**Shape Optimization of High Rise Buildings; Case Study: Iris Bay Tower**

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**ABSTRACT**

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**Background:** Nowadays, optimal design of structures is obviously considered as a critical issue, based on the factors such as: Limited material resources, environmental impacts and technological competitions. Optimal design of constructions is clearly defined as a lightweight, low cost and high durable construction by considering stability function of high rise buildings. By acquiring progressions in computer aid engineering, nomination of such as beneficial techniques is essentially possible by applying finite element based methods. It is obviously included the topology optimization as the main procedure, followed by the shape and size optimization. In the present research, the main substantial impacts of topology and size optimization procedures on multistory constructions are progressively researched by applying finite element based method on optistruct software and the hypermesh tools. The Iris Bay Tower is situated in Dubai, the capital of United Arab Emirates. The building signifies high selected multi story materials, based on the intervening shape of the structure. The main objective of this research is to illustrate topology and size optimization results. Rigorous advantage of the pertinent design is to access the free inner space of the building by the removal of central columns to decrease the compliance from $3.1444 \times 10^5$ to $1.427 \times 10^5$. Consequently, we are able to suggest a feasible optimization design, on the basis of premium results subjected to the main constraints for revealing an optimum construction design in the area of civil engineering. Despite the beneficial advantages of the plan, this project is more expensive and time consuming.

**INTRODUCTION**

Size optimization is the main substantial criterion for the primary design of structural optimization, by the objective of gaining optimum size creation for cross sectional area. The main variable of such design is a cross section area by the thickness or the first moment of inertia, in order to decrease the material mass of the building.

In the beginning of optimization movement during 1960’s, the entire design was merely limited to the size optimization of the frame; (Kikuchi and Suzuki, 1991).

Later in 1973, zienkiewiz and Campbell suggested another substantial feature for the frame, mainly regarded as the shape optimization.

Thereafter, expert researchers have implemented remarkable studies in order to eliminate related short comings.

Shape optimization deal with the optimum shape of the structure, especially on the boundaries in order to reduce main stresses on shape corners.

The main objective of the design is to constrain the materials by modifying related shapes on the boundaries.

In this category, the geometry of structure changes during the process. By the application of such a procedure, all the mesh elements are deteriorated. Therefore, another algorithm for remeshing procedure is requested during the analysis. The most important challenging part of the main process is topology optimization.

The criteria deals with the settlement of material distribution in the design domain in order to reach optimum load path frame.

Computational tools for topology optimization were initially progressed by Bendsoe and Sigmund in 2004. Therefore, many studies have been implemented in order to improve the method. During the structural...
optimization process, initial optimum load path is designed through the topology optimization procedures. By interpretation of this procedure, an engineering design is approved by the application of size and shape optimization progressions of these criteria rely upon a significant initial design of the topology optimization. Based on the suggestions drawn by Arakere et al in 2008, the major weight savings are optimized during the procedure and the remaining minor weight is being saved by obtaining subsequent detailed size and shape optimization over the initial design.

Hence, the application of such a procedure is necessary to reach the reliable design.

**Iris Bay Tower:**

This study deals with performance of topology and size optimization on Iris Bay Tower as the two dimensional shell elements method by applying optistruct software and hyper mesh tools. Iris Bay is a half-moon shaped tower situated in a prestigious business bay area in Dubai. The capital of United Arab Emirates, The building comprises of two double identical curved shells being rotated and cantilevered over the podium which signifies the plan area differentiations in various floors. Medium Levels are particularly large: while upper and nether Levels are rigorously smaller than the main standard area plan. The building is constructed by the commercial means. Number of the office units in each floor varies, due to the area plan. This commercial building consists of 32 floors, 3podium Levels for car park and the main podium roof plan. There exist 920 car parks over the podium and basement plan.

![Iris Bay Tower](image)

**Fig. 1:** Iris Bay (a) side view, (b) front and side view, (c)Back view, (July 2010)

The tower consists of six fast speed elevators, outdoor swimming pools, built on the podium roof and the gym. The front elevation of building consists of seven angled glass areas. Where is, the back elevation of tower includes balconies of round vertical curves.

Architectural height of the bay is 170 m; while the floor to floor to ceiling height is 2,750 mm. (Bayut .com).

Atkins Company has taken the responsibility for commission and consultation of structural, mechanical, electrical and architectural engineering design procedure for the entire managing development of this project. The preliminary construction plan began in 2007. Expert engineers were supposed to complete the structure by September 2010. Hence, it is still under progress, due to the mechanical reasons. Iris bay is regarded as the structural model for the revision of optimization plans on research studies of the project, due to the related complexity and uniqueness of the shape.

The main objective of the plan is organized through final comparison of structural and conventional consequences. By considering the pressure of high wind load on the intersectional element nodes in the structure, we have implemented the present study to propose effective suggestion for minimizing entire structural weight of the building. Figure 1 shows Iris Bay tower from different views.

**Methodology of the shape optimization:**

The present study was accomplished in order to respond to the research questions to reach the main objectives. The procedure is arranged through different phases namely as:

- Pre processor, topology optimization and detailed size optimization. The primary level includes finite element modeling. During this procedure, the entire geometry of tower as the main part of study was constructed by alters in hypermesh. Due to the fact that hypermesh is finite element based software, substantial meshing concepts were applied into the model. The boundary conditions and related load fields were assemble during the primary phase. Estimation of load fields was accomplished by the safety factor of 1.05 based on ECI calculations, considering the wind speed range of 45 m/s drawn by the wind and weather statistics of Dubai Airport.

- The optistruct processor was arranged to introduce the objective function, design variable domains and problem constraints.

By the elimination of structure compliance, due to the 80 percent minimum removal of the materials, objective function was obtained. The design variable was considered as an entire structure, based on the fact that
reducing the materials could only happen in outer shell elements. The next criterion for topology optimization techniques was implemented in order to obtain the initial design. The results of second phase optimization are regarded as the most significant ones among related consequences. Post processor hypherview software was also applied for the possible controlling of the results. The supplement consequences are usually interpreted by the expert engineers. They generally require some improvements. It is intrinsically implemented through changing necessary parameters by running optistruct software for the accession of optimum results.

By adjusting the minimum member size (MINDIM) as it is recommended to be three times more than the average element size, we draw the value of 05. In this case, the discrete penalty parameter for intermediate element densities was assumed as “1”.

By obtaining topology optimization results, the third phase of detailed size and shape optimization was completely implemented. By following this procedure, we access the optimum results. The last phase of this project is categorized upon topology optimization results, due to the size optimization criteria to improve the desired consequences.

The geometry of structure was built on making the model of beam and column, based on the consequences of second phase. The objective function was to eliminate the bulk of materials under the stress constraints.

### Optimization Issues:

This category is divided into two groups: Bound issues and unbound issues. Due to the existence of uncounted bounds for confining the tensions transfigurations and consumable materials, we are merely involved with the bound issues. Optimization methods were primarily applied by Ahn-tuan Nguyen and Sigrid Reiter in 2014. There are different procedures for converting bound issues into unbound issues. The most common field in this criterion is penalty function, bearing the current adopted application in the present paper. In order to discuss the criterion, we draw pertinent equations here:

\[
\text{minimize}: F(X) \\
\text{subject}: \left\{ \begin{array}{l}
  e_i(X) \leq 0 \\
  h_j(X) = 0
\end{array} \right\} \\
(x_L) \leq X \leq (x_U)
\]

Where, \(x\) indicates the design variable and \(F\) signifies the function of optimization issue, being considered as a scale for algorithmic designs and top lay out selection. It is obviously clear that optimization objective function does not adversely affect structural behavior. Therefore, it is necessary to render inequalities of optimum objective function produced in equation (2) as the constraint issues. The sign indicators of \(g\) and \(h\) prelude the circumstances in which want range of changes occur; such as the amplitude, capability to withstand structural loads plus. There applicable standard functions. In this algorithm, we can certainly mention the maximum and minimum levels of utilized bar limitations, changes of vessel concrete wall thickness, highest bar tension and the largest bar shift. The last equation signifies the different design variable limits affecting the computation, derived from non-behavioral structured considerations such as implementation issues in traduced by Sudib Kumar & Mishra et al in 2013. The structural optimization is not considered as a new approach. Hence, many studies have been implemented to estimate the related short comings of the criterion.

Fundamental optimization approaches produced in the area of structural categories include topology, shape and size optimization.

Topology optimization deals with optimum material distribution in the design variable domains by satisfying objective function to meet the constraints mentioned by Ahn-tuan Nguyen et al in 2014. The area includes the modification of structural shape, especially in the boundaries to eliminate the stress levels at the critical points. By the settlement of abovementioned approach, the optimum thickness of structural frames is available.

The objective of function in the structural optimization domains is consequently defined as the elimination of structural compliance in order to improve total performance, as it was introduced by Ralph Evins in 2013.

### Simulation process:

Production of initial accurate data leads to the accession of more reliable results.

Atkins Company compiles the most accurate data, considering iris bay tower as the main consultant society. Because it was impossible to deliver such a data under this period, we collected necessary parameters through different verified websites. Due to the critical role of the simulation data, we started the project by creating the geometry of structure during primary hyper mesh stage. Therefore, necessary coordination nodes were applied in order to clarify the unusual shape of tower. By illustrating exact shape of the structure based on the floor plans, we were succeeded to draw high accurate curves.

Atkins Company has provided high qualified living facilities for the tower in accordance with the application of necessary life standard, being utilized in other Iris building constructions in Dubai. Pertinent sale
conditions and necessary descriptions are also available through the website. By avoiding unsubscribed data on the 18th, 19th and the first three floor plans, the required categories were obtained via the site.

**CAD Modeling Based on BIM:**

In creating different geometry phases, the pertinent floor plan lengths were also required. Hence, available data were merely limited to the area dimensions of each office unit, based on the irregular geometry of until plans.

Due to the unique size and shape of each until, all the instances were separately being measured. The 20th floor is built at the middle of the tower, regarding as the largest floor plan. Thus, areas get smaller, as we react to the upper and nether floor plans. Although it was easy to refer CAD detailed software for the length measurement, we preferred handwork scales. Therefore, we altered the format into images, considering the 4th floor as the base functional area according to the fixed positions of elevator cabs in each floor, other necessary floor plan scales were obtained. The same procedure was applied in each criterion. Figure 2 illustrates the main process of measurement.

**Fig. 2:** Fixing the floor plans scale.

We made verified assumptions in order to reach the optimum coordination shapes of the next closed floors.

The main problem we faced on this phase was the structural domain altitude.

No access was available to the data on podium height, the ground floor and the last two floors which were suggested to be higher than other documents; we accomplished handwork measurements, by comparing ordinary floor height to the final coordination. Thus, we achieved following results:

- Podium height: 23m
- Ground floor height: 7.8m
- 31st floor height: 13m
- Height of the 4th to 31st floor: 11142m, which is totally configured as 170 m.

**Modeling of the elevators and stair:**

Specific places for the elevation settlement are imposed as square holes in the structure plan. Hence, the geometry generation is primarily being considered in the plan. This tower consists of six elevators in two parallel rows, plus two stair corridors. Because, there is not any material utilized in the locations, with no structural performance in the elevations and stair places, no modeling is produced for the area.

Therefore, there are merely existed as two square holes in the plan. Figure 3 illustrates the entire placement.

**Hyper mesh of the structure:**

Hyper mesh is considered as the FEA based tools. By creating the surface structure of the building, meshing objective is necessary for converting the big elements into small pieces. Although the analysis reach a slow process, but small meshing size results on optimum consequences. The small meshing size a long time analysis arrangement running by the powerful computer sets. The selected meshing size for the total of 47240 elements is equal to 1.03 m. whereas, the topology optimization running time is estimated for about four hours. The optimum selected shape element for the structure is considered as the main square format with no triangular object, in the criteria. Because of the irregular geometry of the building, the elimination of triangular elements is
regarded as a critical task. The most significant part of meshing process is to keep the matching point in-between the lines. The progress was quite successful. Figure 4 shows the accurate meshing criteria.

![Figure 4: Mesh line should be in the same line (floor 22 with balcony and wall between floor 21 and 22).](image1)

Fig. 3: Lifts and stairs locations are not modelled.

Fig. 4: Mesh line should be in the same line (floor 22 with balcony and wall between floor 21 and 22).

Fig. 5: Part of the structure with applied load.

The new components were configured in order to simplify the function, by utilizing a remarkable model to modify the feasible errors on the floors and outer wall plans. Consequently, there were 123 components being utilized in this model. Figure 5 shows the signified hyper mesh algorithm for the criteria.

**Shape optimization:**

The detailed shape and size optimization is illustrated in figure 5 which regularly relies on the topology optimization results. Therefore, size optimization of the beams and columns is accomplished in accordance with topology optimization.
The geometry of beams and columns is created along by Abstaining the optimum area of cross sections through the optimization process.

The geometry of building for size optimization is a one-dimensional process (1D). thus, the geometry of structural frame followed by the beams and columns model is originally created on the lines. Pertinent coordinated lines represent the load path frame. The one-dimensional meshing process is currently applied on these lines. The material properties are being adopted based on the 1D element.

The geometry structure for size optimization is rather similar to the topology optimization in order to fill the gaps in between every line edge.

The criteria for geometry of size optimization are shown in figure 7.

**Optimization results:**

In the present research, the process of topology optimization is carried out through the process of topology optimization is carried out through the objective function in order to minimize the structural compliance. The function is applied over different design variable domains, in order to address various structural aspects. The final results are being discussed within 4 separated categories.

The first one is considered as the main part of topology optimization in order to propose structural layouts. Rests of the categories are allocated to address the obvious result differentiations, based on parameter changes. The 4th category signifies the proper position of opening for the modified elevators.
**First category: the structural layout:**

All the elements are included in the design variable domain. The floor elements are defined as non-designable area.

The structural performances of these elements are involved in the domain area. Hence, no material is supposed to remove from the floors.

Therefore, the optistruct software structure produces the optimum layout for the outer shells. The main objective is to minimize load compliance by the 80 percent removal of non-applicable materials. These materials conclude concrete by the young modulus assumption of E=30 mpa and Poisson construction ratio of Q=0.15.

Following by 54 accomplished iterations through DESMAX=80, MINCIM=10 and DISCRETE=01 Scales, the final results for topology optimization are illustrated in figure 8. In this figure, the elasticity or material density distribution of the elements are shown. The red elements signify that the density of area is equal to “01”. This is a sign to modify that these elements are highly significant, due to their nominal stiffness properties.

On the contrary, the blue elements signify the density rate of zero as a sign of low stiffness quality, turning for the removal of these elements; the red elements are eventually equipped with structural load path and the skeleton. The topology optimization is arranged for the settlement of solid and void elements in order to reach the optimum material distribution therefore, all the elements are signified by the red and blue color space for the illustration of solid and void pieces. Based on the SIMP method, the optistruct software develops the significations in non-ordinated colors, due to the enormous limitations of this criterion. The system initializes the elements by providing black and white colors for the compartments.

On the contrary, the gray color signifies parts of the structure built on computational errors. These elements are considered as the deficient parts which should be removed from the structure, based on the analysis and investigations. Therefore, the criteria for engineering liabilities are designated as the arrangement for final load path. These elements are signified by specific color space as a sign of high material density which usually remains within the structure.

**Fig. 8:** Topology optimization results based on MINDIM “10” in four side rotation.

The results of above mentioned procedure signify undeveloped members of the structure. Figure 9 illustrates undeveloped members. Due to the existence of numerous limitations is SIMP system, these members are not adequately progressed.

Expert designers are authorized to take the responsibility for monitoring the progression of requested criteria.

The topology optimization is organized in order to reduce the significant rate of compliance load bar from 3.1444 to 1.427 during the last iteration phase. Figure 10 shows the optimum requested skeleton shape of the Iris bay tower, based on the topology optimization results.

**Second category: the structural layout by pure signified lower value:**

The present category is quite similar to the first one. It deals with the different MINDIM values. The results of topology optimization for Iris bay describe the relevant dependency of optistruct software on MINDIM values. Higher values signify the progression of optimum results. The following scales are applied during the process:
DESMAX= 80, MINDIM=05, and DISCRETE=01. Figure 11 illustrates pertinent scales.

Fig. 9: Undeveloped members by SIMP in side and front rotation.

Fig. 10: Required structural skeleton based on topology optimization result in 3D format.

Fig. 11: Topology optimization results based on MINDIM “5”.

By omitting the MINDIN values from the computational processes, no clear results are achieved in order to distinguish the load path frame of the load path frame of the structure. The value of 05 as it is recommended to be three times larger than the average element of meshing size, improves the results.
Based on the symmetrical loading and structural shape, the design optimization subordinates are considered as symmetrical frame. We did not chive the subordinated dimensions, by applying MINDIM value of 0.5, as it is shown in figure 4.4.

Hence, the problem was solved by the elimination of untested values.

**Third category: The design variable domain of excluding floors:**

In the present case, design variable domains are merely included as the elements of shell. The design optimization criteria involve the structural performance of the floors, without any removal of the materials.

Therefore, the design variable domain concludes all of the involved elements, except for the case of removal which can merely occur on the shells. The design optimization is carried without any consideration of the floors in the design variable domains to signify pertinent substantial role of the element in load bearing function by the relevant impact on removal of the materials.

Results indicate that there are numerous red elements with wider load path in the plan. Figure 12 shows the detailed results of structural performance. Final consequences of the plan seen quite reasonable; according to the fact that load bearing frame of the structure is considered as the single carried option of the elements. The present frame is wider than the one produced during previous optimization process.

Therefore, the layout is quite similar to the one being achieved in the first category.

![Fig. 12: Thickness of 0.2 m for floors, 0.08 m for front view and 0.18 m for other shells.](image)

6.4 Fourth category: The shell thickness of materials in removal process

The wall elements are considered as the design variable domains for removing non-applicable materials. Therefore, topology optimization is carried out in order to signify the effect of defined shell thickness on material distribution.

The final thickness for all the shells was similar and equal to 0.2 m, during the last processes. Whereas, the thickness of front view is 0.08 m, thickness of front view is 0.08 m, thickness of the floors is 0.1 m and the case for other shells is defined as 0.18 m during the present process.

The results of this approach are completely shown in figure 13.

As it is illustrated below, the visual layout frame is wider than pertinent case, drawn in the first category. The final experiment shows that by the elimination of derived thickness, more material is being saved within the structure.

**Fifth category: Defining the appropriate place of opening on the elevators:**

The design variable domain includes all the elements of shells and floors. During the previous topology optimization, the location of elevators and stairs were signified within the architectural floor plans. The detailed criteria are shown in figures 3.1 and 3.4.

In the present process, the main objective is to reach the best feasible location for the elevators opening to match with the optimum design. Therefore, the elevators openings are completely covered by the removal of materials from shells and the floors. By applying this process, the topology optimization layout is drastically changed.

The present case is completely comparable to the first, second and third categories of the final conclusions. Figure 4.6 illustrates the shells layout and figure 15 represents the floors layout.

By the review of floor plan categories, we come across the fact that in the majority of cases, solid elements are situated in the middle of the plan. As it is shown in figures 15 and 16, the red elements are usually positioned at the elevation openings. These parts are signified by the density rate are signified by the structural layout.

The abovementioned elements require a higher amount of reinforcement. Therefore, the position of elevations is not rather proper in the criteria of optimum design.
By the displacement of elevators, position from the middle of the plan to the blue floor area, we are completely capable to reach the optimum design.

**Fig. 13:** Floor area is not included in the design variable domain.

**Fig. 14:** Shell layout of structure.

**Fig. 15:** Topology optimization layouts of a few floors, floor plan 14, 17, 24, 27 from top left to right down.
Conclusions:

The development of new structures require optimum feasible layout for the designated design objectives and relevant constraints during the early stages of design process. The topology optimization design followed by the detailed size and shape optimization is being considered as a perfect premium suggestion for the initial concept design in order to provide the main optimum skeleton layout. Although the topology optimization arranges the layout based on the stress rate of applied loads, the accurate consideration of signified code request in order to provide the durability and stability functions is prominently significant.

Because the specified codes are permanently arranged for the routine structural design due to the resistance of vertical and horizontal members, the revision of code requests is regarded as the most complicated task within the criteria. Size optimization results are interpreted as the initial values for the process by considering the fact that the revision of code request cause for the entire size alteration.

Hence, the expert designers are able to change the layout, due to the provision of code request namely as the shear wall configurations or concise manufacturing settlement. There are not sufficient applicable procedures for monitoring the SIMP process. Therefore, the gray elements grow and the number of undeveloped members arises during the fundamental application the responsibility of designer is to suggest various layout for reaching the optimum feasible approach in order to fix problem.

Because the optistruct function relies on the MINDIM value for the main criterion, due to the depending process of SIMP model on penalized values; the designer is responsible for the checking of different values in order to gain the best possible results.

In addition to the abovementioned criteria, the creation of structural geometry in hyermesh appears as a complicated task and time consuming effort.

The rigorous advantage of applying optimization design on Iris Bay is to access the free inner space for the building, followed by the removal of internal columns in order to decrease structural compliance from 3.1444E5 to 1.427E5. Although optimization results suggest a significant feasible application, subjected by the main constraints for revealing an optimum structural design in the criteria of civil engineering based on the topology optimization; it can be more expensive and time consuming. Consequently, we suggest that because the simplified schemes are possible to design for an easy rebuilt, it is preferable to put the layout for the small structures by the assistance of applying conventional methods.

REFERENCES


