International Journal of
High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

International Journal of High-Rise Buildings
June 2023, Vol 12, No 2, 153-162
https://doi.org/10.21022/IJHRB.2023.12.2.153

The Effect of Plan Shape and Diagrid Angle on Structural Efficiency of Tall Buildings

Amirreza Ardekani and Matin Alaghmandan†

Faculty of Architecture and Urbanism, Shahid Beheshti University, Tehran, Iran

Abstract Achieving sustainable spaces is one of the emerging trends of tall buildings regarding their significant impacts on the cities. Reducing energy consumption and material using is investigated as a widely used approach to achieve more efficient tall buildings. Defining more efficient geometries and form modifications have been adopted for this goal. In this paper the effect of plan shape and diagrid angle on structural efficiency of diagrid tall buildings have been studied. A parametric workbench is applied to generate and analyze models. The goal is to find effective form parameters resulting in more efficient forms. Respectively, all models were generated in Rhino/grasshopper architecturally and analyzed by a finite element plug-in structurally. Based on the results, steeper angles almost cause more displacements and needs to be more stiffened. it can be seen almost more sided models need less weight for the structures and it could lead to more efficient forms.

Keywords Tall Buildings, Plan Shape, Diagrid angle, Parametric Design, Structural Efficiency

†Corresponding author:
Matin Alaghmandan
E-mail:
m.alaghmandan@gmail.com

1. Introduction

1.1. Background

Passing from early tall buildings era to the recent day has upgraded the concerns from primary architectural and structural needs and limitations to sustainability issues. Advancement of science and technology, overcame most of limitations and the competition of achieving taller was spread out over the world. Function of buildings and the location of this competition as pointed in references (CTBUH Statistics), have changed over the time and have turned its face from US to Asia and middle east region. On the other hand, paying more attention to the environment and saving resources has become one of the new world significant issues. Building construction as a main consumer of materials and energy has been focused by researchers for sustainability issues. In this area tall buildings owing to their unique features of using great amount of materials in construction operation and being occupied by huge number of people, demonstrate significant needs of resources and energy. many studies have been carried out in the case of achieving more optimized forms which provide more efficient tall buildings (Moon 2007, Alaghmandan et al. 2016). It should be taken to the account that necessarily optimizing the weight of materials is not the best solution, sometimes clustering similar members and reducing fabrication costs may be the optimization objective (Asadi 2017). Mutual architectural-structural considerations of the form and structure of tall buildings helps in finding more efficient forms.

1.2. Architectural-Structural Considerations on Tall Buildings

Architectural and structural forms are closely inter-connected in tall buildings which cannot be considered separately in design process. Regarding huge dimensions and significant environmental impacts, Proper form of a tall building is influenced by many parameters such as sustainability issues, urban and traffic, aesthetics, functions, economics, etc. In order to achieve an eligible form in which all criteria and requirements are satisfied, close cooperation of architects, engineers and other professionals is necessarily needed from the early steps of design.

In order to have sustainable tall buildings, more efficient forms are needed which can provide more efficient behavior against forces and environmental conditions (Moon 2012). It can be achieved by both structural and architectural strategies. Structural strategies of stiffening the structure and damping may be applied by structural provisions such as selecting appropriate structural systems

and cross sections, adopting proper joints and also using dampers. Although architectural strategies have significant impacts on the structural behavior of tall buildings, their potentials have been underestimated until recent years. The plan geometry as well as the overall form of the building have shown considerable effects on its behavior against lateral loads. Form modifications cause in efficient behavior of the building regarding the primary form characteristics, context properties and type of the effective loads.

Several researches have been conducted on the effective form modifications regarding earthquake loads (Asadi & Adeli 2018, Ardekani et al. 2020, Kim and Lee 2010, Baker et al. 2010, Sadeghi and Rofooei 2018). In the case of wind loads, aerodynamic forms and some modifications are among architectural strategies which can induce wind effects on the buildings. Many studies show that aerodynamic forms may have significant effects on the buildings structural behavior against wind and they are just applied widely in designing tall buildings (Ilgin and Gunel 2007, Amin and Ahuja 2010, Mooneghi and Kargarmoakhar 2016, Mirniazmandan et al. 2018). Xie (2014) counts aerodynamic optimization of building shapes in early architectural design stage as the most efficient way to achieve in wind-resistant design. Tanaka (2013), also studies about aerodynamic behavior of unconventional configurations.

These modifications (Ardekani et al. 2020) are divided in two main categories including major and minor modifications. In major modifications main architectural concept is affected by changes but in minor modifications the main concept is not affected and just some changes are made in corners or façade of the building. Changing plan shape, Setback, tapering, twisting and tilting are among the first group and corner recession can be included in the second one. Xie (2014) classifies aerodynamic optimization into two categories of aerodynamic modifications which refers to limited shape changes such as corner modifications and aerodynamic design which associates with early architectural design that influences the overall form. Also, Tomei (2018) defines three levels of structural optimization that are at the highest level the optimization of tall building form, at the intermediate level optimization of structural system and at the lower level optimization of member sizing.

1.3. Structural systems, Exterior and Interior Systems

Structural strategies for tall buildings have been developed in recent decades. Flexibility of tall buildings has made lateral loads the dominant load in comparison with gravity loads. Therefore, stiffness controls the design results more than strength of materials (Taranath 2004, 2016). Qualified designs which provide enough strength for the building and prevent it from collapsing may not necessarily satisfy the serviceability of the building and provide enough comfort in wind induced motions (Amin and Ahuja, 2010). Wind and earthquake are the main lateral loads that influence on tall buildings structural design. Regarding the location of main lateral structural system within the building or on the perimeter of the building, the structural systems of tall buildings are divided to two main categories called interior or exterior systems (Ali and Moon, 2018). Tube system and its developed successor system –diagrids- are two efficient widely used structural systems for tall buildings included in the second category and outrigger system locates in the

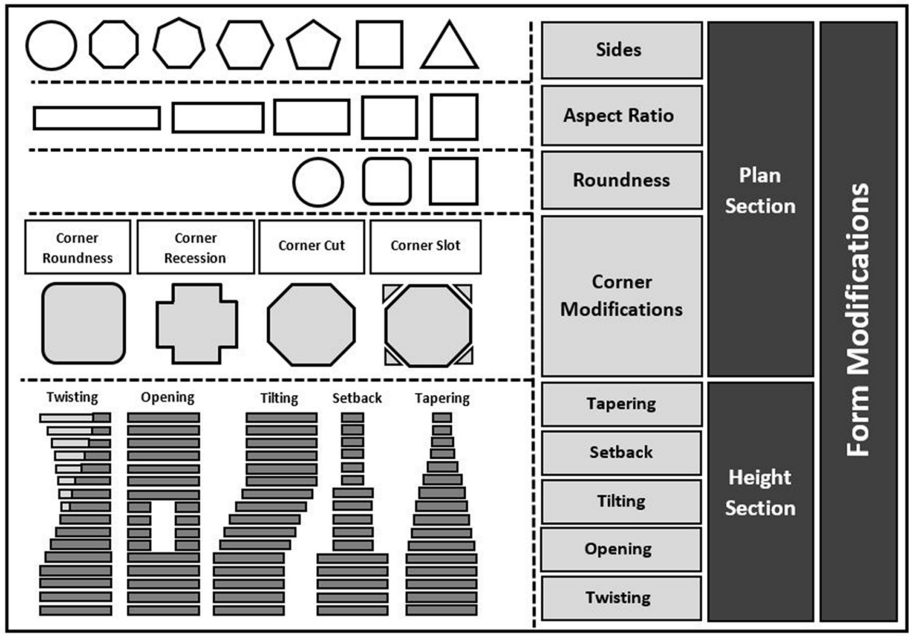


Figure 1. Chart of modifications of form in tall buildings. (Ardekani et al. 2020)

first one. In this paper diagrid system as a qualified efficient structural system for tall buildings due to its unique structural and architectural features has been studied.

1.4. Diagrid Structural System

Diagrids are between most trended structural systems for tall buildings due to their special characteristics. Interesting architectural appearance as well as high structural efficiency of diagrid systems have made them one of the most popular systems between architects and engineers (Boake, 2014). many studies have been carried out on these structures and have developed their features around the world, accordingly. Beside structural advantages, these diamond shaped and triangulated exterior structures (as shown in Figure 2) are among most favorite systems for architects, due to their unique attractive exterior configuration as well as offering more open interior spaces. Regarding the trend of designing more curvilinear and aerodynamic forms, one of the most appropriate candidates among applied structural systems will be the diagrid system (Alaghmandan, et al. 2014).

Diagrid system inherits most of advantageous properties from their predecessor - tubular system - and modifies some disadvantageous of this system. locating diagonals on the perimeter of tubed structure - braced tubular systems - resulted in achieving more effectiveness and more efficient structural behavior. Diagrids as a developed system to braced tubular systems, showed more structural efficiency due to their stiffness and load bearing features (Asadi, 2017, Moon, 2007). The ability of carrying both gravity loads as well as lateral loads (due to special triangulated configuration of members), makes it possible to eliminate almost all conventional vertical columns. Compared with conventional framed tubular structures without diagonals, diagrid structures are much more effective in minimizing shear deformation because they carry shear by axial action of the diagonal members, while conventional tubular structures carry shear by the bending of the vertical columns and horizontal spandrels (Moon, 2007, Asadi, 2017).

Many researches has been conducted on the structural behavior of diagrid structures to develop their features. Especially the parameters of the geometry of the form have been the most studied parameters in this case. Moon (2007) investigates the range of optimal angles for diagrid structure by the proposed stiffness-based methodology of design. He also studied (2008) the effect of diagonal angles on both braced tube structures and diagrids for different heights. He found that in uniform-angle diagrid structures as the buildings height gets taller, steeper angles provide more efficient behavior in the range of 60 to 70 degrees. Asadi (2017) presents a state-of-the-art review of diagrid tall buildings, their configurations and optimal behaviors. (Asadi 2018) studies about structural seismic factors of diagrid structures and Khan and shindeh (2015) make a comparison on structural behavior between a conventional braced tube and a diagrid structure that shows how more efficient behavior can be achieved by deploying diagrid structure. Tomei (2018) studies the topology of the diagrid and angle of diagonals as two key factors on lateral stiffness and structural efficiency which can improve the linear and nonlinear response of the structure under extreme and service loads. Ardekani et al. (2020) conducts a research on the effect of form modifications on the structural efficiency of diagrid structures. Mirniazmandan et al. (2017) also investigate the effect of both different geometric base and top plans configurations of tall building and the angle of diagrid structure on designing efficient tall buildings.

1.5. Wind Loads

Tall buildings in addition to gravity loads, carry considerable amount of lateral loads. The lateral load is as

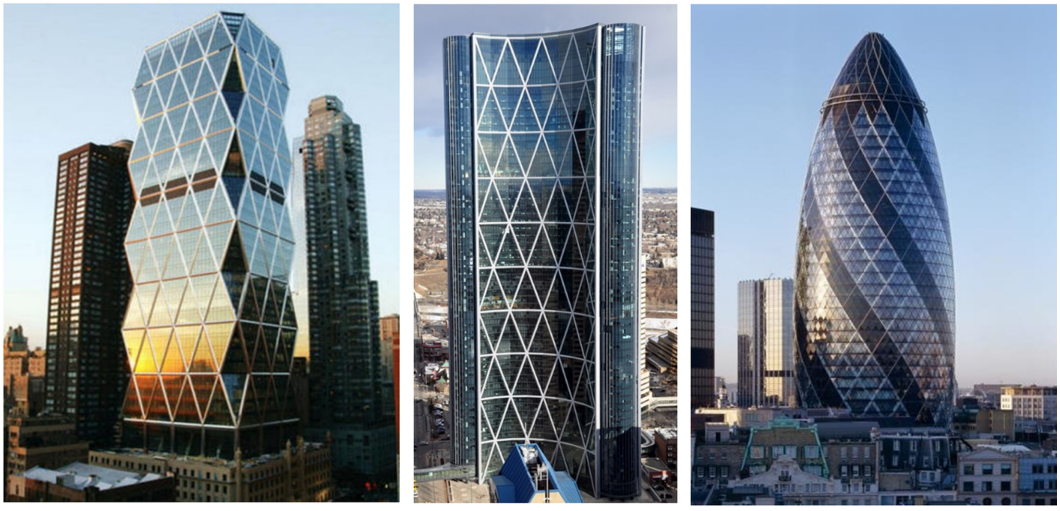


Figure 2. Examples of diagrid tall buildings, from left: the hearst tower (archdaily.com), the bow tower (the-bow.com), the Mary axe 30th tower. (history.swissre.com)

significant that mostly governs the design process of these type of buildings (Taranath, 2004). Depending on the geometrical properties of the form, its structural characteristics, climatic and geological conditions of the region, one of the lateral loads - earthquake or wind - is considered for analysis and design of the building. In the case of wind loads, requirements of human comfort and limiting nonstructural component movements have the most impacts on design and needs to be satisfied.

A structure against wind loads is subjected to time-varying forces including drag (along-wind) forces, lift (across-wind) forces and torsional moments. the cross-wind forces act perpendicular to the direction of mean wind flow. The common source of cross-wind motion is associated with vortex shedding. Un-uniform distribution of pressure on the faces cause the torsional motion (Amin and Ahuja, 2010). It has been recognized that for many high-rise buildings, the crosswind and torsional responses may exceed the along wind response in terms of both limit state and serviceability designs (Holmes 2014). For most supertall buildings, it is often found that cross-wind dynamic response dominates the design wind loads and sometimes causes excessive motions in terms of building's serviceability criterion (Xie, 2014).

The lateral stiffness of diagrid structures is desirable not only for static loads but also for dynamic loads which generate responses in both the windward and across-wind directions. In most cases, the lateral motion in the across-wind direction due to vortex shedding is much greater than the motion in the windward direction. Stiffer structures have a lower probability of the vortex frequency locking on a modal frequency (i.e., a lock-in condition) (Moon, 2007).

2. Research Methodology and Goals

2.1. Parametric Computational Platform

Parametric design method facilitates generating and analyzing a great number of models for making comparisons and achieving efficient models. A parametric model relates all contributed parameters included in the overall form by the rules and constraints. Consequently, the effect of changing every parameter on the other parameters and the main form can be investigated conveniently. In this paper, Grasshopper plug-in on rhinoceros as a powerful tool of parametric modeling was adopted to provide the environment of making models parametrically. All architectural and structural included parameters were defined in the model and the relations between parameters were determined. Intended variation of models were generated and Structural analyses of the generated models were carried on by using KARAMBA3D 1.3.0 WIP as a finite element structural plug-in in grasshopper. The optimized parameters were introduced by comparing the results. Overall view of the study process levels is depicted in Figure 3.

2.2. Studied Parameters

In this research two main architectural parameters of diagrid tall buildings – plan shape and diagrid angle - as two effective parameters on the structural behavior of diagrid tall buildings, are investigated. Plan shape as a main architectural parameter of making the geometry and defining the overall form have shown significant effects on the structural performance of the buildings specially against wind loads. The considered plan shapes of the research include 3, 4, 6, 8 and 10-side equilateral polygons

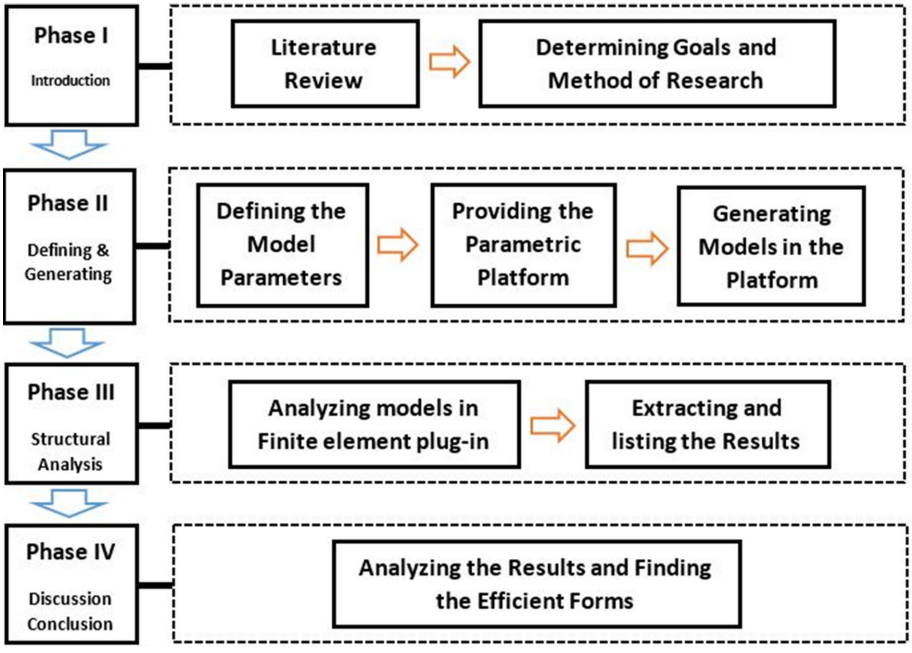


Figure 3. Overall view of the steps and levels of the research

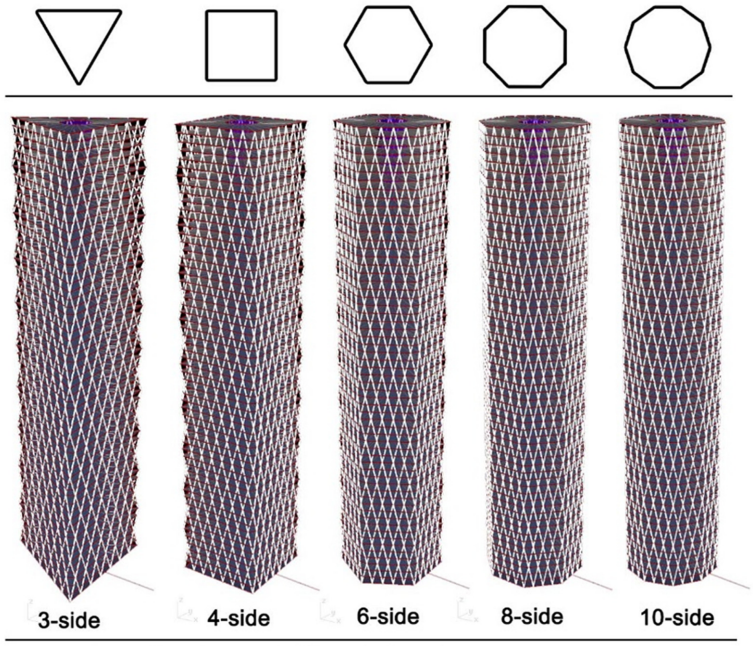


Figure 4. Generation of the models with different plan shapes.

(Figure 4). These polygons represent plans of wide used tall buildings of the world and the series let to find influence of increasing plan shape sides on structural behavior.

The angle between diagonal elements as the second influential parameter affecting on structural behavior of diagrid tall buildings has been studied in this paper. This parameter is determined regarding both architectural and structural criteria. Considering the diagrid module heights, the number of floors between modules of diagrids has been supposed to include six cases of 2, 4, 6, 8, 10 and 12 stories (Figure 5).

2.3. Model Generation and Assumptions

2.3.1. Architectural Assumptions

The main basic model includes a 60 story tall building. The total height of the building is 240 meters considering four meters for every story as a normal height for office buildings (CTBUH). A concrete circle core is included in the middle of the building. The basic floor area of the model is assumed to be 2025 m^2 which results 121500 m^2 total gross area of floors (including core area). It is a fixed number for all variations in order to make comparisons valid architecturally in different models. Other dimensions including length of diagrids and beams,

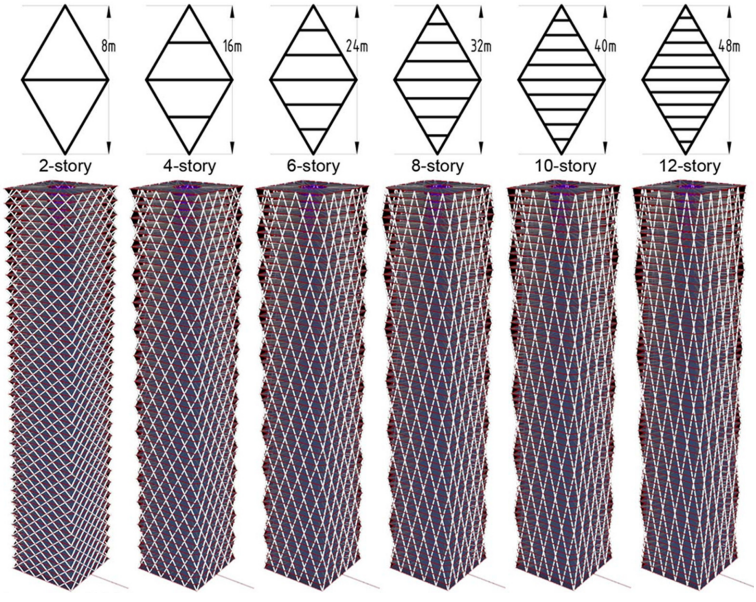


Figure 5. Generations of 4-side model with different diagrid module heights.

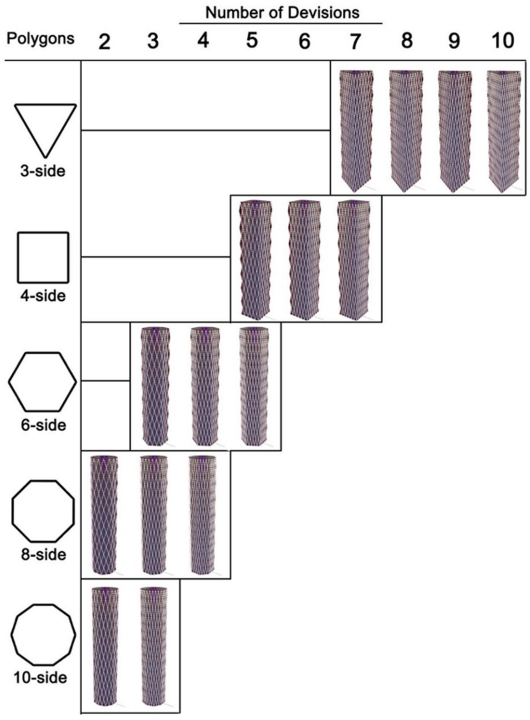


Figure 6. Generated models for the case of 6-floor diagrid module of all plan shapes.

core dimensions, the number of stories between diagrid modules, angle of diagrids and perimeter of the buildings are various due to every model generated in the process. All possible models were generated excluding the models which their length of divisions were out of the normal range. Figure 6 shows the generated models for the case of 6-floor diagrid module of all plan shapes.

2.3.2. Structural Assumptions

The main structural system is steel diagrid system located on the perimeter of the building. Main parts of the structure consist of an inner concrete core, diaphragm slabs, and outer peripheral diagonal grids with perimeter beams which establish the structural main configuration (Figure7). Radial beams connect these inner and outer parts. The thickness of the core is set to 80 cm identical all over the height. The floor slabs are assumed to be concrete rigid shells as diaphragms with thickness of 40 cm. The weight of diagonal elements, perimeter and radial beams is being considered for the comparison weight of models. The core is just contributing for carrying gravity loads and consequently, all the required lateral loads are assumed to be carried by peripheral diagrids.

The beams used in the models, are subdivided into several categories regarding their functions, section properties and materials. Some bear just axial loads and others undergo the bending moments additionally. Functionally they are divided into four categories: B1- Diagonal beams on exterior of the models as diagrid structure elements, B2- Perimeter beams on the levels of

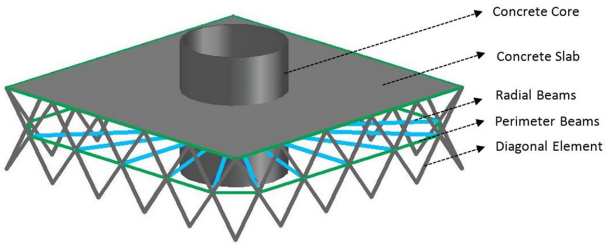


Figure 7. Structural parts and elements of the generated model.

main diagrid joints, B3- Perimeter beams which are not on the main diagrid joints level and B4- Radial beams connecting core and joints on the perimeter beams.

Applied cross sections include circular tubes applied for B1 beams, hollow boxes for B2 and B3 beams and I-profiles for B4 beams. The cross sections extracted from the UK standard list of sections. Beam cross sections has have been selected by optimization process. Three main categories of joints are applied between elements of the model. Supports are all assumed to be fixed at the ground level. Diagrid elements and beams to diagrids are connected by hinge joints and Connections of beams to core has been considered to be fixed.

Steel S235 is applied for all beams and diagrids. Concrete C50-60 is applied for main reinforced concrete of core and slabs (with reinforcement steel BSt500 according to EC2). Regarding considerations, the governing load for this analysis is assumed to be the wind loads. Assuming the function of tall building as office building, dead load is set to 3500 (N/m2) and live load to 2400 (N/m2) due to gravity loads based on ASCE code. The wind load is calculated due to form and structure properties, based on National Building Code of Canada (NBCC). In this code the analysis is operated through three methods of static, dynamic and experimental procedure. The experimental procedure which is related to wind tunnel testing is ignored in this research. Maximum allowable deflection of models is set to H/500 (based on Chicago Building Code (CBC)) and it equals to 0.48 meter (240/500) in the model applied for the paper. In order to make a valid optimization, the demand to capacity (DCR) of elements has been limited to be less than 0.7.

3. Results and Discussion

3.1. Analysis Information

The structural efficiency of the generated and analyzed models of the research have been evaluated and compared through two main parameters (Figure 8): The weight of the diagrids per unit of area which is calculated by dividing the total weight of the diagrid elements to total gross area (TGA) of each model and also Maximum displacement of each model which is dependent on the stiffness of the models.

In this research the diagrid angle is represented by the

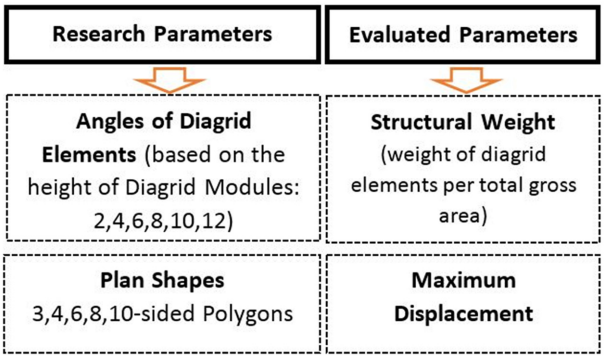


Figure 8. Independent and evaluating factors of the research

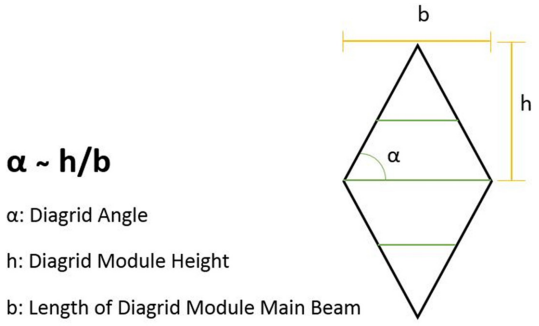


Figure 9. diagram and relation between angle of diagrid and its elements

proportion of the diagrid module height to the length of diagrid main beams (Figure 9). In this relation α is the angle between diagonal elements and h and b are the diagrid module height and length of the main beam, respectively. Considering the impact of the length of diagrid main beams on the results, the models have been compared in three groups. In this way, models with nearly similar length of main beams (joint to joint of diagrid beam) are categorized in identical groups which makes the results more comparable. In every group the difference of angles is shown by the height of modules.

All generated models were analyzed structurally based on the architectural and structural presumptions discussed in section 3. Regarding the geometry of models, the calculated amounts of displacement and weights by the structural plug-in were extracted and listed in several charts. As an example, the amounts for 4-sided model are listed in Table 1. As can be seen in the table, possible divisions of beams are associated with possible number of floors along diagrid module and the structural amounts have been listed accordingly. The Following discussion on the results as explained previously, is divided into three parts based on similar diagrid beam lengths.

3.2. Joint to Joint of Diagrid length (Beam) is 5 - 6.75 (m)

Limiting the length of main beams makes it possible to compare the results in similar conditions. Also in this way the height of modules is associated with the angles and

Table 1. Geometrical and structural values of the generations of 4-sided analyzed models

Number of Divisions on Sides	Number of Floors along Diagrid Module	TGA plus Core Area (m^2)	Average of Diagrid Angle	Minimum Beam Length (m)	Maximum Lateral Displacement (m)	Diagrid Weight Per Unit Area (kg)
5	2	122880	49	9.050967	0.613365	64.38151
6	2	122880	43	7.542472	0.583108	63.45947
7	2	122880	39	6.464976	0.569549	61.88314
5	4	122880	29	9.050967	0.518541	58.93229
6	4	122880	25	7.542472	0.497214	59.29932
7	4	122880	22	6.464976	0.489611	59.59391
5	6	122880	21	9.050967	0.501672	58.14372
6	6	122880	17	7.542472	0.505358	58.63119
7	6	122880	15	6.464976	0.51375	59.12679
5	8	122880	16	9.050967	0.522656	57.78646
6	8	122880	13	7.542472	0.535387	58.30973
7	8	122880	11	6.464976	0.54668	58.94775
5	10	122880	13	9.050967	0.544414	57.68555
6	10	122880	11	7.542472	0.561961	58.2544
7	10	122880	9	6.464976	0.572398	58.96078
5	12	122880	11	9.050967	0.562695	57.72542
6	12	122880	9	7.542472	0.577501	58.47249
7	12	122880	8	6.464976	0.589104	59.16911

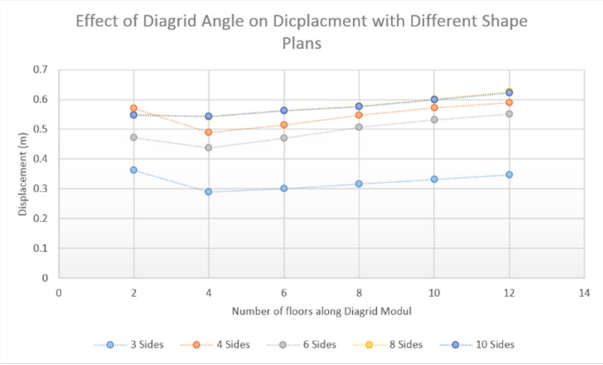


Figure 10. Chart of displacements of models with the beams in the range of 5-6.75 m.

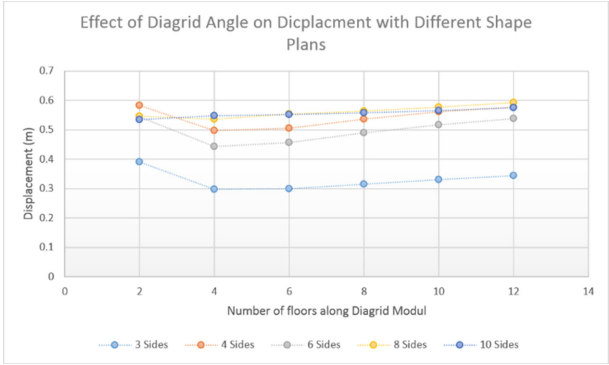


Figure 12. Chart of displacements of models with the beams in the range of 6.8-8 m

can represent the angles consequently. As depicted in Figure 10 for the range of 5-6.75 m of length, increasing the number of floors between various plan shapes (implicitly increasing the angle), roughly cause a near linear increase in maximum displacement of the models or in other words steeper angles results in less structural stiffness. Ignoring plan shape effects, it can be seen that the stiffness is decreased by increasing the angle of diagrids in this range. It should be noticed that there is an exception for the two-floor case that causes more displacement out of the linear flow of other models. The minimum displacement belongs to 4-floor models and the maximum belongs to 12-floor models. Considering the effects of plan shape, the 3-side model shows considerable less displacement from more sided models in all angles. The most displacement belongs to 10-side model.

In the case of structural weight (Figure 11), two different trends can be seen in the charts. More sided geometries including 8-side and 10-side plans demonstrate an almost linear relation between increasing angle and the weight of models. On the other hand, the 3 to 6-side models do not depict a considerable change in the weight of materials and the weights are in a close range. In similar to the maximum displacement results, 2-floor diagrid models – slower angle- show exceptional more weights from the other models. In the case of plan shapes, 8 and 10-side models are considerably heavier than less sided models. The most weights belong to 8-side (60-63 kg) models and 4-side models have (59-62 kg) the least weights.

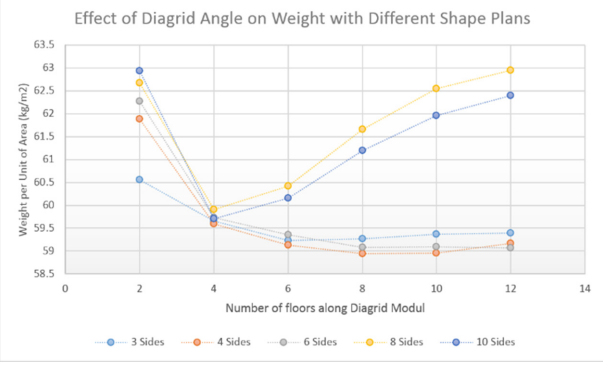


Figure 11. Chart of structural weights for models with the beams in the range of 5-6.75 m.

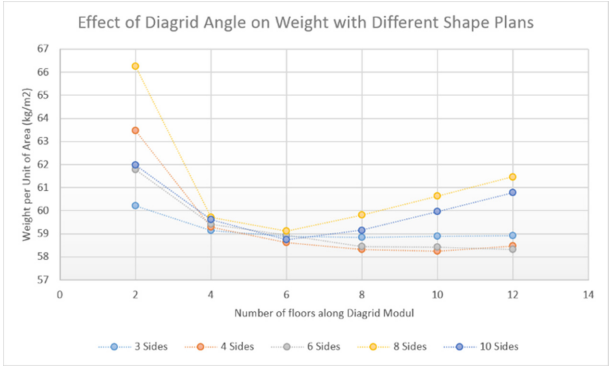


Figure 13. Chart of structural weights for models with the beams in the range of 6.8-8 m

3.3. Joint to Joint of Diagrid length (Beam) is 6.8 - 8 (m)

As depicted in Figure 12, the behavior of models is almost similar to the last group. An increasing trend of displacements can be seen when moving to greater number of floors among diagrid module. 3-side models show a reasonable reduction in displacement and more sided models show less structural stiffness. The least displacements are associated with 4-side models in all plan shapes.

The trend in weight results (Figure 13) shows a weak correlation between number of plan sides and the weight per unit of models. The most structural weights are related to 2-floor models (smaller angles) and it decreases in the models with steeper angles. 8 and 10-side models show an increase in lager angles unlike 3 to 6-side models which show a constant trend in larger angle models.

3.4. Joint to Joint of Diagrid length (Beam) is 8.4 - 10.4 (m)

Considering the charts of the most longer divisions of beams (Figure 14 and 15), shows that again the same

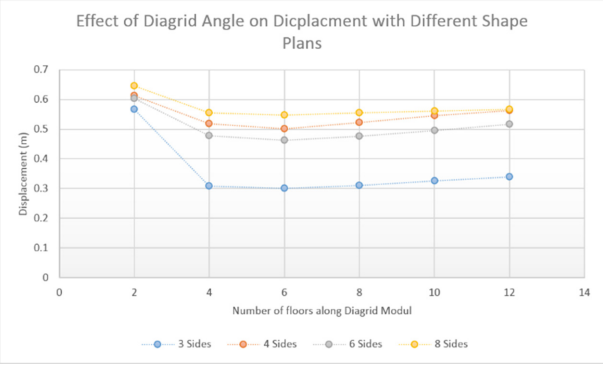


Figure 14. Chart of displacements of models with the beams in the range of 8.4-10.4 m.

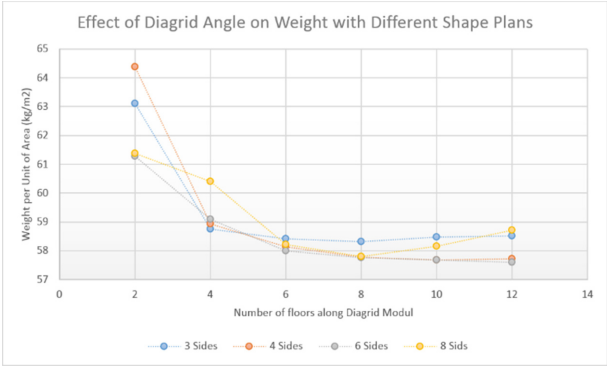


Figure 15. Chart of structural weights for models with the beams in the range of 8.4-10.4 m.

trend can be found out for the displacement parameter. Models with the larger angles have the most displacements and the 6-floor module has the least displacements. In the case of weight efficiency, unlike other groups, closer amounts can be seen in all plan shapes. lower angles are associated with less weights and it changes to a uniform trend from 6-floor modules to larger angles.

4. Conclusions

Regarding sustainability issues, many studies have been carried out to reduce the amount of material and energy consumption in all related disciplines. In this paper the effect of geometrical characteristics of a diagrid tall building on its structural behavior has been studied to find solutions that lead to less material using. Plan shape and the angle between diagonal members as two effective parameters were studied. Concluding from the results, the impacts of the geometry is undeniable on the structural behavior of diagrid tall buildings. Regardless of plan shapes, increasing the angle of diagonal elements leads to less stiffed models although it is very limited. 2-floor cases demonstrate more displacement as an exception of the trends. 3-side models, have the least maximum displacement in all groups of study. Also it should be noticed that almost more sided models show more displacements while some exceptions can be found. In the case of structural weight, more sided models are more influenced by changing angle of diagrids. As it can be understood from the charts, 8 and 10-side models generally have more structural weight than lower sided models, although this impact is limited in lower angles.

References

Alaghmandan, M., Elnimeiri, M., Krawczyk, R.J. and Buelow, P.V., 2016. Modifying tall building form to reduce the along-wind effect. CTBUH Journal, (2), pp.34-39.

Ali, M. M., and Moon, K. S. (2007). Structural Developments in Tall Buildings: Current Trends and Future Prospects. *Architectural Science Review* 50(3), 205-223.

Ali, M. M., and Moon, K. S. (2018). Advances in Structural Systems for Tall Buildings: Emerging Developments for Contemporary Urban Giants. *Buildings* 8(8), 104.

Amin, J. A. and Ahuja, A. K. (2010). Aerodynamic Modifications to the Shape of the Buildings: A Review of the State-of-the-Art. *Asian Journal of Civil Engineering (Building and Housing)* 11(4), 433-450.

Ardekani, A., Dabbaghchian, I., Alaghmandan, M., Golabchi, M., Hosseini, S.M. and Mirghaderi, S.R. (2020). Parametric design of diagrid tall buildings regarding structural efficiency. *Architectural Science Review*, 63(1), pp.87-102.

Asadi, E. and Adeli, H., (2017). Diagrid: An innovative, sustainable, and efficient structural system. *The Structural Design of Tall and Special Buildings*, 26(8), p.e1358.

Asadi, E., and Adeli, H. (2018). Seismic Performance Factors for Low-to Midrise Steel Diagrid Structural Systems. *The Structural Design of Tall and Special Buildings*, 27(15), e1505.

American Society of Civil Engineers (ASCE)/Structural Engineering Institute. Minimum Design Loads for Buildings and Other Structures. ASCE/SEI 7-05, American Society of Civil Engineers, Reston, Virginia; 2006.

Asghari Mooneghi, M., and Kargarmoakhar, R. (2016). Aerodynamic Mitigation and Shape Optimization of Buildings. *Journal of Building Engineering* 6, 225-235.

Baker, W., Besjak, C., Sarkisian, M., Lee, P. and Doo, C.S. (2010). Proposed methodology to determine seismic performance factors for steel diagrid framed systems. *CTBUH (Council on Tall Buildings and Urban Habitat).*

Boake, T. M. (2014). *Diagrid Structures, Systems, Connections, Details.* Bassel: Birkhäuser.

CTBUH. (2018, July 28.07.2018). Buildings: 875-North Michigan Avenue. Retrieved from The Sky Scraper Center: The Global Tall building database of the CTBUH: http://www.skyscrapercenter.com/building/875-north-michigan-avenue/345

Holmes, J.D. (2014). Along-and cross-wind response of a generic tall building: Comparison of wind-tunnel data with codes and standards. *Journal of Wind Engineering and Industrial Aerodynamics*, 132, pp.136-141.

Ilgin, H. E. and Gunel, M. H. (2007). The Role of Aerodynamic Modifications in the Form of Tall Buildings

Against Wind Excitation. *Metu Jfa*, 2(24), 17-25.

Khan, R., and Shinde, S. B. (2015). Analysis of Diagrid Structure in Comparison with Exterior Braced Frame Structure. *PG Student, Department of Civil Engineering, Jawaharlal Nehru Engineering College*, *Aurangabad, Maharashtra, India.*

Kim, J., and Lee, Y. H. (2010). Seismic Performance Evaluation of Diagrid System Buildings. *The Structural Design of Tall and Special Buildings*, 21(10), 736-749.

Mele, E., Toreno, M., Brandonisio, G. and De Luca, A. (2014). Diagrid Structures for Tall Buildings: Case Studies and Design Considerations. *The Structural Design of Tall and Special Buildings*, 23(2), 124-145.

Mirniazmandan, S., Alaghmandan, M., Barazande, F. and Rahimianzarif, E. (2018). Mutual effect of geometric modifications and diagrid structure on structural optimization of tall buildings. *Architectural science review*, 61(6), pp.371-383.

Moon, K. S. (2008)a. Optimal Grid Geometry of Diagrid Structures for Tall Buildings." *Architectural Science Review*, 51(3), 239-251.

Moon, K. S. (2008)b. Material-saving Design Strategies for Tall Building Structures. *Proceedings of the CTBUH 8th World Congress, Dubai, United Arab Emirates.* Vol. 34.

Moon, K. S. (2012). Sustainable Structural Design of Contemporary Tall Buildings of Various Forms. *CTBUH 9th World Congress*, China.

Moon, K.S., Connor, J.J. and Fernandez, J.E. (2007). Diagrid structural systems for tall buildings: characteristics and methodology for preliminary design. *The structural design of tall and special buildings*, 16(2), pp.205-230.

Tanaka, H., Tamura, Y., Ohtake, K., Nakai, M., Kim, Y.C. and Bandi, E.K. (2013). Aerodynamic and flow characteristics of tall buildings with various unconventional configurations. *International Journal of High-Rise Buildings*, 2(3), pp.213-228.

Sadeghi, S., and Rofooei, F. R. (2018). Quantification of the Seismic Performance Factors for Steel Diagrid Structures. *Journal of Constructional Steel Research*, 146(2018): 155-168.

Taranath, B. S. (2004). *Wind and Earthquake Resistant Buildings: Structural Analysis and Design.* Los Angeles, CA: CRC Press.

Taranath, B. S. (2016). *Structural Analysis and Design of Tall Buildings: Steel and Composite Construction. Boca Raton*, FL: CRC Press.

Tomei, V., Imbimbo, M. and Mele, E. (2018). Optimization of structural patterns for tall buildings: The case of diagrid. *Engineering Structures*, 171, pp.280-297.

Xie, J. (2014). Aerodynamic optimization of super-tall buildings and its effectiveness assessment. *Journal of Wind Engineering and Industrial Aerodynamics*, 130, pp.88-98.