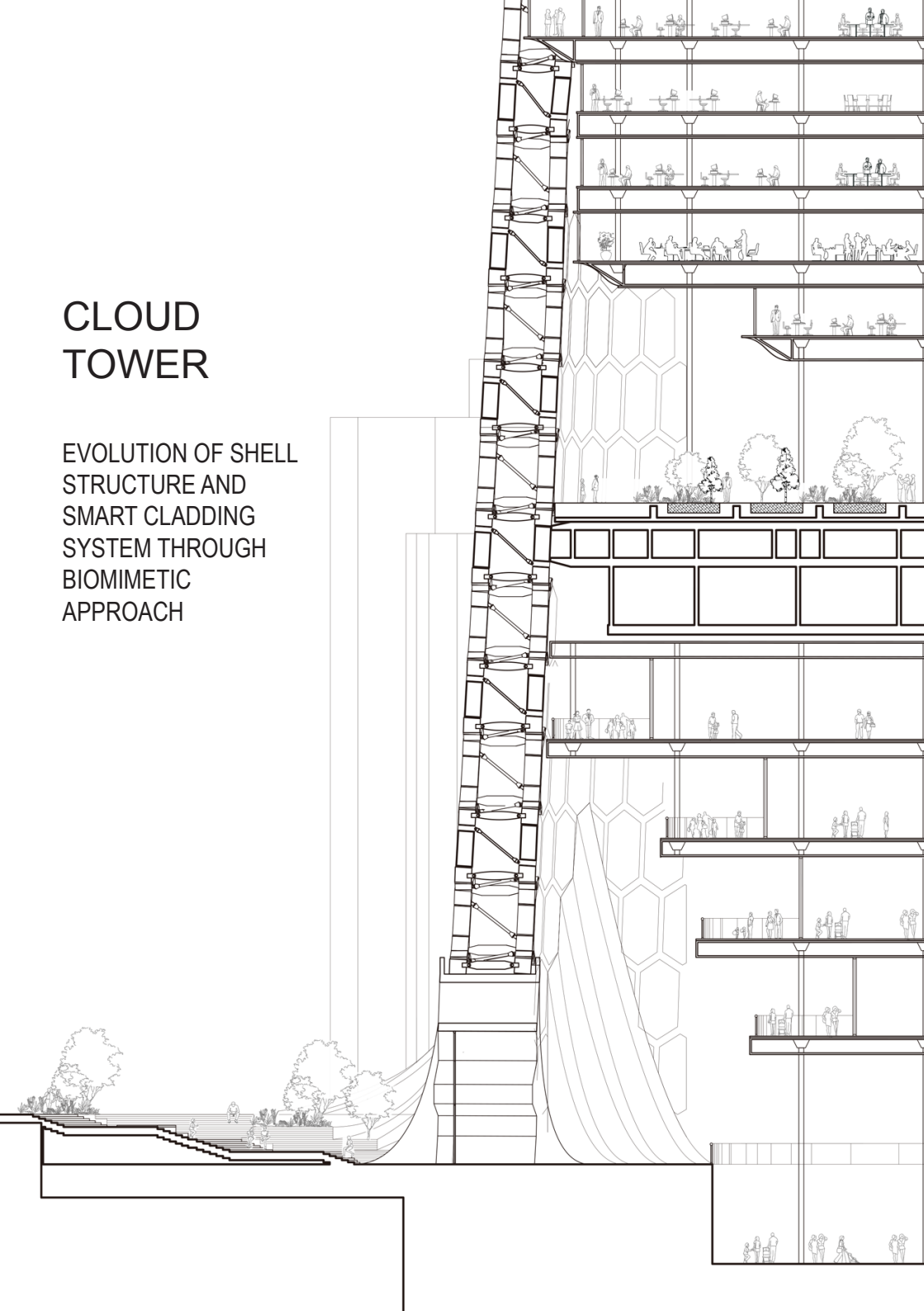
CLOUD TOWER

EVOLUTION OF SHELL STRUCTURE AND SMART CLADDING SYSTEM THROUGH BIOMIMETIC APPROACH



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EVOLUTION OF SHELL STRUCTURE AND SMART CLADDING SYSTEM THROUGH BIOMIMETIC APPROACH

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M.Arch. 2 Thesis
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ABSTRACT --- RESEARCH

Around 100 years ago, Le Corbusier suggested new material and technology results from a new form of architecture, hence, the new city. His insight comes true. Now we get our new material and new technology, what will be the next?

To get a glance on future, understanding the past, see the present, and search for potential systems is a good approach. For the development of the contemporary architecture, specifically, the high-rise, is the history of the development of three systems, the structure for support, the facade for protection and regulation, the service for transportation.

Every time, when there is the breakthrough, the complexity, the mass, and the design potential increase. And some of the architects takes the integration as a good tool for space making.

Man do things in different systems, how about nature? Nature handles the task in a more integrative comprehensive way. By the same module, which is, the cells, undergoes different optimisation, they show a range of behaviour and hence, from the molecular level to tissue, from organ to holistic, they show a different hierarchy of evolution and the simplicity of the rules behind shows the elegance.

A system, that handles static, vertical loading, in a compact context, light, void, flexible, huge height depth ratio, is chosen. And the system is a kind of grass, the bamboo. To describe the bamboo, it is a pneumatic double curved thick cellular system with service integrated. To learn from it, a profile and a proper facade structure are required.

The shape chosen is the hyperboloid, one of the very few vertical shells that handle the vertical and lateral load well, we can describe the profile in different ways, which also means the load path chosen. We learnt how nature do structure, how does it do facade? A facade system that limited the joint number, component length, with almost equal spacing, simple operation results in unlimited profile? Two systems show such merit, the geodesic dome presented by Fuller, and the carbon fibre system. Which inspires use, a developable structural cell with high transparency and light weight can be developed.

The learning from nature, with the integration, the computation: simulation, parametric, BIM, can form an architecture by the bottom-up approach, we become the rule setter rather than the parameter, and the system tells you what they want, for a good performance. To bring the simplicity of nature into architecture is my hypothesis for the new architecture.

KEYWORDS

Mega-tower, Biomimetic, Computation, Environmental

1920s
Situation:



Heavy, Packed Paris
1920s

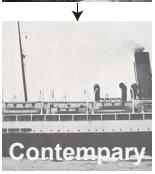


Condition:



Material:
Masonary

Technique:
Craftmanship



Material:
Steel and
Glass

Technique:
Fabrication

Design:



Brighter
Lighter
Stronger Architecture



City Planning
That can free up more
land



Reality:
Shatin, 1990s

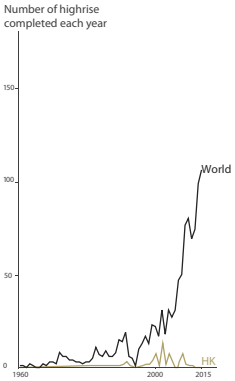
2016
Situation:

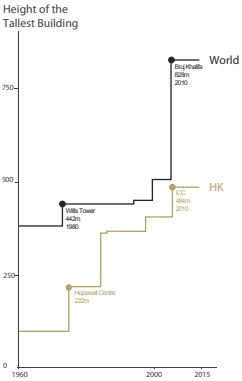


Manhattan



Hong Kong





Condition:



Material:
Steel and Glass

Technique:
Fabrication

Design:



Carbon
Fibre

PTFE

?

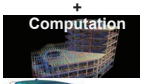
+



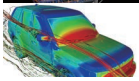
CNC

3d Print

+



Building Information
Modeling



Simulation



Parametric

Figure 1. Present Situation
The change in technology and material brings us a new method of handling new challenges.

ISSUE

High-rise was once the suggested solution for the urban development. Claimed by Le-Corbusier, the new architecture should be light and bright, compared with the old age stone building, which is dark and heavy. The new architecture should be a machine for living. Base on the above paradigm, he suggested the famous new town planning of Paris, to free up the ground level for open greeneries and vehicles, residents can enjoy the streets in the sky.

The insight of Le-Corbusier is very precise, and most of his prediction on the usage of the technique, that is, glass and reinforced concrete, happens nowadays. The high density of the cities is achieved under the evolution of human society.
And hence, we are not at the stage that the central part of cities suffered from over-density. Cities like New York, Hong Kong and Manhattan suffers from the over-density of towers. At our age, we can still claim that such context is very specific and rare. But we can see the continuous trend of the establishment of the high towers all over the world, the rate is increasing gradually, with the increase in global population, we can simply foresee that the high-density tower contest will become increasingly common in the future.

Considering the new materials, for example, PTFE and glass, carbon fibre and concrete, and read the comparison said by Le-Corbusier a century ago. The comparison between masonry and reinforced concrete, the difference is humble, we get stronger and lighter material, hence, we need the new system for the architecture, for a lighter, brighter but stronger architecture. We should learn from the ship making, the car making industry, they have gone beyond us.

Our tower now takes the role of the stone house mentioned by Le-Corbusier. In our age, we need our new architecture.

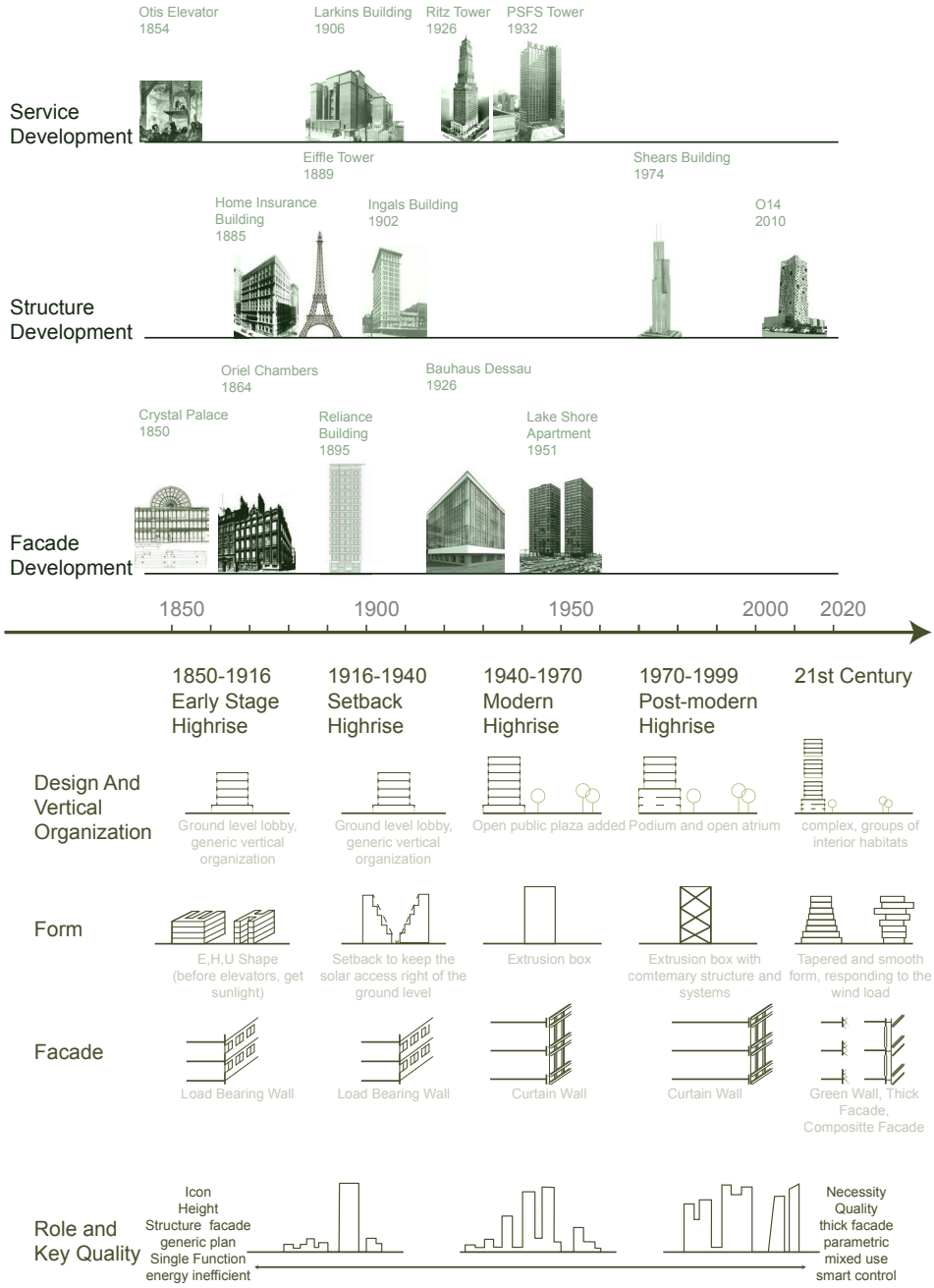


Figure 2. History of Innovation

The innovation is mainly brought by few innovation of buildings, the increase in degree of integra-tion is also shown.

ANALYSIS--- High-rise Brief History

‘As an architect, you design for the present, with an awareness for the past, for a future which is essentially unknown.’

Spoken by Norman Foster, the idea of understanding the constraint through learning from history, understanding the potential through examples of the extraordinary cases, hence learn from systems that get the potential for further integration and creating new future, can be a good approach. From the analysis of the contemporary architecture, in specific, the high-rise, we can concentrate on the key issue.

The main design Issue of high-rises: The Structure, The Façade, The Service

When we read the development of the high-rise, we can discover that the innovation this kind of architecture mainly can be classified as the above category, the structure for supporting, the façade for protecting and the service for transporting, the innovation mainly improves few elements, the light, the indoor environment quality, and the floor area. Innovations result in higher efficiency and hence a higher design potential, which results in the increase in height and complexity of the buildings. In 1853, Elisha Graves Otis invented the world’s first safety lift, this form of new vertical transportation enables the stacking up of stories; The crystal palace in 1850 demonstrated the potential of the prefabrication and the combination of flat glass with steel frame; the establishment of the Eiffel Tower in 1889 suggested the new potential of reaching sky height; the Larkins Building, designed by Frank Lyold Wright, in 1905, shown the potential of creating indoor environment regulated by central air system; the Bauhaus Dessau, built in 1926, gave the prototype of contemporary curtain wall system; the PSFS Tower, as the integration of all the achieve mentioned above, voiced out the new form of International Style tower.

Started from it, the general setting of high-rise system setting is mature and the principle is generally followed. Although the composition of curtain wall, external shading, integration with the green wall, and few thoughts of parametric profiles was tested, the principle, which is, the light, glass façade, which are generally not operable, as protection skin, is followed.

Same as the façade, the structural principle is also formed and was generally followed. Although the material often shifted between reinforced concrete, steel, and their composite; the core can be split or centralized; the principle of 'the core as a stiff main support structure connected to a stiff shell, our bundle of tubes, or another stiff core; horizontal structural member transfers the lateral loading and live load at between, usually as a beam' is followed.

For the service system, the principle of 'main system providing heat exchange, vertical transportation for passengers and materials, were kept at the roof, refuge floor and underground; the vertical piping is hidden at the central of the building, service systems at each floor are hidden at the ceiling sandwich, no matter above or below head' is followed. The integration of three systems, in general cases, are humble and mainly exists in the spatial arrangement, but not in function integration.

The general history can also be described as the struggle for light. At the early stage (1850-1916), the façade needed to serve the load bearing function, which meant the opening can just be small while the small opening results as the dark interior space and the limited depth of the building, form of the building were hence limited to the E or H shape. The development of the curtain wall from 1916 to 1940 caused the paradigm shift and the hybrid, setback high-rise was the mainstream, on an average of 10 to 30 stories, a rectangular plan, planar façade started to take place, and the depth allowed increased. From 1940 to 1960, the modern high-rise, with the generic plan and

mature, mirror-like façade, was dominant.

We can see three struggles started at this stage. First, the need of increase of height caused the increase of footprint of the buildings, in which the depth of the building plan increases, second, the increase in height deepen the detachment of the high floor to the ground, which caused discomfort; third, the increase in opacity of the façade caused the uneven light distribution. Over-exposure and under-exposure happened at the same time.

This caused the start of the post-modern high-rise stage from 1970 to 2000. Hybrid usage of a tower, insertion of sky atrium, more fluent and free form, thick façade, double façade, green façade, kinetic façade, all these methods were tested to improve the indoor environment and create a comfortable natural lighting.

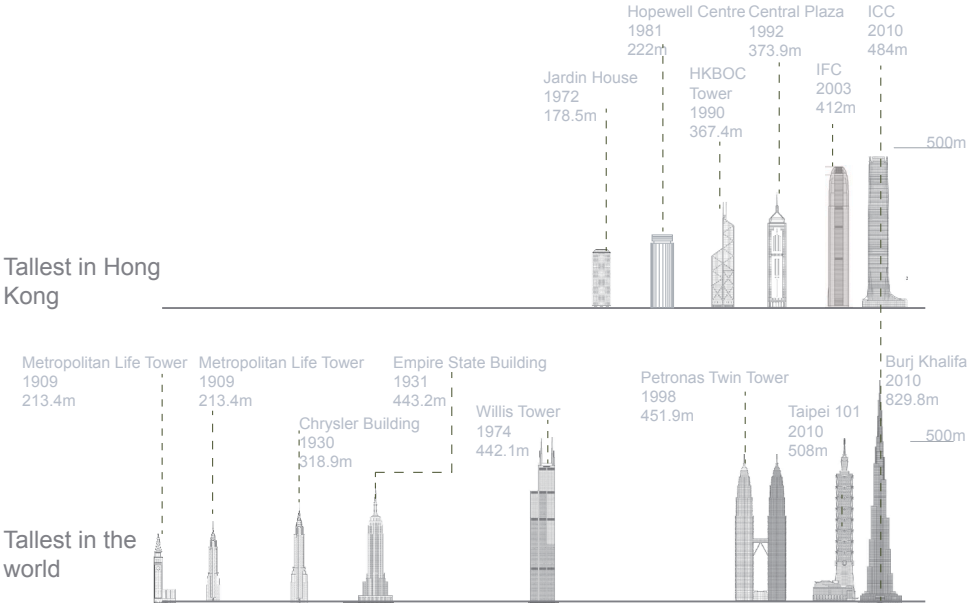
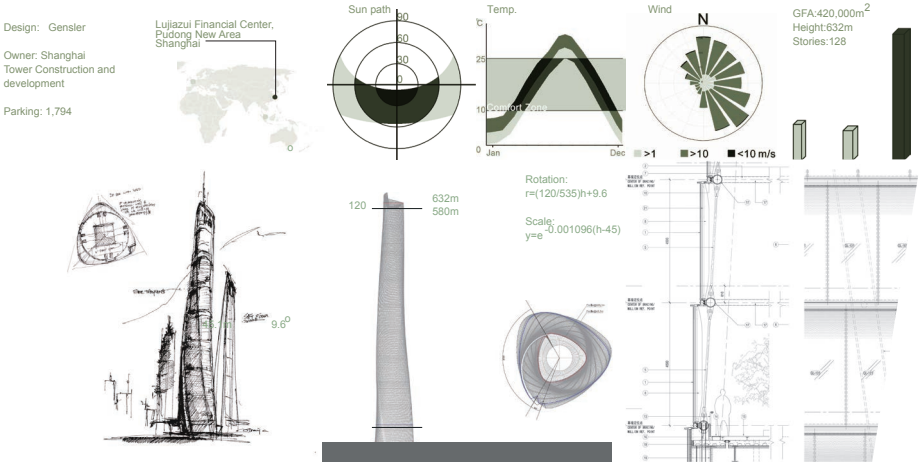


Figure 3. History of Tallest Towers



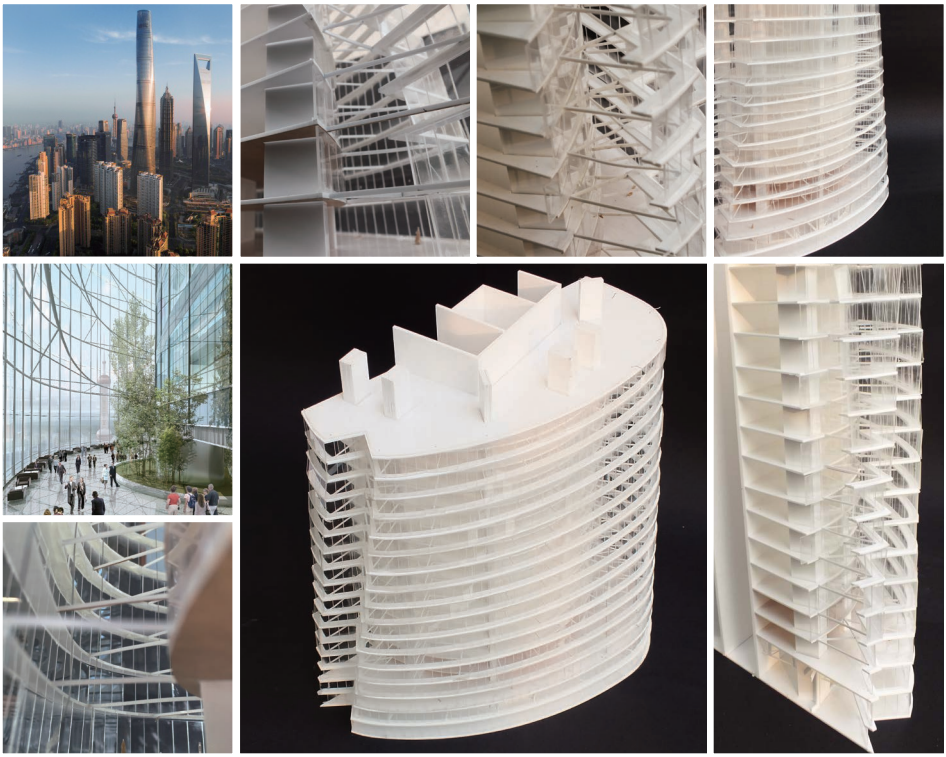


Figure 4. Analysis of Shanghai Tower

The profile formula and the design sketch shows how the start-up concept can lead the design de-cision from the form to the detail.

Case Studies

The design in sky habitat in towers can be done only in an integrative approach, with the effort of choosing the right systems and comprehensive collaboration. Three cases were chosen as a study of contemporary methods.

Shanghai Tower

For the Shanghai Tower, the architect described as, ‘The most efficient core shape, which is the rec-tangle, covered by the most efficient façade profile, which is circle, protected by a dynamic shield minimizing the wind load.’ The most eye-catching part of the tower is his profile, a round-edged, triangular shape plan with a taper as wind-guide, rotate and scale down with the height, resulted as a twisted and tapered profile. With the collaboration of the wind engineers, they can choose the most optimized shape in wind-performance, profile, and floor area.

The twisted profile contradicts with the need of the rigid floor plan, the architect decided to hang the façade outside the inner skin, which raised the potential of increasing the flexibility of the façade, each groups of the façade, which is composed by 13 to 15 stories, can move up and down within 250mm, which reduced great amount of wind load.

By all the methods mentioned, architects can hence reduce the structure load and hence, structure sizing, which increased the usable floor area and sky atrium can be created even under high land price.

St Mary Axes

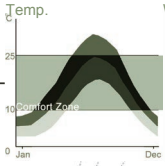
Design: Foster + Partners

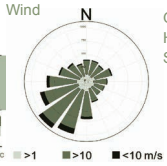
Owner: Evans Randall; IVG

Parking: 272

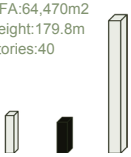


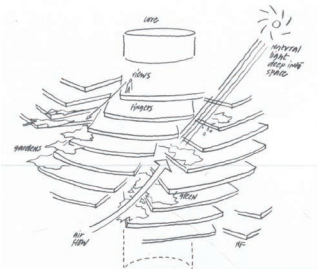


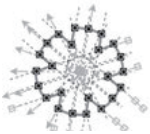


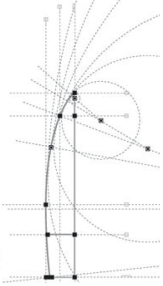


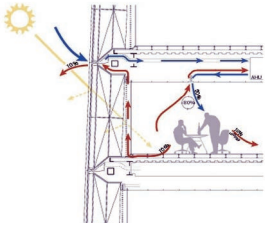
GFA:64,470m2
Height:179.8m
Stories:40



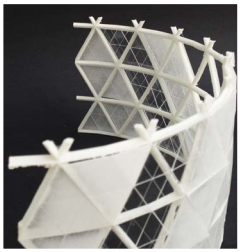






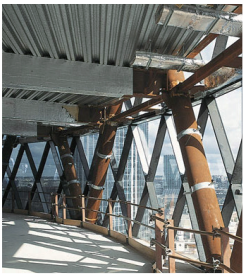


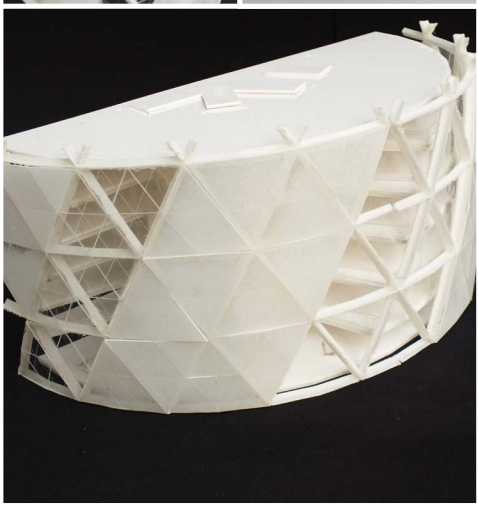














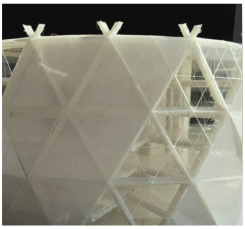


Figure 5. Analysis of St. Mary Axes
The initial needs lead to the twisted atrium, hence the choice of the structure and the profile.

St. Mary Axes

For the St Mary Axes, Norman Foster wanted to increase the depth of the building, light shall be able to penetrate through, stack effect shall be induced to regulate the indoor environment, a twisted atrium is suggested. To achieve so, a stiff, rigid external tube is required, such that floor slabs can be hung between inner and outer tube.

To do so, a double spiral diagrid structure is used, and the penalization as a mixture of triangle and rhombus shapes are used. The fully dynamic shape can be panelized that only one panel, which is the tip, need to be curved glass, rest are all planar glass, while the shape and the logic of penalization can easily be described by formula, this makes the building becomes one of the textbook examples of digital architecture.

The disadvantage of the system is the high rigidity and heavy self-weight. Since the load transfer is heavily dependent on the triangulated shell structure, we can imagine that if the building is scaled up, the diameter of the shell would increase exponentially with the height, which would heavily affect the opacity of the outer façade. It means that the structural scheme may not be scalable.



Figure 6. Analysis of the Commerzbank
The utilization of the proper structure leads to a neat solution for the spatial arrangement showing beauty of rhythm.

Commerzbank

The challenge taken by the Commerzbank is creating large void in mega-tower. To do so, the archi-tect used the side-core scheme, the core is split into three mega-columns, while the floor-slabs are hanged between the cores, the system is mainly under suspension. This move allows the architect cre-ate a set of dynamic atriums by simply rotating one set of floor plan.

The disadvantage of the system is the concentration of loading, we can imagine that once we scale up the building, the deflection difference of the three cores will increase, so as the span of the floor slab in between, the connection for the slab and core, needed to take the load of stabilizing the three cores, the suspension loading and the self-deflection, which means the building may tear himself apart un-der strong wind. It means that the structural scheme may not be scalable.

The Biomimetic Approach: How Nature Works

The most optimised system is the nature, the difference between man-made systems and the natural system is significant, which means that the fundamental issue would result in the limitation of our biomimetic design. The reason of the fine optimisation of nature system is the harsh natural environment, which means the evolution can be considered as a large trial and error test, ran for millions of years.

The basic difference is the nature system develops in their complexity while human system develops by the increase in complicatedness. Which means that nature world uses a single type of unit, which is, the cell, to compose into systems hence the organism, although the form and performance are differ-ent, the basic composing principle is the same, from a cockroach to an elephant, from the liver to the brain. While for a man-made system, the tasks need to be handled by different systems, and there is no universal cross-disciplinary unit.

The hierarchy in the structure in nature is much finer than the human system. Which can be proven by the comparison of scales in systems. In the natural organism spectrum, we can see that from the smallest scale (100nm, which is the virus) to their largest member (100m, the largest trees), the spectrum of organisms is continuous, the evolution happens on every scale. While for man-made machines, we can see a huge gap between the 100nm scale, the starting-up Nanotechnology, to 0.1 mm, the fine mechanism, there is almost nothing between them, which means we can hardly simulate the hierarchy between the scales mentioned, our material composition is not as fine as the natural material. Comparing to the natural system, our structure is rather monolithic.

Another fundamental difference is the assembly process, for organisms, they undergo composition by growth, there is

no clear line of the ‘end’ of the composition, the relationship between composition and repairing is close and can be concluded as the metabolism, while for the human architecture, in general, the phase of the construction and the repairing, aging, is clear. It means the construction pro-cess of man-made architecture can hardly do the response to the natural environment.

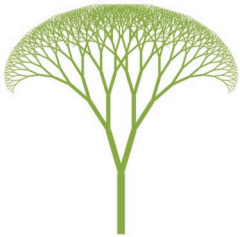
The cellular system with the growth process results the organism can undergo real-time response to the environment, the parts need to be thickened can meet the requirement and so as the elimination of the redundant part.

Nature also tries to limit the data that it needs to handle, to keep the good balance between the system, the order kept in the genetic code, and the chaos, the adoption of parameters from the natural environment. The tools are the fractal, ratio, segmentation, and patterns through basic rules.

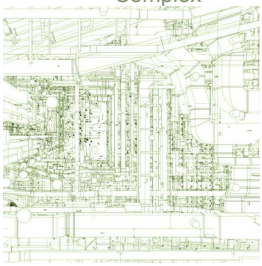
Take the growth of the trees as an example, the growth of the branches follow the Fibonacci sequence and once the tip of one branch is broken, the other branches would take up the left space, the sizes of each division are on ratio, it means that by only considering the size of the stem, ratio, and the degree of hierarchy, the size of every item at any stages can be estimated. On each leaf of the tree, the main vascular bundle would first divide the leaf area into zones, and the secondary vein will do the further division, hence the process would be repeated. Again, the segmentation works with the fractal, keeps the simple rule in the complex system.

For the design of a biomimetic system, the simulation will replace the part ‘growth’, we would try to set up the growth pattern for the structure, and set up in the environmental parameter. The difficult part is we cannot simulate the ‘accident’ in the growth process, the result of the simulation would be too perfect. The balance between spatial arrangement and physical condition is also a concern is the setting-up process.

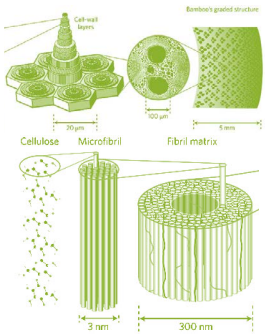
Nature:
Complicated



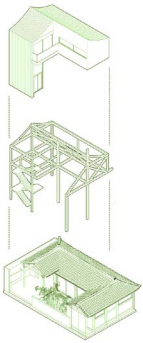
Man-Made:
Complex



Nature:
Hierrachi in Structure



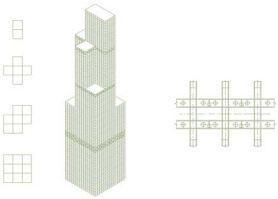
Man-Made:
Monolithic



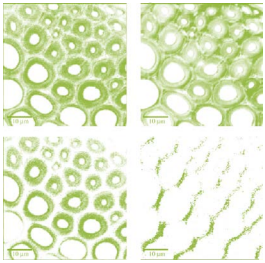
Nature:
Cellular Structure and
Segmentation



Man-Made:
Unit Structure and
Zoning

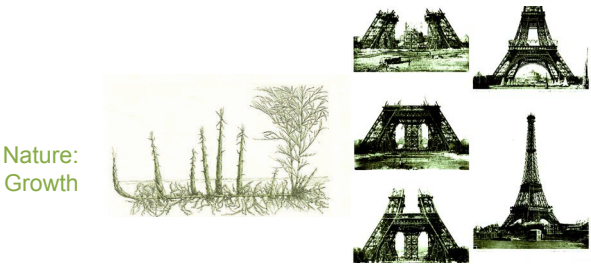


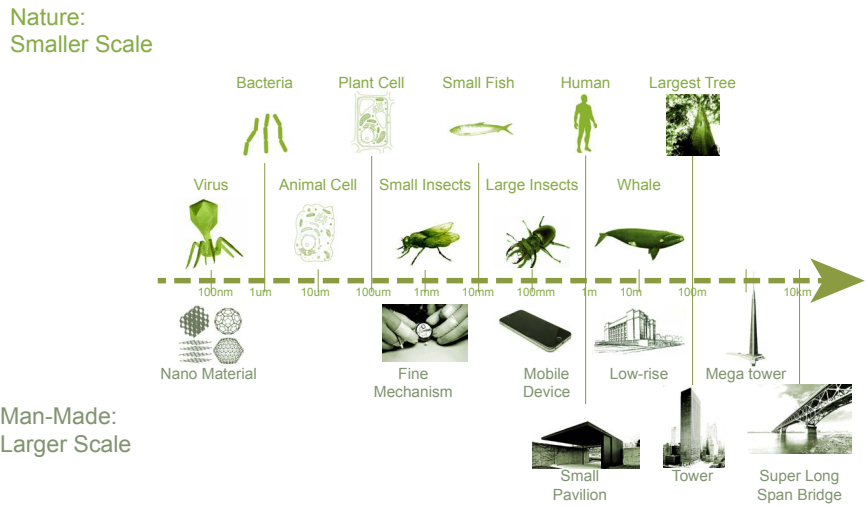
Nature:
Allow Stiffness Variation and

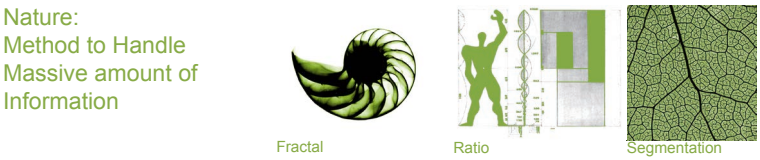


Man-Made:
Less Variation









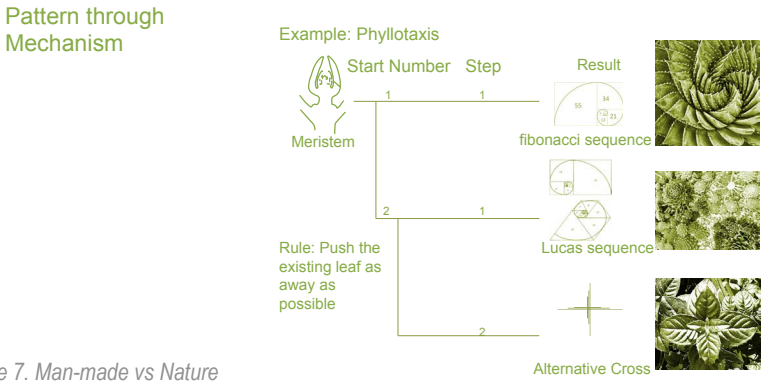


Figure 7. Man-made vs Nature
The difference in scale of the systems between man and nature brings a fundamental difference, the learning would be in the method rather than a direct copy.

System Study: Bamboo Structure

The choosing of the natural structural system that to be learnt shall serve the basic challenge of the high-rise, it needs to be a vertical load bearing system, high height-width ratio, in dense context, flexible structure that withstands wind load well, and with the large void. All these criteria suggest bamboo and tree are preferable systems, in specific, bamboo is better.

In comparison, bamboo is a kind of ‘grass’, which gets shallow root, it is lighter than tree system, as it gets a hollow structure. Its branches, comparing to the stem, is very light and negligible, which keeps bamboo as mainly a tower structure. The tree system is a result of evolution for a different concern. The tree needs to take up maximum area for each individual, the stem serves as the base of loads of cantilevers, it needs extra strength and hence shows a solid stem.

In this case, we can discuss the hierarchy and structure in a more detailed manner.

The optimization for organisms happen from a molecular level, take the cell wall as example, cell wall is composed of cellulose, which can be further examined as a bunch of polysaccharide chain, the chain is tied and twisted as a cable, hence a tendon, then each ‘tendon’ interweave as a non-woven fabric structure, which becomes a strong multi-directional fabric structure.

This ‘fabric’ would wrap up a plant cell, once the plant cell sap (water capsule of the plant cell) expand, the cell would become a water balloon with the rigid wall. The cells are then packed, held together by Van der Waals force, forming the tissue.

The tissue, formed by cells with varied sizes, can be roughly divided to the vascular bundle, the ground tissue and the epidermis. The vascular bundles are arranged in a Fibonacci Spiral pattern to ensure an equal spacing for an even

distribution of water and nutrient, the ground tissue fills up space and creates pressure to the relatively dense epidermis. On the other words, the system is pre-stressed by the expansion of the ground tissue, and that is the reason for the elasticity of the fresh bamboo.

The bamboo tissue then forms the thick double curved hollow section, the hyperbolic shape gives a good load transfer path. The node serves as an outrigger truss, which makes the bamboo works as a group of spring connected is series.

We may consider the bamboo as a double curved pneumatic multi-layered flexible thick shell structure with outrigger integrated with service system, to further analyze it, we need to consider the exist-ing strategy used by high-rise, the basic structural principle, the method describing the double-curved profile and its behavior, and the penalization method for structural shell façade system.

Arrangement and Structural behaviour:

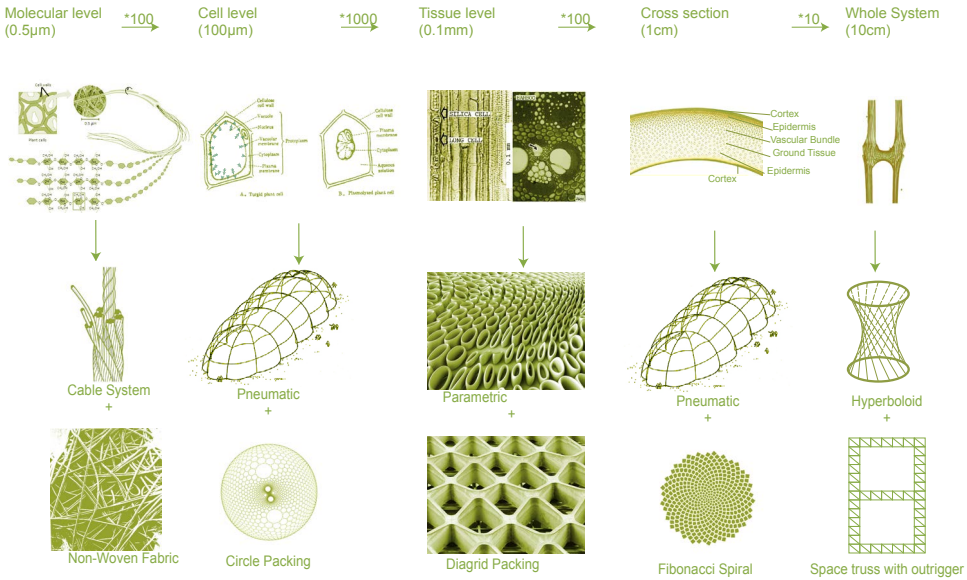


Figure 8. Structural Hierarchy of Bamboo
The structural behavior of bamboo can be analyzed in different levels, and they show the differ-ence but still be composed by single system.



Figure 8a. Structural Comparision of Tree and Bamboo
Through comparision, the structural merit of bamboo is clear.

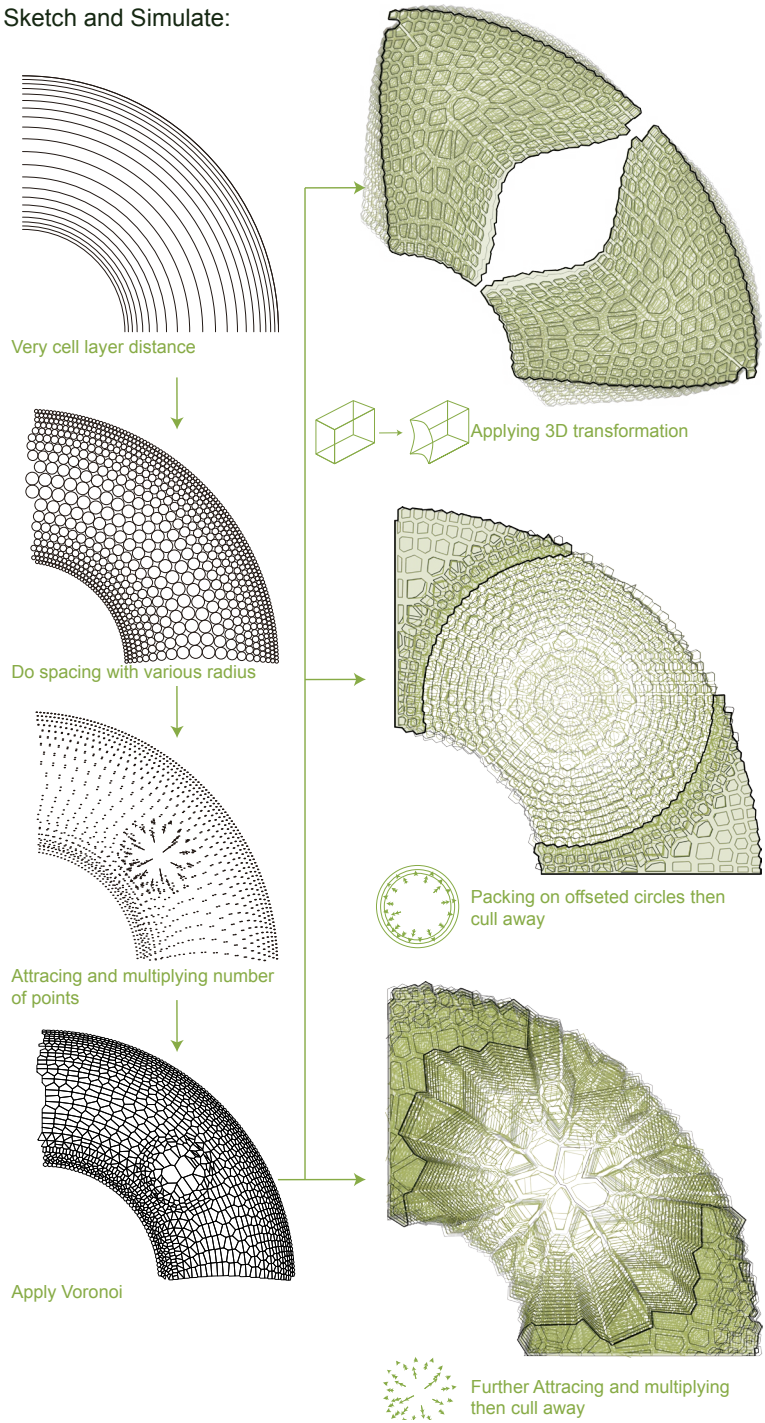
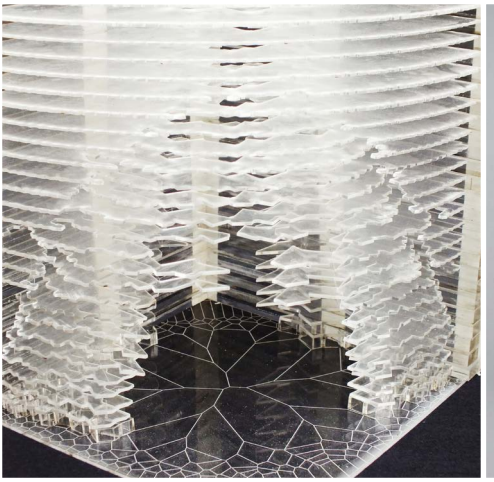
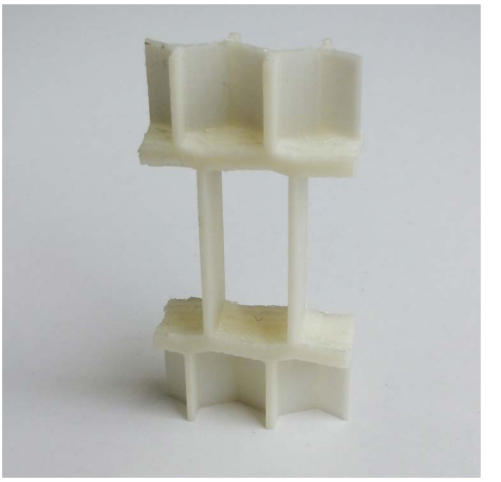
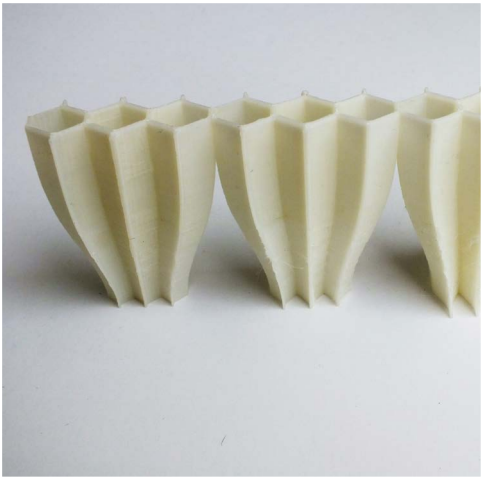


Figure 8b. Sketch and simulate
The different ways to simulate and draw the bamboo cells configuration.



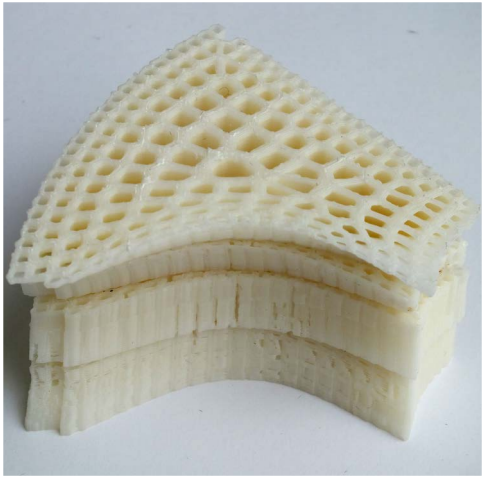










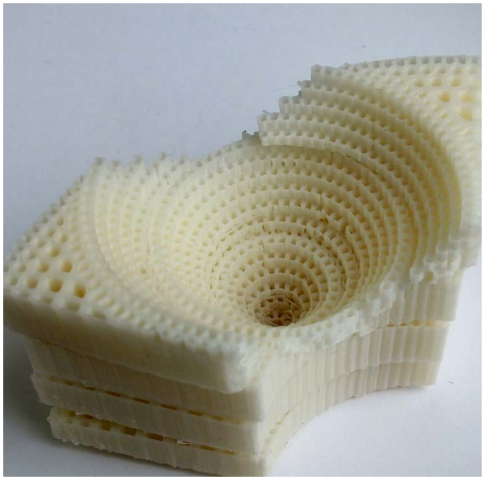



Figure 8c. Sketch model
The sketch and parti of bamboo cell structure and configuration.

Tall Building Structure System, Loading, and Its Influence onto Spatial Performance

To discuss the relation between structural behaviour and the performance of the tall buildings, a short review on the structural design principle and the loading of the high-rise is necessary. They are the guidance on the choice of systems.

In general, the efficiency of material undergoes tension is slightly better than on compression, and the bending shows much worse performance. It is because structural failure that happens in the tensile system, can only be the tearing apart of the material; under compression, buckling can happen before material limit; for bending, a material can undergo torsion, shearing, buckle and that means low efficiency.

Not only the type of forces but also the distribution of force and the moment is also counted. The basic principle is dispersing the force to the whole system as even as possible, the less concentration spot of force the better, the weaker moment created the better, and the larger force can be absorbed, like damping, the better.

The basic loading of high-rise can be divided to vertical and lateral. For the vertical loading, which varies in a steady manner. Even for live load, a human would not be heavy in one second then becomes zero weight in the next second. The loading increases in proportion with height generally. While for the lateral load, which is mainly the wind load, the point load increases with height, until certain height, depends on the roughness of the surrounding (the height of the building, the topography, etc.), the point load becomes constant. The wind varies with season, when blowing, it shows a periodic pattern, it can form turbulence, and hence become drifting or sucking force.

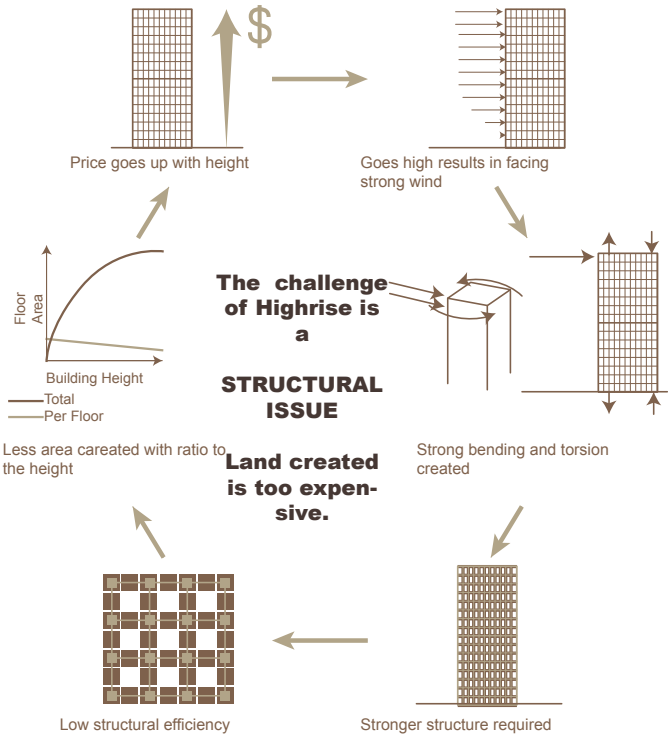
On the other words, gravity load can humbly be affected by profile, flexibility, or damping, but wind load can be reduced by the methods mentioned above. The method of structural optimisation can be defined as, reduce wind load, reduce gravity load, and increase cross section.

Some of the systems can be considered as a reference. The truss system, showing a light weight, even load spreading system, with high integration potential with the service system; the suspension system, which is funicular, can vary the form with force, shows high efficiency in material, can be the structure for holding floor slab; the pneumatic system, which is funicular and always as a pre-stressed system, balanced by the surface tension; the shell system, which allows the point load transfer as the compression through arch or compressing ring, these systems and the principle can be in inspiration for the building.

Figure 9a.

Viscious cycle of the relationship between structural loading and the building price.

Viscious Cycle



There is a vicious cycle, the rent goes up with height, while strong wind would be faced with height, which creates strong bending and torsion, which causes stronger structure built, which implies larger dead load, hence results as lower structural efficiency, which results less area created with ratio to the height, since floor area is rare, price goes high. We can conclude that huge part of the challenge of the high-rise is a structural issue.

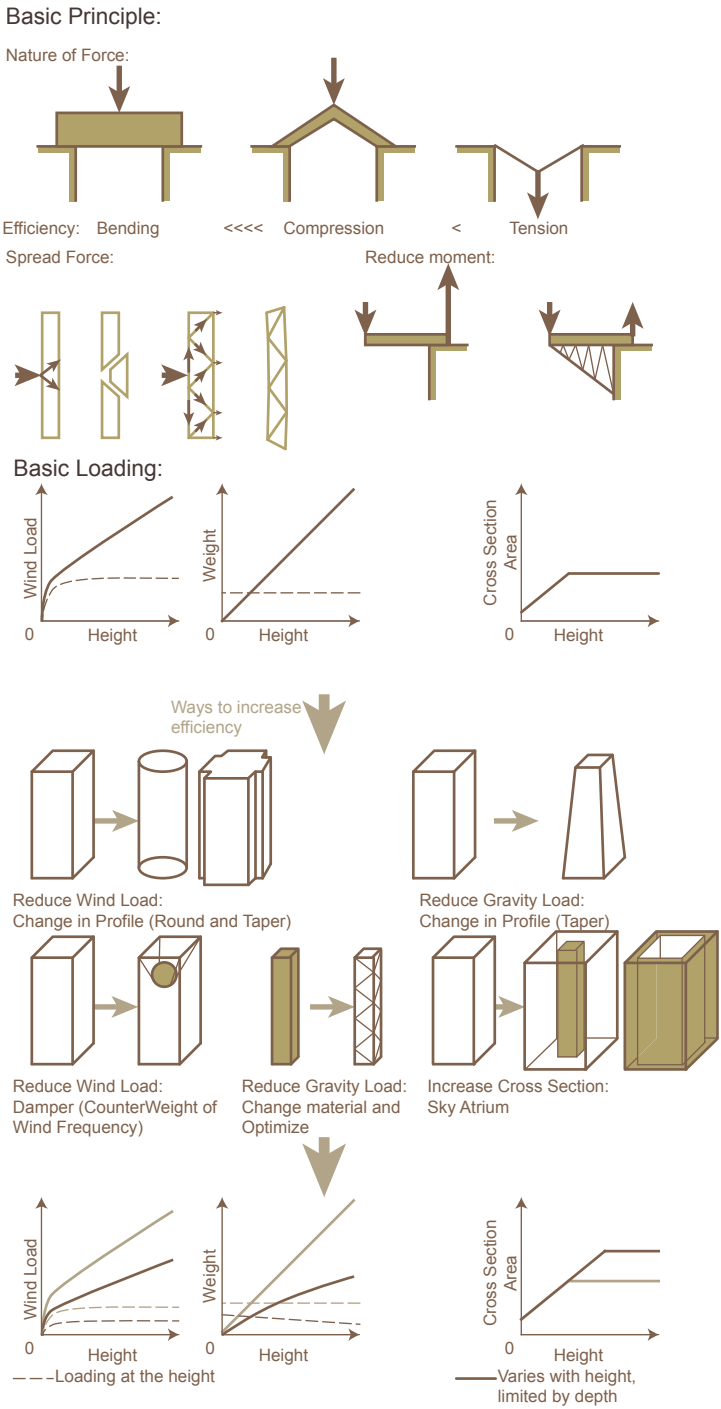
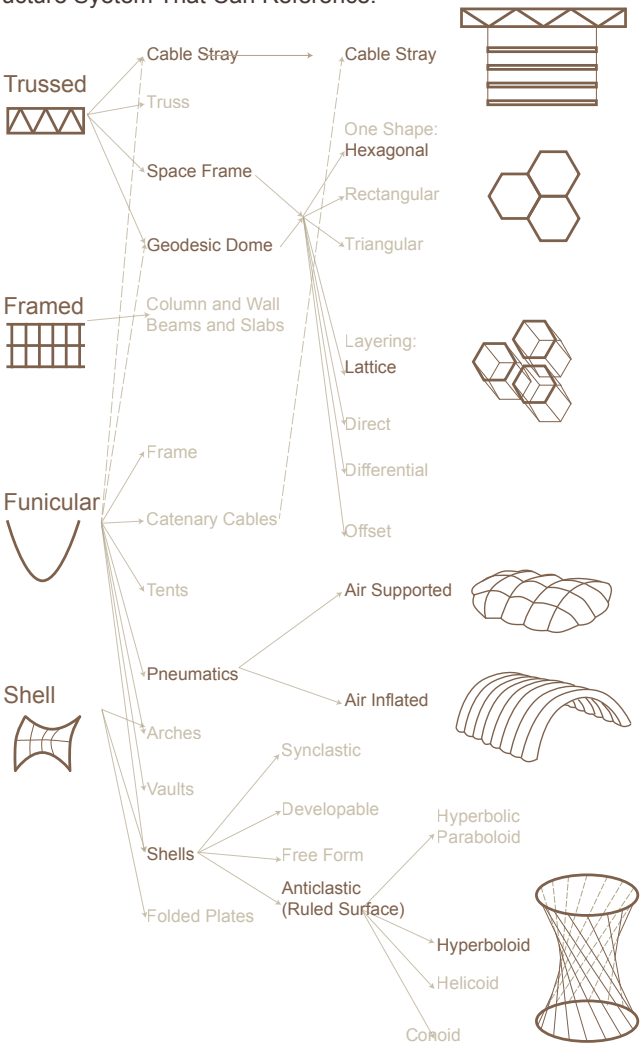


Figure 9b. Optimization Approach
The approaches that can be adopted to optimize the structure.

Structure Syetem That Can Reference:



Existing Structure:

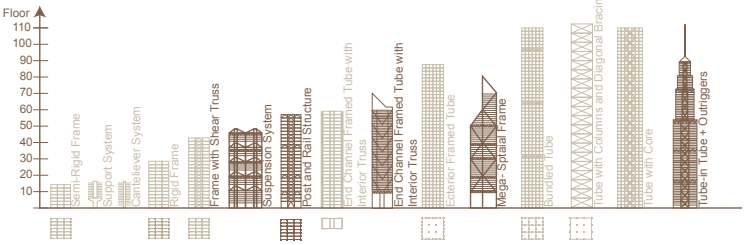


Figure 9c. Choice of Systems
The choices of structural system that are similar to the bamboo structural systems.

Structural Façade: Geodesic Dome and Carbon Structure

Quote by Buckminster Fuller, ‘the sophistication of a building varies inversely as its weight’, the system we need to choose shall have high transparency and structural integrity.

Space frame can be one of the best choices. The grid shall be developable into multi-scale, that is, the further division shall be able to be done within frames, or small frames shall have the ability to construct a bigger unit. The systems shall show a deep structural depth and exists in long span; the system shall show huge redundancy and multi-load path. In which, space frame fulfils all the requirements.

Another question shall be asked is which kind of frame shall be chosen, in which shape and by which method. The choice is limited to regular tiling polygon due to the intention of keeping minimum kind of units and joints. Comparing the square, the triangle and the hexagon, the rectangle is not the priority as it shows a two-way grid, huge deformation can easily be formed by point load. The triangle is very stiff and exists as the only shape showing self-stabilization, but the amount material required is required within the three shapes, the high rigidity makes the grid impossible to absorb force by deformation. The hexagon shows the highest efficiency in space packing, which gets the name of the geodesic grid, the grid with shortest structural member required, it is a three-way grid and is shows elasticity.

Within the four packing methods, direct, offset, differential, lattice, the lattice method is chosen as it is the only method to keep every unit replaceable.

Another issue is the deformation of the cells on a free-form surface, the mapping of the grid can cause the uneven density

of the structure, non-controllable joint angles, and non-uniform grid area. All of them are not desirable results. Is there a suitable natural system we can refer?

The system we refer shall get an equal-distance structural member, the joint that gets only three connections, similar cell size, and a simple operation method for changing the surface profile. There is a system matching the complex requirement, and that is the carbon fibre system.

Three simple rules compose carbon fibre molecules, forming three joints with adjacent members, inter-atomic distance is constant, the connections on the atom repels others, which means they will maximise their connection angles, and the angle would be equal due to equal repulsion.

The composition of carbon fibre bases on only five basic members and two operations, the result profiles are limitless. The basic components are the layers, which is the graphite form, the sphere, which is the Bucky Ball, and the three kinds of tube (armchair, Zigzag and Chiral), the fiber can be skewed or undergo heptagon joint and pentagon joint, to scale, to shear, to twist, and transform to different shapes.

Simple construction rules, simple members and simple deformation operation but results as the high level of flexibility of shapes.

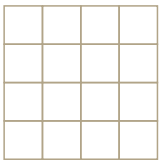
The inspiration from biomimetic and the carbon fibre study suggests some of the operation for the structural façade, like blurring the boundary between the primary, secondary structural component, and optimising the structural component through the structural hierarchy concept.

Since the hexagon is a shape with direction, a penalization method matrix can be set up, variation on the number of layers and pattern configuration on both the base grid and elevation

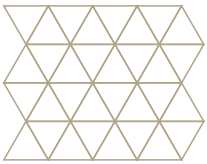
grid, the penalization method are the parameters, just on the rough list below,
7 base grid * 4 elevation grid * 2 penalization method = 56 combinations.
The variation in method and spacing of the grid, then the optimisation and sizing of the components, would take an important role in the design process.

Choice of Grid:

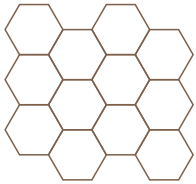
Choice with regular tiling polygon



Rectangle



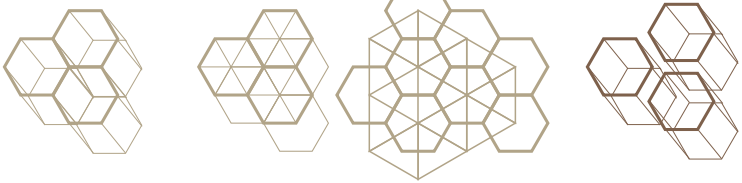
Triangle



Hexagon

Way of grid	2	3	3
Angle	90°	60°	120° (Largest)
Length under same area	1.075	1.225	1
Performance	Shear	Rigid	Elastic

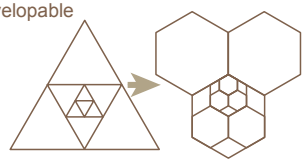
Choice of Lattice:



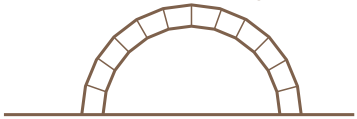
Direct	Offset	Differential	Lattice
Component Based	Component Based	Component Based	Unit Based
Repetitive	Change shape	Change shape	Repetitive

Geodesic Grid:

Developable



Deep Span and Light



Multi load path, Huge Redundency

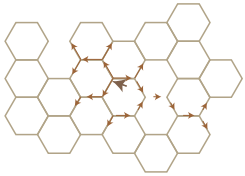


Figure 10. Choice of Grid and Lattice
The choices of grid and geometry can heavily affect the structural behaviour.

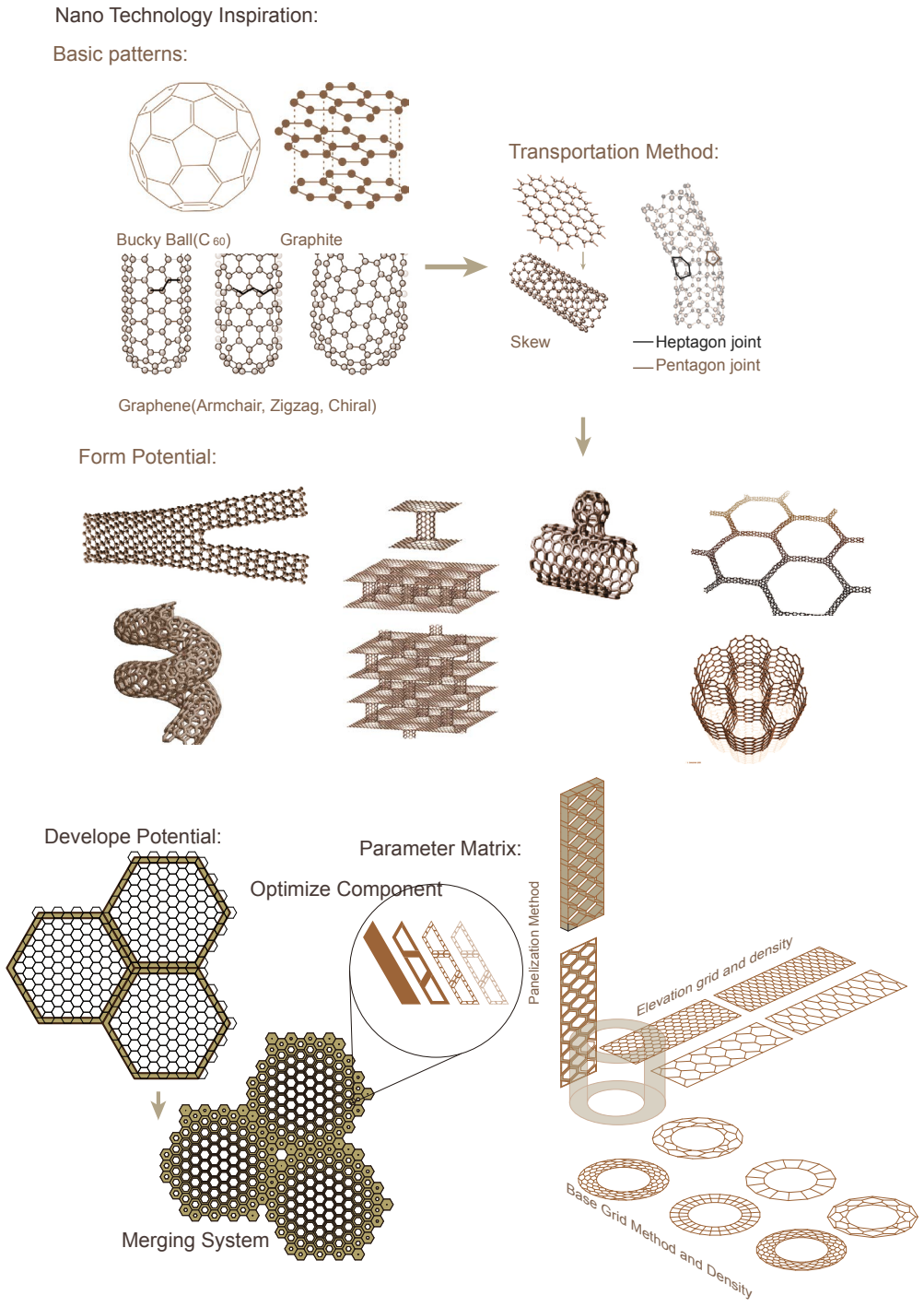


Figure 11. Nano-Technology Inspiration
The idea of changing configurations, rather than changing component lengths, can still change the profile with generally hexagonal packing.

Geometry Study: Hyperboloid

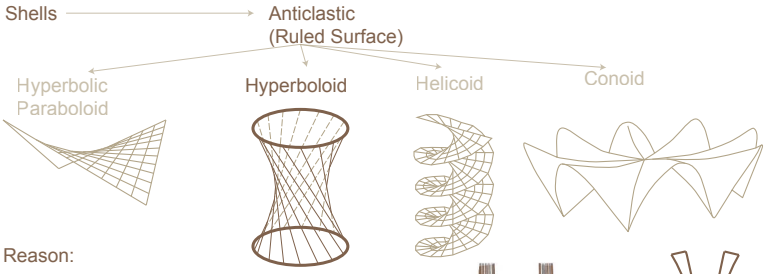
The method of describing the bamboo profile, and find out the structural behaviour is important. The study focus on the shell structure, a vertical self-supported shell is preferred. The suggestion is the hyperboloid, one of the members of the parabolic shell family. All the parabolic shells are ruled surfaces, which means on every point of the shell, we can find a straight line lying on it, penetrating the point, and passes through the edge.

Few ways can be used to describe the profile, first, is to rotate a straight line along a circle or ellipse, second, is to rotate a hyperbola, these two methods show also the ways of consideration of the load path. We can consider the load passes to ground through a triangle, or through a series of arches and ring. The shapes result from a high performance and loading capacity, the form is used for tall frame and heavy loadings such as the light-house, cable tower and water tower. The nature of the force acting on the ring varies with the component spacing and the waist neck ratio, which means optimisation can be done through the profile.

NiGRE Tower is chosen for the case study, a detail structural analysis is found and we can have a discussion on the deformation pattern. The NiGRE Tower is a multi-stack hyperboloid tower, the multi-stack form helps to regulate the decrease in radius of height, allow larger freedom on form design and space making, the balance of force on the connection rings can also be achieved.

The structural study shows the deformation mainly happens around the ring, and the force may change from compression to tension. Base on the research, it is suggested to transform the shell to a double-layered system, and strengthen the ring part, covering the whole profile by the space frame system mentioned in the previous section can form a more strengthened system.

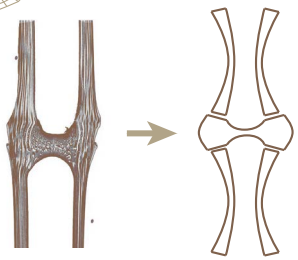
Choice of Geometry:



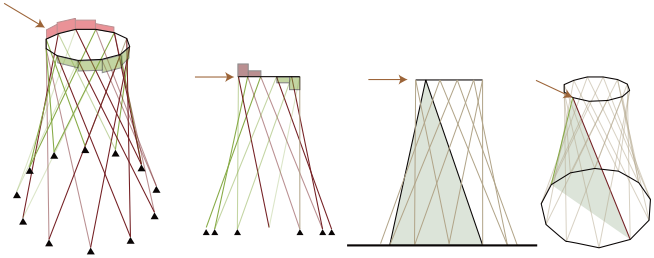
Reason:
Only Vertical Shell

Light weight but strong load capacity on both VERTICAL and LATERAL loading

Load Path as arch and suspension, results high efficiecy and freedom in structural arrangement



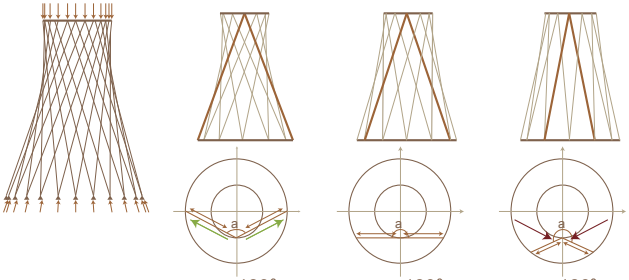
Performance Under Laterial Loading:



Tension
Compression

Single point loading can transfer through compression and tension, each point can form triangular plan and transfer loading onto ground floor.

Performance Under Vertical Loading:



a<180°
Tension
on Ring

a=180°
Equilibrium
on Ring

a>180°
Compression
on Ring

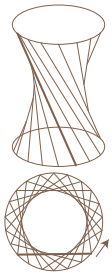
Varies with spacing and waist neck ratio, the magnitude and nature of force on rings varies, to further control the ratios, structure can be optimized.

Figure 12. Hyperboloid Geometry

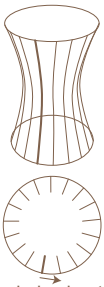
The method of grometry formation of hyperboloid shows the behaviour and the structual strength.

Load Path and Geometry formula:

Way to Define a hyperboloid:



Rotate line along an axis



Rotate hyperbola about an axis



Create 3 lines skewed to others

Case Study:

NiGRE Tower
Year:1929 Height: 130.2m

Character: Multi Stack of tower sections



Adziogol lighthouse
Year:1911 Height: 64m

Character: Central Core supported with Suspension

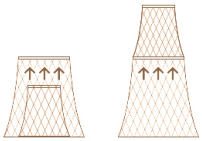


Kolomna Watertower
Year:1902 Height: 34.1m

Character:
Heavy gravity load



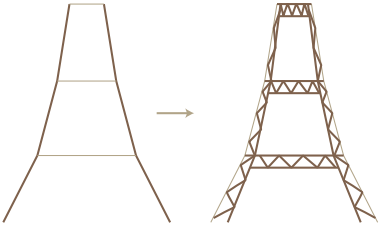
Building Sequence:



Upper section assembled by stage inside the tower section

Sections placed on top of each other using pulleys and winches

Weakness and reinforcement:



Ring

Thicken and Truss

Profile

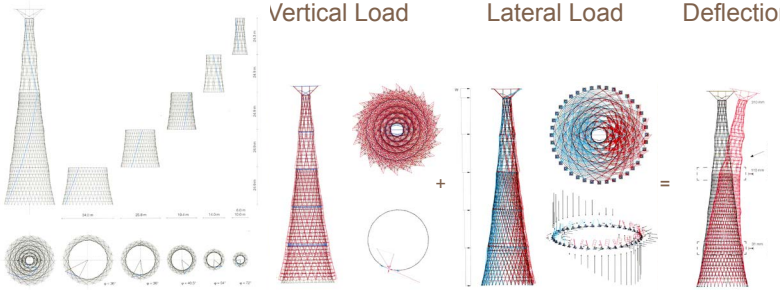


Figure 13. NiGRE Tower Structural Analysis
The structural analysis shows the weakness of the multi-stack hyperboloid.

First Trial: Massing

The massing and the proposed scheme shall show all the things learnt from the studies. It starts to form a block, to minimise the wind load, the tower shall be round and tapered. The massive building would be divided into different zones for reducing the loading of the service system, to set up outrigger trusses for reducing the torsion and moment under wind, the form shall then undergo geodesic grid division, hence the building can be built by individual units, then the sizing of the members of cells shall be optimized, some of the members are thickened to become main load path, while some shall be lightened in order to become a flexible membrane, which can vibrate under the wind, to absorb forces, the shell would be composed in multi-layers, to create not just the great structural depth, but also to create the space for service, transportation system passing through. Inside the façade and be-tween the façade, the floor slabs shall be hanged.

The arrangement brings few merits, first, all services and structures are transferred to the skin, which creates the probability of removal of the central core. The floor arrangement is freed up and a real open plan can be set up. The removal of the central core makes the suspension of floor slab possible, not to mention the reduction of the structural member size, the possibility of a column-free floor is created, we can achieve this by increasing the stiffness of the floor.
Since the main floor slabs and central part of the building do not serve as structure anymore, a sky garden with clear ceiling can be created.

The hanged floor slab can swing and counter move with the building motion, which transforms all the live load of the building to the damper weight, which stabilises the building. The cell unit façade creates the opportunity of repairing the structure. For an organism, it can undergo instant response, under continuous stimulation, it can undergo adaptation by strengthening needed

part and weakening redundant part. The cell unit not just allow repairing but also the metabolism of the building.
The whole building can undergo pre-stress in different scales.

On the tiling scale, every PTFE is inflated, it means pre-stressed by air-pressure. We can pressurise the intra-façade chamber, which can result as the pre-stress of some parts of the façade.
The cable hanging the floor slab is pre-stressed, it means the whole stacking unit is under tension, the process of pre-stressing would keep the building light but rigid.
The PTFE and the intra-façade are pre-stressed, it means they have flexibility and can absorb the wind force through vibration.

Evolution of Massing:

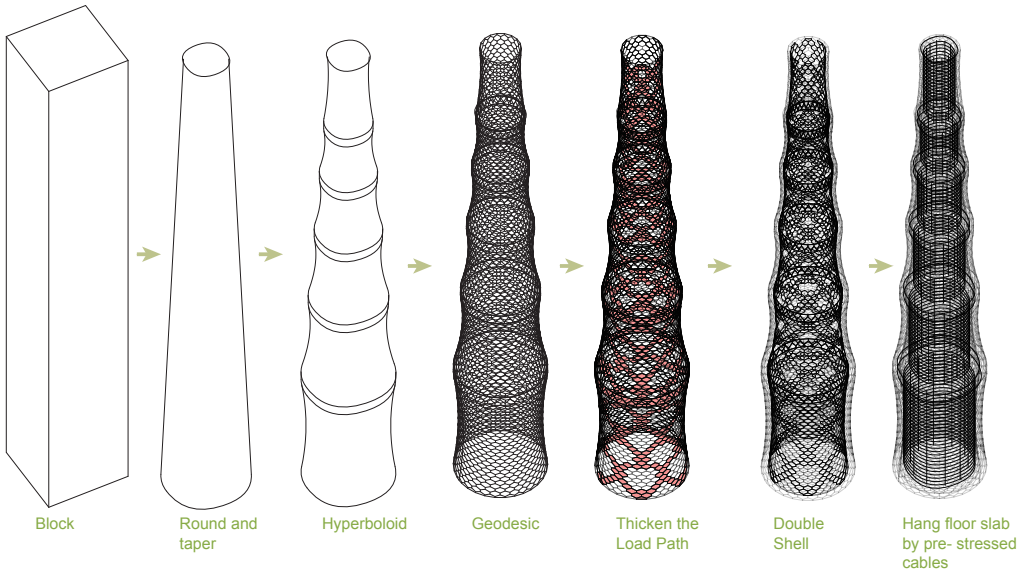


Figure 14. Massing Devalopment

Schemetic Section:

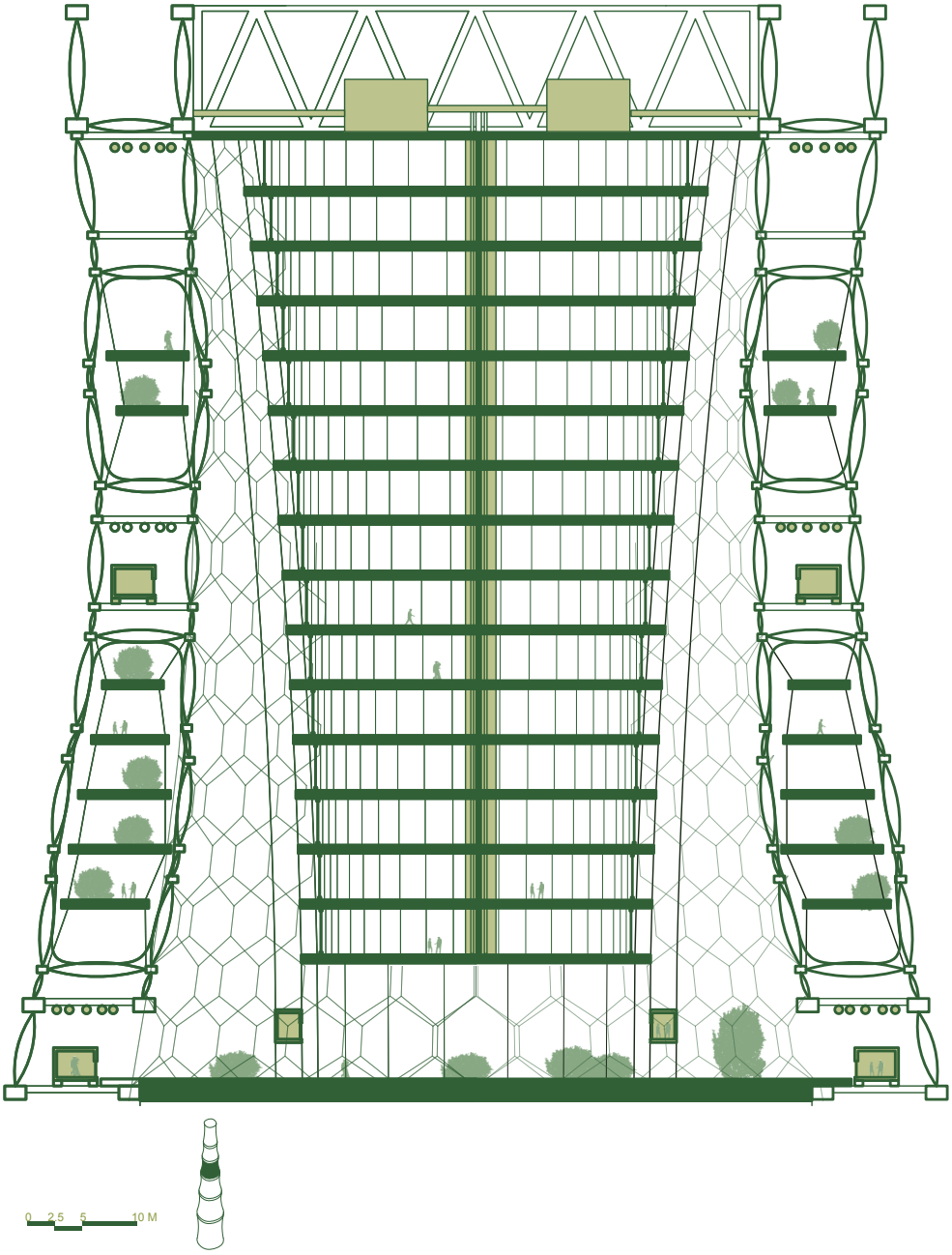


Figure 15. Diagrammatic Section

Triangulation On Double Curved Profile

Hexagonal packing on double curved surface can cause distortion, we can get a fine packing of hexagons on a circular tube, but not no a double curved surface. the problem we cannot keep the area, the angle and the edge length even at the same time. Keeping the angle as constant results in uneven in the area of cells, keeping the area constant results the bow-tie shape in the concave surface, while keeping the area results in variation in shapes, from the pentagon to heptagon.

To further investigate about the packing of polygons, two approaches are tried, first is the circle packing on double curved surface, second is the meshing machine in grasshopper, rhino.

We got the function called 'mesh dual', which can transform the triangulated mesh to a collection of polygon cells. The function allows certain freedom is meshing, to follow the rule for the even angle or even edge length, the importance of following the profile which contrasts with the importance of keeping the cell size; all these results in the control of the final meshing.

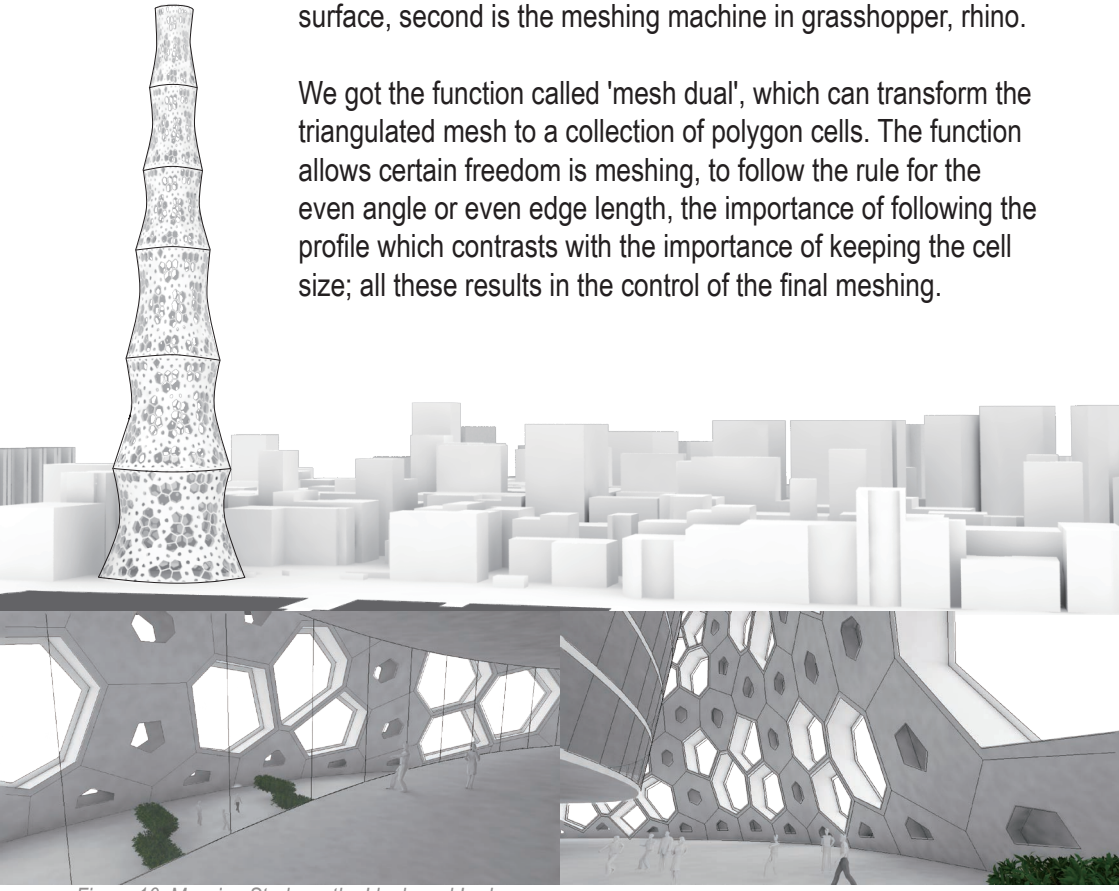


Figure 16. Massing Study on the 'dual mesh' scheme

The problem of the meshing machine is losing control in array patterns of the cells, we can hardly predict the position of mullions, we can not array the cells according to the floor height, every cell would be unique, which means the standardisation will not be possible. The angles among cells would be irregular, which means calculations will be difficult and the assembling will be difficult, every component needs to be unique. Although the method gets high adaptivity into shape, it is not practical.

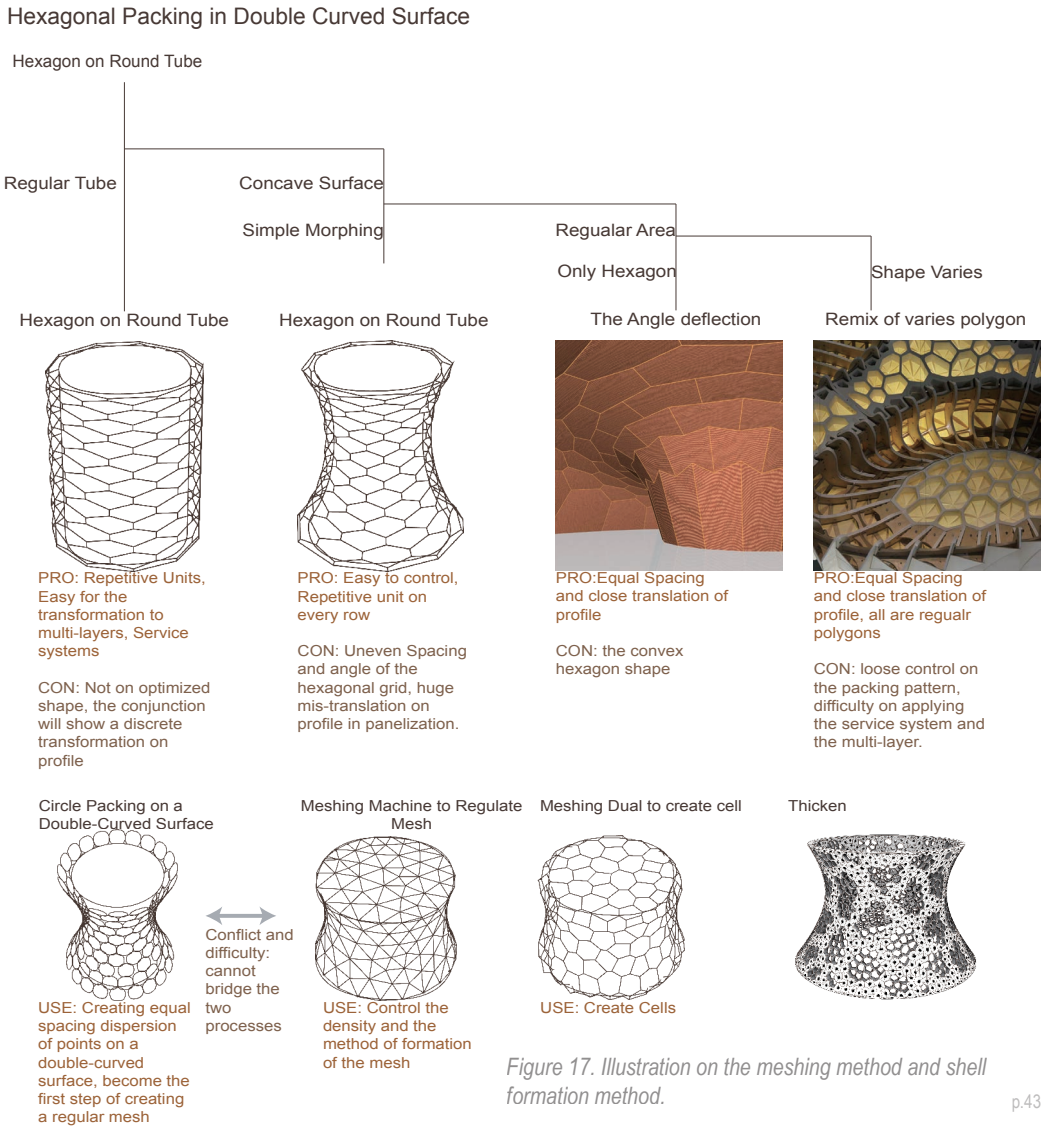


Figure 17. Illustration on the meshing method and shell formation method.

Structural Optimisation

Another approach is getting a structural optimisation tool for different shell grids, to see if we can get a tool to examine the exoskeleton behaviour, which parts are referring to which kinds of loadings. The tool we chose is the plugin Millipede in grasshopper, rhino.

The Millipede is a relatively serious optimisation tool for design, which results in a requirement in detail component setting and yet, it still gets some critical weaknesses that limit the tool as just a design reference.

The system is defined by material, cross section and boundary connection, the pre-set material include steel, iron, aluminium, glass and most of the common materials, we can define the component cross section profile and all the dimensions. The boundary conditions, which means the connector to the fixed ground, can be controlled by six boolean options, RX RY RZ TX TY TZ. RX stands for rolling through x-axis while TX stands for transition through x-axis. By controlling the six parameters, we can create fix joints, hinge joints and roller joints through the XYZ axis.

The optimisation method can further be defined as the 2d plane optimisation, the shell optimisation, stress line pattern optimisation, frame optimisation and finally a solid optimisation.

At first, the 3d optimisation is used as the tool of form finding, but the trial is not successful as the fineness of the simulation relates inversely with the complicatedness of the simulation method, the form extracted is quite rough and gets a humble amount of reference value.

For the another extreme, the planar optimisation can show a nice pattern and with a fast optimising speed, since the force can only stay on the working plane, the shearing, torsion, and

bucking can hardly be reflected in the planar optimisation.

While the methods left, the frame and the shell optimisation, the frame optimisation shows a more relevant result.

For the optimisation of frames, a matrix can be set, with the two shell pattern shapes, the rectangle and the hexagon, for each shape, the patterns are further divided into 1, 2 and 3 degrees of structure. For the type of forces, we mainly investigate the self-weight, the lateral push, the inward pressure onto the shell and torsion onto the shell. To keep the test fair, the number of iteration of the shells are kept constant, which is 50 in the tests.

From the tests, the multi-layered structures show a general tendency, that is the structure would generally converge to the member with the higher level. The another observation is, the single-layered structure takes more iterations to deform. The even distribution of structural member matches with the structural need of shell structure more, as the loading can be evenly distributed.

There is a limitation on the structural analysis. First, the nature of the nodes are pre-set as the fixed joint, no further nature can be defined, second, the thermal factor can not be simulated by the plugin, buckling within the component is neglected, and the factor that concentration of the loading causing partial structural deformation and failure can not be simulated. That is the reason of the tendency on the thickening of the main structural members.

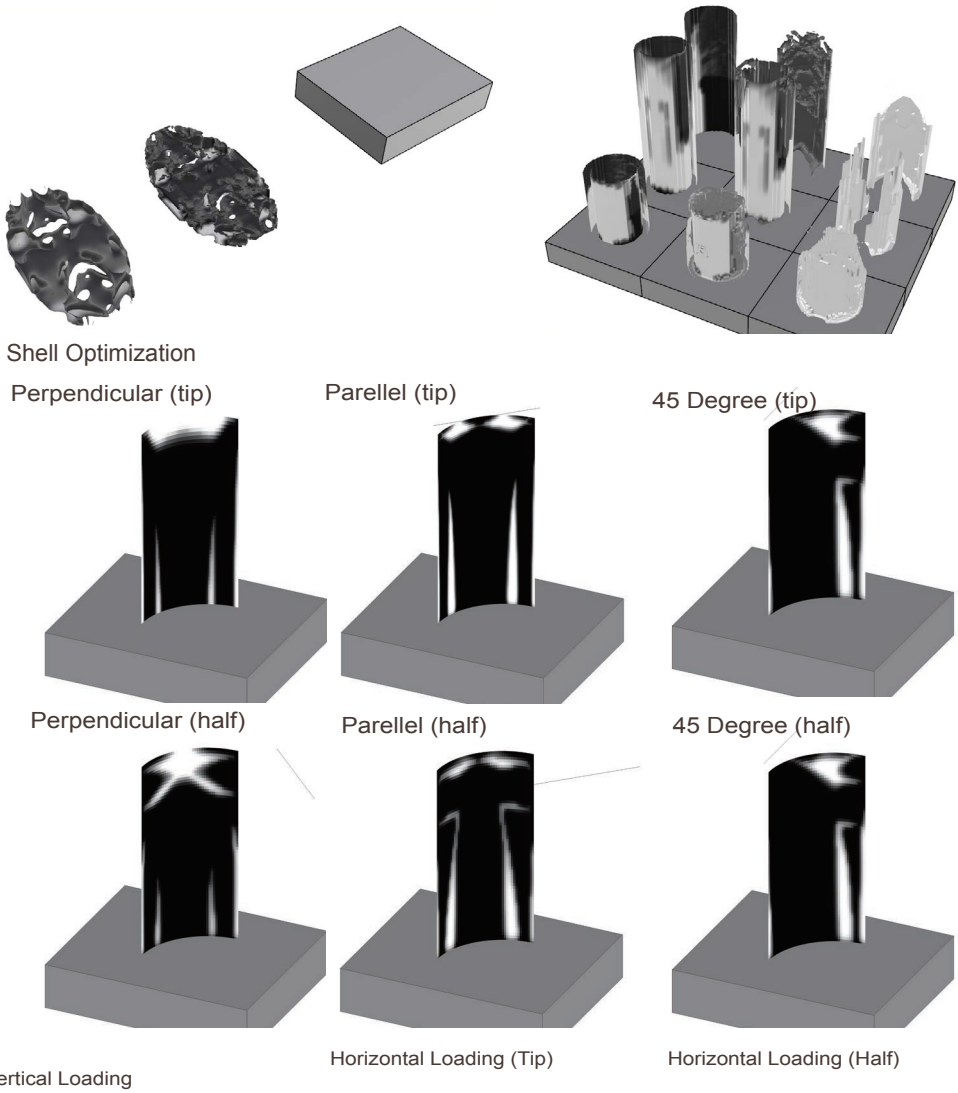


Figure 18a. Solid, shell and surface structural optimization

Structure Optimization (Framework)

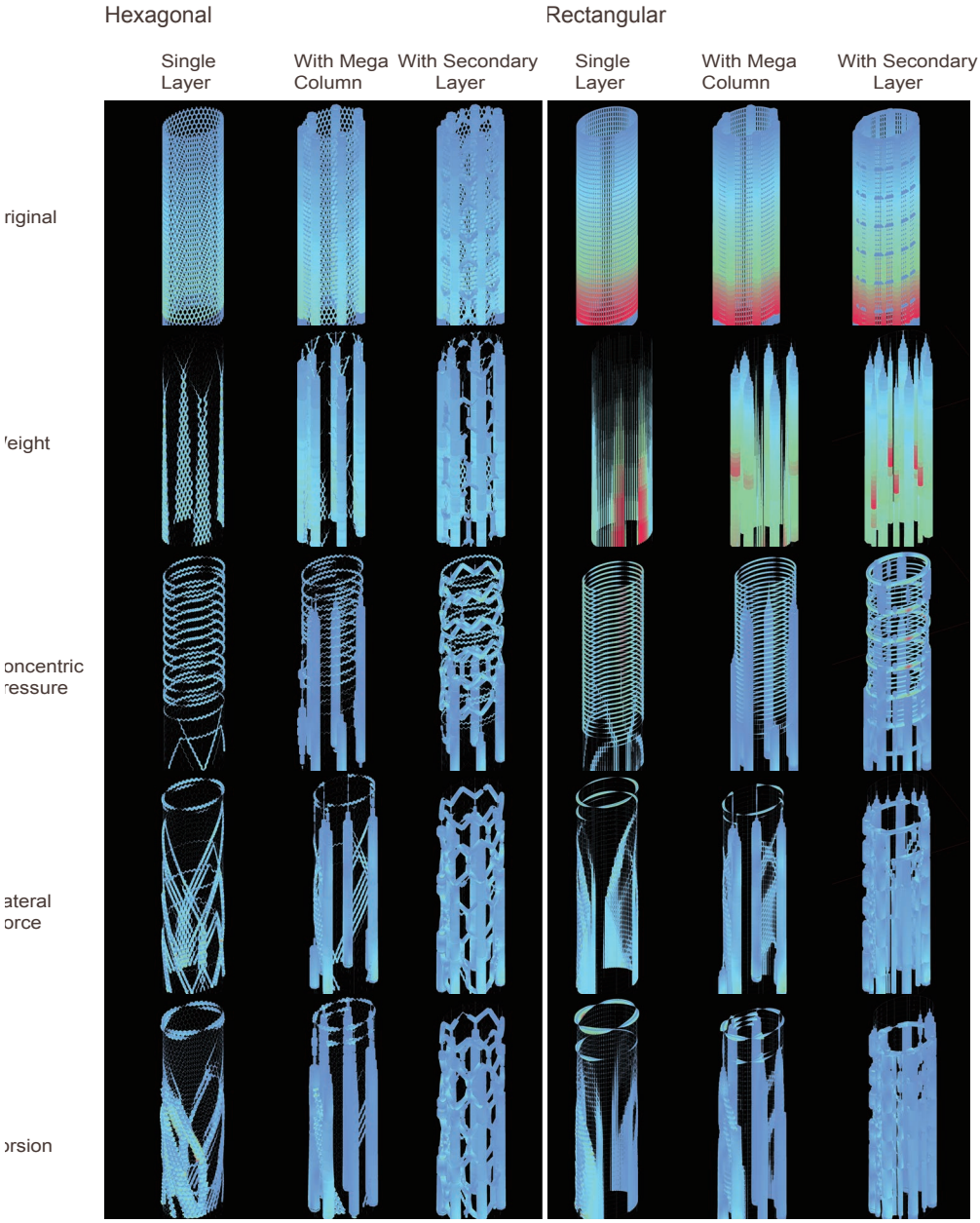


Figure 18b. Frame optimization

Massing ---
Ellipse Profile with Layered Structures

An ellipse profile with layered structure scheme is drawn under the experiment, the lift cores are arranged as 4 mega columns, mega-frames are used for lateral fixing and holding the structural floor, the air filled PTFE is infilled in the mega-frame.

Such scheme is abandoned in the early stage due to few reasons, first, loading is heavily concentrated onto the four mega-columns, which makes the conjunction between column and frame under huge pressure, the component will be huge and not efficient. It does not correspond the bamboo structure, which is a tube with loading evenly distributed, the ellipse shape resolves the issue about the building depth but increases the wind loads.

Start with this trial, we try to keep our scheme not using structural transition core, the lift core is kept standing alone. The consistency of structural system is a concern and need to be kept.

Figure 19. Ellipse Profile with Layered Structures

Massing

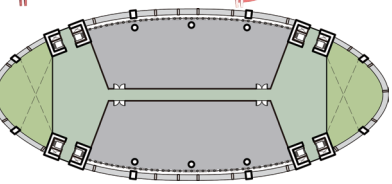
Structural Sequence

The tapered side cores act as the 4 main mega columns, size and number of lifts varies with the transportation loading.

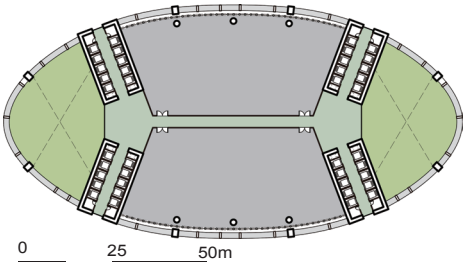
The insertion of the refegee floor and as the weight transition, the rest floor slabs are hung as suspended floors.

The mega truss serves from stablizing the mega columns from buckling and twisting.

PTFE bubble units serves as climate barriar and an elastic buffer for wind load.



6st Sector
140th Floor



1st Sector
5th Floor

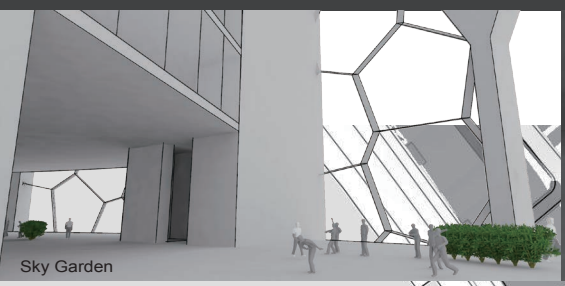
Sky Garden

Corridor

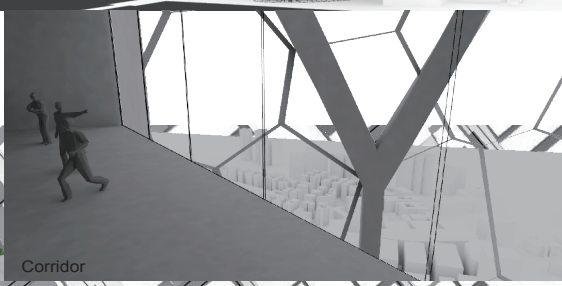
Office

Air Filled PTFE

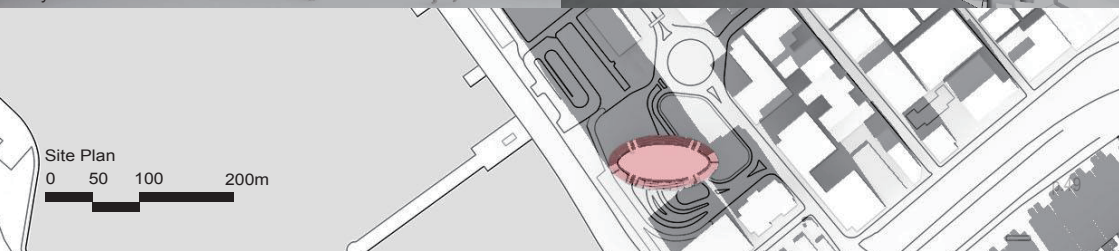
0 25 50m



Sky Garden



Corridor



Site Plan

0 50 100 200m

Physical Model Trials

Rather than computational trial, efforts are also put on physical models, the models are used to test the relation between the proportion of the cells, the structural strength and the weight. Start from the original module, the double layered hexagonal cells are arrayed as a cylinder. The another approach is to stick a bundle of hexagonal tubes to form a big one. The cylinder gets a high transparency but a weak structural strength. The bundle one shows a good vertical strength but very low opacity, how to get a balance becomes the main task.

Few approaches are tested, the first one is the change in length of the cells, as a direct reference from the bamboo, the height and depth of the cells are doubled while the width is halved. The trial is not successful as the weight of the model increased significantly but the strength just shows a mild improvement. The degree of opacity on a contrary decreases drastically.The another approach is applying a hyperbolic shape to the profile, the stiffness increases without the increase in weight, the opacity is high, which is successful.

The third approach is the increase in structural level, we double the cell sizes but infill the cell with hexagonal panels, the weight decreases while the strength increases. The problem with this approach is the increasing of points of weaknesses, the conjunction points become fragile while the long components are weak. From further examination, we know that the strength comes from fixing the hinge joints of the cell conjunctions.

From the above experiment, a final structural scheme is proposed. The cells remain as the single level double layered hexagonal cell, while the lateral support is triangulated, the joint is fixed, on the model scale, by glue. The top and bottom are fixed by rigid frames, to keep the double curved profile of the shell. As such approach, both opacity, weight and strength show a fair performance without fragile points.

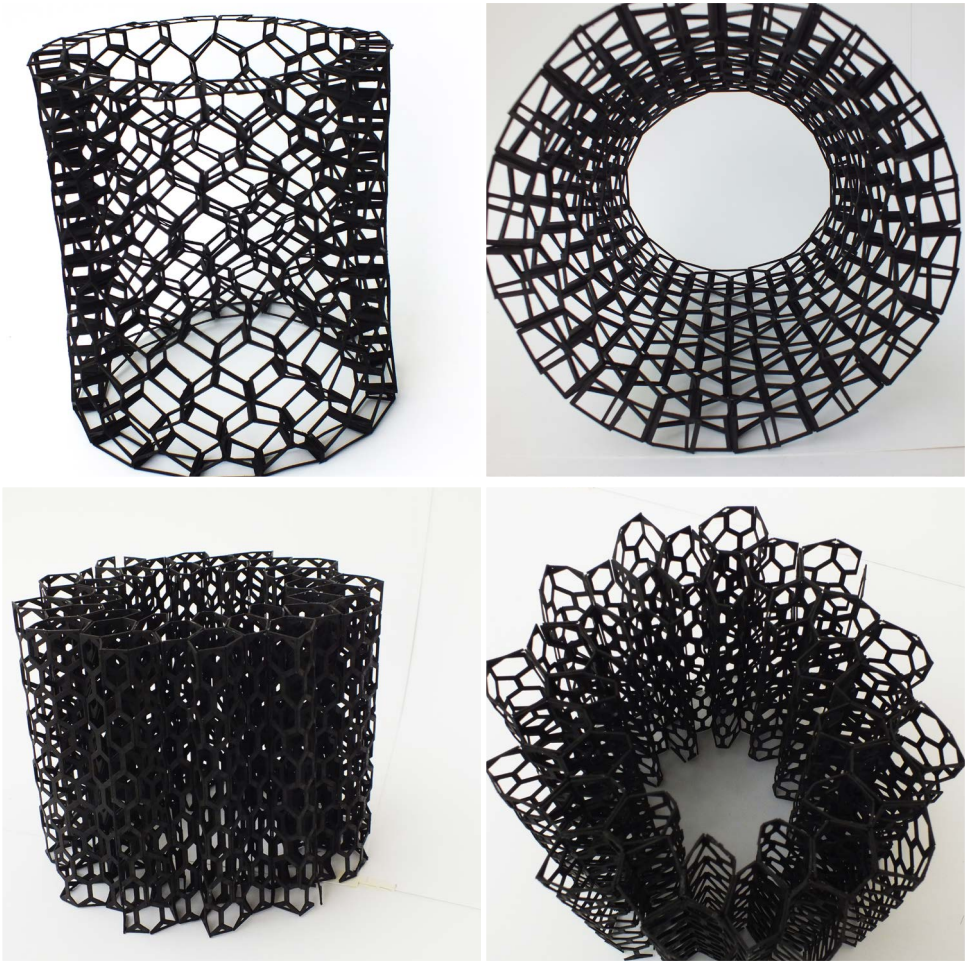
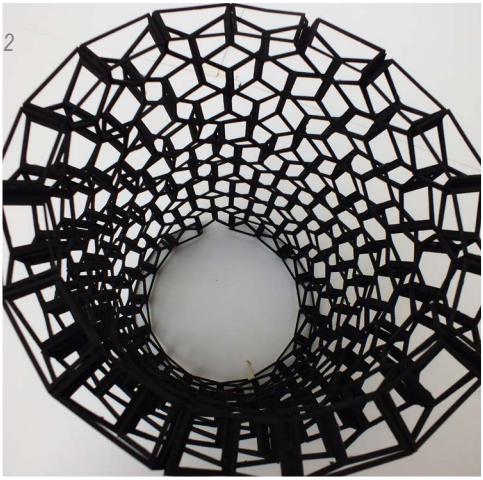


Figure 20 Physical trials
Top: Hexagonal cell cylinder Bottom: Hexagonal cell bundle



1



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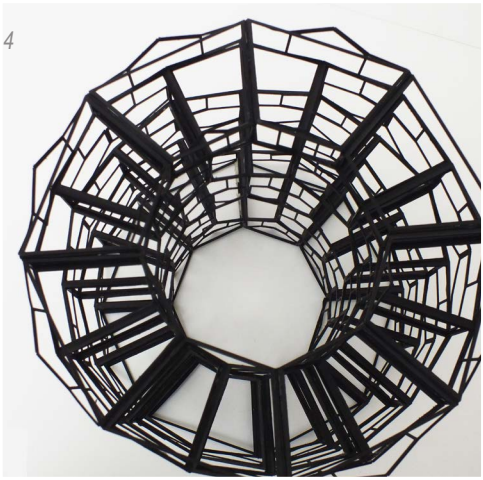


4



5



6

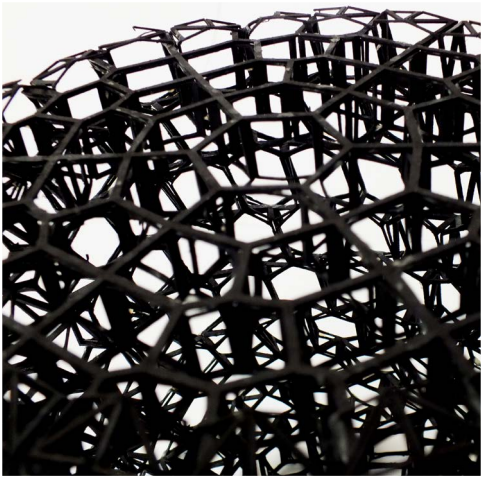






Figure 21 Physical solution trials
Left 1, 2: Hyperbolic profile
Left 3,4: Panel Infill
Left 5,6: Long Cells

Right: Final Solution

Massing ---
Twisted Profile with Layered Structures

The another massing is a direct reference from Shanghai Tower, the twisted profile with floor slabs seating inside. The issue is the variation of the length of the structural member would be too large and this makes the sizing very difficult. the direct attachment of the floor slab onto the outer shell results losing in elasticity. The implementation of three split cores result in weakening of the grid shell and the conjunction between the core and the shell becomes an issue again.

The large cells on proportion increase the depth of the cell, which keeps the interior of the tower dark. Due to such reason, a circular floor plan with single structural degree becomes the final decision.



Figure 22. Massing of Twisted Profile with Layered Structures

Solution on Change in Profile

Mentioned in the previous paragraph(Triangulation on Double Curved Profile), the tapered shape of the building results in decrease in radius with height, since the height of the cells are defined by the floor height, which is a constant, decrease in radius, under the constant division, would cause deformation of the hexagons. To solve such issue, a mutation in the grid to decrease the division is suggested.

Due to the mild change in profile, as the ratio between the total building volume and the cell volume is large, a local mutation rather than a big move in the whole grid system is more sensible. The mutation level would be hidden within the double-deck structural floor, which means the mutation can only be seen outside but not the building users. As the mutation level is the individual cases (2 out of 90 levels), we can handle them individually.

This brings challenges to the structural floor. the floor should be able to fit with the change in division and decrease in radius. It needs to be a pattern that not converging to the centre point, we would not prefer more than 30 structural members converging to a centre point, it should allow feasibility of attaching suspension columns onto the structural floor with an even spacing. Base on the reasons above, the truss would no be a simple hexagonal or circular grid.

The trial is then tried on four approaches, the first is the Fibonacci series, few mutations are drawn with the diagrid, the second approach is doubling the division among the rings, but with different starting number results in different number of division, the third is the same starting number but with different ways of mutation at the rings, resulting a different end edge number. The last approach is a gradual increase, first, divide the circle into sectors and in each sector, division increases by 1 with the increase in numbers of rings.

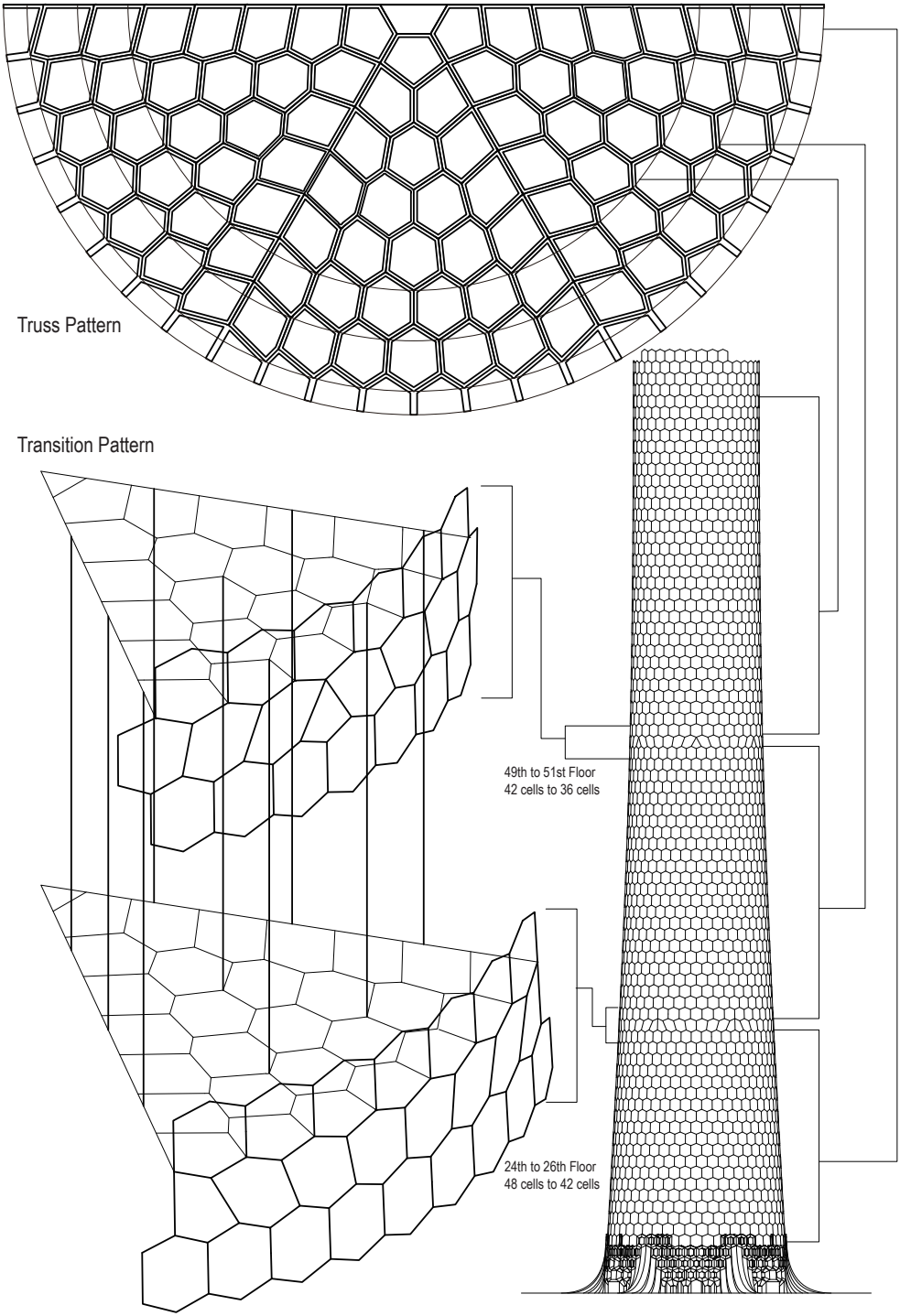
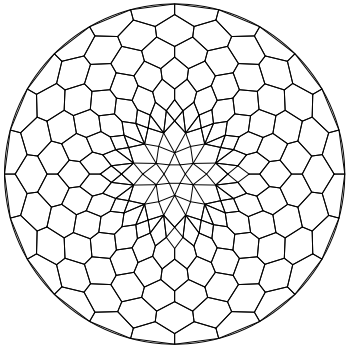
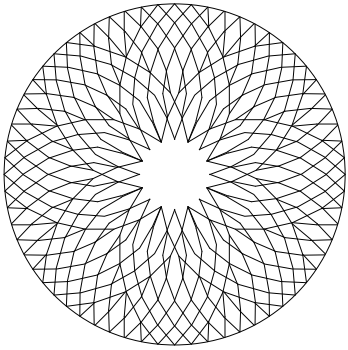
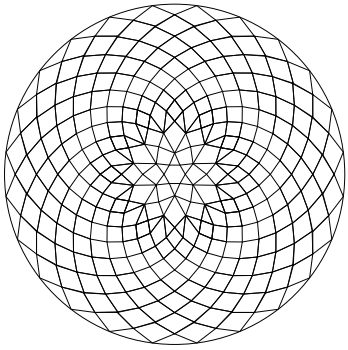


Figure 23. Final Solution of the Profile Change and the Truss System for The Structural Floor.

Trial: Fibonacci Series

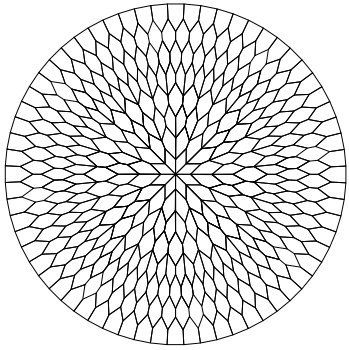




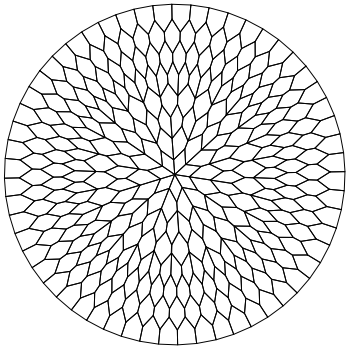


0 10 20 40m

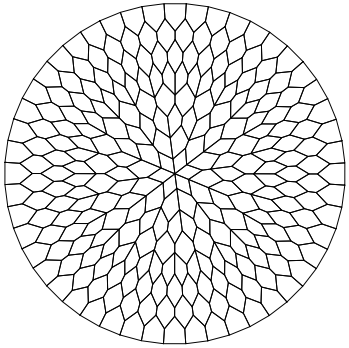
Trial: Different Starting Point



8 to 16 to 24 to 32 to 64

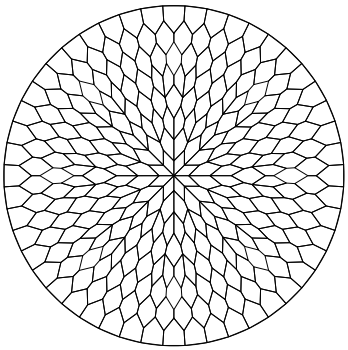


7 to 14 to 21 to 28 to 56

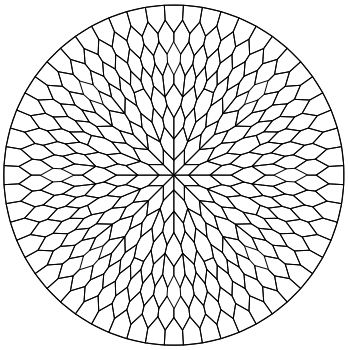


6 to 12 to 18 to 24 to 48

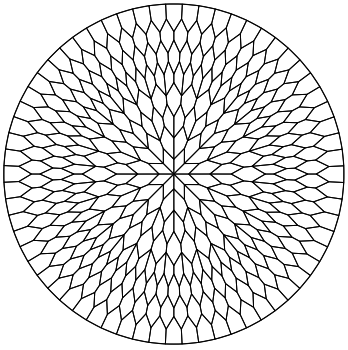
Trial: Same Start Point and Mutate



8 to 16 to 32 to 48 to 48

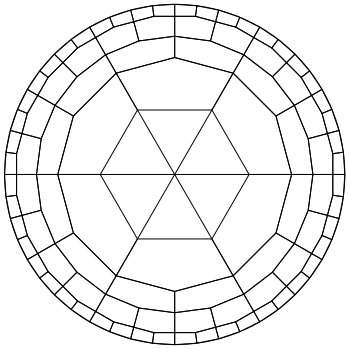


8 to 16 to 32 to 56 to 56

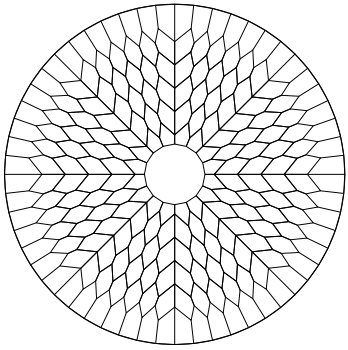


8 to 16 to 32 to 64 to 64

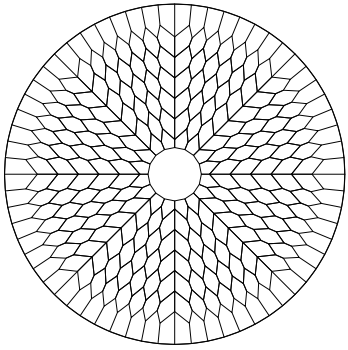
Trial: Gradual Increase



Rectangular Multiply



1 to 2 to 3 .....to 8 x 8(Version 1)



1 to 2 to 3 .....to 8 x 8(Version 2, Chosen)

Figure 24. Trials on Truss System Applying on All Floors.

Joint and Detail Design

About the joint, the starting issue is about how to simplify it. Base on the design, the joint would need to connect 4 to 7 members. Connecting 7 members onto one point requires a high precision and the feasibility is low. The another concern is the feasibility of using 3d printing for the joint. Not concerning about the price, the strength can not be guaranteed as the welding environments can hardly be controlled in-situ while prefab in the factory by 3d printing would take an unreasonable working time. Base on the concern above, dividing the joint into the sheet based component is more reasonable.

The joint follows the logic that the main member attaches to the join while the secondary member attaches to the main member, so the number of joints overlapping each other can be decreased.

After few trials as shown, the design of joints undergoes a sandwich approach, the connector embrace the main member connecting plates and the main connecting plate holds the secondary member connecting plate. A five layered sandwich is formed. The degree of freedom of every individual hinge joints can be adjusted.

This makes the opening of every joint relates to at least 3 members, the joint plate, the main component and the related secondary component. The joint cutting logic mainly follows the triangle plane formed by the related main and secondary member, as shown in the diagram.

The rectangle is finally chosen for the profile of the main component, as it can increase cross section area without increasing the visual obstacle, the circle is chosen for the secondary component as the joint directions at both ends may not be parallel.

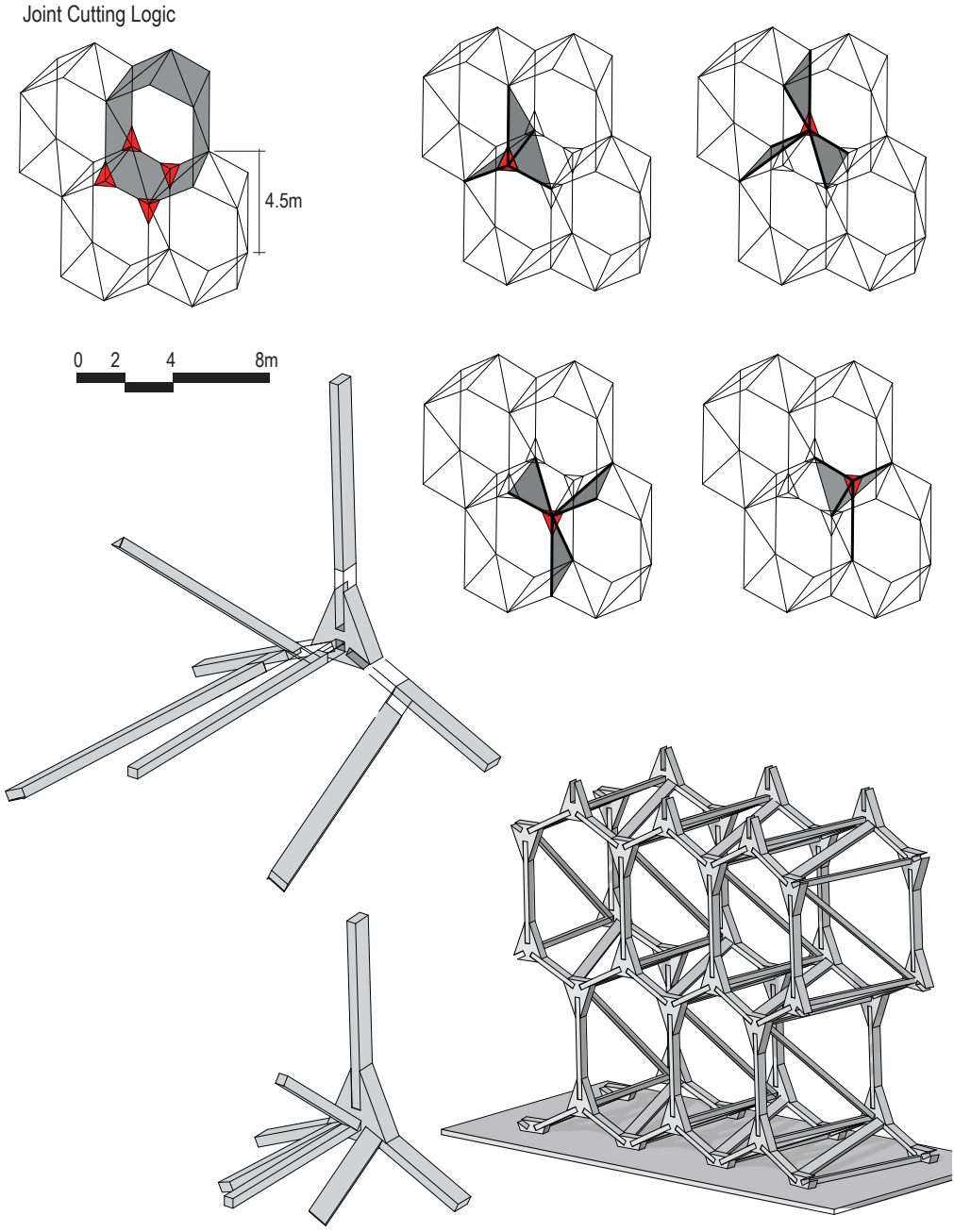
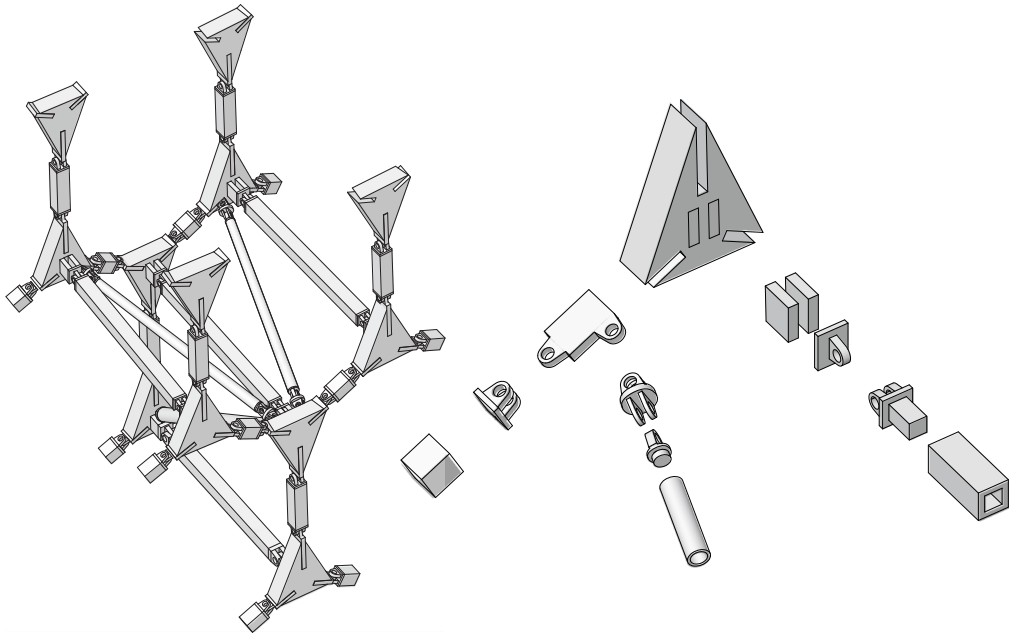


Figure 25. Joint cutting and Assembling Logic

Joint Detail Trial 1



Joint Detail Trial 2

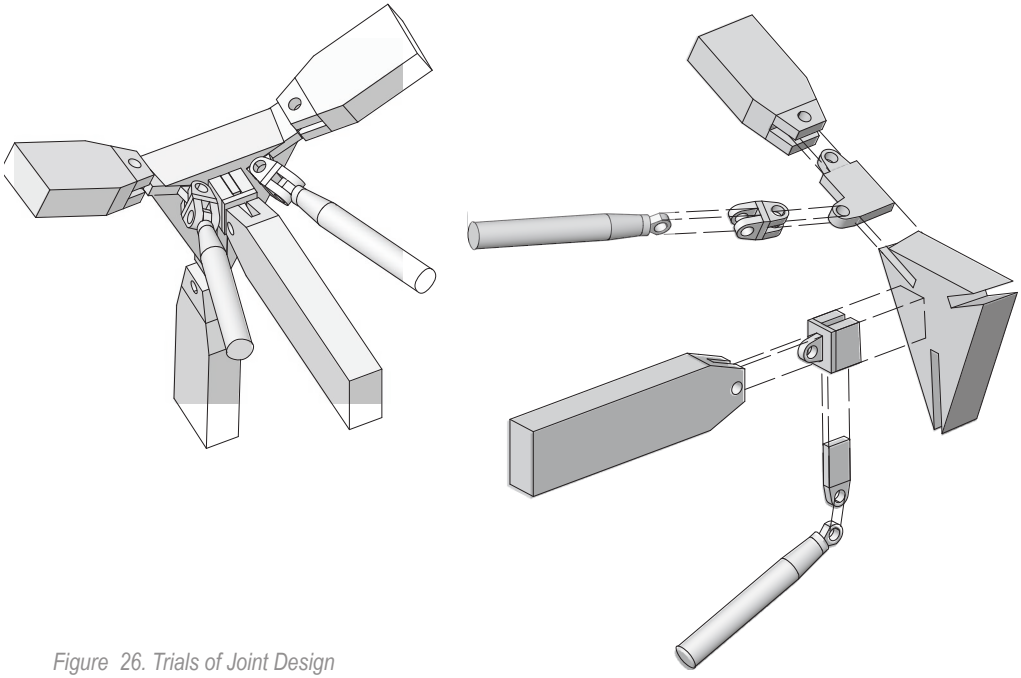


Figure 26. Trials of Joint Design

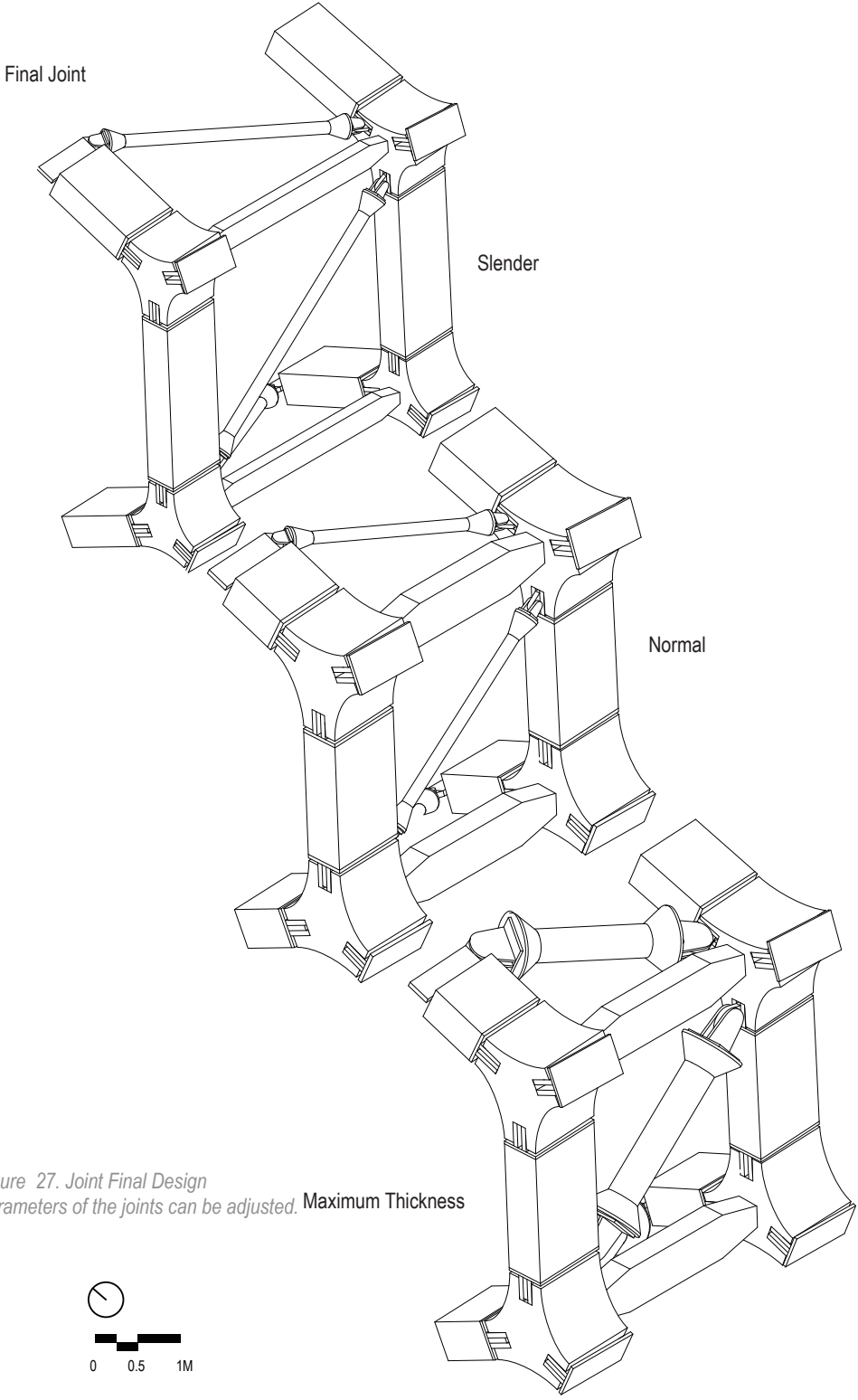


Figure 27. Joint Final Design
Parameters of the joints can be adjusted.

Site --- Kwun Tong

Kwun Tong is a unique site and it is a good spot for a new commercial tower. It is the suggesting new CBD of Hong Kong, the main spot in the planning 'Energising Kowloon East', it means that the transportation facilities are ready for the further development. We can also see from the MTR proposal, the Kwun Tong extension line is now on service. Within the district, a suspended railway is on construction progress, connecting the Kai Tak Cruise Terminal and the Kwun Tong Station. It is also near the East Corridor Highway and surrounded by the Bus Terminal and the Kwun Tong Pier. It is a natural traffic node of the district.

Reading the demographic data of CENSUS and the OZP, we can conclude that the old Kwun Tong Industrial District, which is the proposing CBD area, separates the residential area, which is a relatively ageing area, away from the sea-front. An improper development can result in the formation of a commercial barrier.

The Kwun Tong Sea-front is a well developed public space, which shows a high potential for developing an urban hub.

Studying the urban topography of Kwun Tong, we can conclude that the topography is quite flat and the fragments of urban fabric require a strong anchor, to become the gateway and bust up the development of Kwun Tong. At the chosen site, which is the conjunction point of all the situations mentioned above, a building with a certain height, can facilitate the development of the new CBD.

Reading the larger context, we can see that the spot lies on a certain amount of view corridors. It can be seen from both sides of the Victoria Harbour.





View

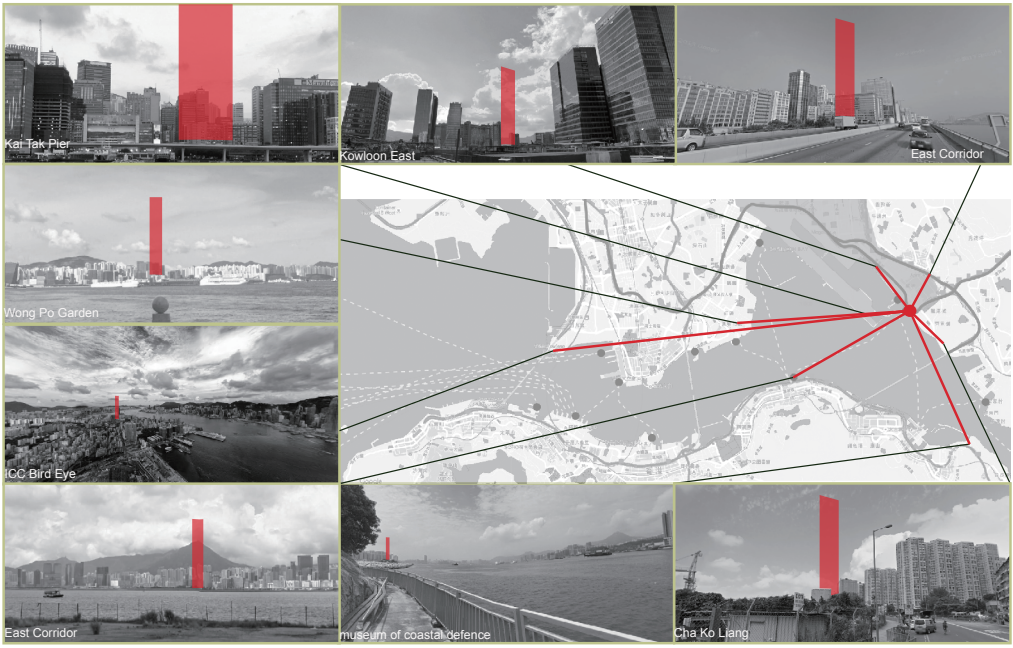


Figure 28. 1 to 5000 model Urban Profile Study and Illustration in view corridors

Demographic

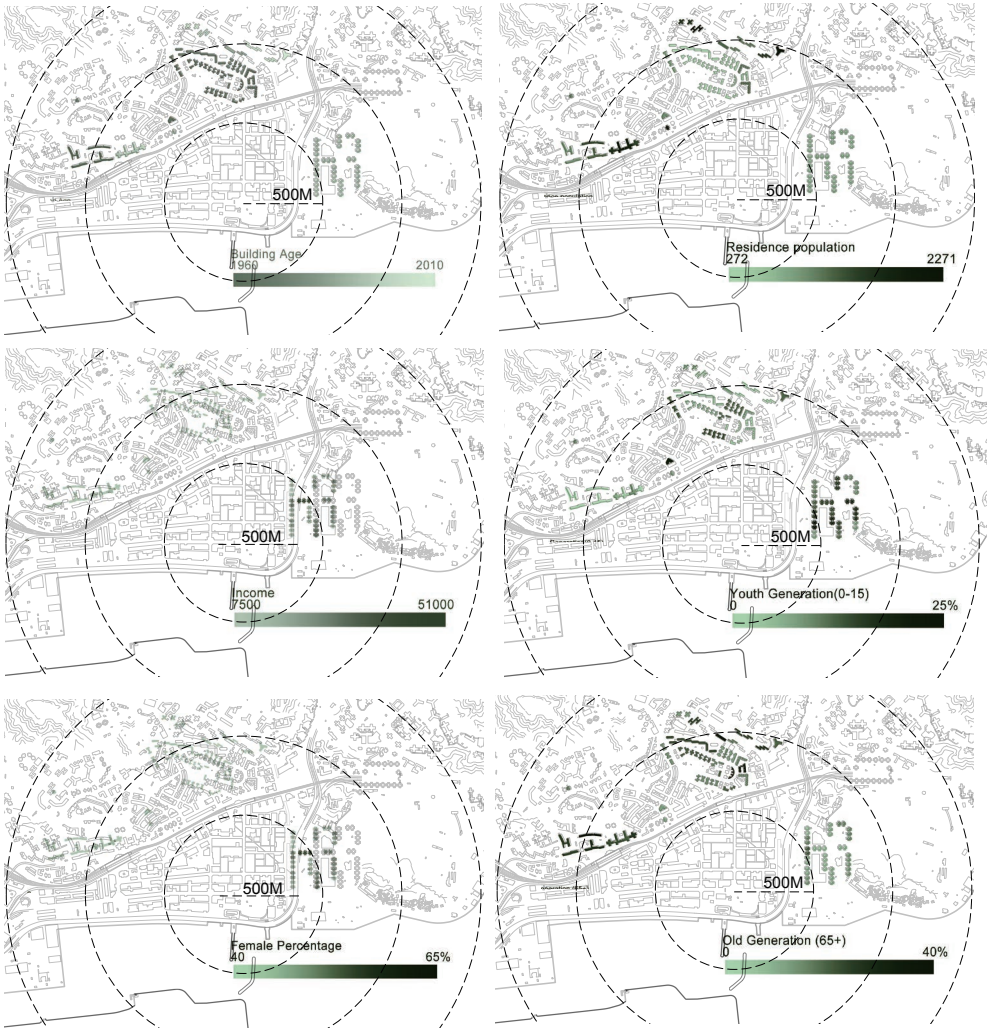
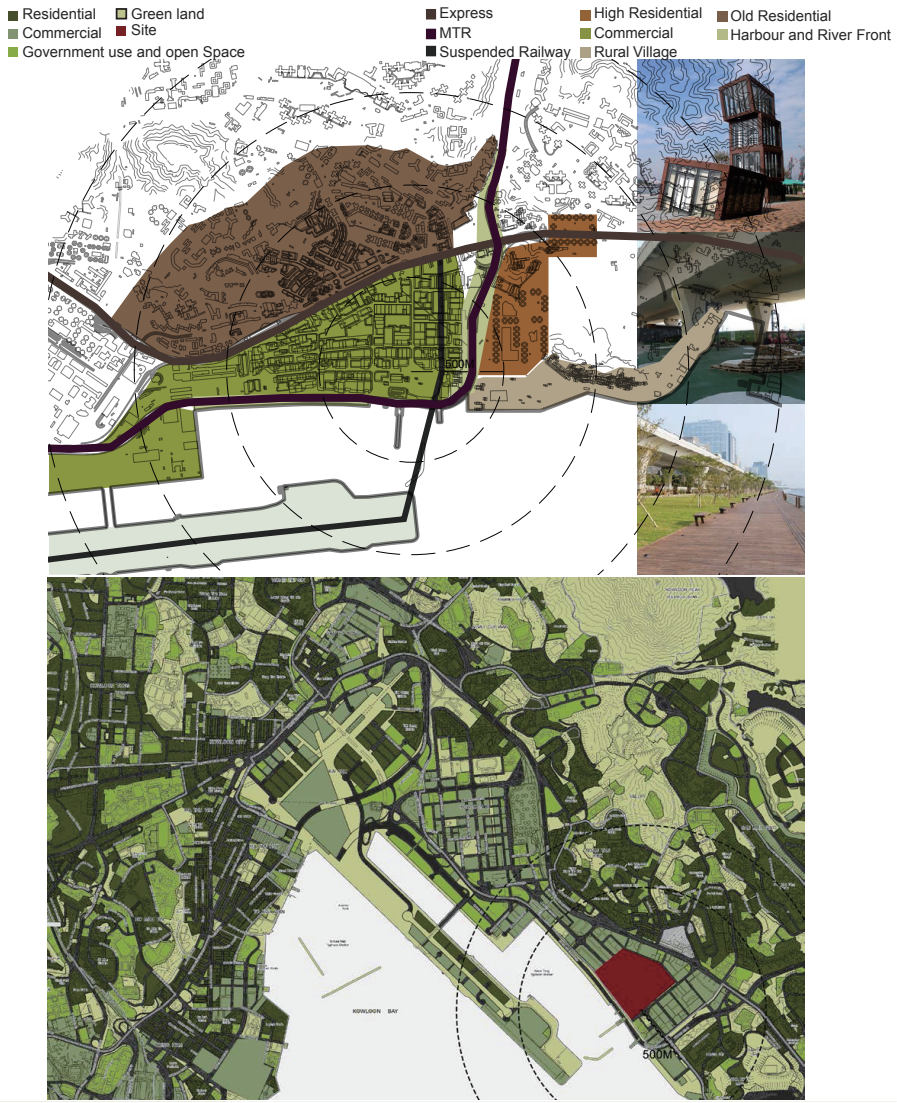


Figure 29. Mapping of Demographic Profile of Kwun Tong

Zoning



Traffic

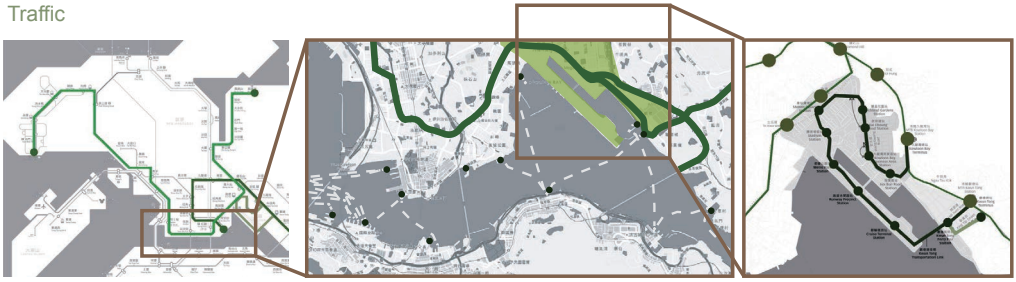


Figure 30. Zoning, OZP and traffic Situation of Kwun Tong

ABSTRACT --- DESIGN

This project aims at providing an alternative suggestion for tall buildings, providing space for users walking through different stories and embraced by greenies.

The second aim is the lightness. Minimising self-weight results minimising structural loading, forming a positive feedback loop. Lightness is also the structural dream and the requirements of a green building.

The conventional approach, the tube-in-tube structure, cutting the activities highway confined by the central core and facade system, the rigid framing also limit the middle spatial fluidity.

To seek for alternatives, the natural highrise is studied, that is, the bamboo. It gets the structural merit meets the requirement. It is light, developable, tall and with shallow foundation, the transportation cores, which names vascular bundles, is arranged according to the transportation needs only.

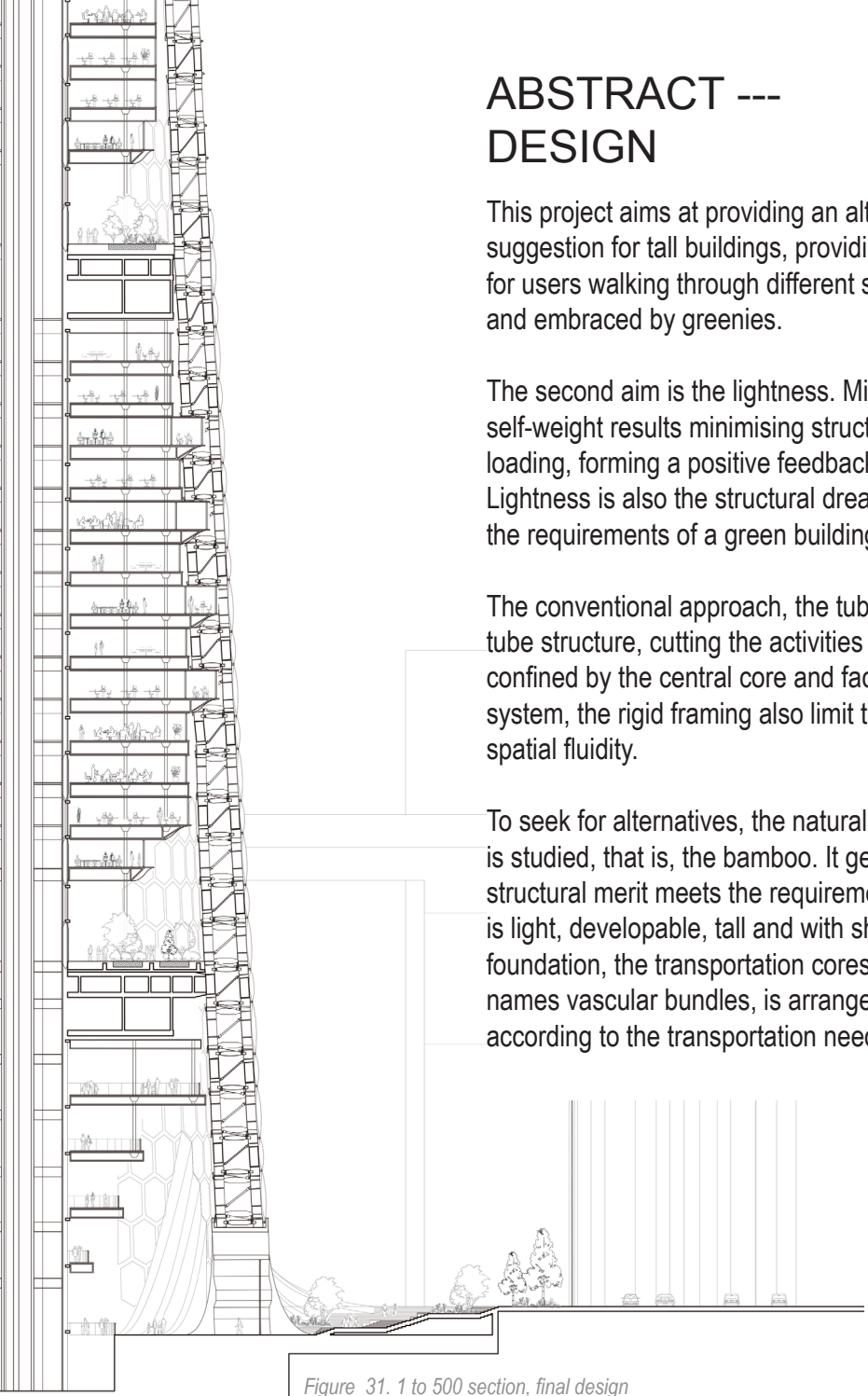


Figure 31. 1 to 500 section, final design

These are achieved by the integrated thick shell hyperbolic mega-frame system, every interval is locked up by nodes, which serves similarly as the outrigger trusses, the central void is formed which further enhances the lightness. The fibrous molecular structure provides elasticity for the whole system.

The main challenge of obtaining this structural logic is the opacity. Light needs to pass through. The nanotube structure inspired the study in plane geometry. Hexagon packing obtains the highest efficiency in packing while triangle provides rigidity. Following the thick shell structure approach, the double layered hexagonal shell is laterally connected by triangulated lateral supports.

Elasticity is achieved by the modular design, suspended floor and the PTFE air cushion installation. The hinge joints allow a slight movement in building a profile and air cushion allows vibration, which absorbs the lateral periodic wind load. The suspended floor not just reduce the structural member size, but also provide free slab opening opportunities and transforming the live loads as dampers.

The PTFE air cushion just gets 1 percent of weight compared with double glazing facade but serves similar thermal and optic performance.

The high translucency and unique structure result in a discrete day and night outlook. Considering the fabric of Kwun Tong, the developing CBD of Hong Kong, the new tower can serve as the gateway of the town, acting as the main anchor for the urban development.

The structural behaviour of the system is investigated and applied to a conventional commercial tower function, exploring the spatial potential provided.

Site Plan --- 1 to 5000

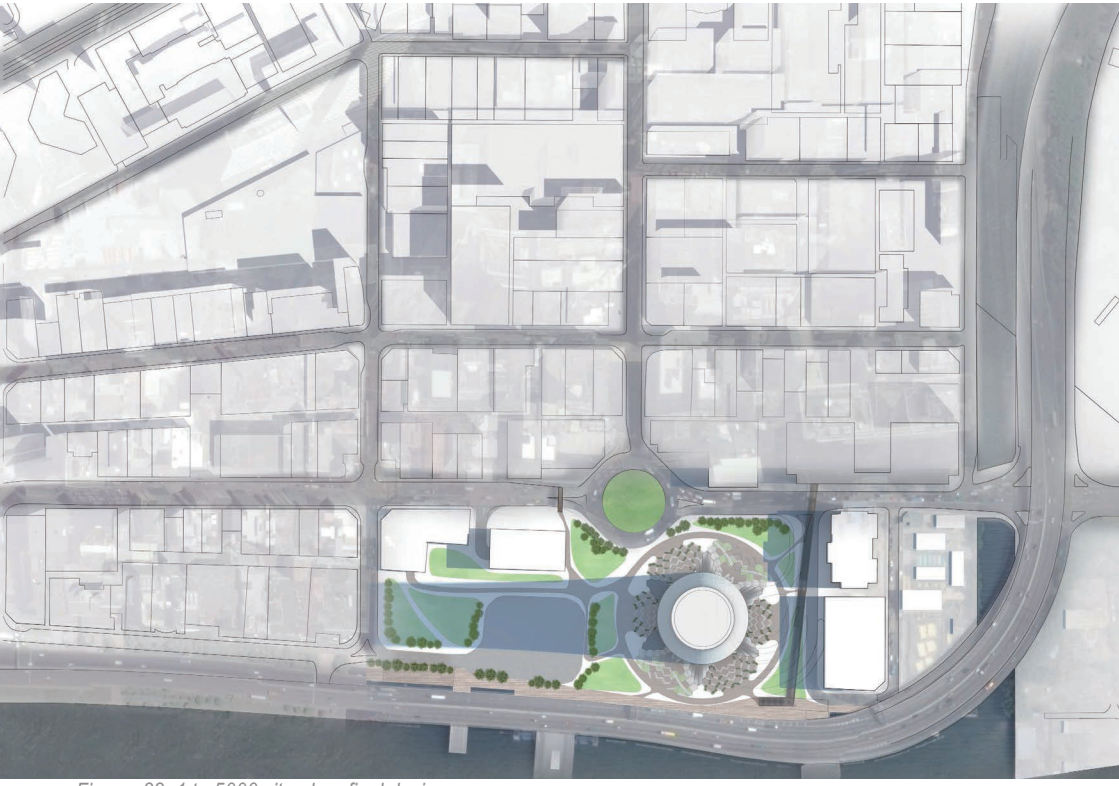
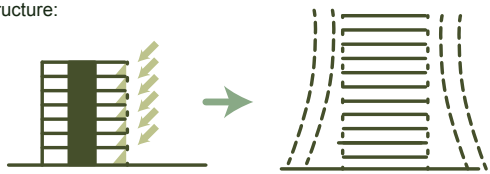


Figure 32. 1 to 5000 site plan, final design

Structural Diagram

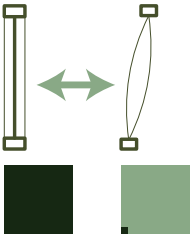
Design Idea:

Shell Structure:



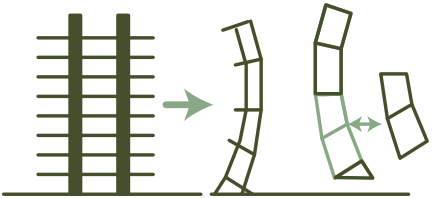
Shell Structure allows shifting of the core, increases the flexibility in spatial arrangement

PTFE:



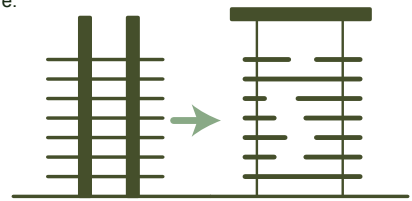
PTFE only weights 1 percent of the glass in same covered area.

Repairable:



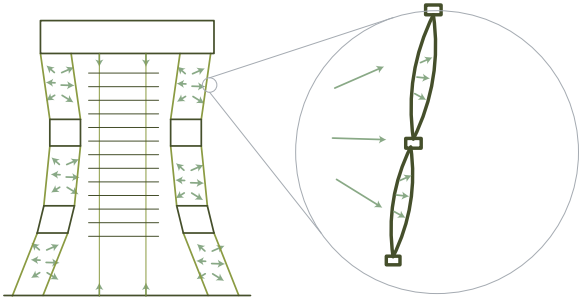
Huge Redundency and assembling Structure results in replacable strucuture.

Suspension:



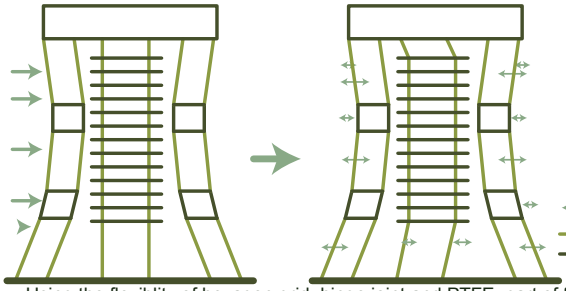
Suspened floor results thin column and a higher freedom in ifloor slab opening.

Pre-stress:



By hanging floor slab through pre-stressed cable and the PTFE cushions, the structure is pre-stressed, hence, becomes light but rigid.

Flexible:



Using the flexiblity of hexagon grid, hinge joint and PTFE, part of facade can absorb wind load. Counter movement of cabled floor slab, increase the comfort of tenent and acts as damper, further decrease deflection.

Figure 33. structural diagram, final design

Function Distribution

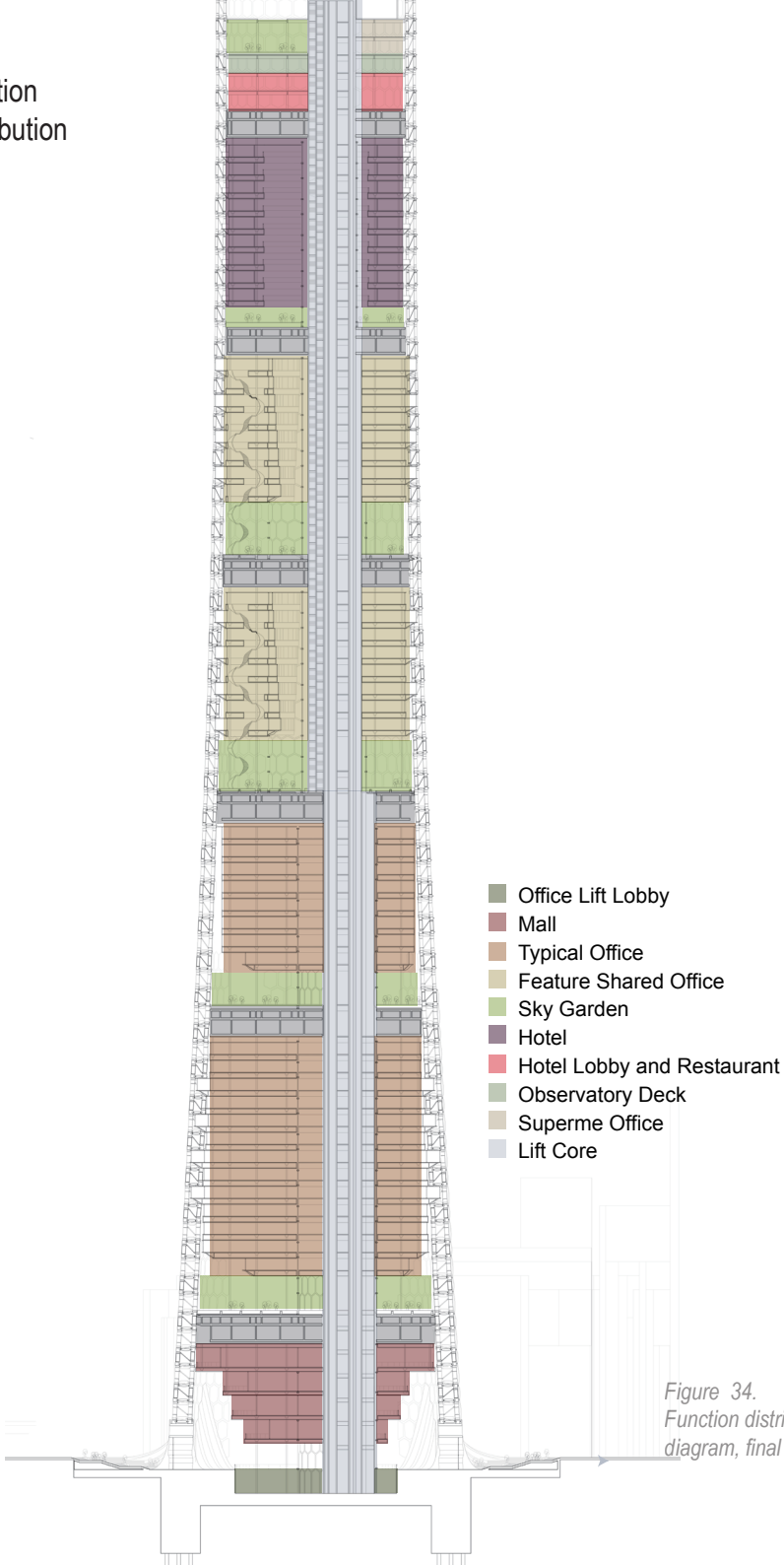
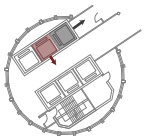
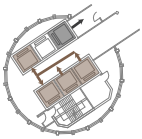


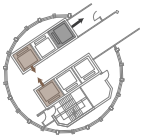
Figure 34.
Function distribution diagram, final design

Vertical Circulation

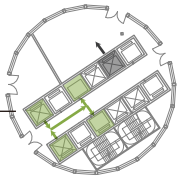
The circulation scheme mainly divide people to 4 streams: office at LG, tourist at 1F, service and superme office user at LG, all users are diverged away from GF to free up ground floor as public open space.

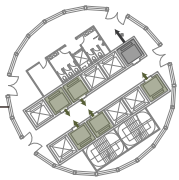


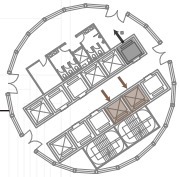


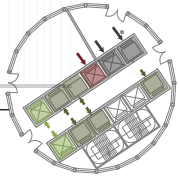












- GF Entry
- Underground entry: From Car park
- Hotel and Observatory Deck Lift
- Feature Office Lift
- Typical Office Lift
- Service Lift
- Superme Office Lift

Figure 35.
Vertical Circulation diagram, final design

Day



Figure 36a.
Day Exterior Rendering, final design



Figure 36b.
Night Exterior Rendering, final design

Perspective Section

The design with 6 entrances embraced by sunken plaza forms a fluent transition between the indoor and outdoor public space, the continous esculator forms a dynamic flow within the upper level stores while all office users are diverged further downwards to the sunken lift lobby.

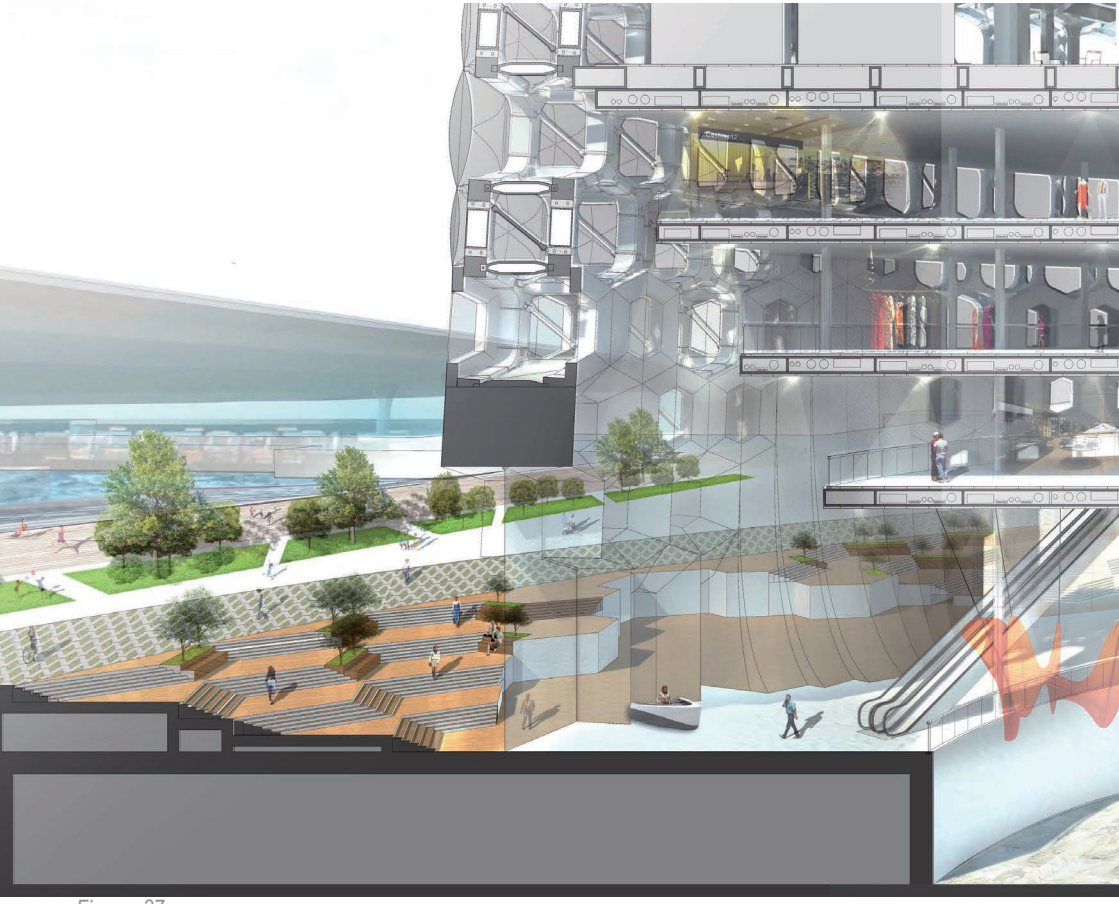
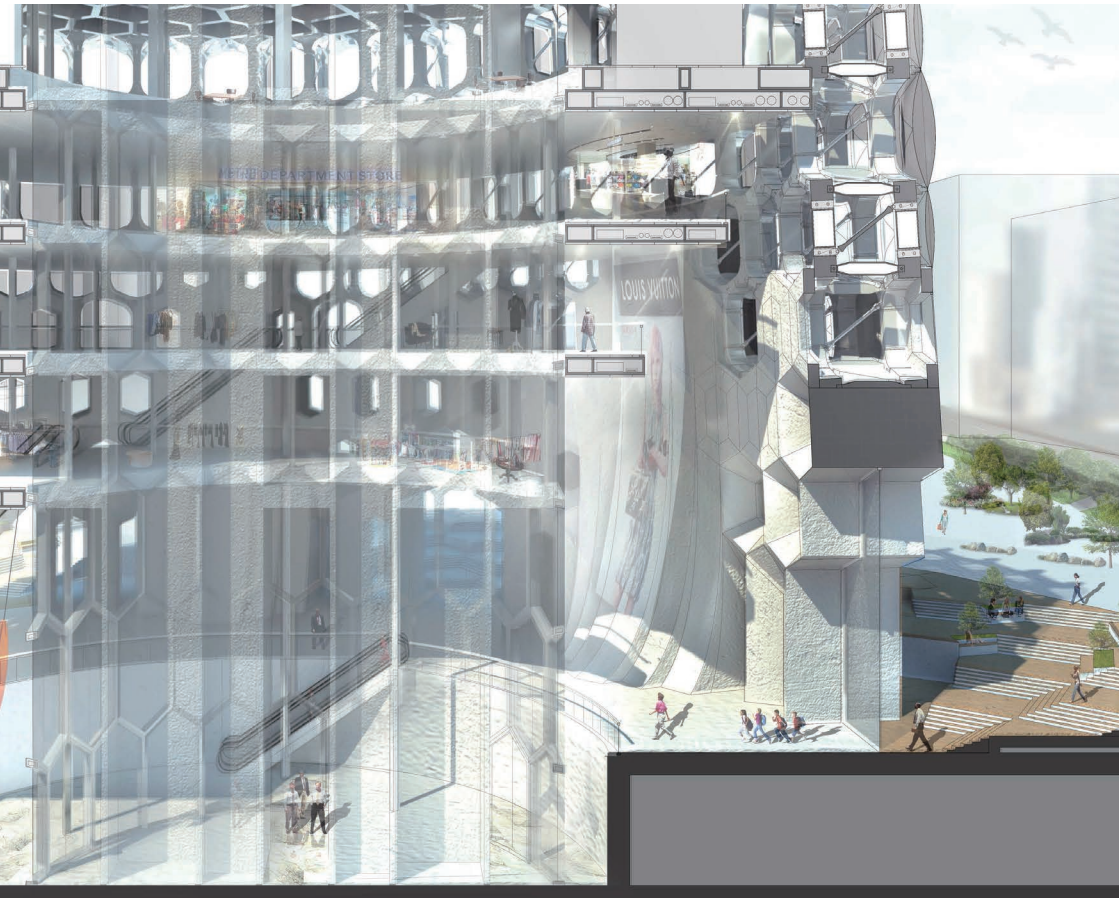
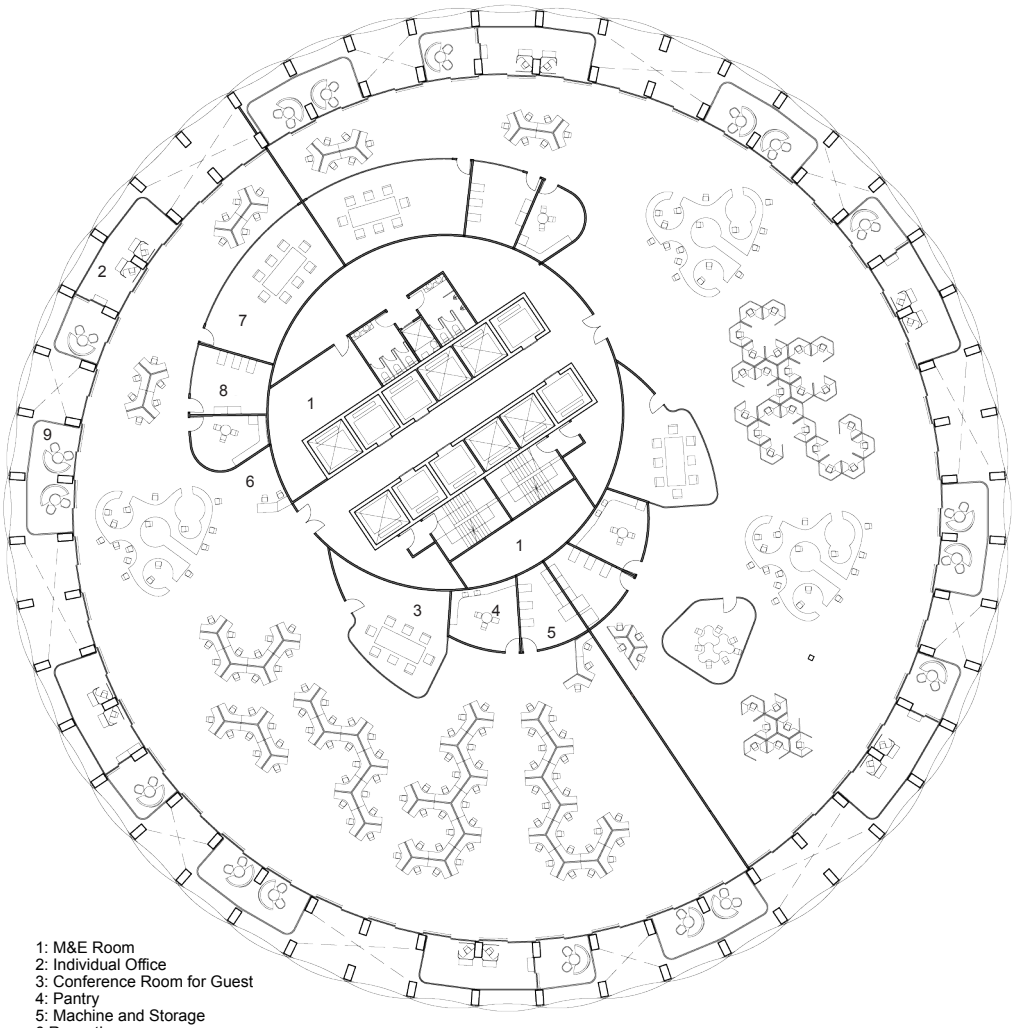


Figure 37.
Ground Perspective Section, final design


LOUIS VUITTON

1 to 500 Typical Plans

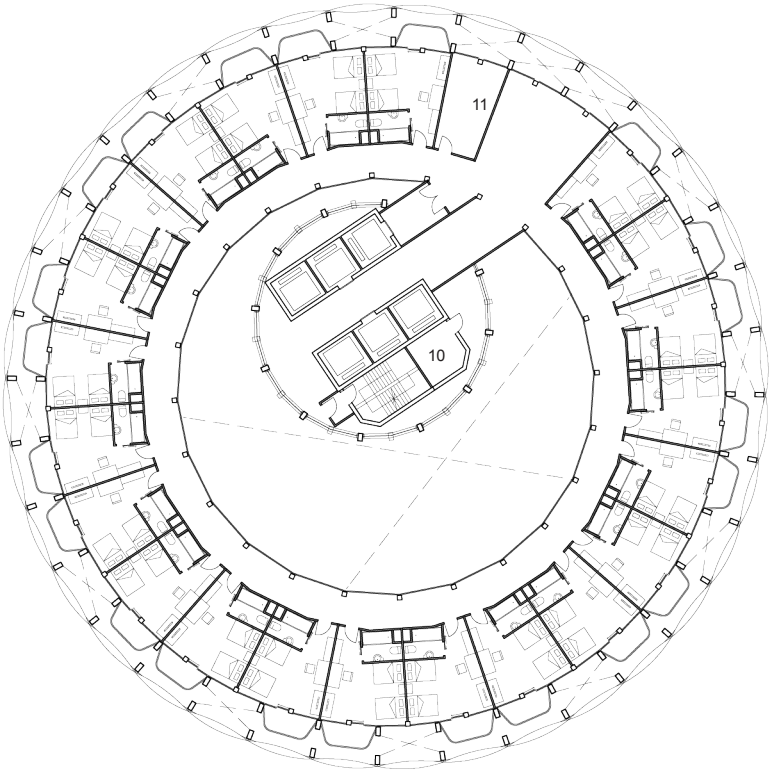
Shifted core allows light penetrate through the central atrium and allow larger open space for the sky garden.



1: M&E Room
2: Individual Office
3: Conference Room for Guest
4: Pantry
5: Machine and Storage
6 Reception
7: Main Conference Room
8:Storage Room For Manager
9: Balcony

10-25 th Floor, Typical Office

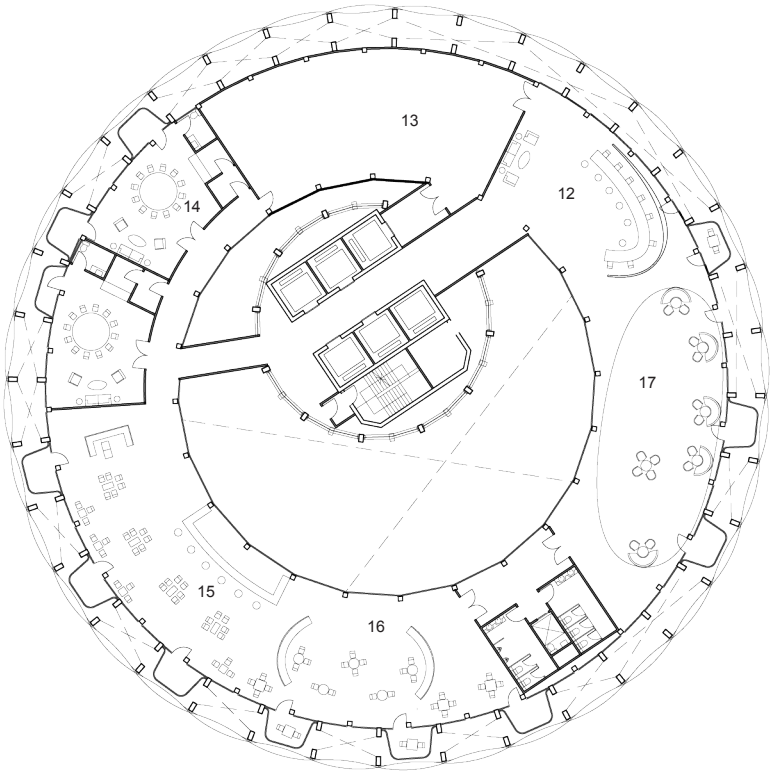
Figure 38.
Typical Office Floor Plan, final design



10: M&E Room
11: Back Of House

65 to 75th Floor, Hotel Room

Figure 39.
Hotel Floor Plan, final design



12: Check in Counter
13: Kitchen
14: Dining Room
16: Buffet Zone
17: Watiing Area
15: Bar

76th Floor, Hotel Lobby and Restaurant

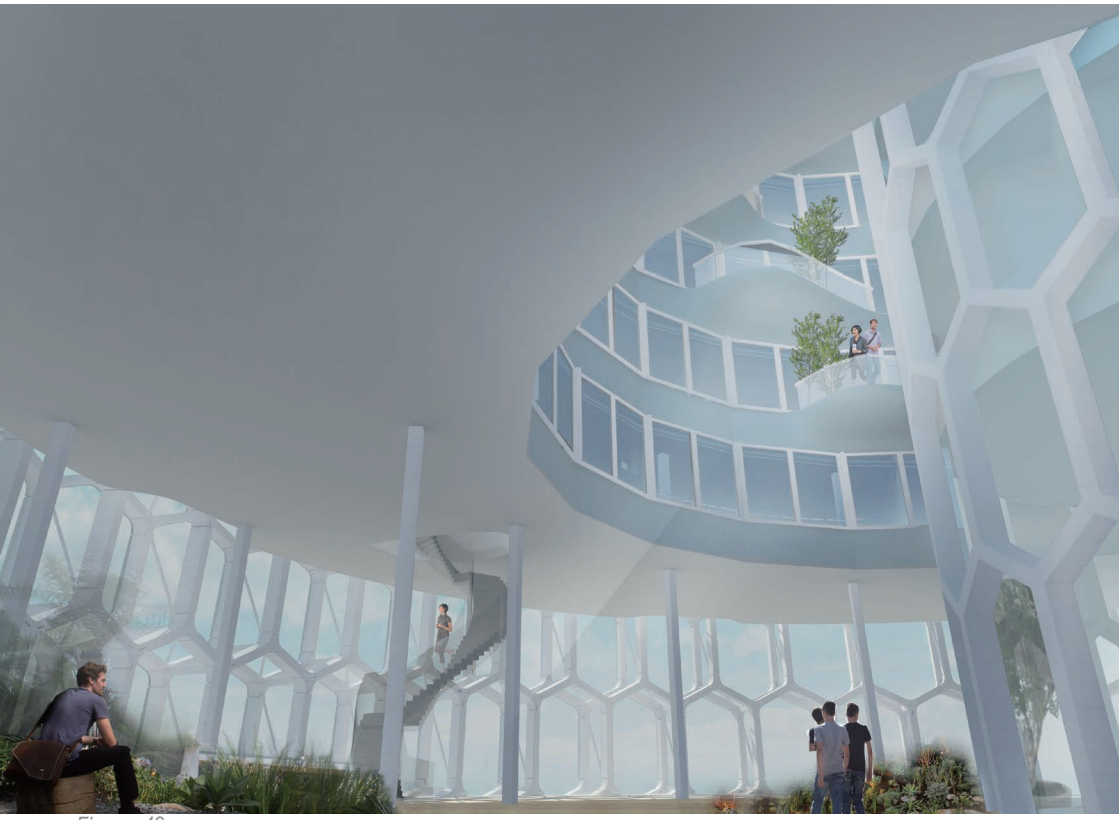
Figure 40.
Hotel Lobby and Restaurant Floor Plan, final design

Atrium



Figure 41.
Atrium Rendering, final design

Sky Garden



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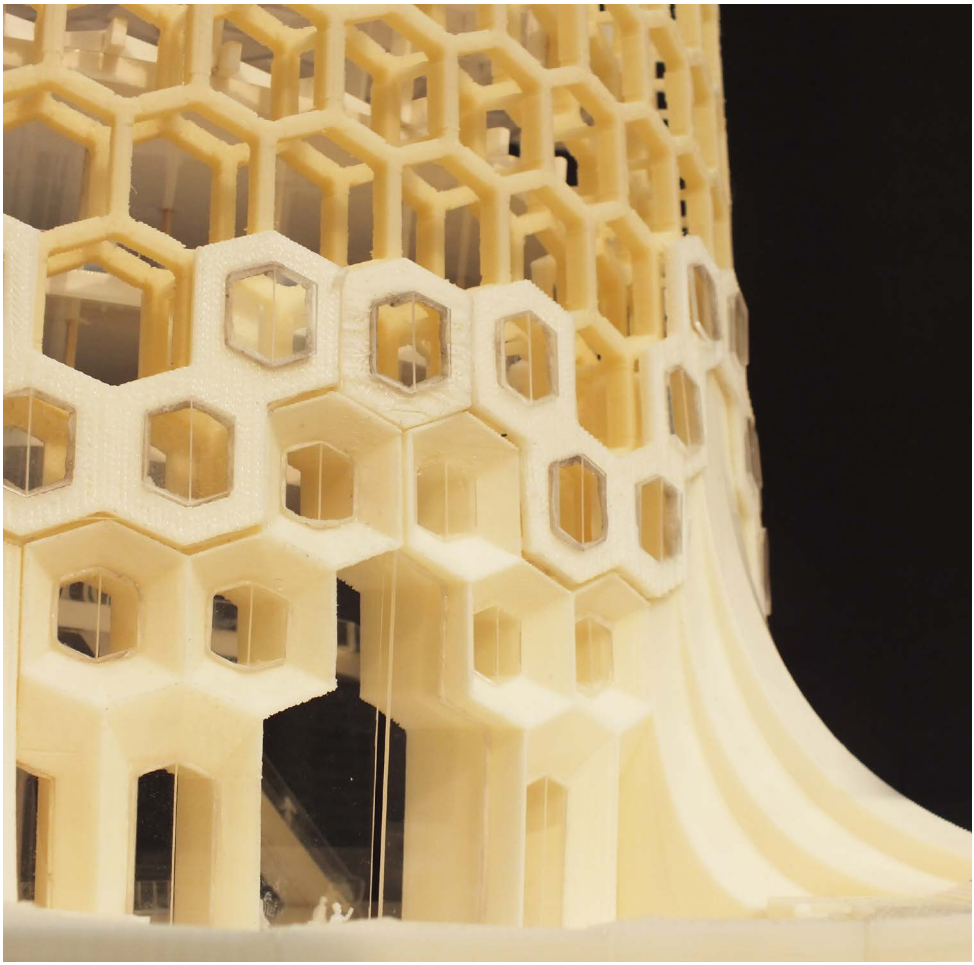
Sky Garden Rendering, final design

Co-working Office



Figure 43.
Co- working Space Rendering, final design

1:200 Final Model



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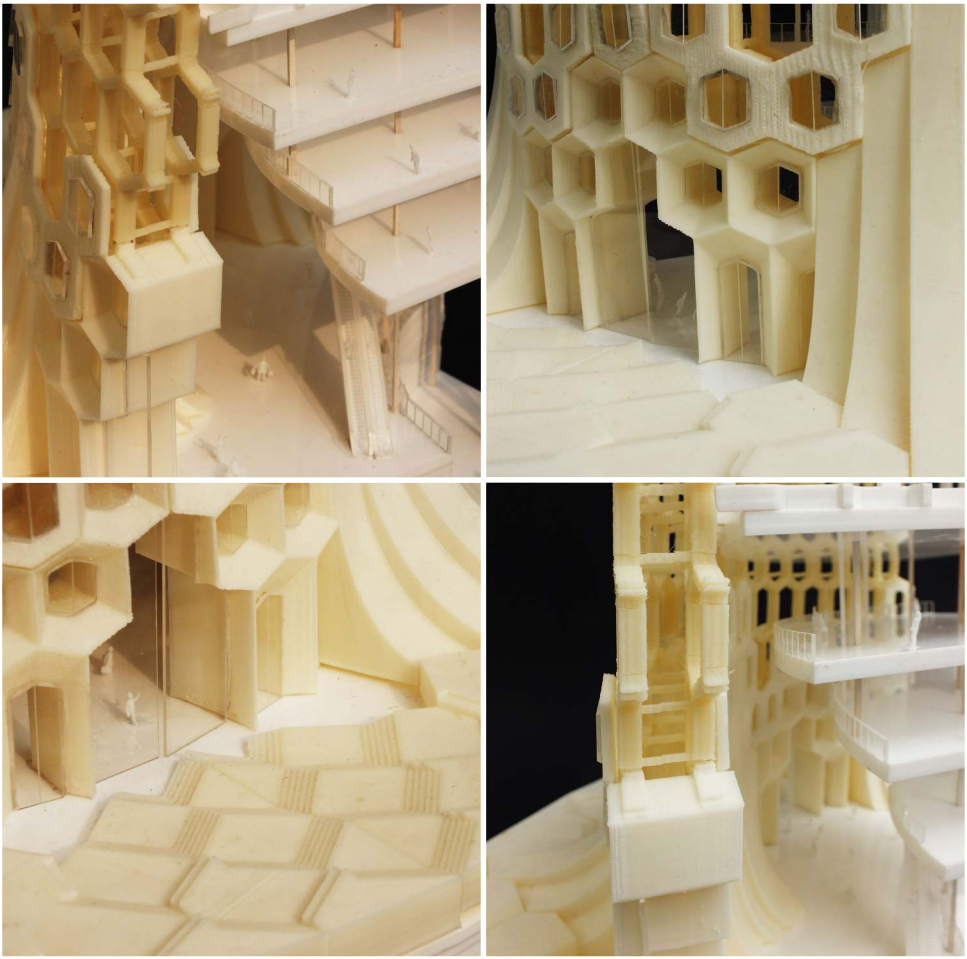

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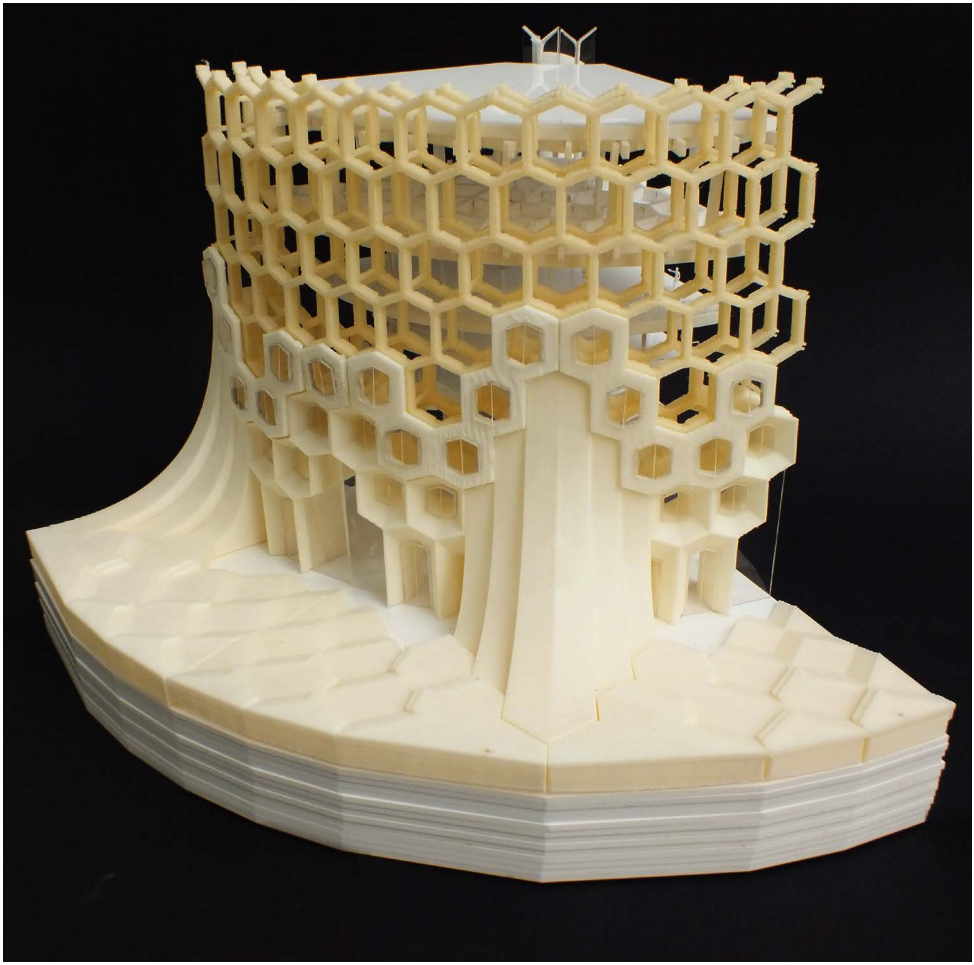

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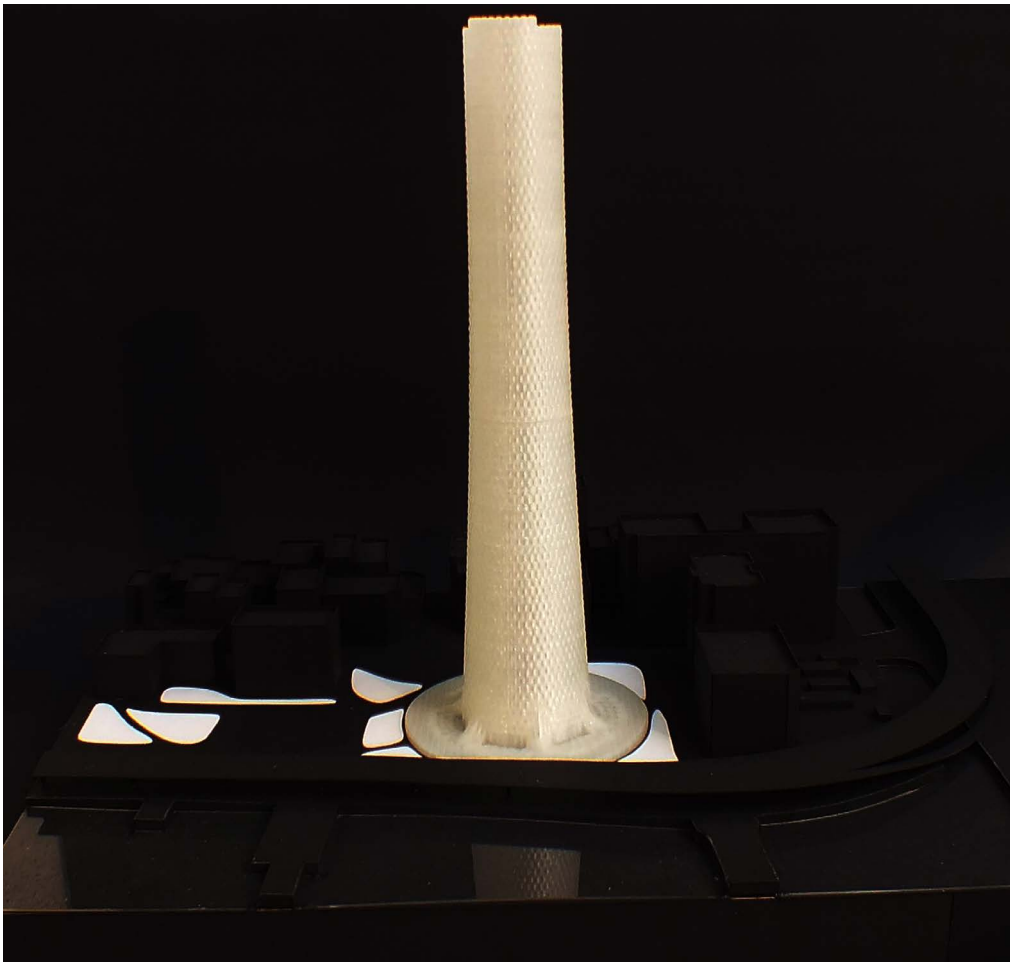
1:1000 Final Model



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CONCLUSION



Figure 49.
1 to 1000 final model photo, final design

This project aims at suggesting a way of construction such that metabolism can happen in Architecture. The building can grow like nature, can repair like nature.

In the progress of implementation, a large amount of conflict happens, the conflict between feasibility and the design aim, space and the construction, etc. The crude prototype just shows the concept and there is still a long way to go.

As a personal feeling, parametricism and the increase in computation power will cause a fundamental change in architecture, with compromise onto existing building technology, the room of design is unlimited.'

Quoted from Frank Lloyd Wright, 'Every great architect is - necessarily - a great poet. He must be a great original interpreter of his time, his day, his age.'

I want to become one of the interpreters.

BIBLIOGRAPHY

Matthias, Beckh, Hyperbolic Structures, Shukhov's Lattice Towers: Forerunners of Modern Light-weight Construction, West Sussex: John Wiley & Sons, Ltd., 2015

John B., Space Grid Structures: Skeletal Frameworks and Stressed-Skin Systems, London: The MIT Press, 1968

Michael Pawlyn, Biomimicry in Architecture, London: RIBA Publishing, 2011

Petra Gruberi (ed.), Biomimetic in Architecture: Architecture of Life and Buildings, New York: SpringWien New York, 2011

Olga Popovic L., Andy Tyas, Conceptual Structural Design: Bridging the Gap Between Architects and Engineers, USA: ASCE Press, 2003

Fuller Moore, Understanding Structures, USA: The McGrawHill Companies, Inc., 1999

Nassim Nicholas Taleb, Antifragile: Things That Gain from Disorder, USA: CITIC Press Corporation, 2013

Francis D' Souza, Karl M. Kadishi (ed.), Handbook of Carbon Nano Materials Volume 5: Graphene – Fundemental Properties, USA: World Scientific Publishing Co., 2012

Akbar R.Tamboli(ed.), Tall and Supertall Buildings: Planning and Design , New York: Council on Tall Buildings and Urban Habitat, 2014

Le Corbusier, Towards a New Architecture, New York: Dover Publications, 1986

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Thank you for all my helpers and staff of school that provided support. Thank you for everyone that provided help and care. This can not be done without any of you.

Name	Scope of production assistance
Ms. Erica Hung	Assembling of 1 to 200 final model
Mr. Ken Lau	Adding people onto perspective section
Mr. Sunny Poon	Adding people onto the building section
Mr. Hei Wong	Provision of 3d printing service for PLA printing of 1 to 1000 model
Mr. Chandler Lam	Assembling of 1 to 200 final structural model

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