. The monopole tower life cycle cost is 3,201,846.8 EGP compared to 4,380,419.9 EGP for the lattice tower. This is due to its smaller footprint; therefore, fewer rental rates and less security are needed to guard the site. Therefore, it is recommended to use a monopole tower inside the city while using the lattice tower in open terrain subjected to high wind speeds.

Funding
This work was supported by STIFA under Grant [number 43204]

Author details
Yasmin Elhakim1,2
E-mail: yasminmohamd@aucegypt.edu
Tawfik Ismail1,2
Irene Fahim3
1 Smart Engineering Systems Research Center (SESC), Industrial Engineering Department, Nile University, Giza, Egypt.
2 Construction Engineering, the American University in Cairo, New Cairo, Egypt.
3 Wireless Intelligent Networks Center (WINC), Nile University, Giza, Egypt.
4 National Institute of Laser Enhanced Sciences, Cairo University, Giza, Egypt.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Optimum Selection of Communication Tower Structures Based on Wind Loads & lifecycle cost analysis, Yasmin Elhakim, Tawfik Ismail & Irene Fahim, Cogent Engineering (2022), 9: 2132656.

References
Al-jassani Azhar, A. M., Inam JH, A. S. (2018). Detailed comparison study among 3 cell tower alternatives (triangular, square lattice towers and monopole) preliminarily based on specific case requirements. MOJ Civil Engineering, 4(5), 394–401 doi:10.15406/mojcej.2018.04.00134
Ali, S., Fsheem, M. I. (2022). Analysis and design of telecommunication monopole towers with and without camouflaged. International Journal of Innovative Science, Engineering & Technology, 9(2), 2348–7968. https://ijset.com/vol9/v2/IJSET_V9_I02_12.pdf
Ansi-Tia-222-G., (2005). Structural standard for antenna supporting structures and antennas . Telecommunications Industry Association, Standards & Technology Department, USA.
Asentria Corporation (2019). “Telecom sites physical security: How telecom network operators and tower companies can improve physical security at base stations and protect their networks”. https://www.asentria.com/wordpress/wp-content/uploads/2019/08/telecom-sites-physical-security-whitepaper.pdf
Asyraf, M. R. M., Ishak, M. R., Sapuan, S. M., Ilyas, R. A., Rofidah, M., & Razman, M. R. (2020). Evaluation of design and Simulation of creep test rig for full-scale crossarm structure. Advances in Civil Engineering, 2020, 10. Article ID 6980918. https://doi.org/10.1155/2020/6980918
Fabrimet. “Advantages of Lattice Towers” Retrieved 2 April, 2022. https://www.fabrimet.com/en/Advantages-of-Lattice-Towers.php
Fuller, S. 2016. “Life cycle cost analysis”. National Institute of standards and technology, 2022. WBDG. https://www.wbdg.org/resources/life-cycle-cost-analysis-lcca
Gao, S., Wang, S. (2018). Progressive collapse analysis of latticed telecommunication towers under wind loads. Hindawi Publishing. Advences in Civil Engineering, 2018(ID), 3293506. doi:10.1155/2018/3293506
Graves, H. M., & Philipson, M. C. (2000). Potential implications of climate change in the built environment. Foundation For The Built Environment.
Gregory, J., 2017. “Building life cycle cost analysis with hazard resistance”. Webinar. https://www.youtube.com/watch?v=9MFu1PxV7Epc
Gregory, Jeremy. (2017). “Building Life Cycle Cost Analysis, Incorporating Hazard Resistance”. YouTube
### Appendix A

#### Table A1. Tilting & deflection of lattice and monopole towers

| Tower Type        | Comparison Criteria | Location 1 (Category B) | Location 2 (Category C) | Location 1 (Category B) | Location 2 (Category C) |
|-------------------|---------------------|--------------------------|--------------------------|--------------------------|--------------------------|
|                   |                     | Load 1                  | Load 2                  | Load 1                  | Load 2                  |
|                   |                     | Output                  |                          |                          |                          |
|                   |                     | Def (mm)                | Tilt (degrees)          | Def (mm)                | Tilt (degrees)          |
| Lattice Tower     | Wind Speeds         | 100                     | 99.65                   | 0.2455                   | 101.37                   | 0.2493                   |
|                   |                     | 130                     | 166.12                  | 0.4074                   | 169.02                   | 0.4139                   |
|                   |                     | 140                     | 192.13                  | 0.4709                   | 195.5                    | 0.4784                   |
| Monopole Tower    | Wind Speeds         | 100                     | 120.37                  | 0.2409                   | 147.4                    | 0.3043                   |
|                   |                     | 130                     | 203.31                  | 0.4064                   | 245.94                   | 0.5029                   |
|                   |                     | 140                     | 235.77                  | 0.4712                   | 284.51                   | 0.5806                   |

Elhakim et al., Cogent Engineering (2022), 9:2132656
https://doi.org/10.1080/23311916.2022.2132656
### Appendix B

**Table B1. Life cycle cost assessment for both towers in general topography**

| Cost Description                  | Monopole Tower | Lattice Tower |
|----------------------------------|----------------|---------------|
| Total cost (EGP)                 | 171,146        | 101,120       |
| Material cost                    | 171,146        | 101,120       |
| Transportation & installation cost | 17,115        | 10,112        |
| Total Direct Cost                | 188,261        | 111,232       |
| Overhead & contingency           | 47,065         | 27,808        |
| Total initial cost               | 423,586        | 250,271       |

| Maintenance cost (EGP)/year      | 3,423          | 2,022         |
| Operation Cost (EGP)             |                |               |
| land/year                        | 216,000        | 360,000       |
| security/ year                   | 30,000         | 60,000        |
| Total operating cost/year        | 246,000        | 420,000       |

| Total operating & maintenance cost (EGP)/year | 249,423 | 422,022 |
| Disposal cost (EGP) (Relocation Cost) | 22,115 | 15,112 |

**Table B2. Present value life cycle cost of monopole tower vs lattice tower in general topography**

| Cost Description                                      | Monopole Tower | Lattice Tower |
|-------------------------------------------------------|----------------|---------------|
| Present Value of maintenance & Operating cost (EGP)   | 2,351,288.54   | 3,978,369.01  |
| Present value of the disposal cost (EGP)              | 1,267.36       | 866.05        |
| Total life cycle cost (EGP)                           | 2,776,142.39   | 4,229,506.33  |

**Table B3. Life cost assessment for both towers at a crest**

| Cost Description                  | Monopole Tower | Lattice Tower |
|----------------------------------|----------------|---------------|
| Total cost(EGP)                  | 513,438        | 303,359       |
| Material cost                    | 513,438        | 303,359       |
| Transportation & installation cost | 102,688       | 60,672        |
| Total Direct Cost                | 616,126        | 364,031       |
| Overhead & contingency           | 184,838        | 109,209       |
| Total initial cost               | 1,417,089      | 837,271       |

| Maintenance cost/year(EGP)       | 15,403         | 9,101         |
| Operation Cost(EGP)              |                |               |
| land/year                        | 228,000        | 372,000       |
| security/ year                   | 42,000         | 72,000        |
| Total operating cost/year        | 270,000        | 444,000       |

| Total operating & maintenance cost/ year | 285,403 | 453,101 |
| Disposal cost (Relocation Cost) (EGP) | 108,688 | 66,672 |
### Table B4. Present value for the total cost of the towers at a crest

| Cost Description                              | Monopole Tower | Lattice Tower |
|-----------------------------------------------|----------------|--------------|
| Present Value of maintenance & Operating cost (EGP) | 2,690,471.04   | 4,271,342.24 |
| Present value of the disposal cost(EGP)       | 6,228.73       | 3,820.87     |
| Total life cycle cost(EGP)                    | 4,113,789.10   | 5,112,434.27 |

### Table B5. Hazard repair cost in general topography

| Hazard Repair cost (General Topography)       | Monopole Tower | Lattice Tower |
|-----------------------------------------------|----------------|--------------|
| Total Initial Cost                            | 423,586.49     | 250,271.27   |
| Failure of 20% of the tower members (EGP)     | 283,802.95     | 100,609.05   |
| Failure of 30% of the tower members(EGP)      | 425,704.42     | 150,913.58   |
| Total collapse of the tower itself(EGP)       | 1,419,014.73   | 503,045.26   |
| Total life cycle cost in case of 30% failure of tower members | 3,201,846.80 | 4,380,419.91 |

### Table B6. Hazard repair cost in a crest (elevated terrain)

| Hazard Repair cost (Elevated Terrain)         | Monopole Tower | Lattice Tower |
|-----------------------------------------------|----------------|--------------|
| Total Initial Cost                            | 1,417,089.00   | 837,271.00   |
| Failure of 20% of the tower members (EGP)     | 949,449.63     | 336,582.94   |
| Failure of 30% of the tower members(EGP)      | 1,424,174.45   | 504,874.41   |
| Total collapse of the tower itself(EGP)       | 4,747,248.15   | 1,682,914.71 |
| Total life cycle cost in case of 30% failure of tower members | 5,537,963.55 | 5,617,308.69 |
Appendix C

Figure 1. Research analysis method.
Figure 2. Lattice tower.
Figure 3. Monopole tower.
Figure 4. (a) Deflection at location 1, wind speed 140, load 1. (b) Deflection at location 1, wind speed 140, Load 2. (c) Deflection at location 2, wind speed 100, load 1. (d) Deflection at location 2, wind speed 100, load 2.
