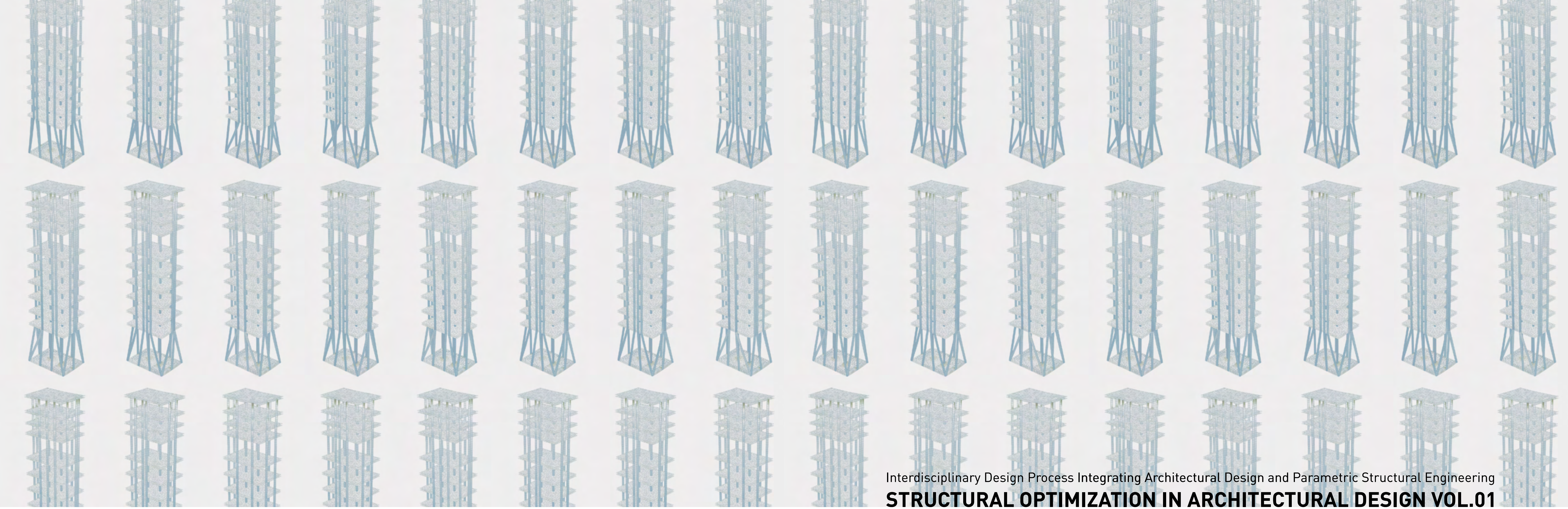

Interdisciplinary Design Process Integrating Architectural Design and Parametric Structural Engineering

STRUCTURAL OPTIMIZATION IN ARCHITECTURAL DESIGN VOL.01

STRUCTURAL OPTIMIZATION IN ARCHITECTURAL DESIGN.VOL01
Interdisciplinary Design Process integrating Architectural Design and Parametric Structural Engineering

H Architecture
This research paper was written by Dongil Kim and Jaekyung Jake Han at H Architecture, 2019.

H Architecture

Interdisciplinary Design Process Integrating Architectural Design and Parametric Structural Engineering

STRUCTURAL OPTIMIZATION IN ARCHITECTURAL DESIGN VOL.01

H Architecture

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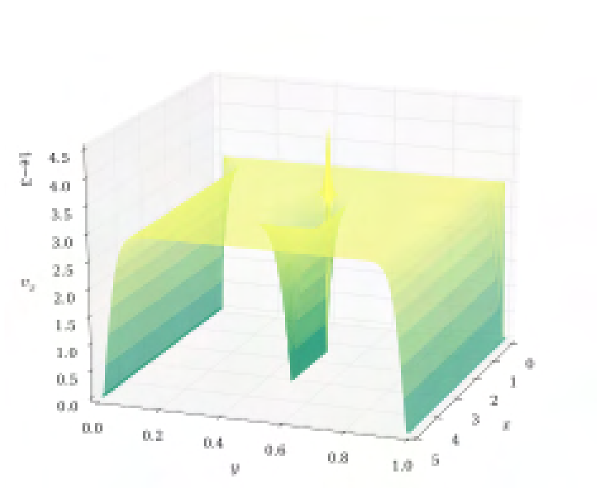
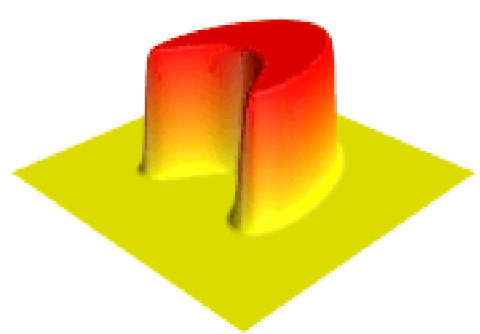
INTRODUCTION

Parametric Structural Design and Optimization

Top: Navier–Stokes differential equations used to simulate airflow around an obstruction as a finite element method (FEM)
Middle: A visualization of a solution to the two-dimensional heat equation with temperature represented by the third dimension as finite element method (FEM)
Bottom : The finite element method (FEM) definition extracted, https://en.wikipedia.org/wiki/Finite_element_method.





The finite element method (FEM) is the most widely used method for solving problems of engineering and mathematical models. Typical problem areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The FEM is a particular numerical method for solving partial differential equations in two or three space variables. To solve a problem, the FEM subdivides a large system into smaller, simpler parts that are called finite elements. This is achieved by a particular space discretisation in the space dimensions, which is implemented by the construction of a mesh of the object: the numerical domain for the solution, which has a finite number of points. The finite element method formulation of a boundary value problem finally results in a system of algebraic equations. The method approximates the unknown function over the domain.[1] The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. The FEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function.

Parametric Structural Design and Optimization

Computational design in building practice

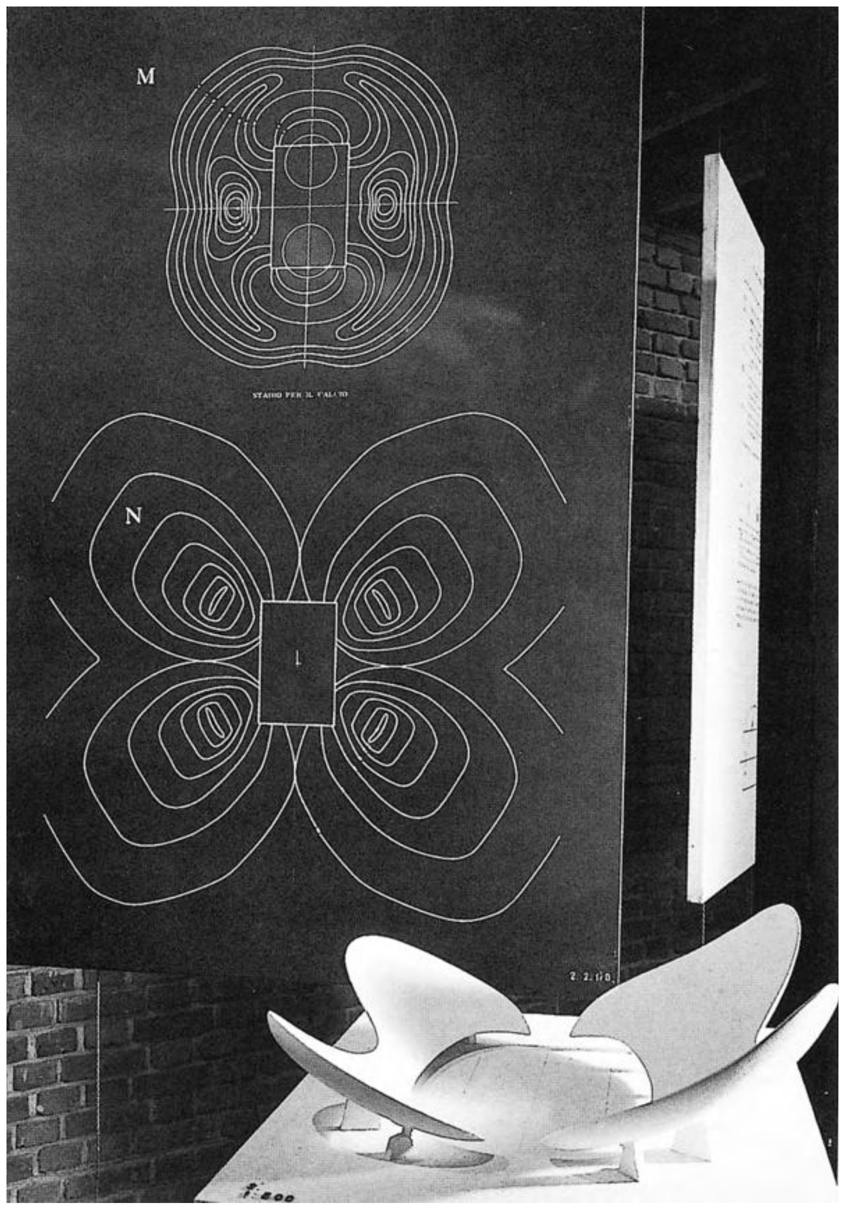
Parametric structural design and optimization procedure has been utilized a complex projects which only high-skilled designers and engineers could operate. The comtemporary the architectural research in design computation had catapulted the development of various software such as *Karamba 3D- parametric engineering*, made parametric architectural design and structural optimization routines be accessible to designer and architects. By utilizing these software, architects has been able to conveniently design a structurally intelligent lightweight organic form in schematic design phase. This chapter presents literature reviews on parametric design, finite element analysis, and its optimization.

REVIEW OF LITERATURE

Parametric in Structural Engineering and Architecture

Structural Optimization in Contemporary Practice

Top: Parametric Stadium in 1960 by Luigi Moretti



Parametric in Structural Engineering and Architecture

Computational and Algorithmic Design for Design Innovation in Architecture

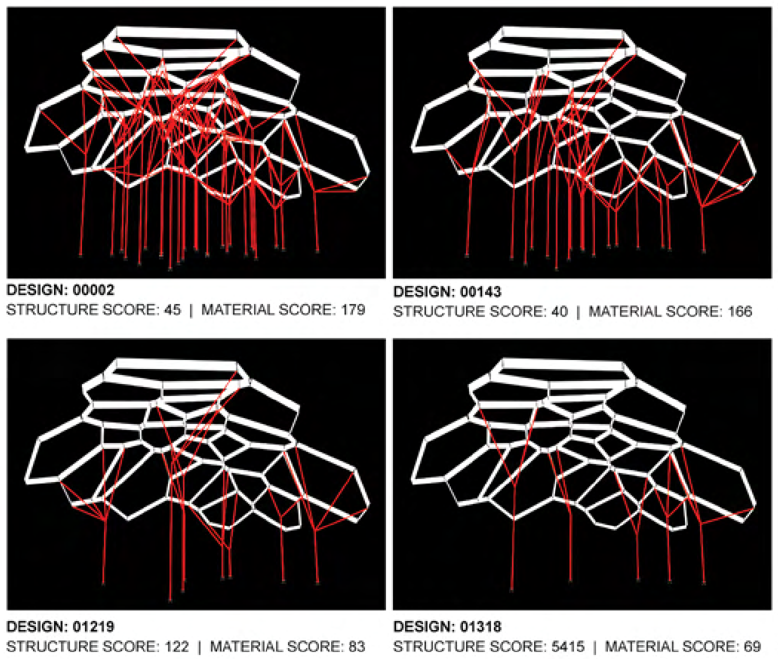
Luigi Moretti was the first architect who extensively wrote about parametric architecture in 1940s (Bucci and Mulazzani, 2000). Moretti defined the parametric architecture as a study of architectural system in which its goal is to create a relationship between the dimensions that depend on various parameters (Bucci and Mulazzani, 2000). Thus, in the parametric design process, a set of parameters drives the changes in the form, and relationship between geometrical entities is defined by various constraints. In parametric architecture, a parameter and a constraint are formulated by architects based on the design requirements including site analysis, performance and aesthetics.

Parametric architecture has been recently developed into a formalized version of avant-garde architectural style under the name 'parametricism' in which equations dictate forms. Patrik Schumacher, a principal of Zaha Hadid Architects defines parametricism as a new style after modernism, while considering post-modernism and deconstructivism as a transitional episode between those two. Schumacher stated that an architectural design inherently includes a parametric process and that an architect has always operated a parametric fashion. All the more, an architect Roland Hudson said that all of the design is essentially parametric.

Grasshopper is a plugin software for Rhinoceros 3D that recently won fame for its user-friendly parametric modeling capability from architectural academia. Rhinoceros 3D is a Computer Aided Design application that focuses on producing freeform surfaces, while Grasshopper functions as a platform that allows for designers to plug or unplug different functions.

Currently, Building Information Modeling (BIM), *a process supported by various tools, technologies and contracts involving the generation and management of digital representations of physical and functional characteristics of places (extracted from wikipedia.org),* has been widely used by architects using software such as ArchiCAD (Graphisoft, 2017), Autodesk Revit (Autodesk, 2017) and Digital Project (Digital Project, 2015). However, the limit of BIM program is that they are not considered for schematic design than Rhino/Grasshopper. The reason is that architects often dive too

Top: 3D modeling and finite element analysis (FEA) by the living

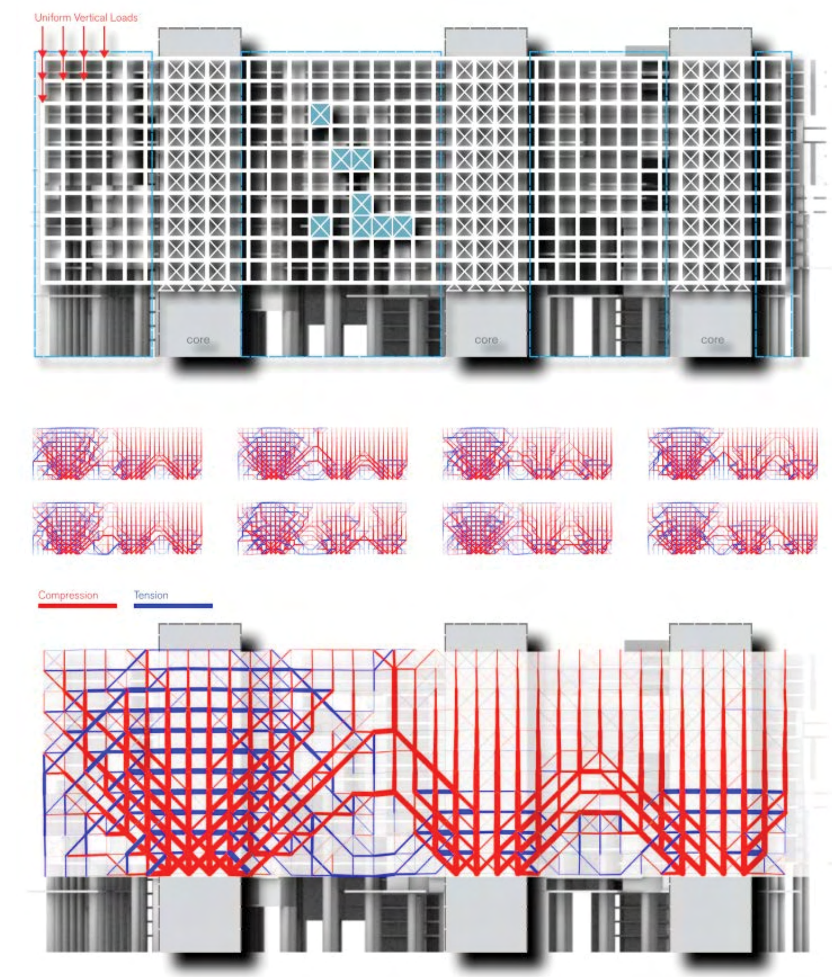


deep quickly into the details of construction, cost, and dimensions when using BIM and thus they are restricted in changes of building form. BIM tends to focus more on the details of the design because of its object-based representation instead of raw geometries representation. Although BIM brings digital model and realization closer, Rhino/Grasshopper is more flexible for design exploration and is, therefore, more appropriate for the schematic design. For instance, Revit has a broad object library for modeling purpose, but it has limitations on parametric rules dealing with angles and does not support complex geometries and curved surfaces. Digital Project has robust features for modeling and controlling surfaces, but the new users generally face a steep learning curve to properly use this software. These are the reasons to select Rhino/Grasshopper for the proposed structural optimization methods.

Grasshopper is considered to be user-friendly by many architects due to its geometric visual scripting capability for conducting parametric modeling. On the other hand, an alternative software Generative Component (Bentley, 2017) uses a scripting language for parametric modeling and it does not offer the graphic capability of Grasshopper. Also, Grasshopper allows functional customization using script method.

The combination of accurate surface representation and geometric visual scripting capability makes Rhino/Grasshopper an ideal tool for design exploration during the schematic design phase.

Top: Structural Optimization through Evolution: An example of a optimized planar structure section for given boundary conditions by Martha Tsigkari1, Angelos Chronis1, Sam Conrad Joyce1, Adam Davis1, Shuai Feng1, Francis Aish1



Bottom Left: British Museum Great Court
Bottom Right: British Museum Great Court Final Optimization Surface Model

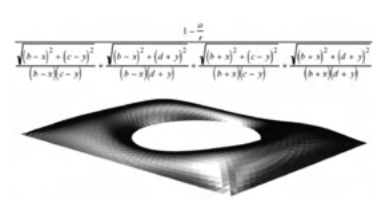
Structural Optimization in Architecture

Structural Optimization in Architectural Practice

Computational design is a design methodology in which the output is generated by a set of rules or algorithms, normally implemented on the computer. Recent study *"Integrating Parametric Structure Analysis and Optimization in Architectural Schematic Design Phase"* by Nixon Wonoto at Clamson University, well demonstrates the recent precedents for structural optimization.

'Integrating Parametric Structural Analysis and Optimization in the Architectural Schematic Design Phase 'Chapter 2.2.4.1 Structural Optimization in Architectural Practice and 2.2.4.2 Structural Optimization in Architectural Research'

"An example of structural optimization using prototyping can be seen in Gaudi's Work. Gaudi conducted the optimization for the arches of the Convent of Santa by utilizing the notion of the hanging chain model based on the catenary principle. Using this catenary principle, Gaudi produced an optimal arch that closely followed the line of compressive force then became economical in its use of material. For the experiment, Gaudi attached bags of sand to a web of strings, which hung in catenary curves to represent the masses of the static loads of the structure. This was done to reveal the shape of the chapel as a result of the loading. In this case, prototyping and casual inspection were used to optimize the structure intuitively, and the criterion of the optimization was structural performance.



Top: Qatar Education City Convention Center

Shape optimization using analytical method can be seen in the design of the British Museum Great Court. A surface function with a singularity at the boundary was developed mathematically to represent the roof of the museum. A mathematical function defining the surface was developed to satisfy the boundary condition acting as the constraint function in the optimization. The optimization was to find a surface shape that represented a good fit between the architect's early proposal, the structural loading and bearing criteria. In this case, the optimization problem was solved analytically.

An example of structural topology optimization can be seen in the design of the Qatar Education City Convention Center. The structural optimization problem was solved numerically with the help of the design engineer Mutsuro Sasaki using evolutionary structural optimization for the detail information of evolutionary optimization.

An evolutionary structural optimization was conducted to acquire the shapes of the Sidra trees that form the façade of the building. The trees were 'grown' using an optimization solver by iteratively removing the smallest amount of stressed material from a block until the residual structure used the least amount of material. The objective function of the numerical structural optimization problem was then the weight of the structure to be minimized.

Top: Rectangular Stadium in Melbourne, Australia

Another example of a structural optimization solved problem numerically is the design of the rectangular stadium of Melbourne, Australia by Philip Cox Architect with the help of the engineering firm Arup Group. The goal of the project was to create a dome structure that is as light and stiff as possible and also divisible into easily fabricated units. Specific protocols were developed to ensure the consistency between flexible surfaces and structural lines of force.

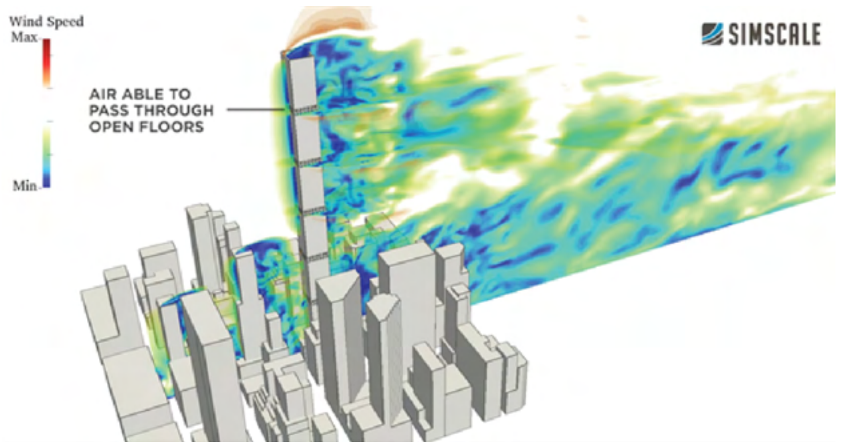
Recently many researchers in the field of architecture have been interested in structural optimization for form-finding. An example of structural optimization using numerical trial and error optimization can be seen in the work by Al-Haddad (2006) whoconducted a parametric study for shape optimization of a dome structure. The structural analysis was carried out using Finite Element Analysis. The optimization consisted of stiffening the locations of the structure where significant deformation occurred by an iterative trial and error process.

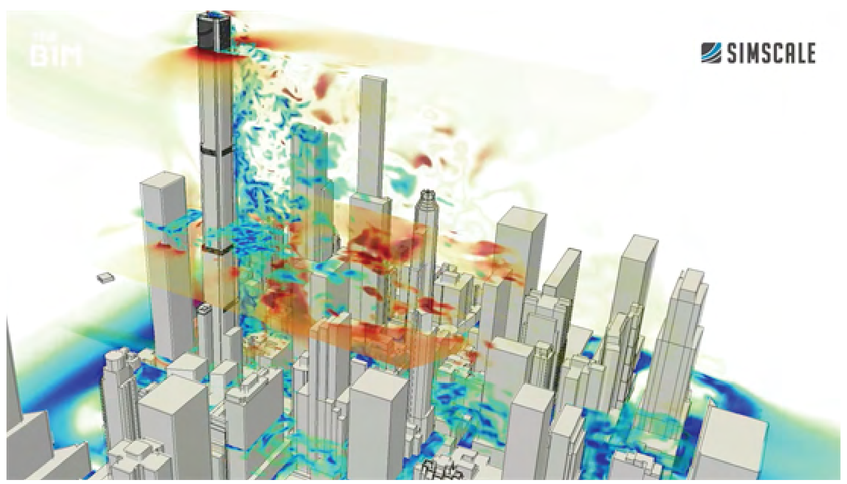
Von Buelow studied the integration of parametric modeling using Generative Component (Bentley Systems, 2017), STaaD (Bentley Systems, 2017), and Genetic Algorithms. Genetic Algorithm was used as a stochastic optimization approach for conducting structural optimization of the tessellated roof with a hexagonal grid pattern."

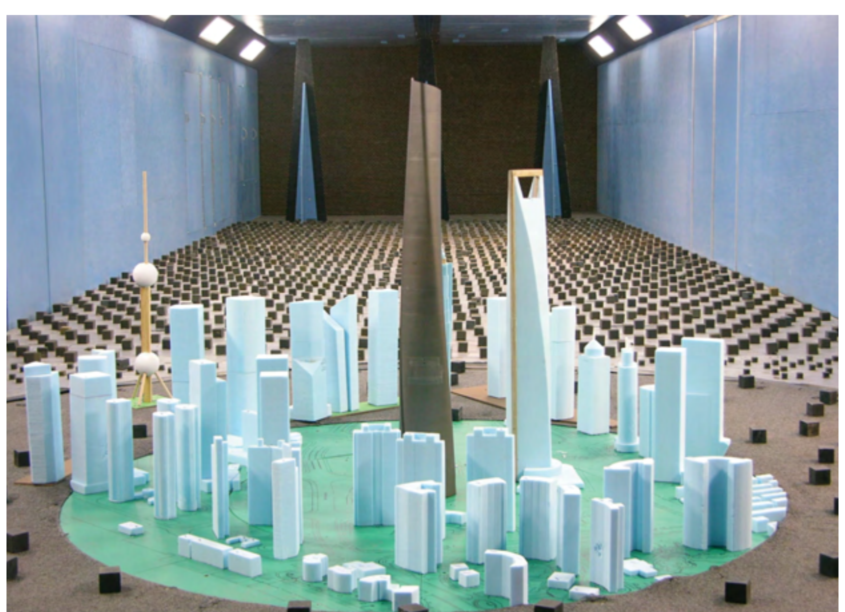
Other researchers in architecture used a structural optimization method as a form-finding method to design a truss tower, large concrete roofs and Voronoi's cell structure."

1) Wonoto, Nixon. Integrating Parametric Structural Analysis and Optimization in the Architectural Schematic Design Phase. Clemson University. 2017

Top: Simulation of New York's 432 Park Avenue carried out with SimScale analyzed 400 seconds of real-time transient flow
Middle: Simulation of New York's Central Park Tower's irregular facade breaks up wind loads with SimScale
Bottom: Shanghai tower wind tunnel performance analysis







Structural Optimization in Contemporary Practice

There are traditional models for highrise building analysis and simulation on structural quality. It is an intense and rigorous process to verify the performance. However, recent technological enhancement allows closer communication between the architects and engineers.

This research aims to demonstrate the dynamic relationship between architectural design and structural engineering on early design study, and will focus on three types of structural optimizations in: size, shape and topology. For size optimization, domain of a design model and state variables are known as a priori and are fixed throughout the optimization process. For shape optimization, the purpose is to search an optimal configuration domain of the design model so that the shape itself becomes a design variable. Shape optimization is relatively more complicated than size optimization. Finally, topology optimization involves the change of element connectivities and is usually considered as the most complex type of optimization among the three.

The mathematical representation of a structural optimization problem consists of design variables, objective functions, and constraint functions. Geometrical related variables are the design variables. Displacements, stresses, forces, and strains are usually the quantitative measures to represent the goal of the structural optimization. Geometrical or structural quantities such as maximum stress and displacement are commonly used to express the constraint function mathematically. The constraint functions represent the feasible region of the optimal solution.

APPLICATION

Application on Super Slender Tower

Application on 267 Broadway Tower

This research has been conducted on a series of area in the 267 Broadway Tower projects. The projects are closely collaborated with Structural Engineer, WSP USA, and the development of computational system on schematic design and design development phase has been set up at H Architecture. This case study has been focused on how to optimize the structural efficiency while considering diverse parameters in program, heights, and system changes on super slander tower. This research focuses on three specific parts of design process in the aforementioned project, 267 Broadway Tower in New York City.

First chapter explains "Lateral Force and Displacement based on the building height, column position, and intermediate bracing system(called Out-rigger)". This study allows dynamic changes in sectional program distribution for schematic design.

Second, "Material and Displacement Optimization on Column Positions" chapter aims to explore how to optimize the column positions on top five floors where program changes from hotel(Residential) to event space(Commercial). This is to achieve panoramic view with minimal number of columns and removal of corner columns.

Last chapter of this research, "Material Distribution on Structural Optimization", is to find the ideal structural member distributions in terms of material. The study result represented in this chapter is the ideal condition of structural optimization in terms of material efficiency, even though it might be less cost effective.

These sets of studies focus on parametric engineering optimization in the conventional form of architecture and expects to serve as a prototype for future projects at H Architecture.

METHODOLOGY

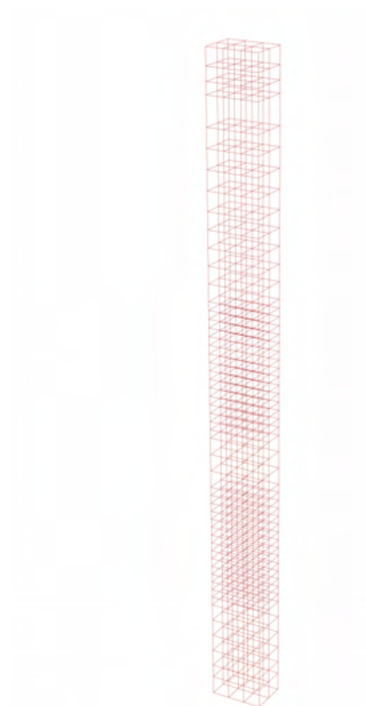
01. Geometry Fundamental of Super Slender Tower
02. Lateral Force and Displacement on Super Slender Tower
03. Material and displacement Optimization on Column Positions
04. Material Distribution on Structural Optimization

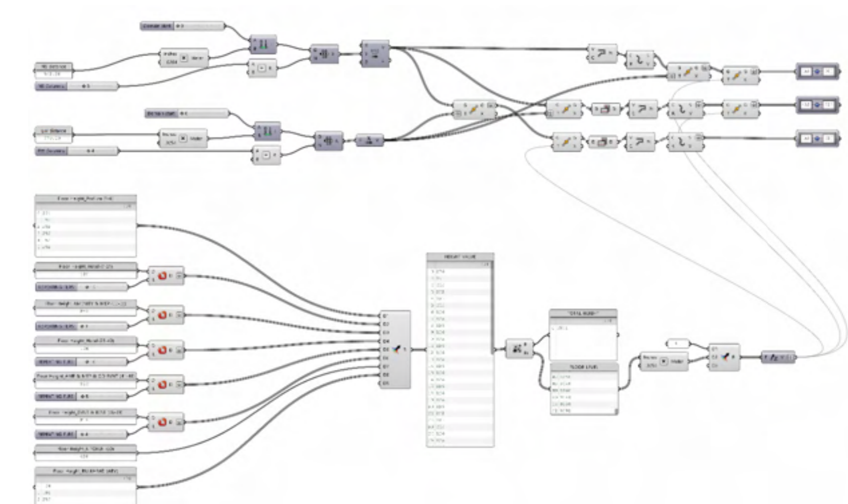
METHODOLOGY.01

Geometry Fundamental of Super Slender Tower

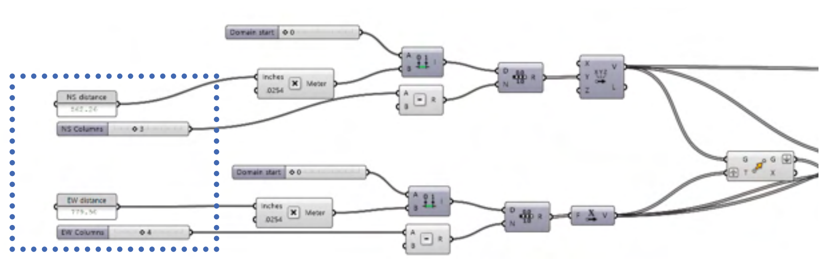
Geometry Fundamentals of Super Slender Tower

First Chapter of this research demonstrates a preset geometry of super slender tower. A recent project, 267 Broadway project at H Architecture is a provocative mixed use tower in the heart of lower Manhattan. This slim tower which is approximately 780-ft in height and 40-ft in width is designed through the integration of appropriate building code, structural, building systems and a series of algorithmic experiments. The building program arrangement is based on the NYC Building Code and regulations, structure, and constructibility in juxtaposition to the displacement simulation that instructs the mass to resist lateral forces. This chapter introduces how to preset the dynamic relationship between architectural and structural system setup including different floor height, structural grid, and intermediate bracing based on the program change and lateral forces. These parameters are the fundamental of this research to optimize the system in creative responsive and innovative way.





Base Geometry for Structural Simulation



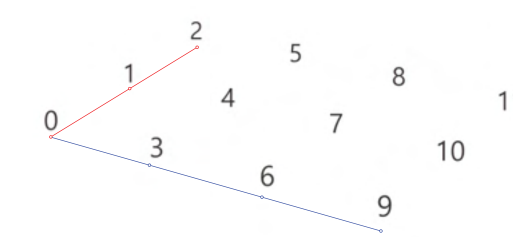
Setting up Column Location

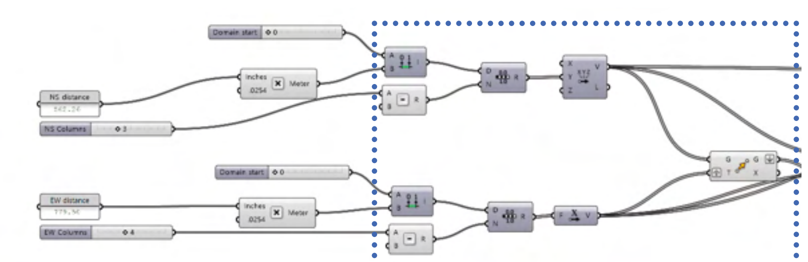
1) Define length north-south(NS) in coordination

2) Set number parameter to identify the number of NS-columns

3) Define length east-west(EW) in coordination

4) Set number parameter to identify the number of EW columns



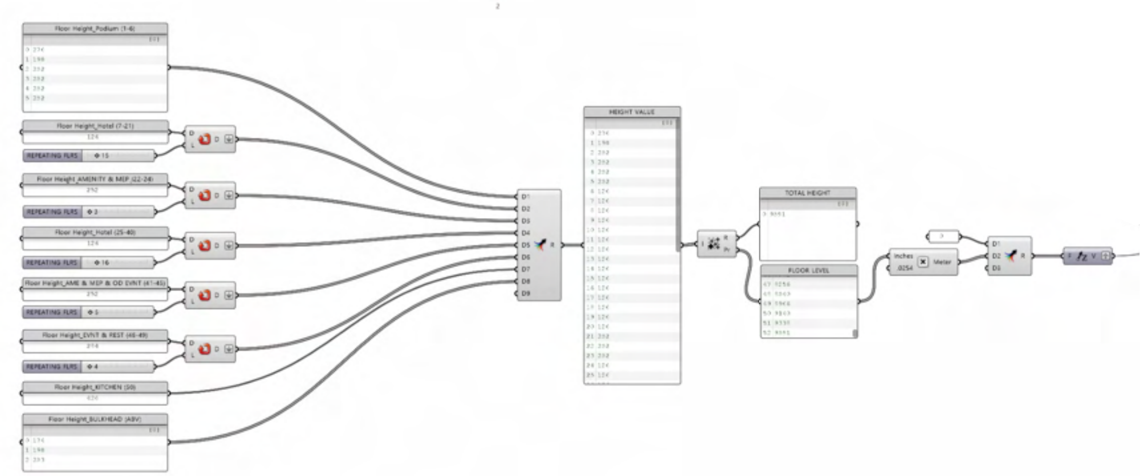


1) Create polyline based on NS column location to create individual beam structure

2) Explode the polyline and copy in accordance with EW column location

3) Flip the list Structure and repeat the procedure for EW structures

In structural analysis using Karamba, all imperial units needs to be converted to a metric unit. By simply multiplying the specific number, units can be converted easily In this case study, inches used in this building design multiplied by 0.254

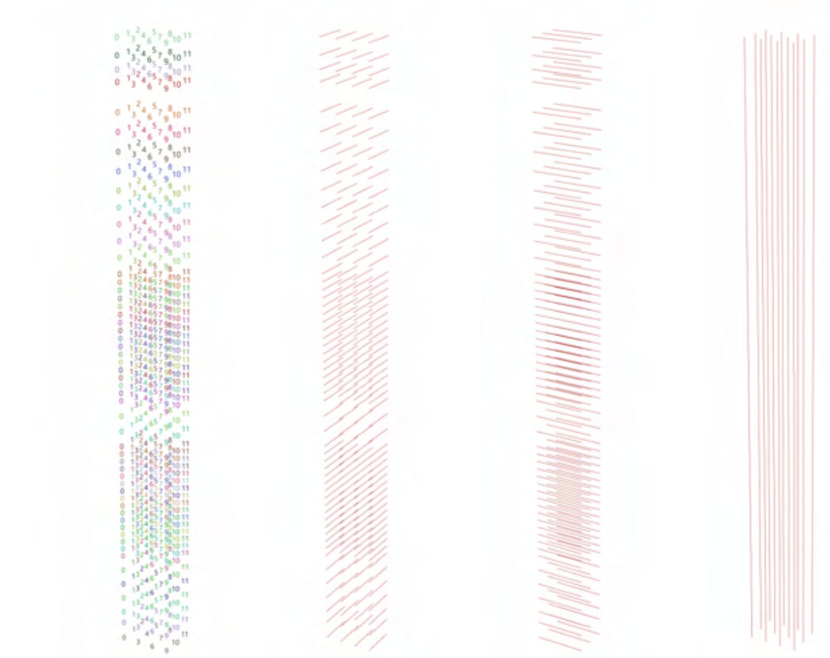


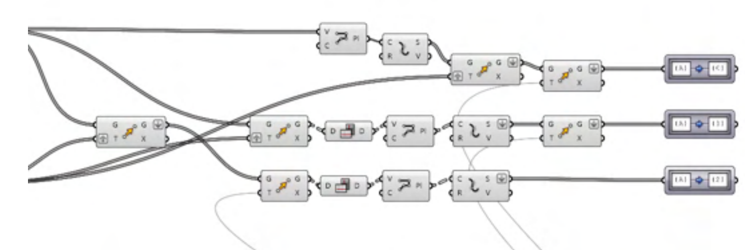
Setting up Floor Heights

1) Set the number parameter to identify heights of the floors either adjustable or fixed

2) merge heights data based on program arrangement

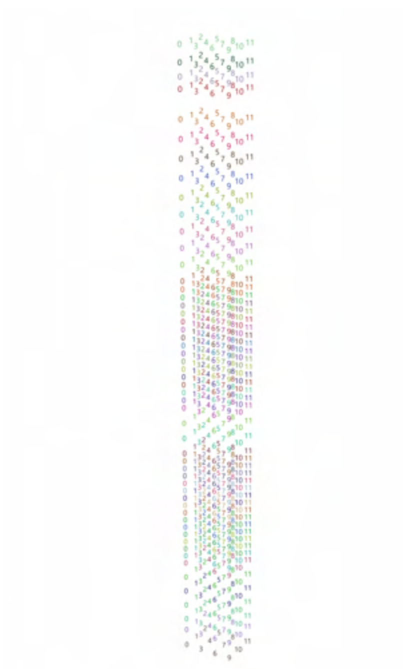
3) Connect the all height to mass addition measure the total building height and each floor levels

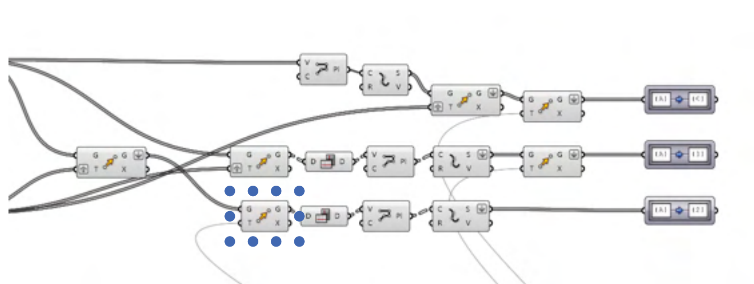




1) Apply Floor levels(Z Vector) to curves from columns(on X, Y Vector) locations

2) Generate vertical polylines and break down to extract columns for floor by floor





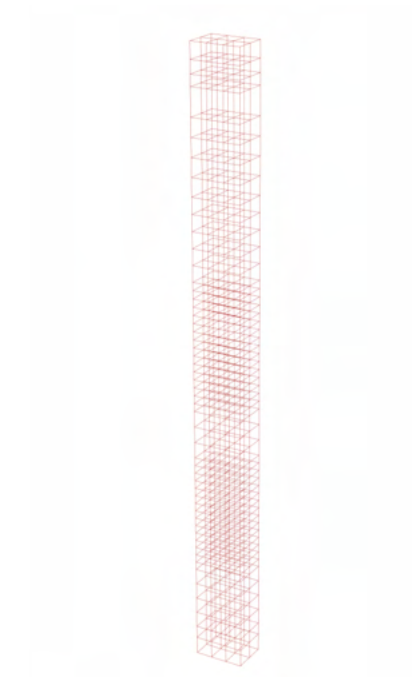
Fundamental Parameter has been established.

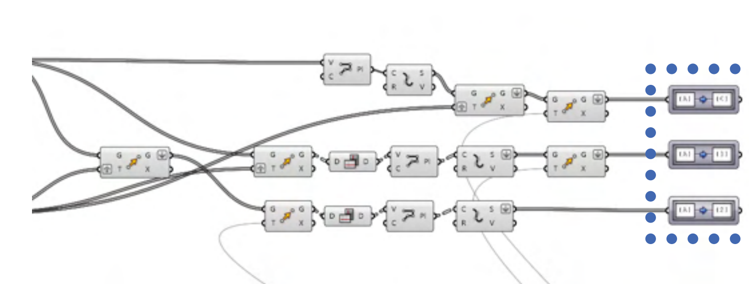
Now we have two crucial elements for structural optimization.

1) Curves transform to compute structure beam

2) Points transform to compute connection condition of the each beam elements

3) The list of geometry and data structure serve as the sequence of data set





1) The list of geometry and data structure serve as the sequence of data set

METHODOLOGY.02

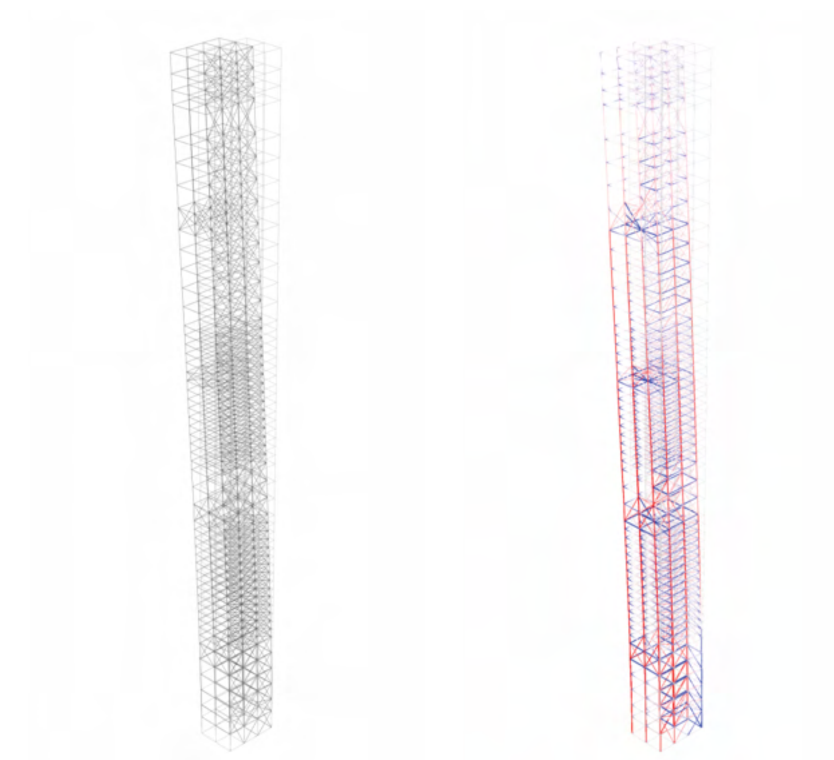
Lateral Force and Displacement on Super Slender Tower

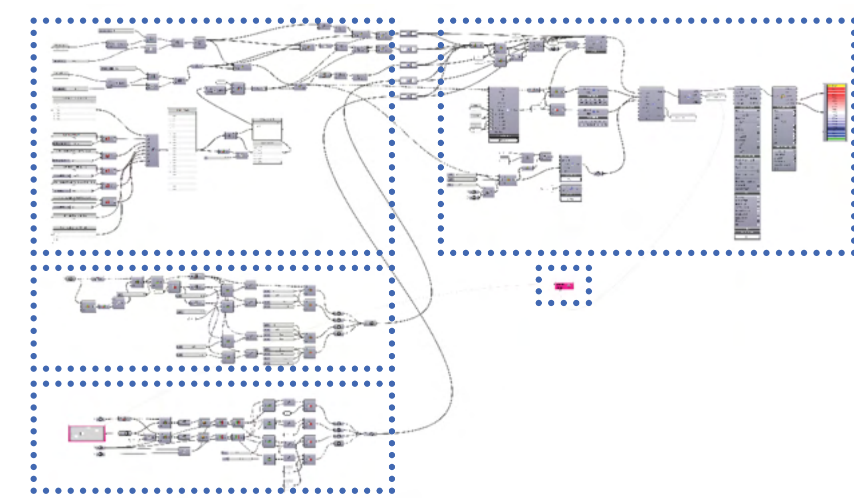
Lateral Force and Displacement on Super Slender Tower

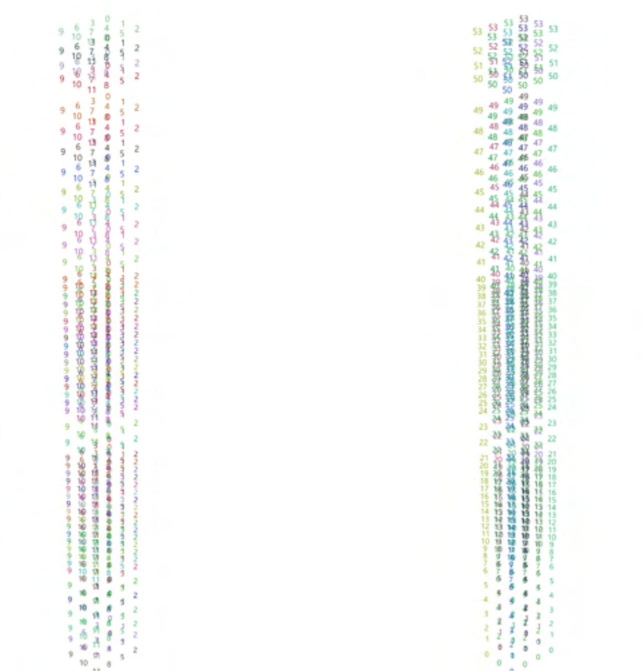
This chapter introduces structural optimization to develop structural resistance to lateral forces such as wind and seismic. The strategy is to distribute a series of intermediate bracings (Out-rigger) as a parameter to optimize building structure in response to the lateral load at a given architectural configuration. An evolutionary solver is set up to optimize the position and configuration of intermediate bracings to achieve minimum deflection. This exercise is very crucial for a super slender tower in architectural and structural design process. This aspect would be applied to any high-rise tower design in early design phase.

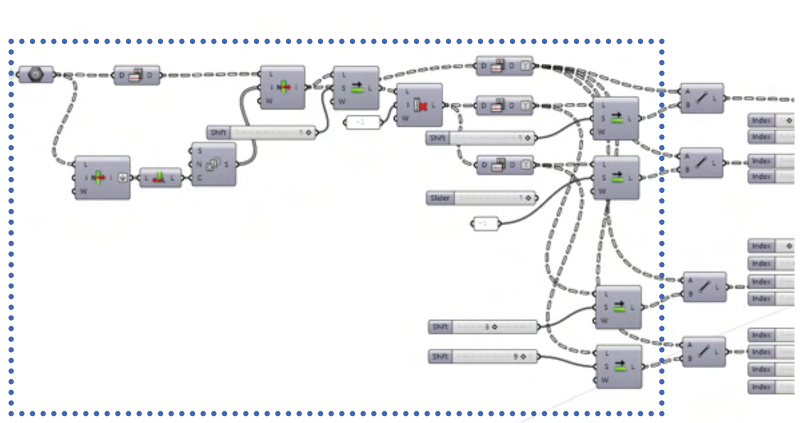
The work flow of this section is following order and objective.

- How to set up outrigger geometry in Parametric way
- How to connect it to Karamba3d software for calculation
- How to get the best location for outrigger by using evolutionary computing







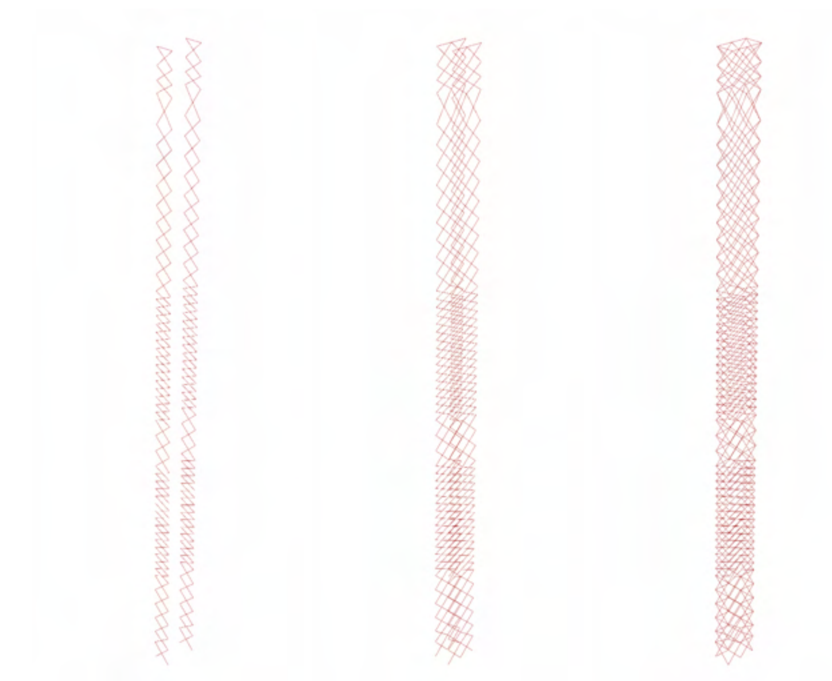


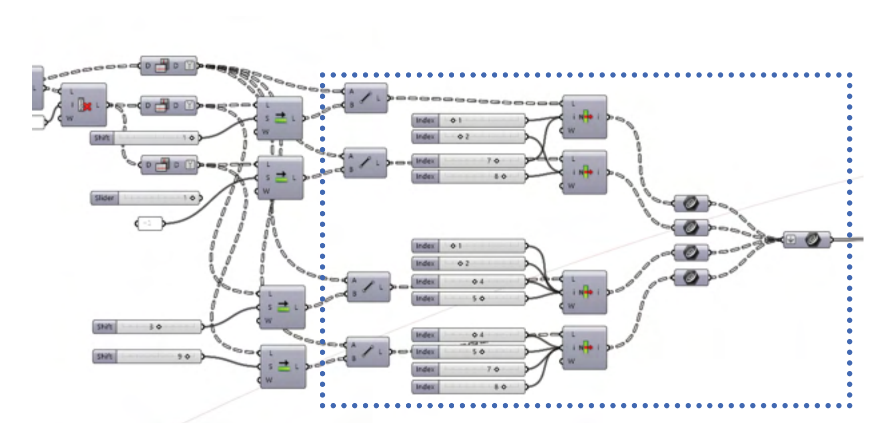
Setting up Shear wall Geometry

1) Bring points from Base Geometry

2) Flip the list to be organized by floors

3) Shift the list and create floor by floor connections

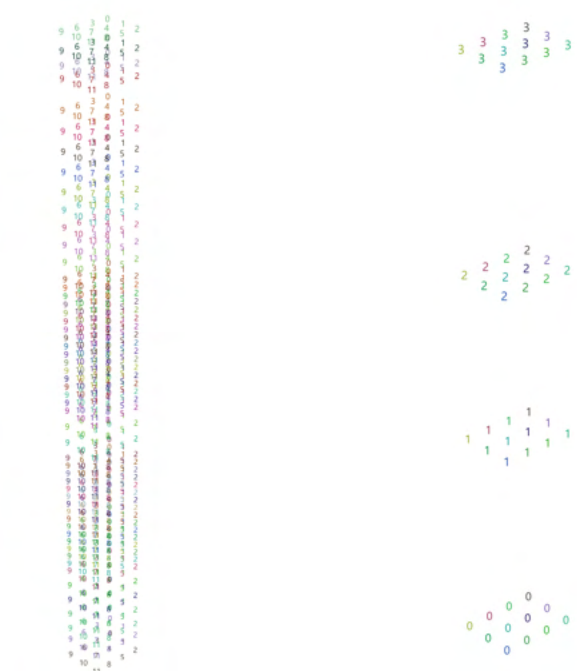


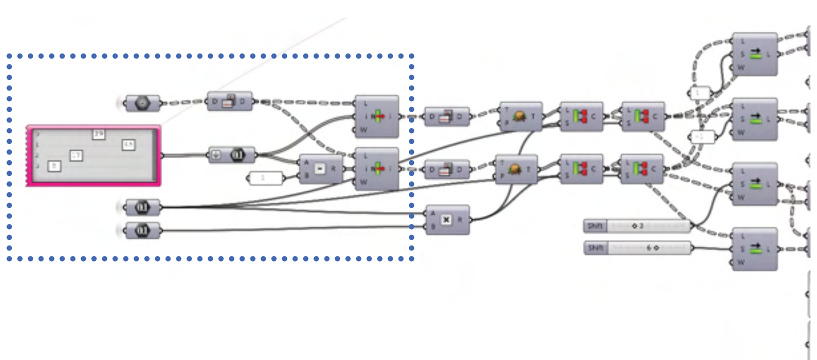


1) Generate NS bracing

2) Generate EW bracing

3) Assemble



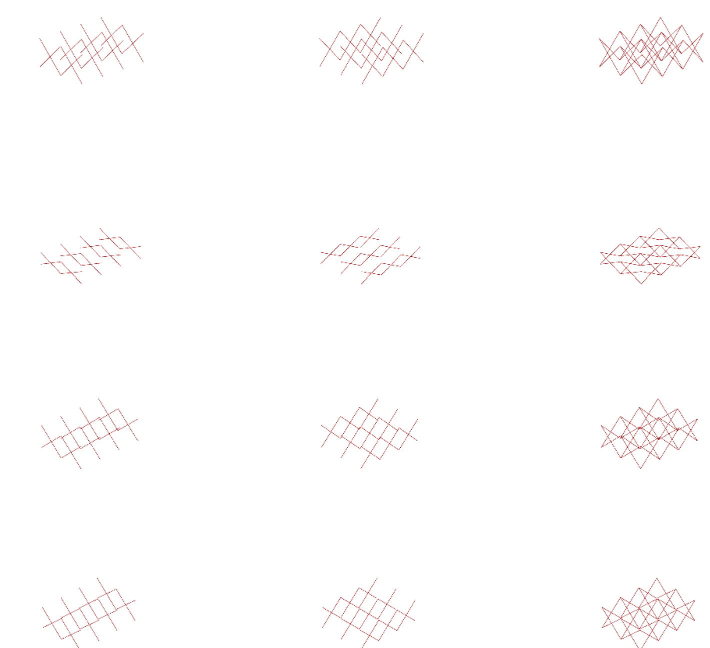


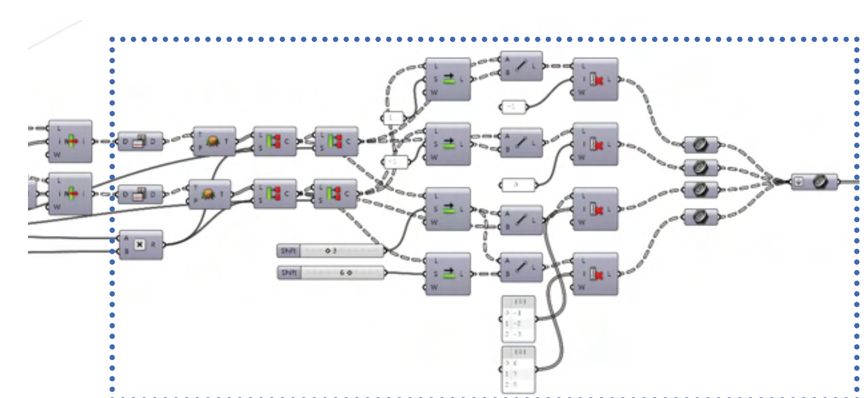
Setting up Outrigger Geometry

1) Bring points from Base Geometry

2) Set multiple numbers as a list for outrigger location (floor)

3) Flip the points and create lists of points for outrigger geometry generation



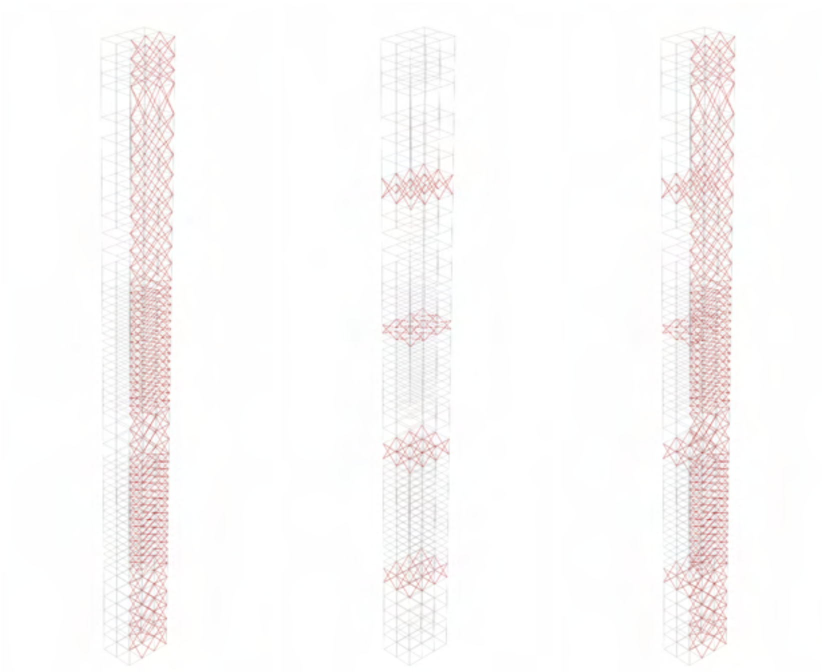


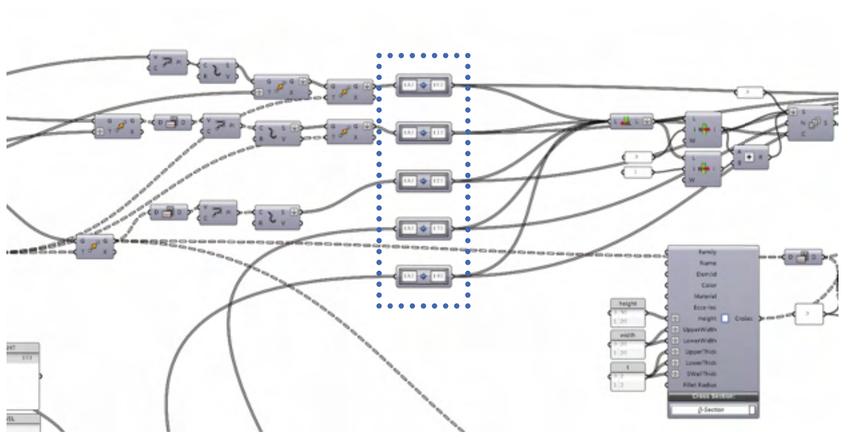
To identify intermediate bracing(Outrigger) location

1) Create NS outrigger

2) Create EW outrigger

3) Assemble the data set



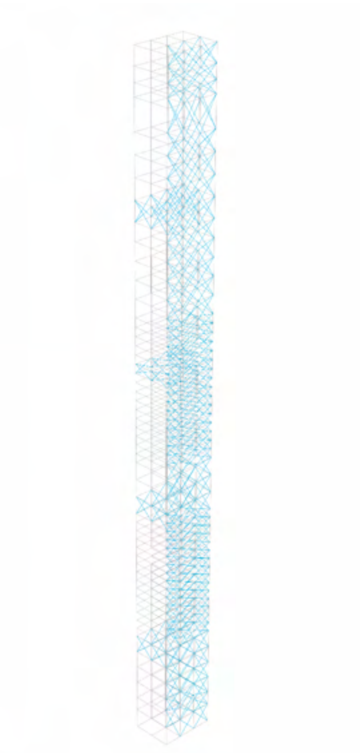


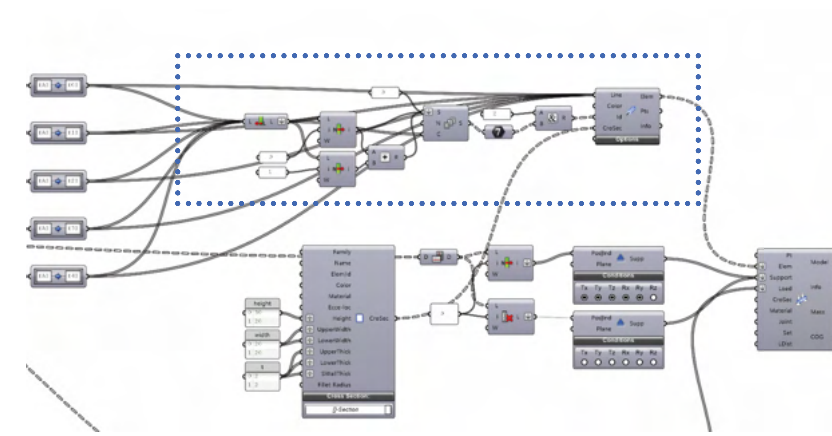
Assemble and Organize

1) Assemble shear wall & outrigger geometry with base geometry

2) Use path mapper for the proper element ID control during the simulation

3) numbers in path mapper components representing the order of data alignment



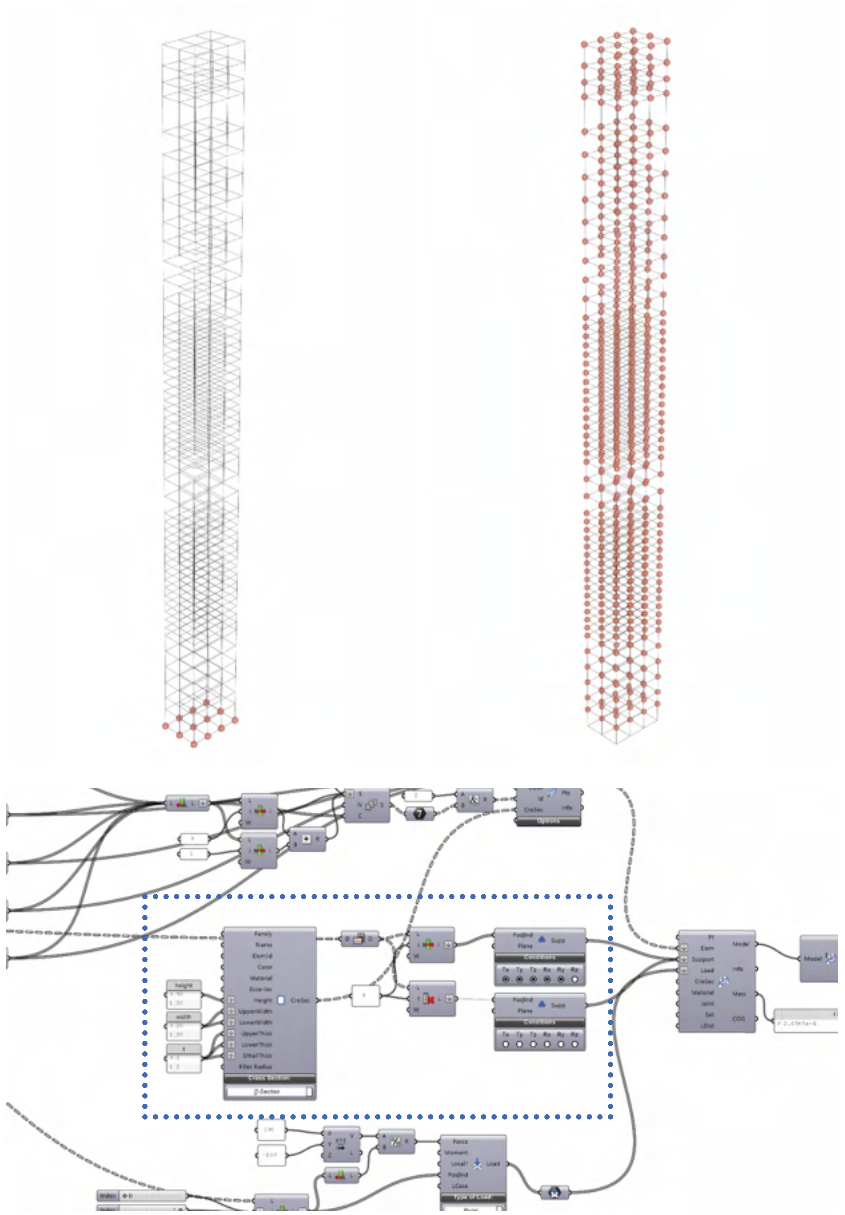


Beam Setting

1) Curves to line2beam

2) create list for element IDs

3) Define the cross section of the elements

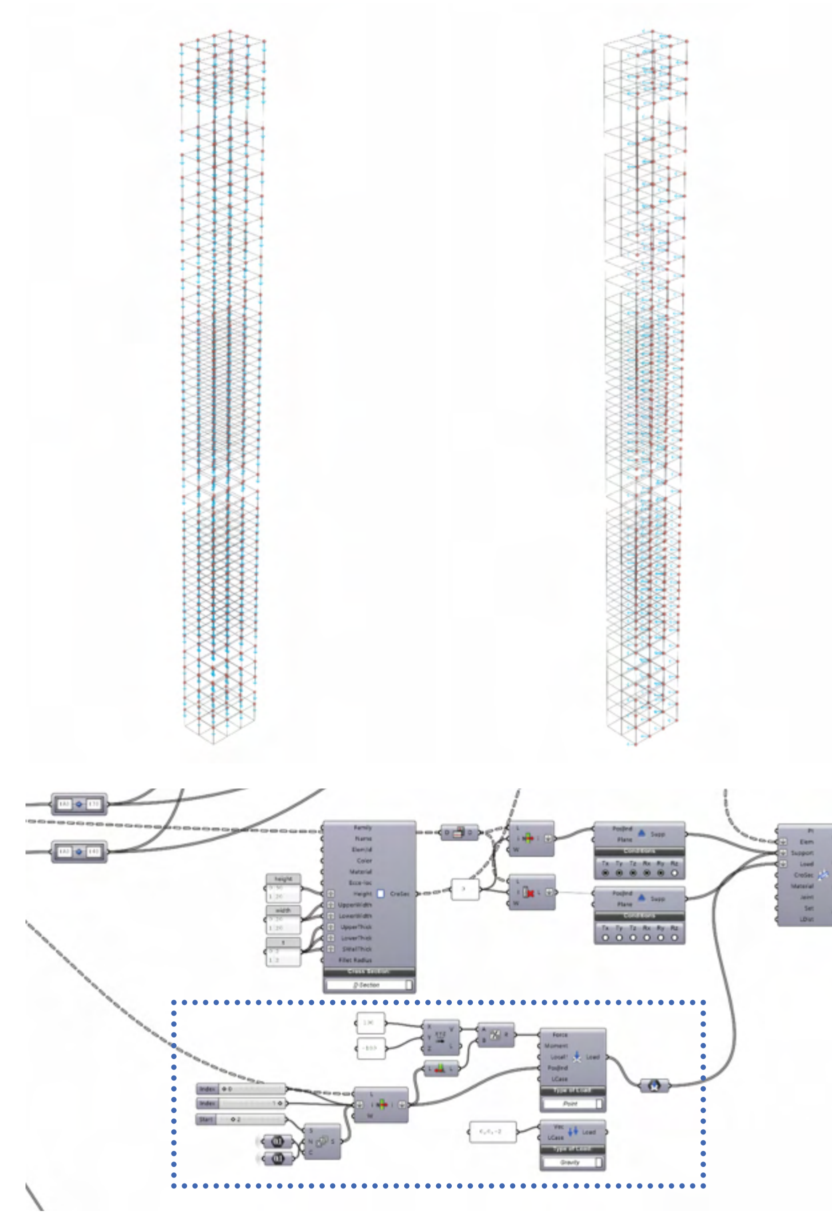


Support Setting

1) sorting out the lowest points for Grasshopper support

2) sorting out the rest of the points for connection

3) set up proper torsion and rotation direction

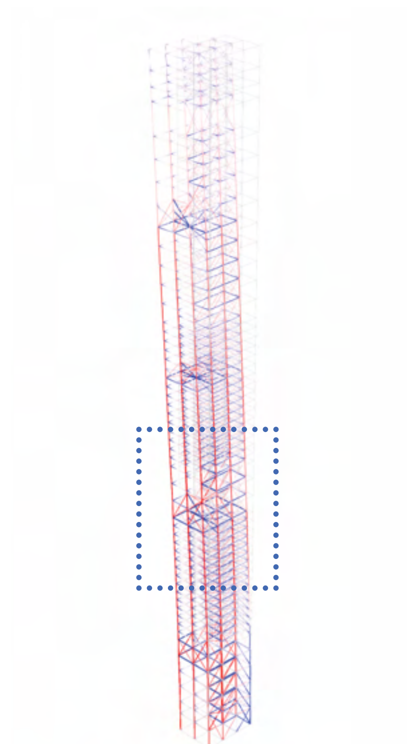


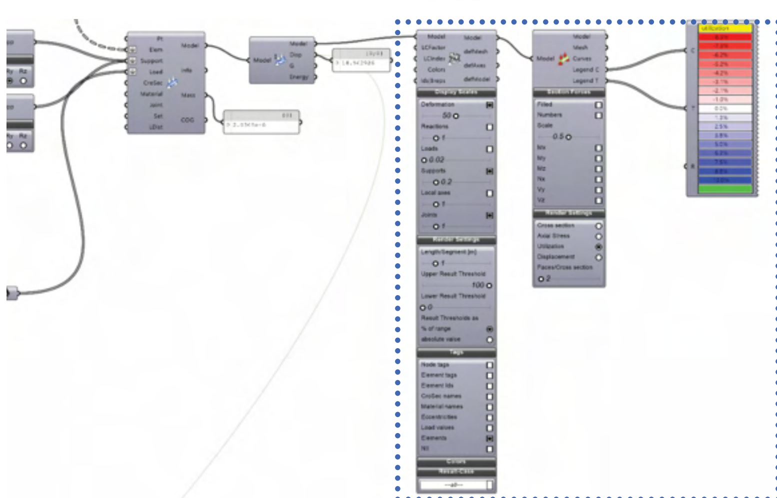
Load Setting

1) Set up lateral wind load to the points facing wind direction

2) Set up vertical Gravity load for every points

3) Connect it to the solver



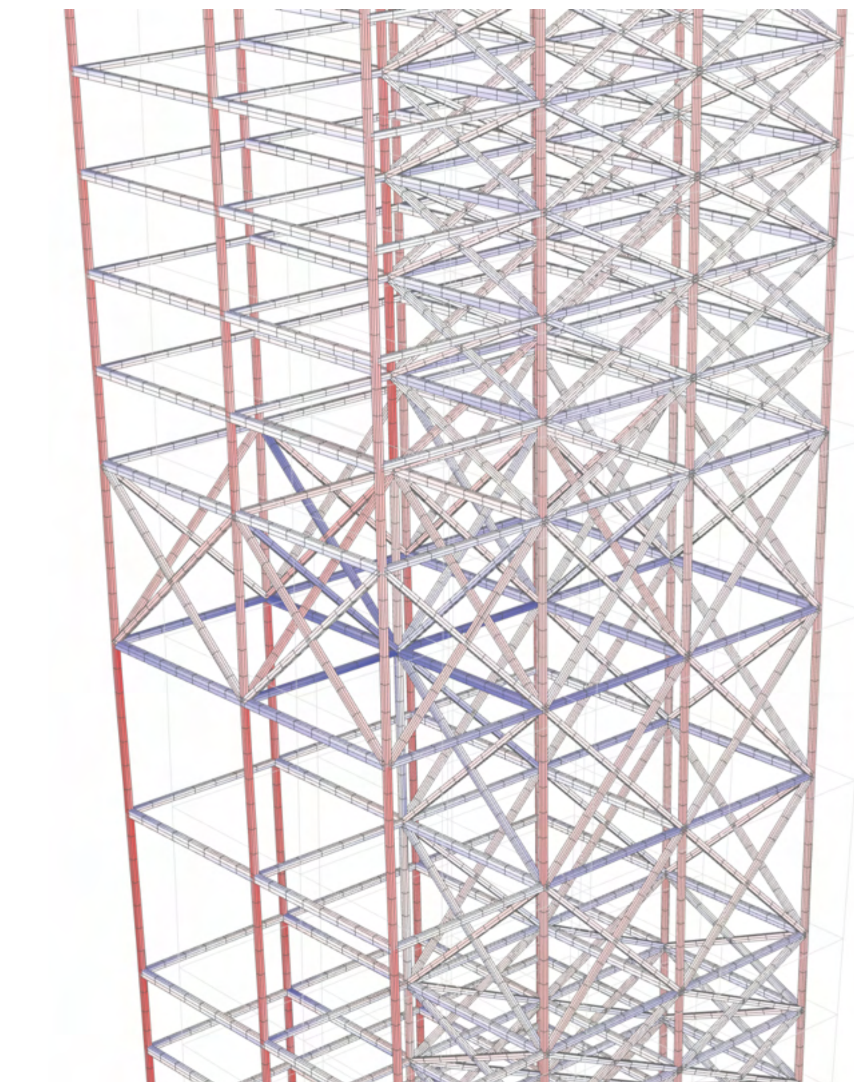


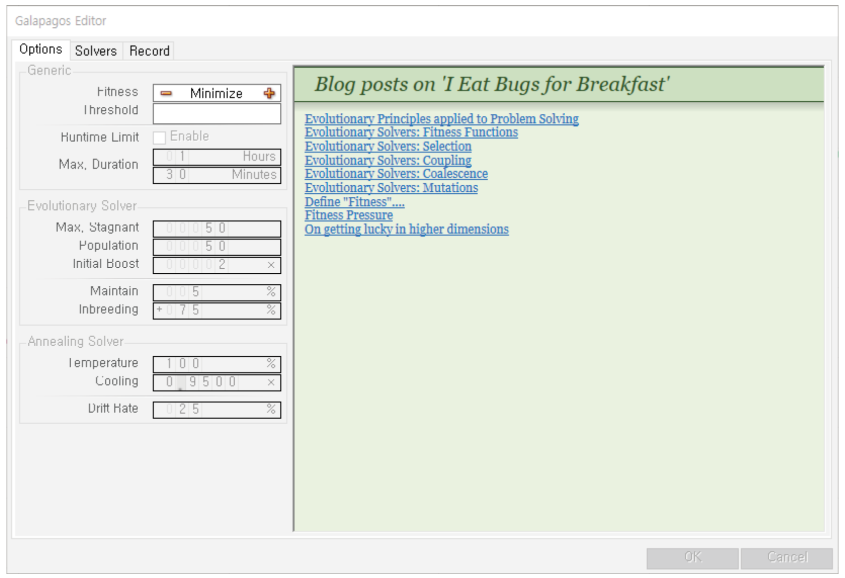
Running Simulation

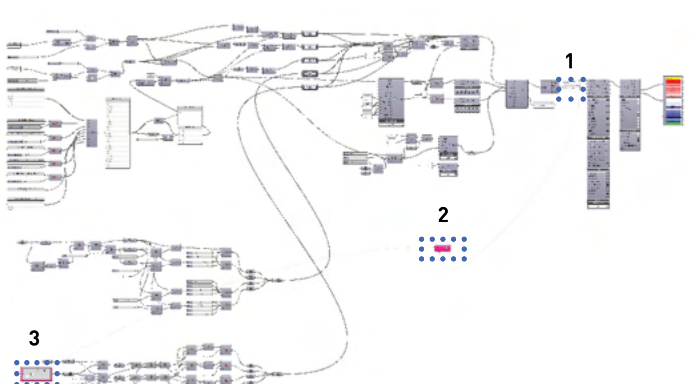
1) Connect all prepared items to the solver

2) Set up Visualization settings

3) Simulation will start automatically







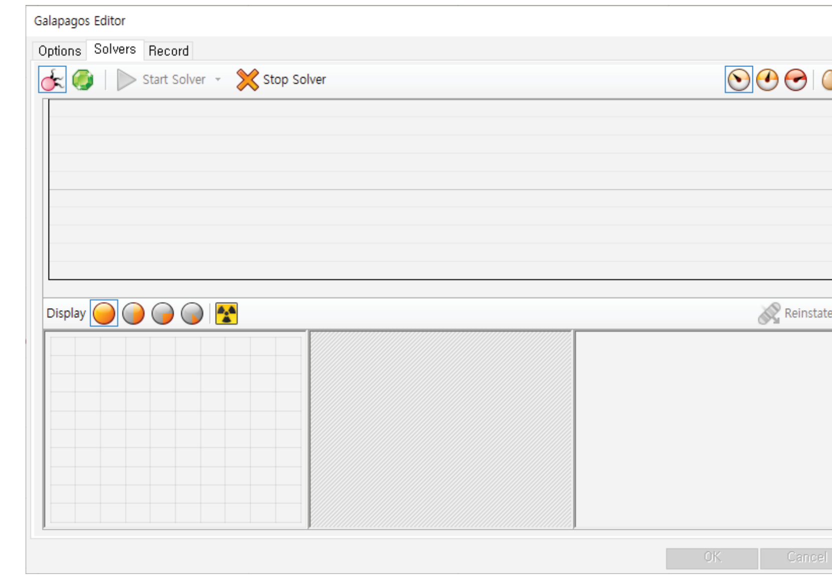
Evolutionary Optimizing

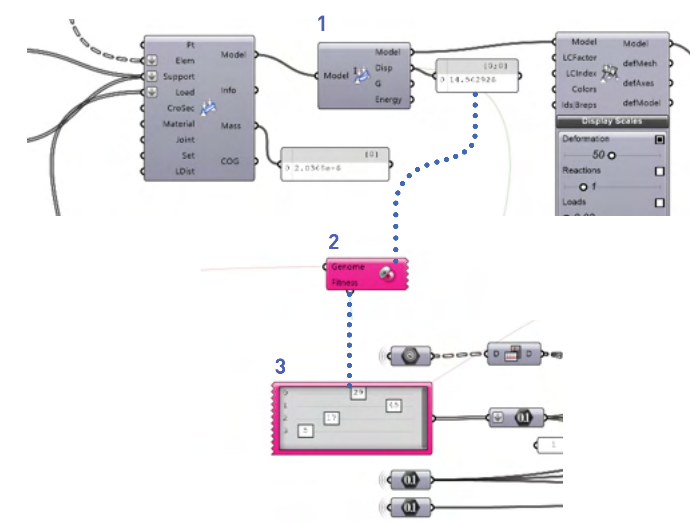
1) Connect Gene-pool to Genome

2) Connect Displacement to Fitness

3) Set the Fitness to be minimized

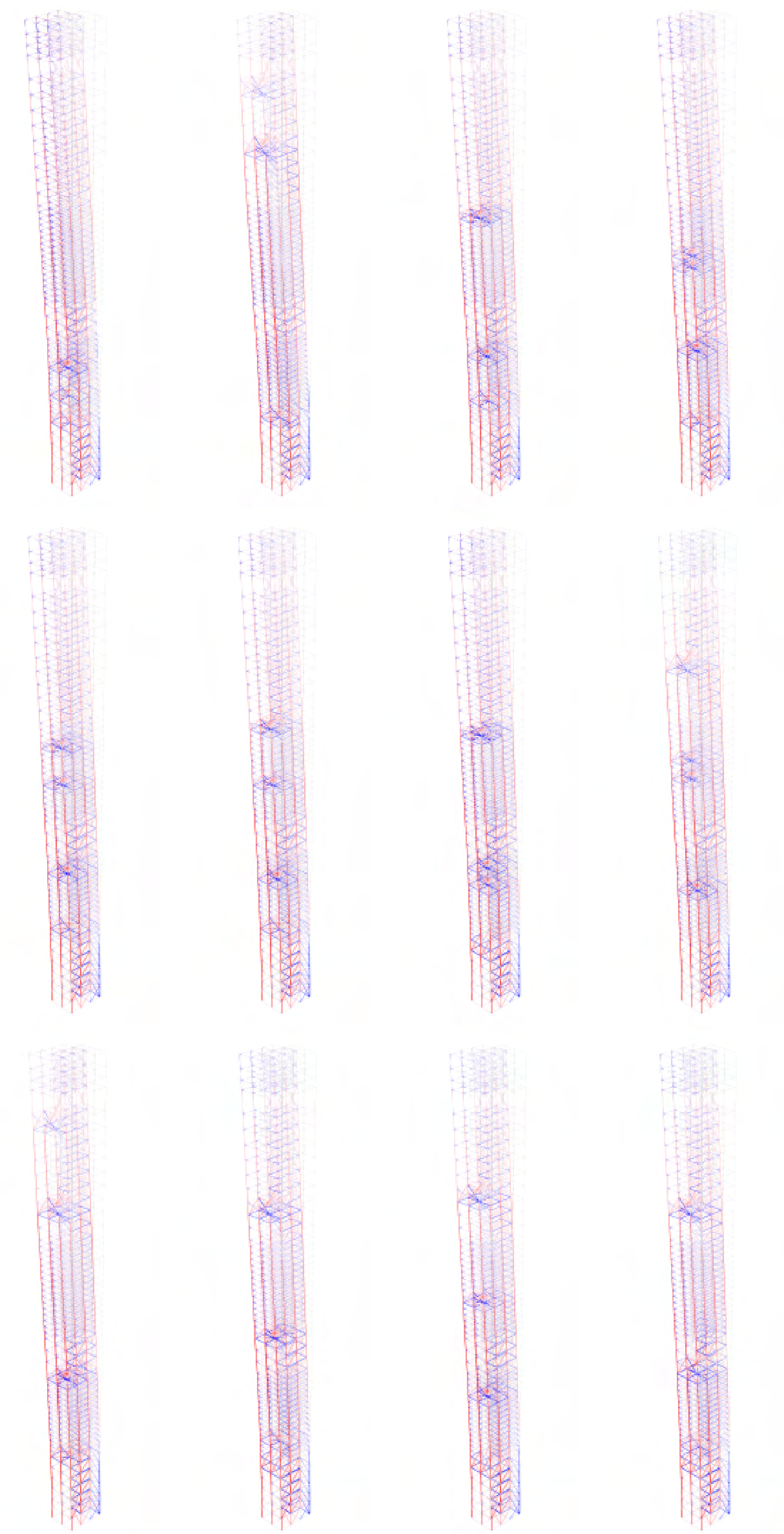
4) To Solvers tab



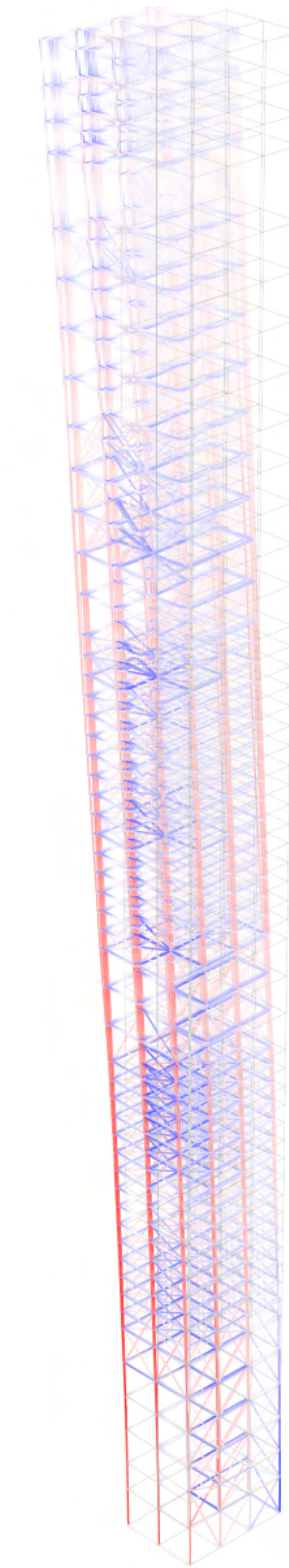


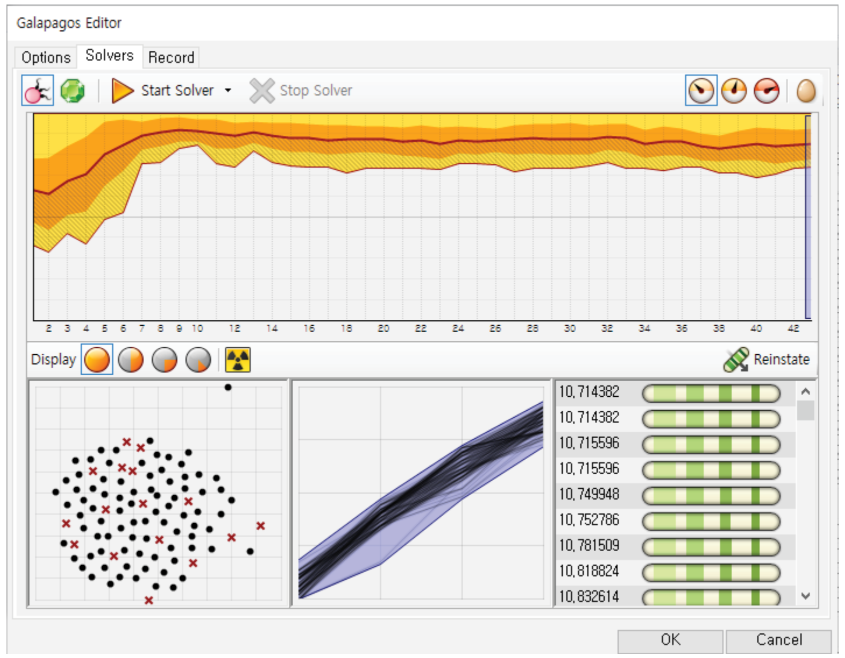
1) Operate evolutionary solver by clicking start solver

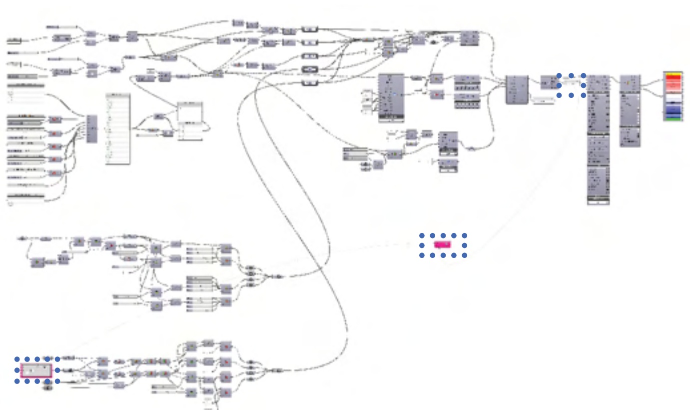
Displacements in different outrigger locations



Displacements in different outrigger locations







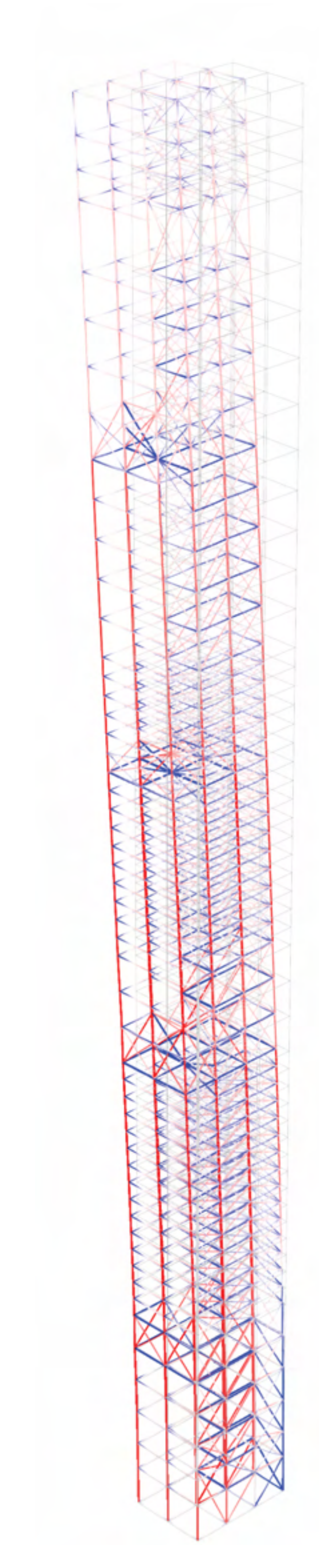
Pick the best

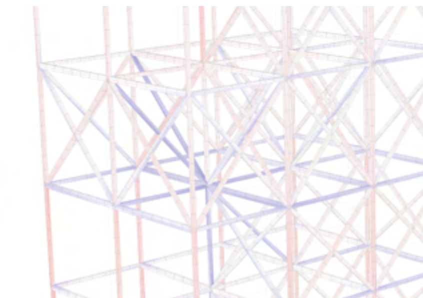
1) Click the top item from the list

2) Click reinstate button

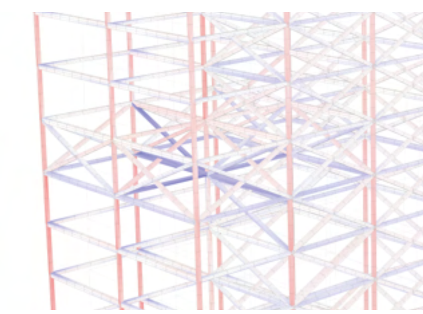
3) Gene-pool will be adjusted in accordance with the step 2

Optimized Outrigger location

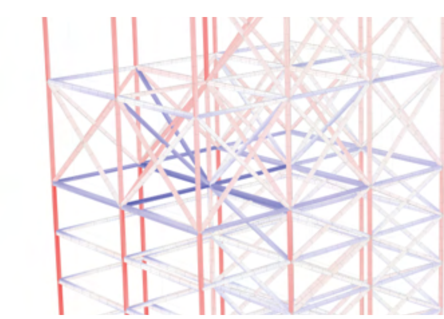




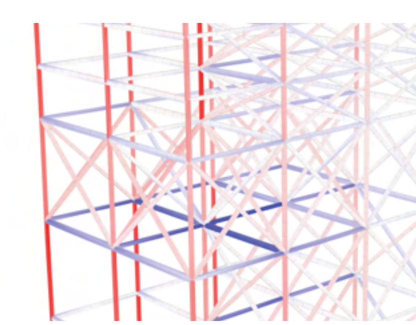
46th Floor



34th Floor



22nd Floor



6th Floor

METHODOLOGY.03

Material and displacement Optimization on Column Positions

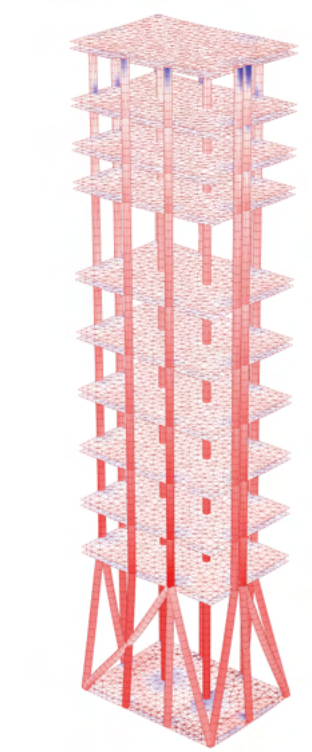
Material and displacement Optimization on Column Positions

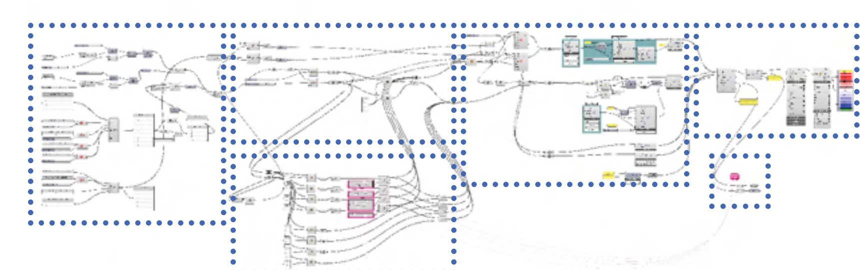
This chapter is to optimize column positions for the referred project, 267 Broadway. The tower is vertically divided by two different space program as a transient residential is located at lower part of twer and an assembly space is located at the top. The transient residential at lower part of tower requires dense structural distribution with more columns based on the room arrangement while the assembly space on upper part of tower pursues a minimum view restriction with less number of columns and the removal of the corner columns. This study aims to investigate how to optimize the structural shift in an effective and creative way.

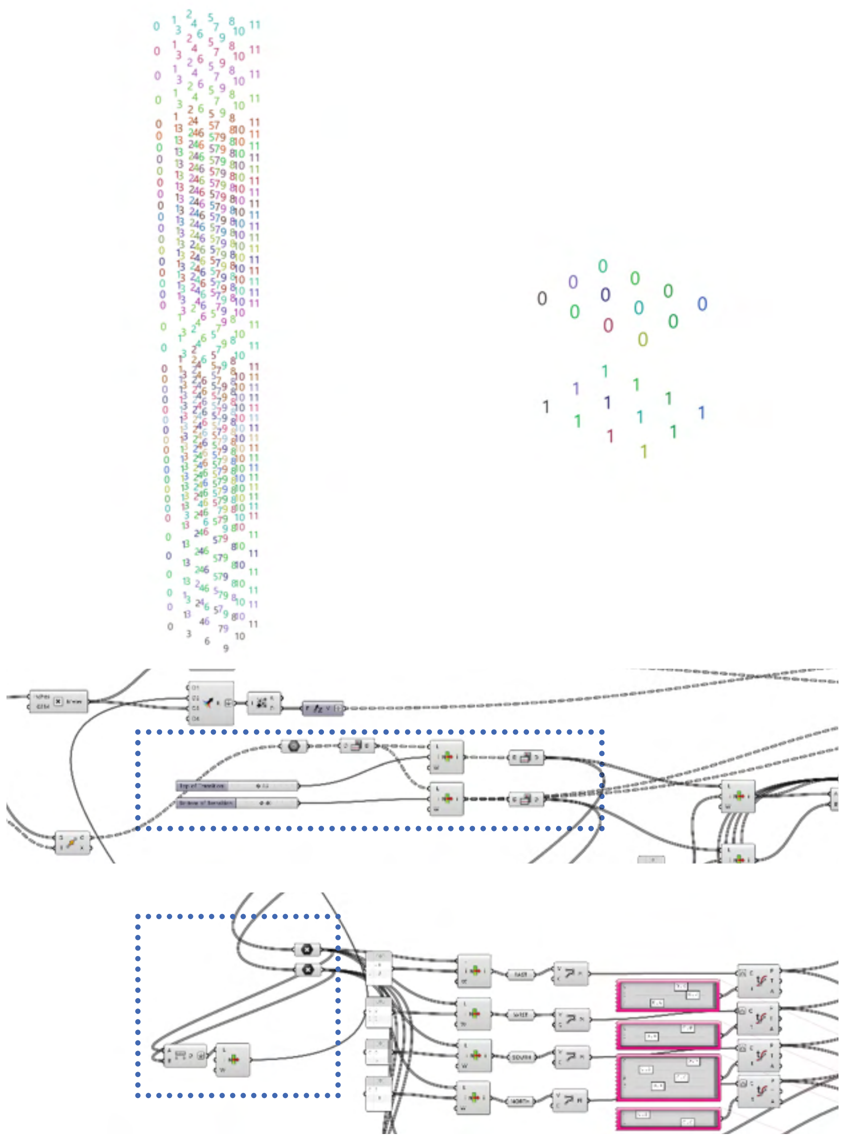
The parameter of the column transfer is dependent on total mass of materials and structural displacement to resist lateral force.

The work flow of the relocation of the columns is stated below.

- How to set up column transferring geometry in Parametric way
- How to connect it to Karamba3D for calculation
- How to get the best option for transferring columns using evolutionary computing





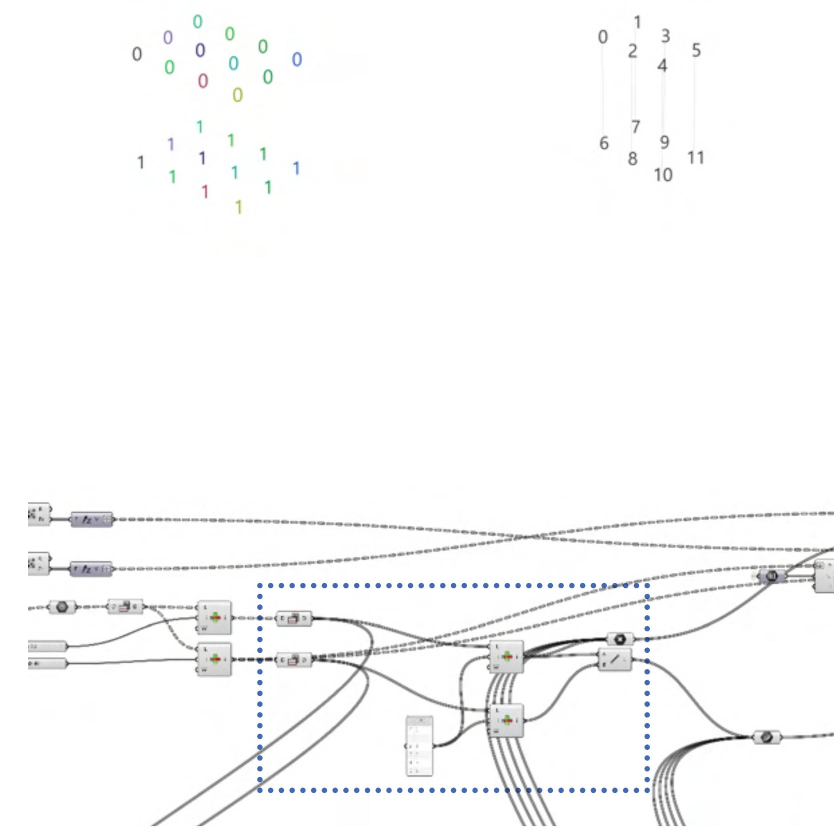


Extract data from Base Geometry

1) Find points from introduced base geometry

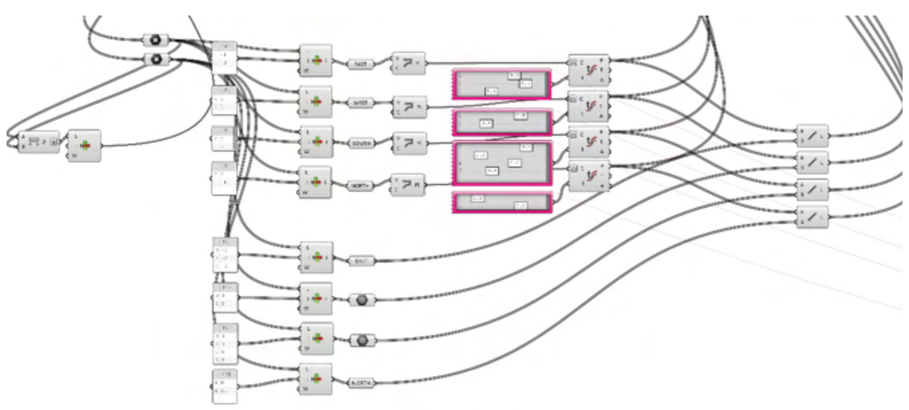
2) Flip the list to be organized by floors

3) Extract designated portion of the column transfer



1) Extract core wall parts of the points for non-transferring elements

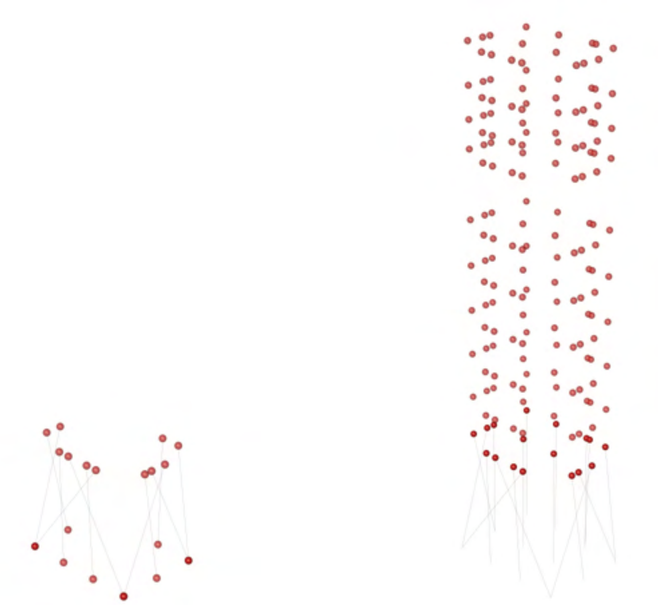
2) Generate vertical members for the core wall part

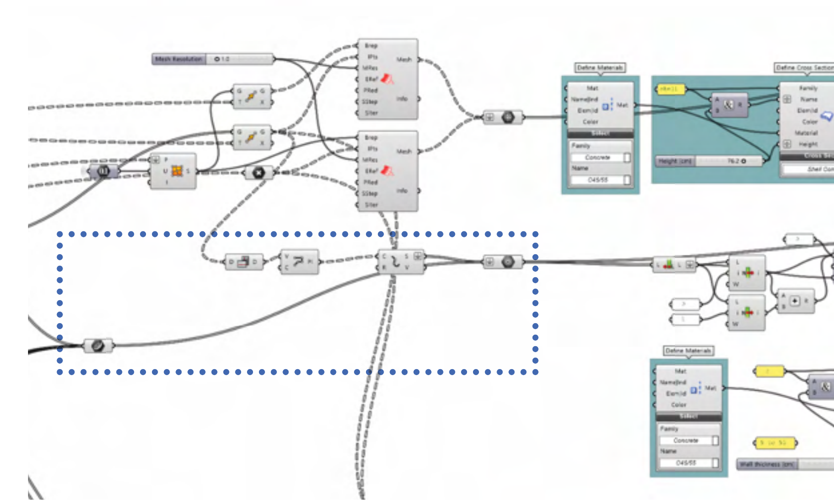


1) Bring points from base geometry

2) Flip the list to be organized by floors

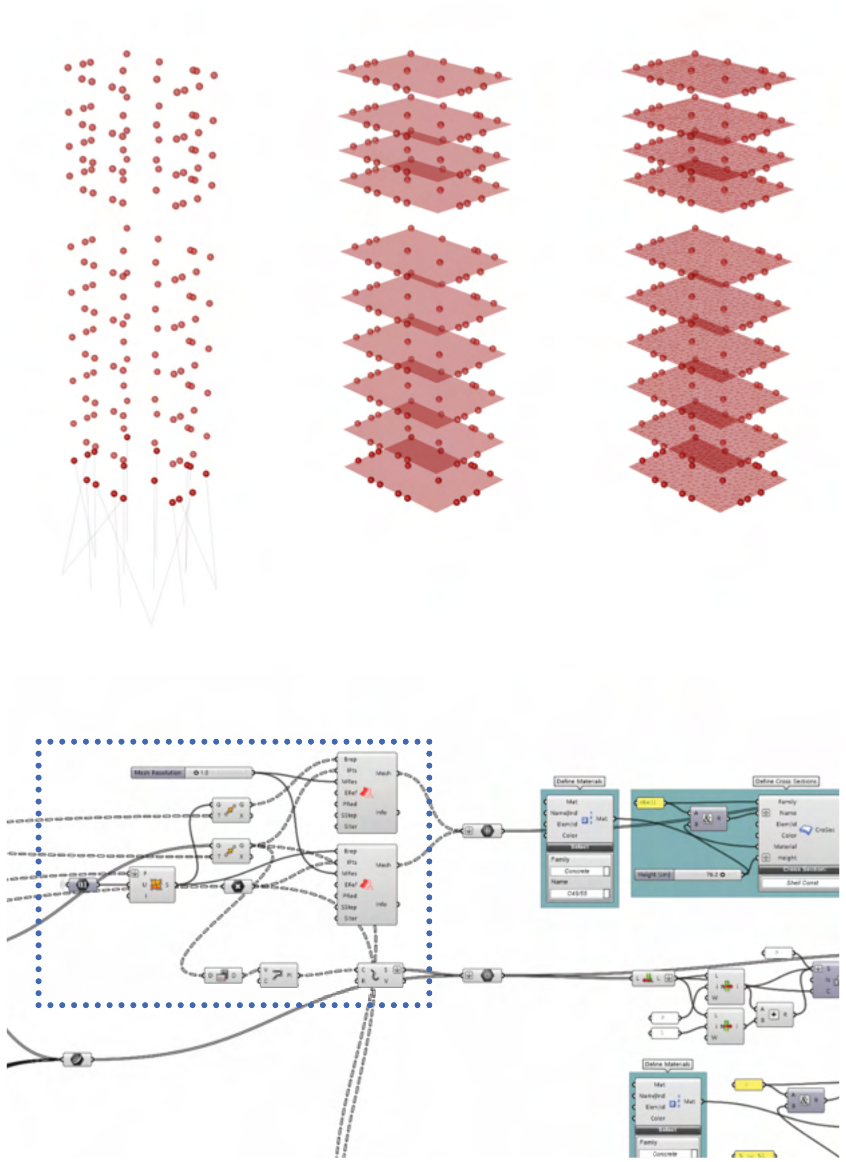
3) Extract designated portion of the column transfer





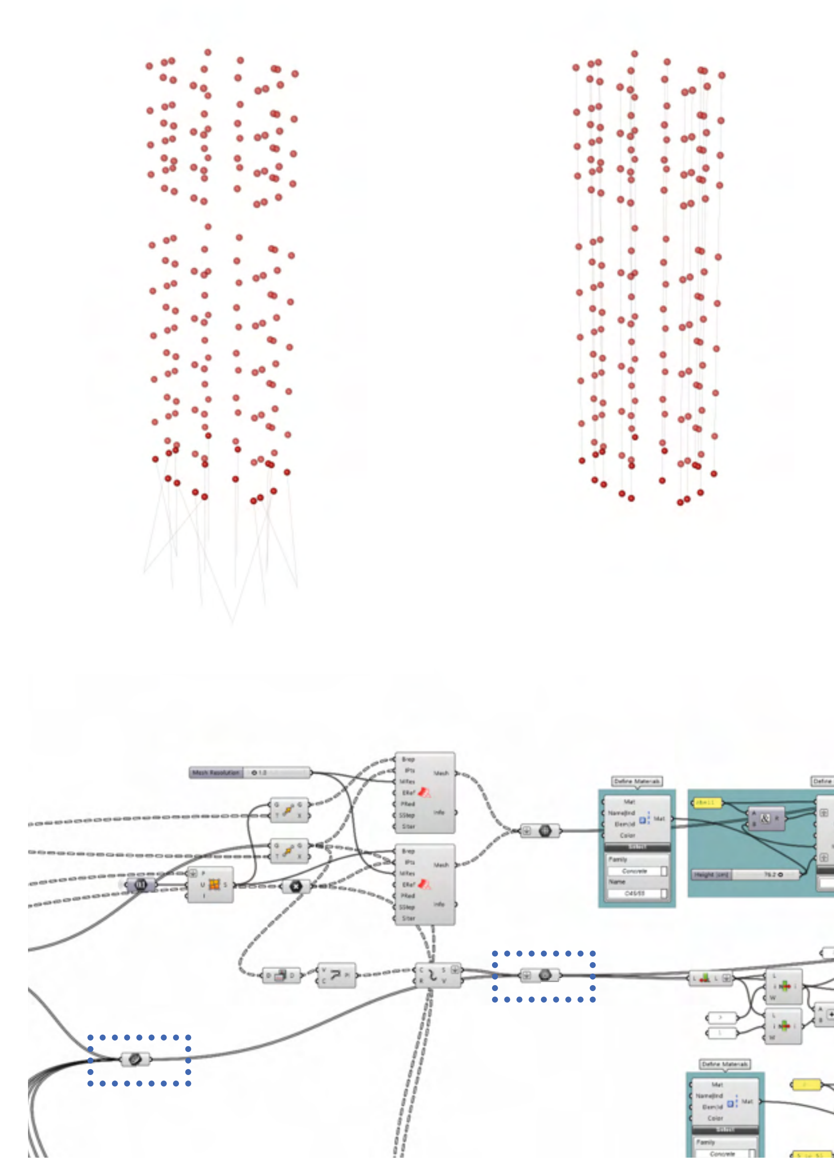
1) Sorting out the point for upper part of the transferred column

2) create points for each floors above the transfer



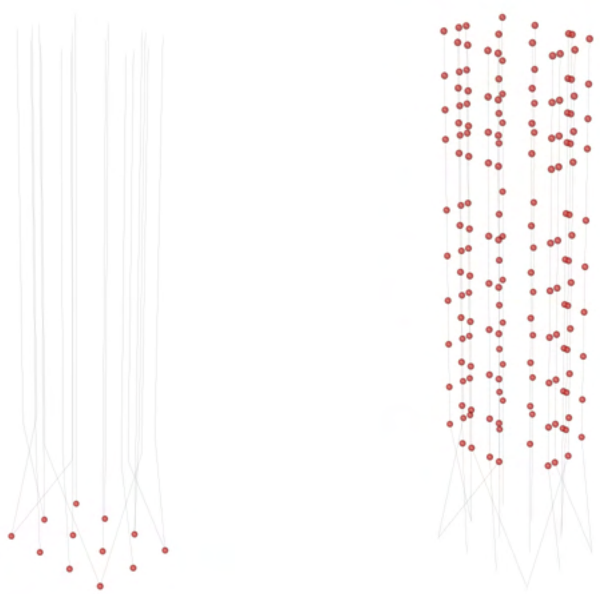
1) Sort out the points to create slab geometry

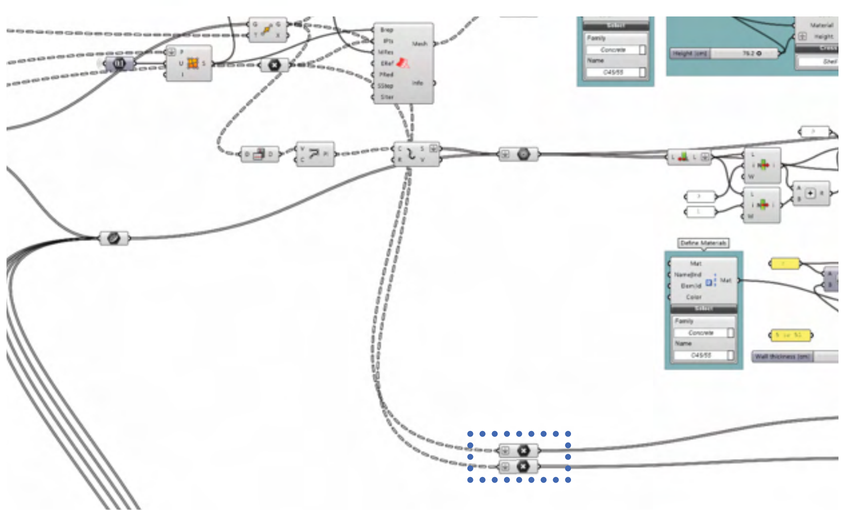
2) Create boundary representation(brep) and convert it to mesh



1) Sort out the points above column transfer

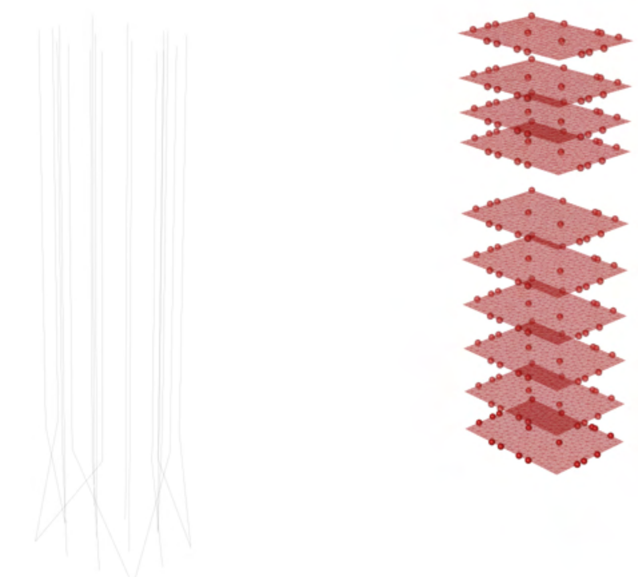
2) Generate vertical members for the column above

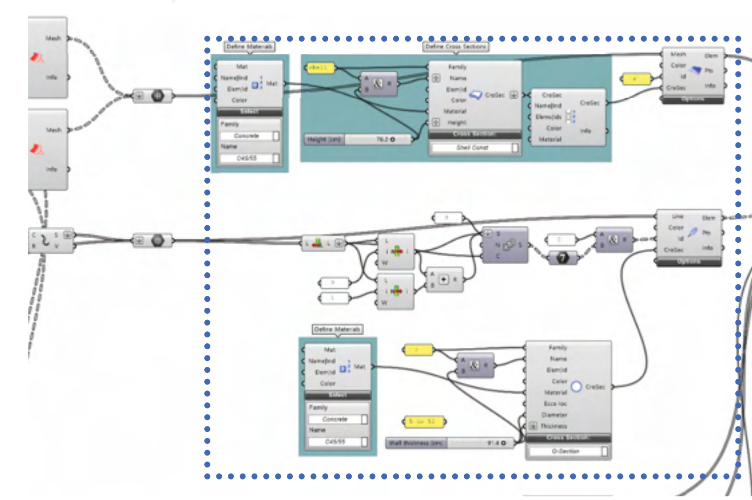




1) Sort out the points at the bottom of the transfer

2) Sort out the points above the transfer

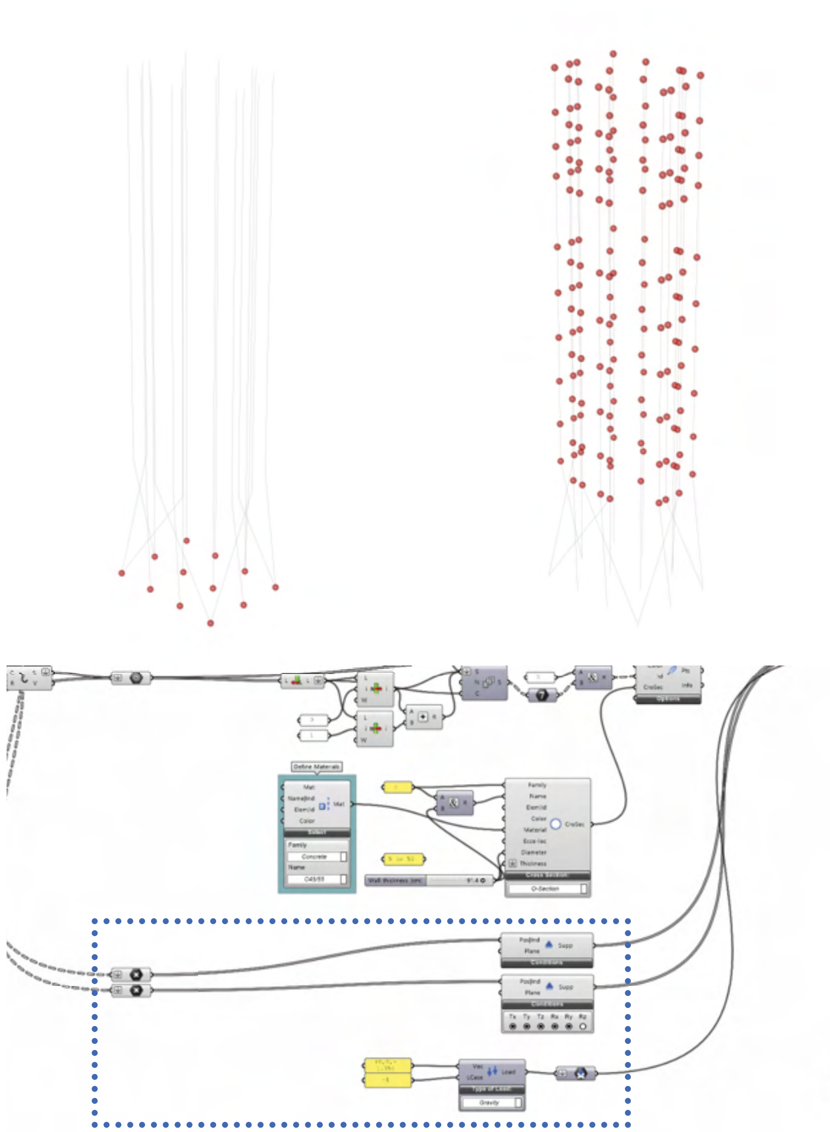




Element Setting

1) Connect vertical curves and mesh to specified element setting component

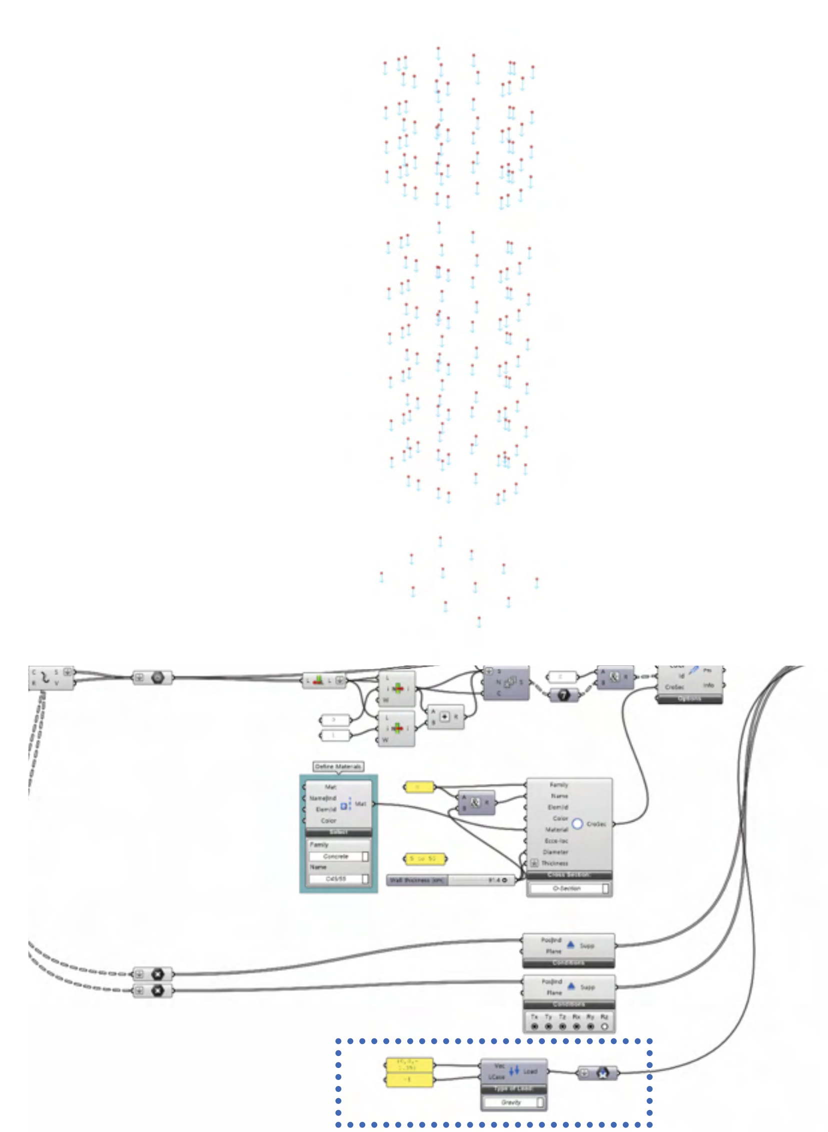
2) Set up cross section and material properties for the slab and column



Support Setting

1) Sort out points at the bottom and set it as a base support

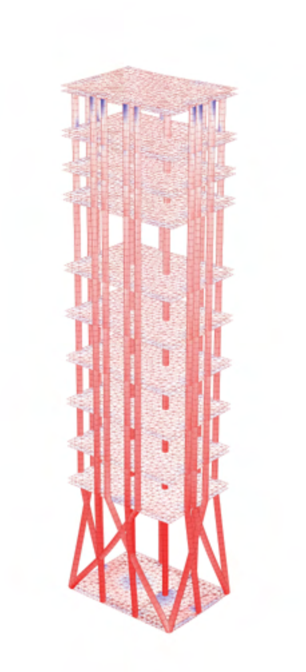
2) Sort out points above transfer and set it as a structural connection

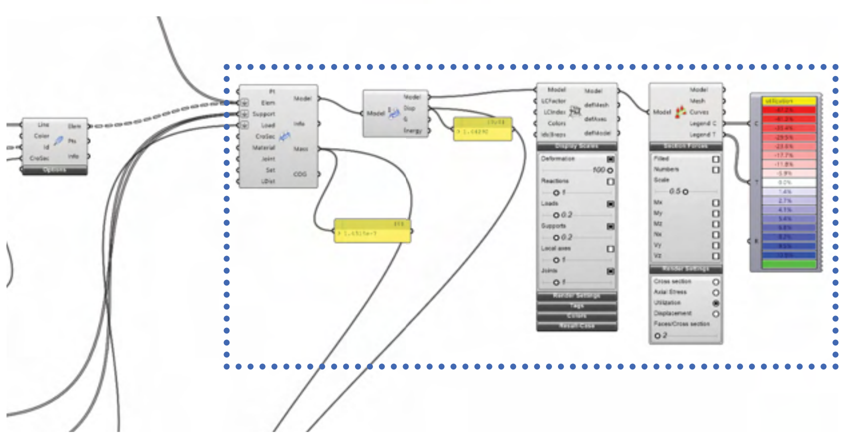


Load Setting

1) Sort out every points in the base geometry and other Additional geometry

2) Apply gravity load for the simulation



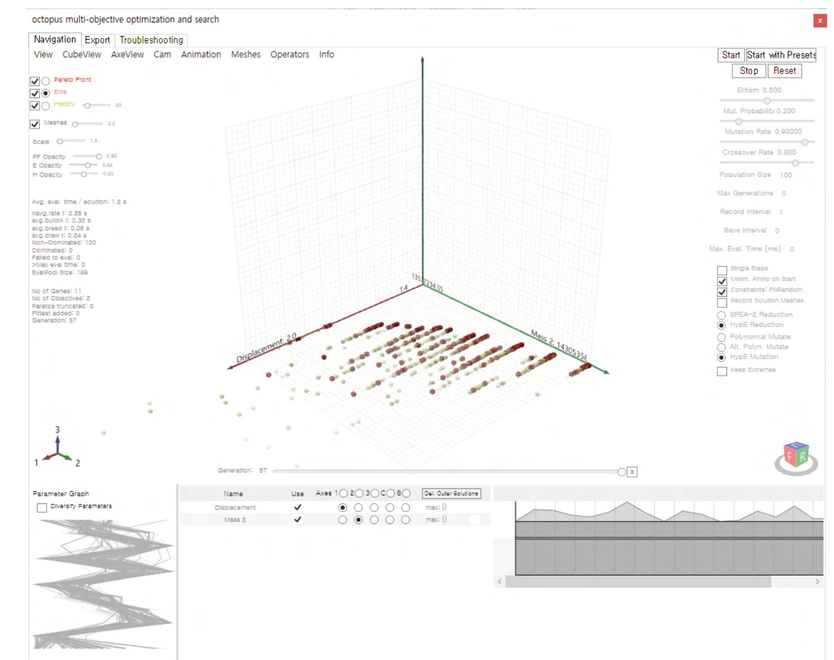


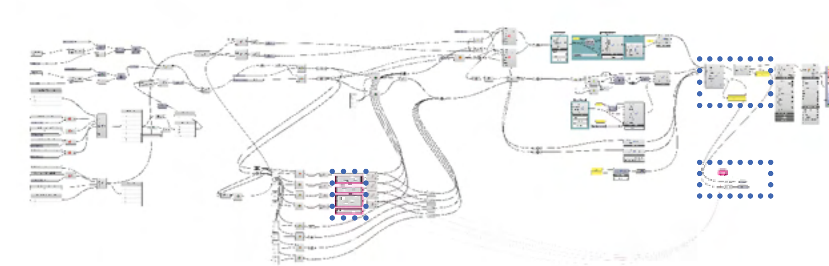
Running Simulation

1) Connect all prepared items to the solver

2) Set up visualization settings

3) Simulation will start automatically



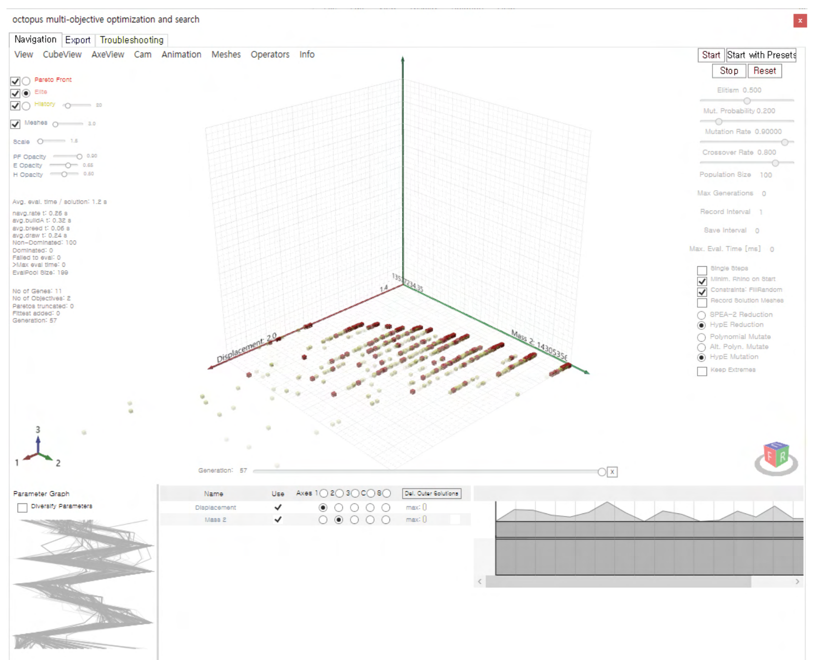


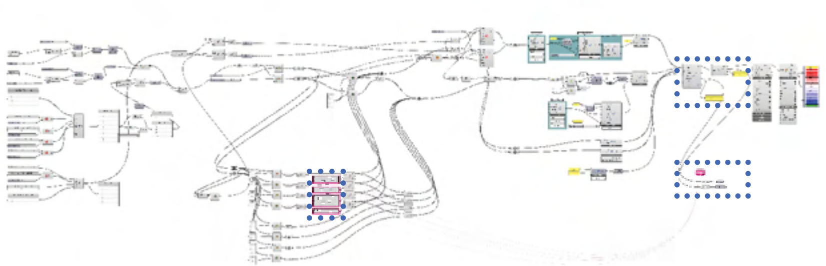
Evolutionary Optimizing

1) Connect Gene pool to Genome

2) Connect Displacement and Mass to Octopus

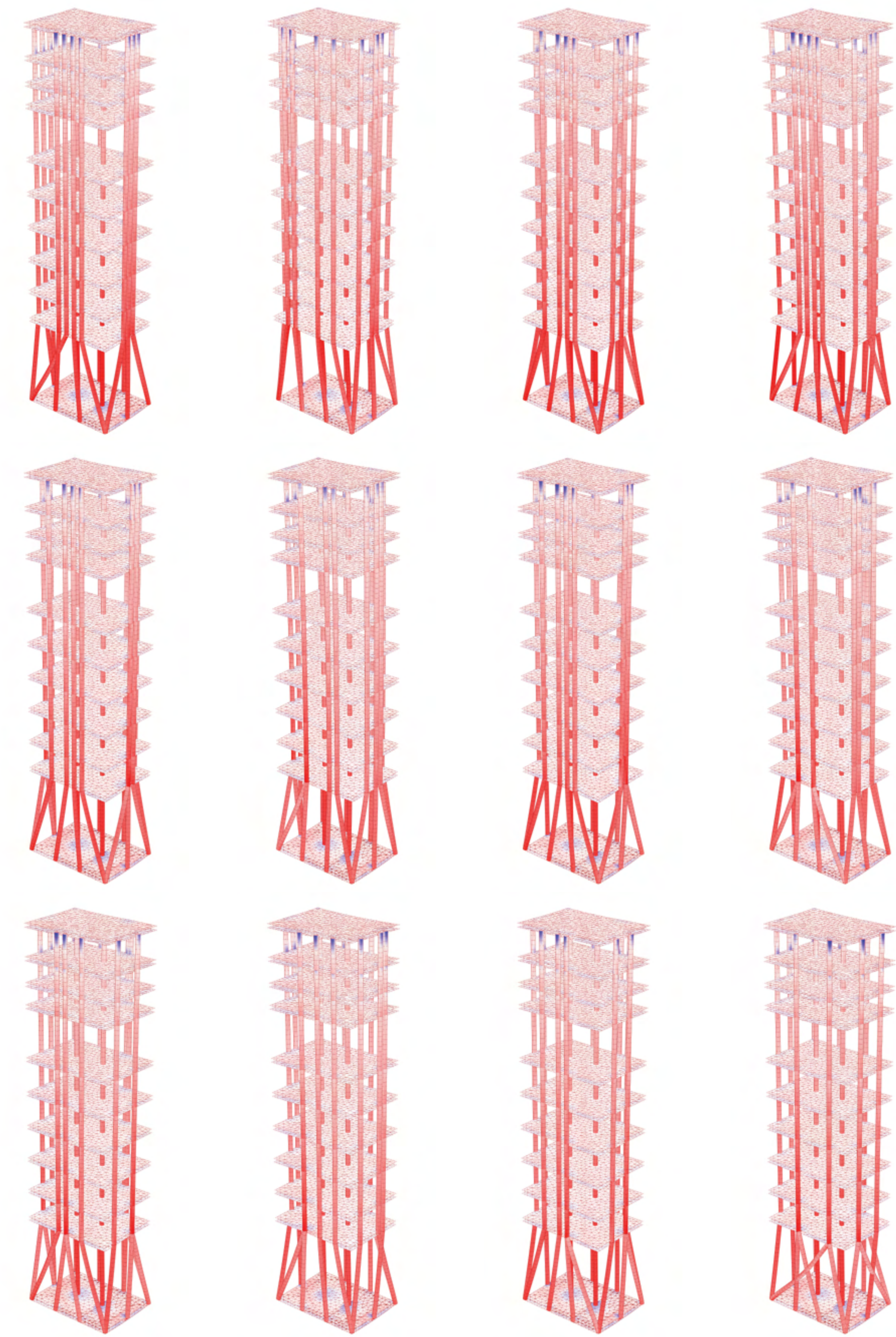
3) Double click the octopus component

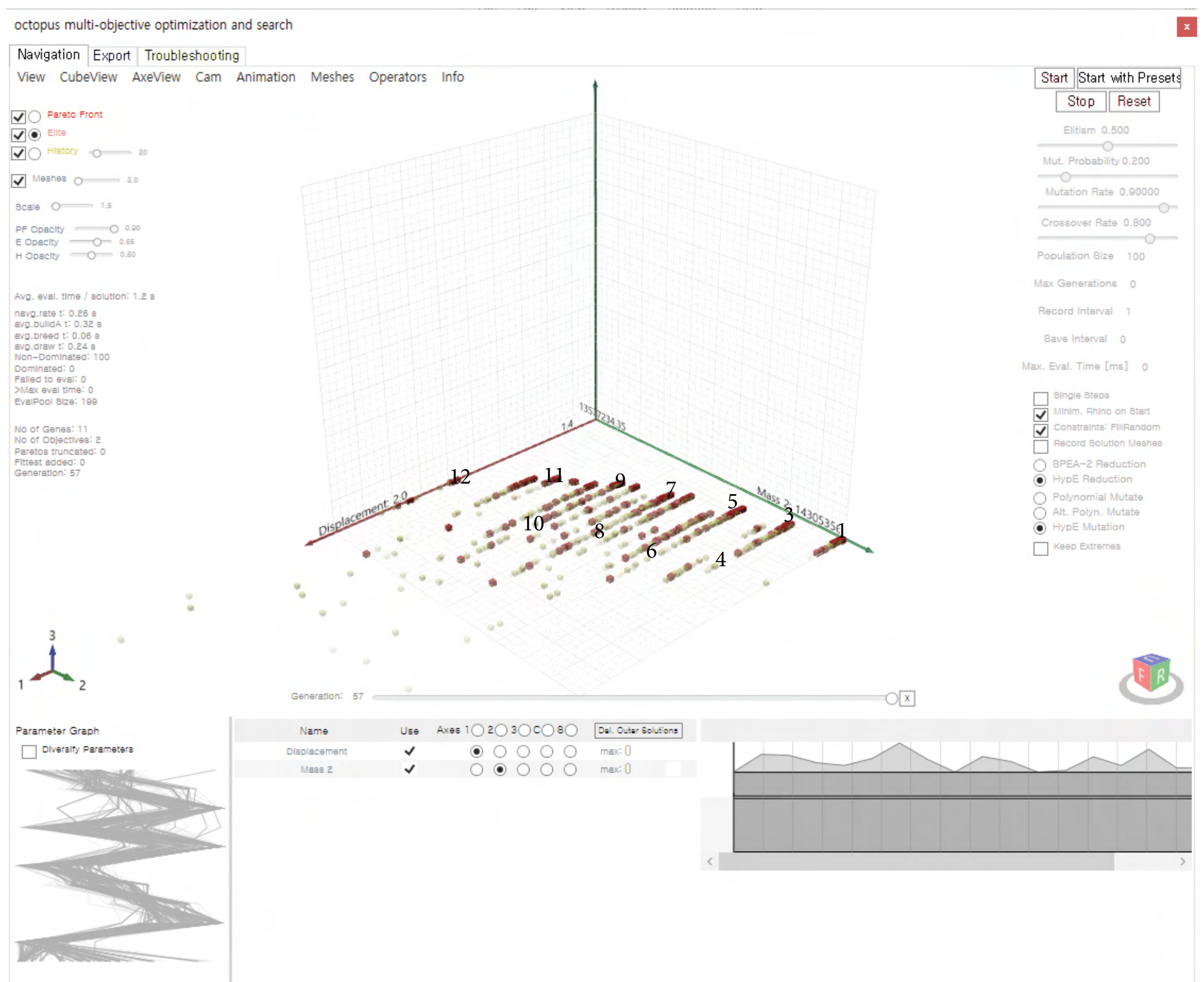


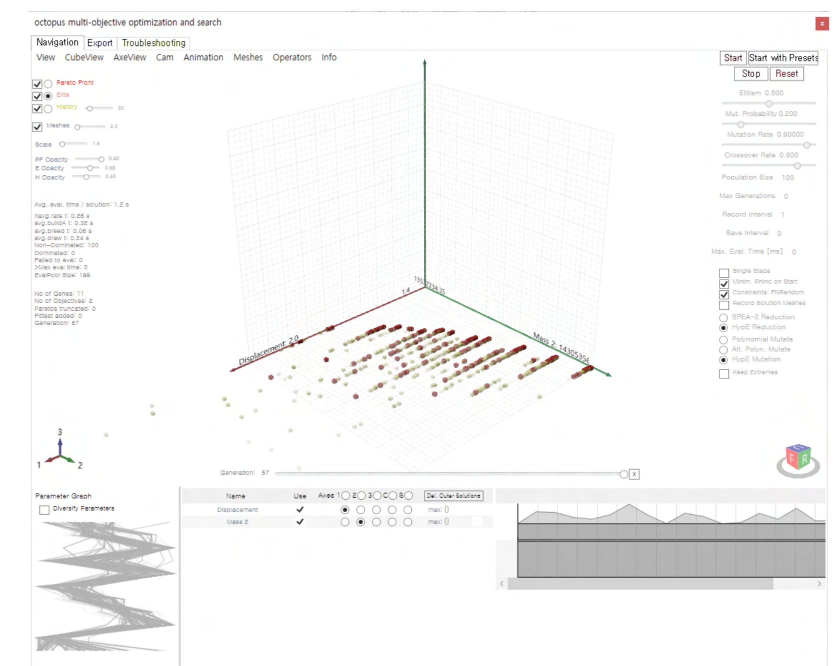


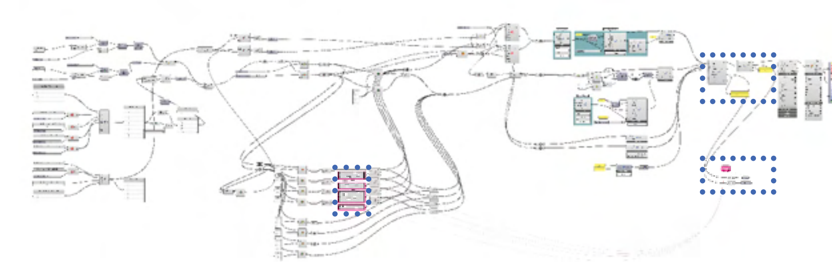
1) Check settings

2) Start by clicking start







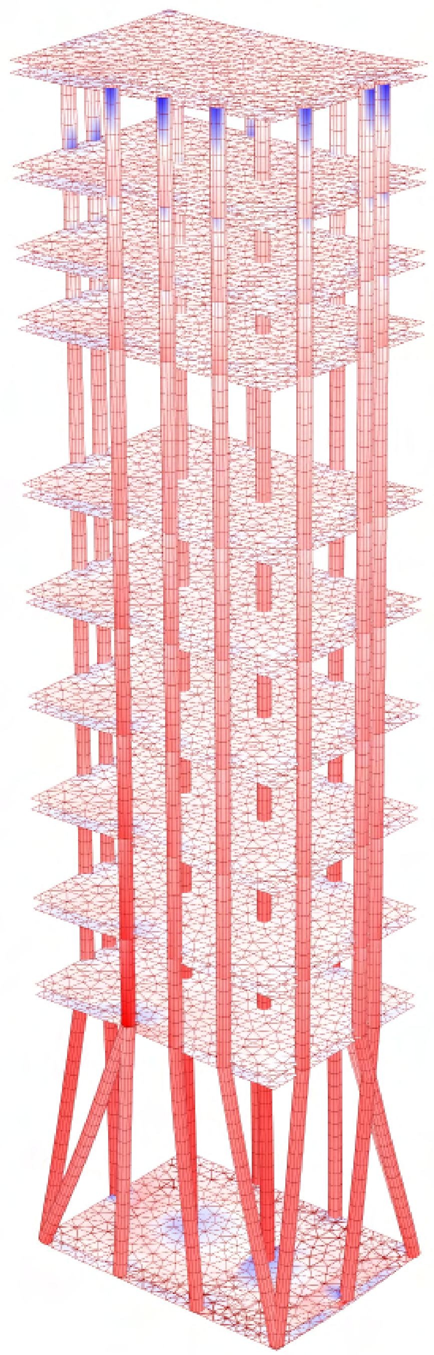


Evolutionary solver

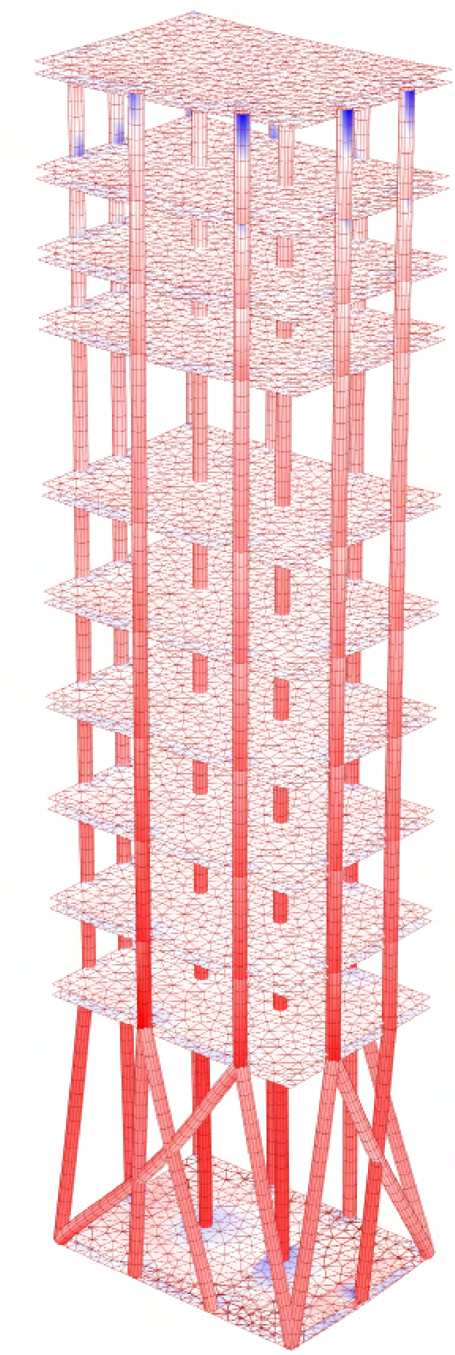
1) Right click the proper item from the octopus display

2) Click reinstate

Top tier options with three column on south face



Top tier options with two column on south face



METHODOLOGY.04

Material Distribution of Shear Face on Structural Optimization

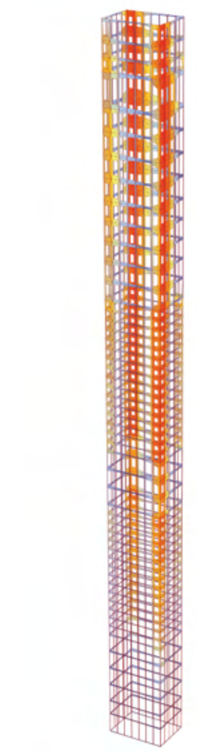
Material Distribution of Shear Face on Structural Optimization

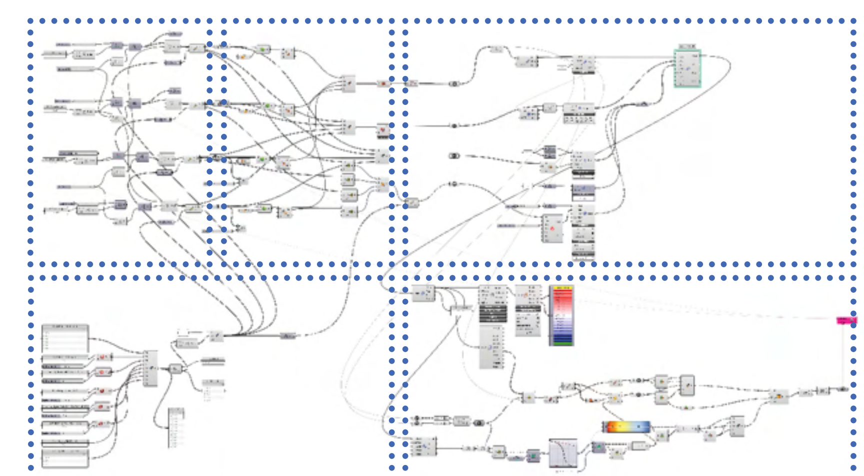
The intent of the last chapter is to find out how varying aperture openings affects the structural performance if the main structure is a perimeter shear wall. This study demonstrates configurations to compare different sized aperture openings that maintained the wall's structural performance against horizontal forces. To simulate this, studies were undertaken with the height of the tower and the number of the floor as fixed variables, and the depth and height as active variables.

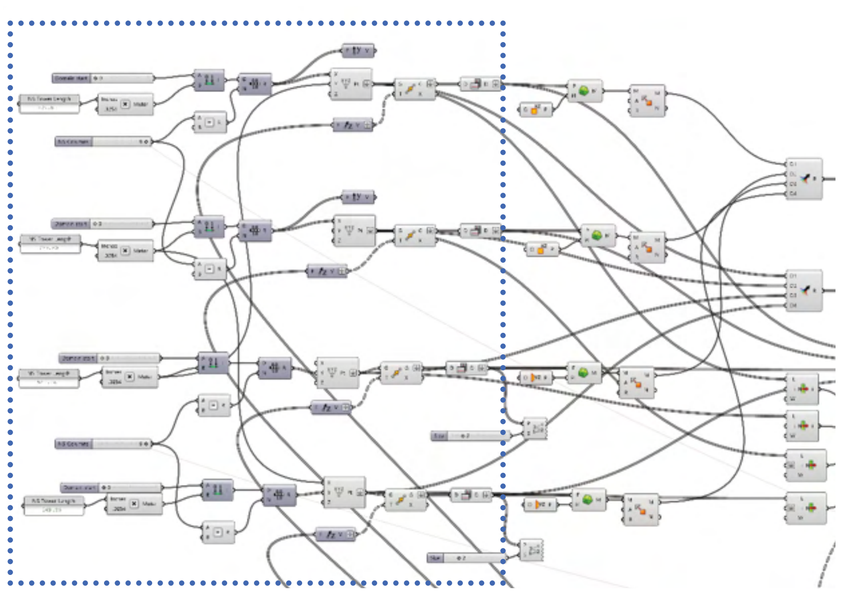
The raw results had a wide range of size. This can be rationalized by engineers and architects who rearrange the aperture widths into certain number of module widths and heights. The final result can be transferred into a global structural analysis program.

The work flow of the Load Bearing Envelope Structure is following order and objective.

- What to prepare for material distribution in load bearing envelope
- How to connect it to Karamba3D for calculation
- How to apply the feedback from structure analysis to design

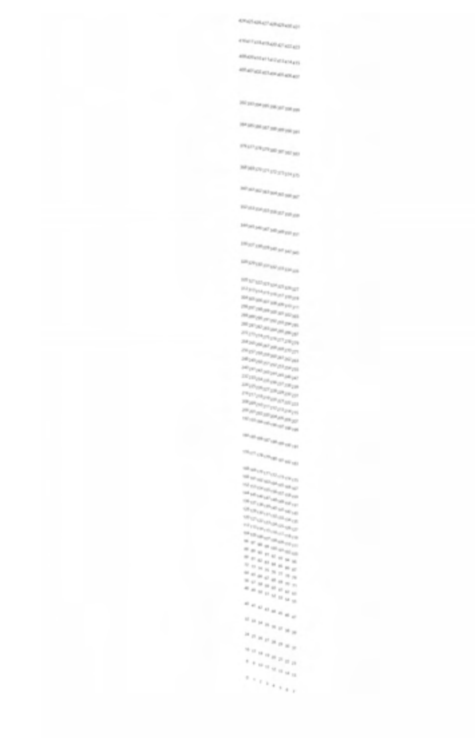


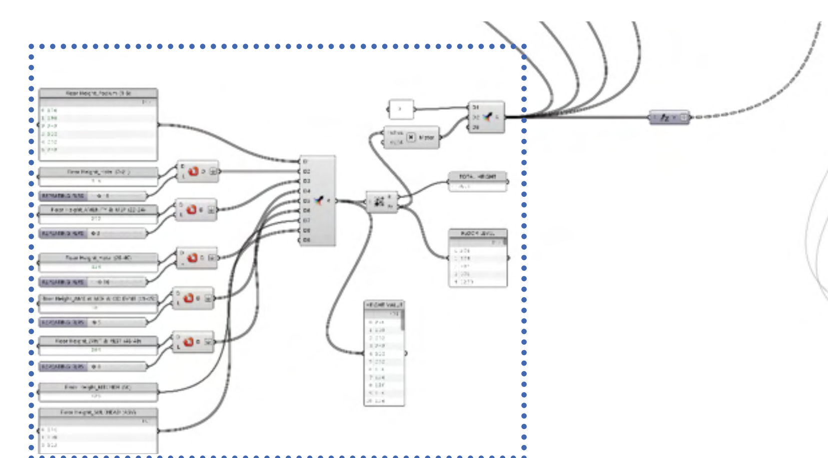




Extract data from Base Geometry

1) Extract points for the elevation parts

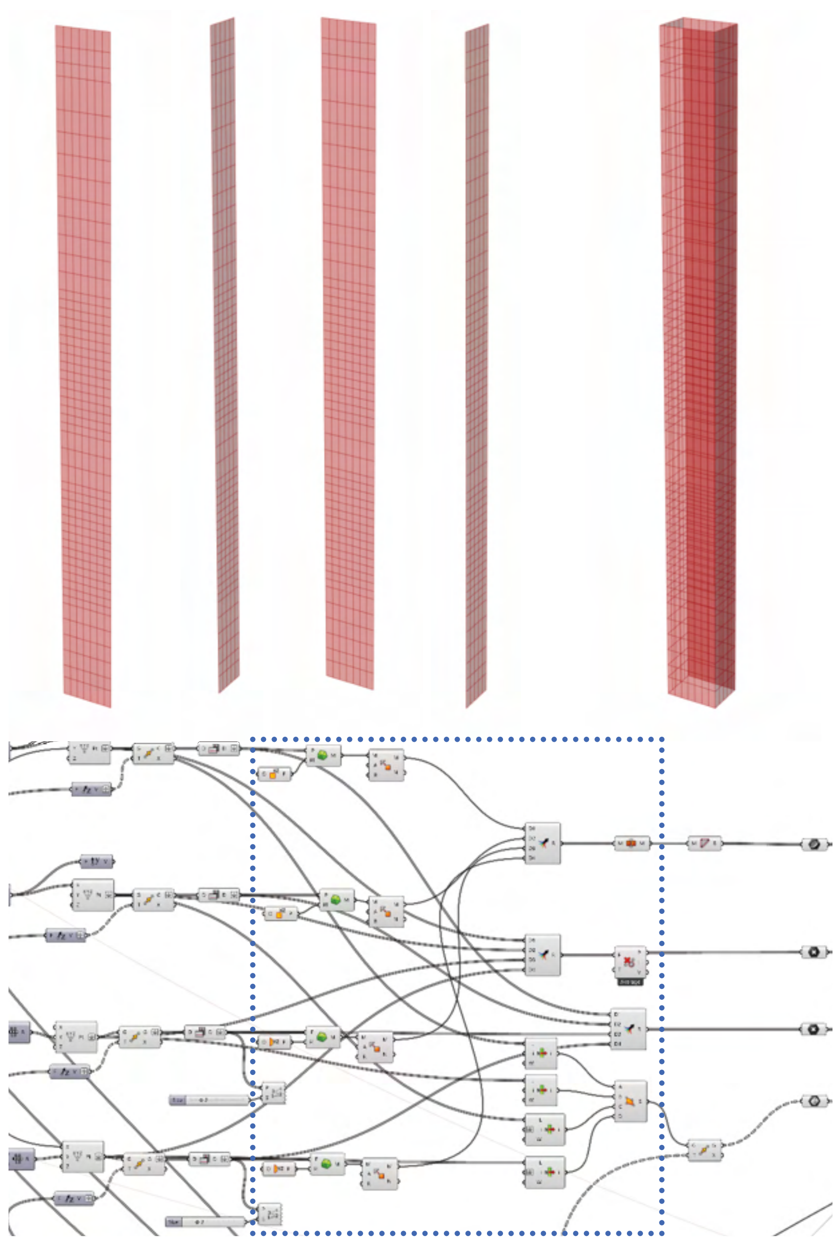




1) Extract points for the elevation parts

2) Extract height factor from base geometry

3) Combine and clean up the point lists for the generation of meshes representing the structural facade

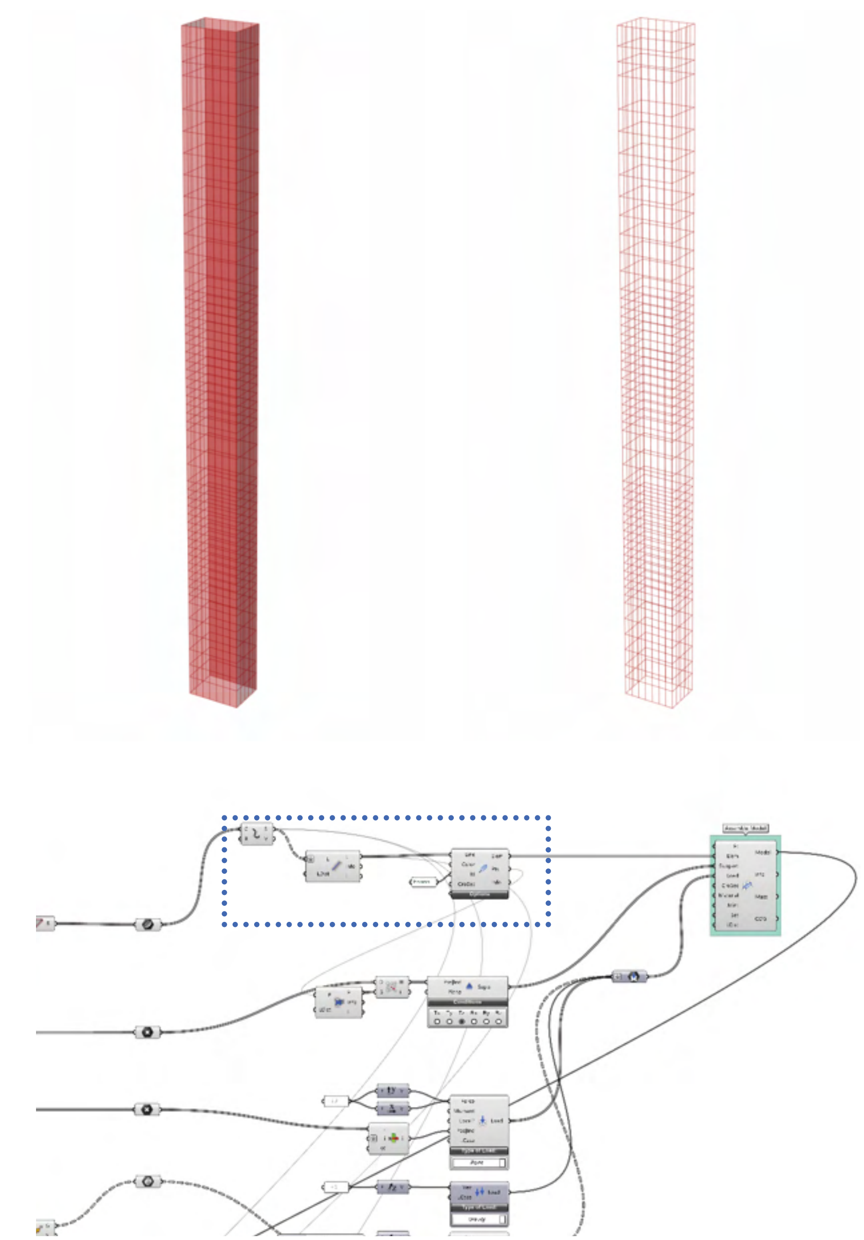


Generate Facade geometry

1) Sortout and organize the points from the base geometry

2) Create mesh with properly organized point lists

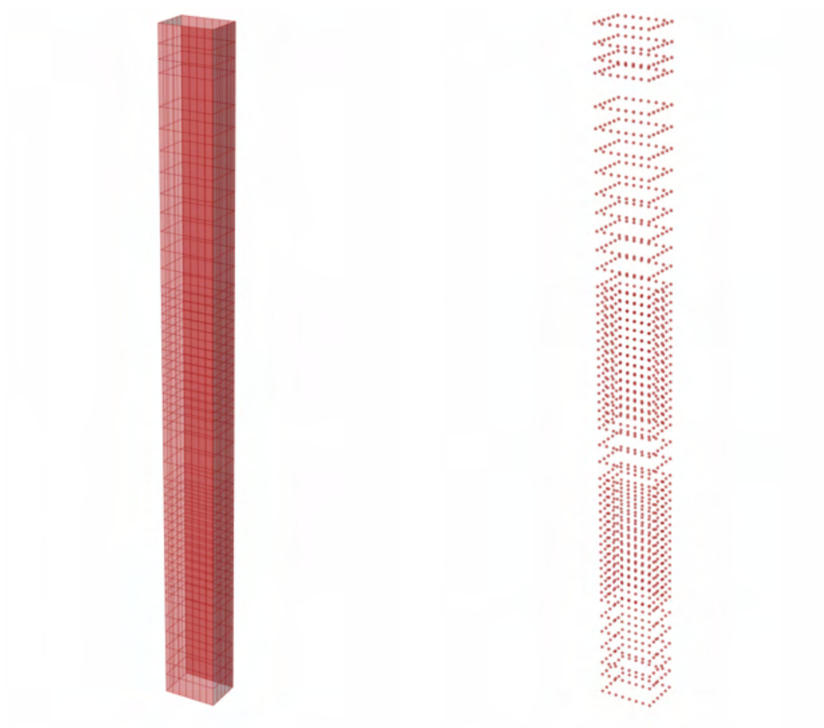
3) Assemble it

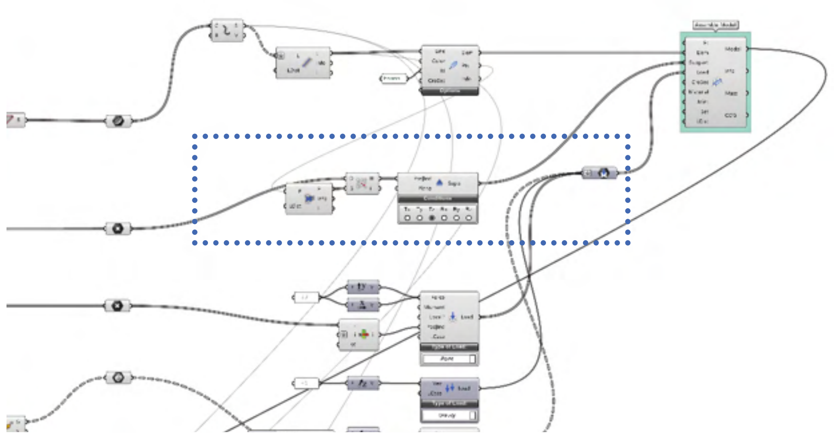


Element set up

1) List up the mesh edges

2) Connect it to line2beam to make beam type structure calculation

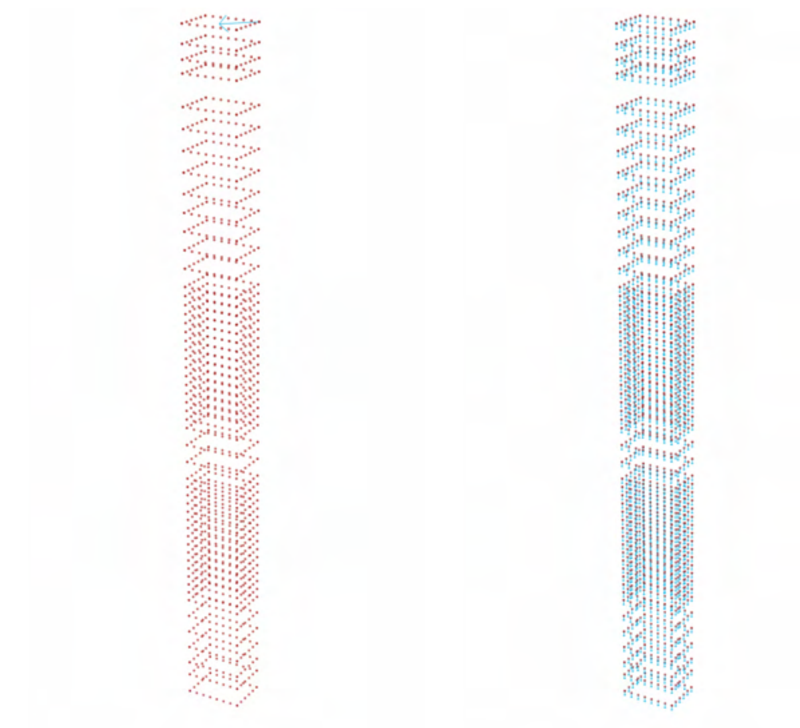


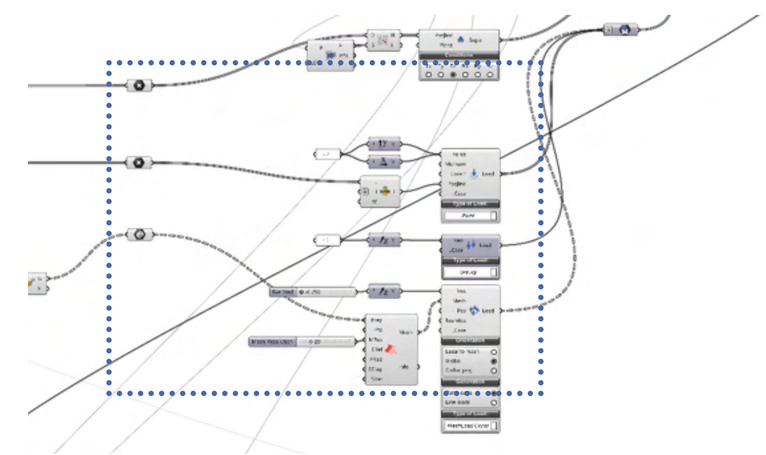


Support set up

1) Sort out and organize the points from prepared mesh

2) Convert it to support and apply proper support set up





Load set up

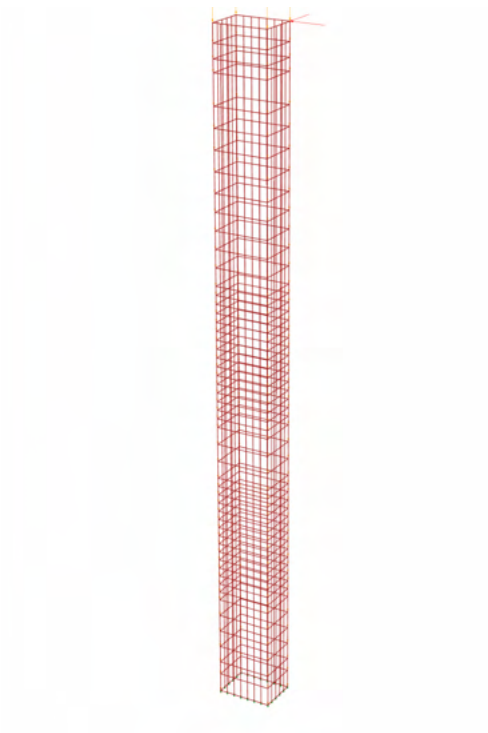
1) Sort out the points facing wind load

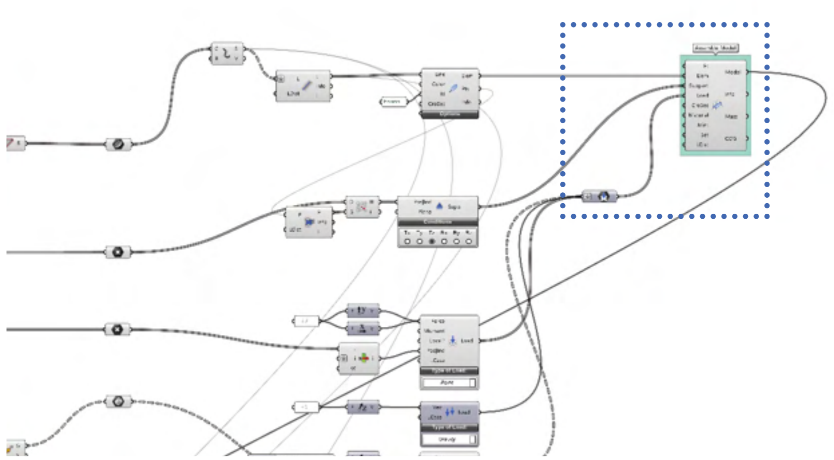
2) Apply wind load with proper dominant direction of the wind

3) List up all of the points in structure

4) Apply gravity load with designated number (vary depending on region)

5) Apply live load to mesh item with designated number (vary depending on program)



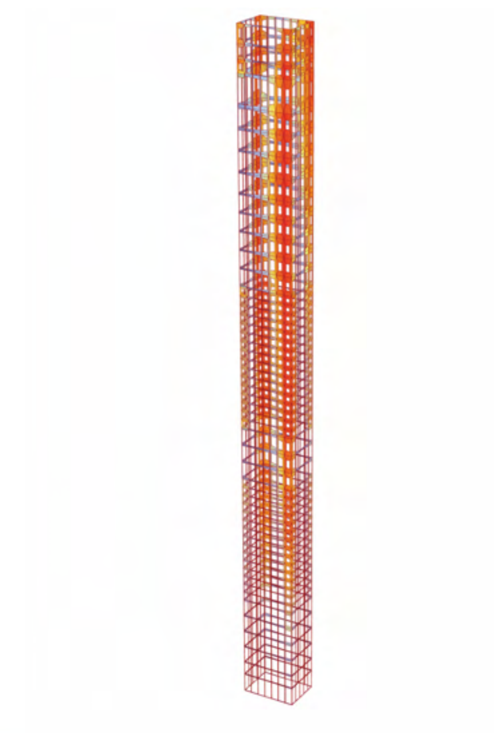


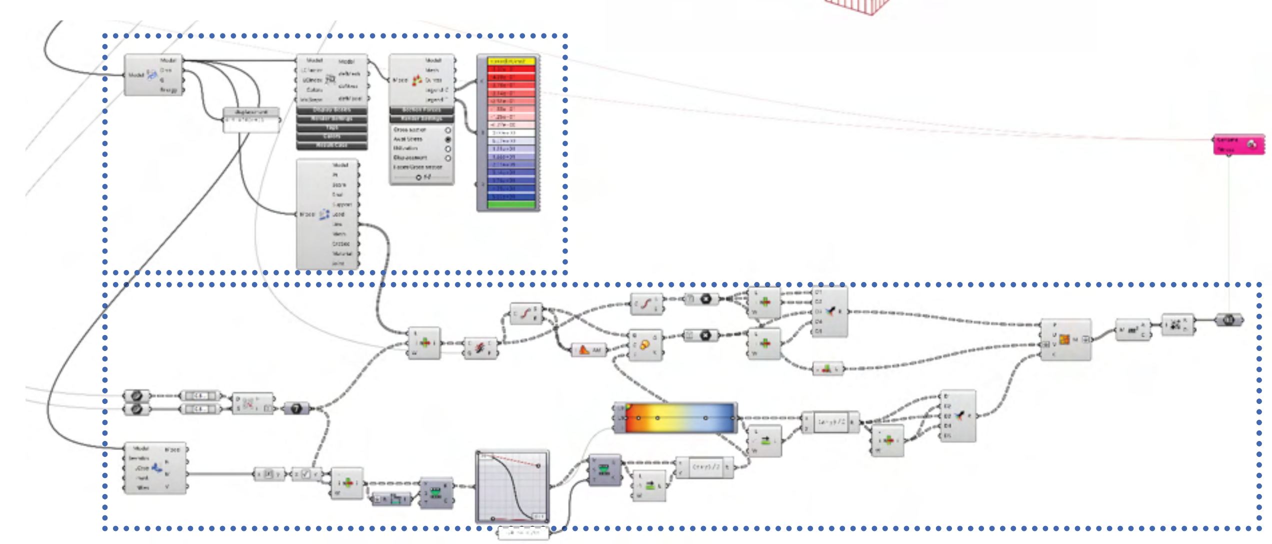
Structure Simulation

1) Connect element, support, and load value to the solver

2) Set up the visual settings

3) Check automatically created simulation result





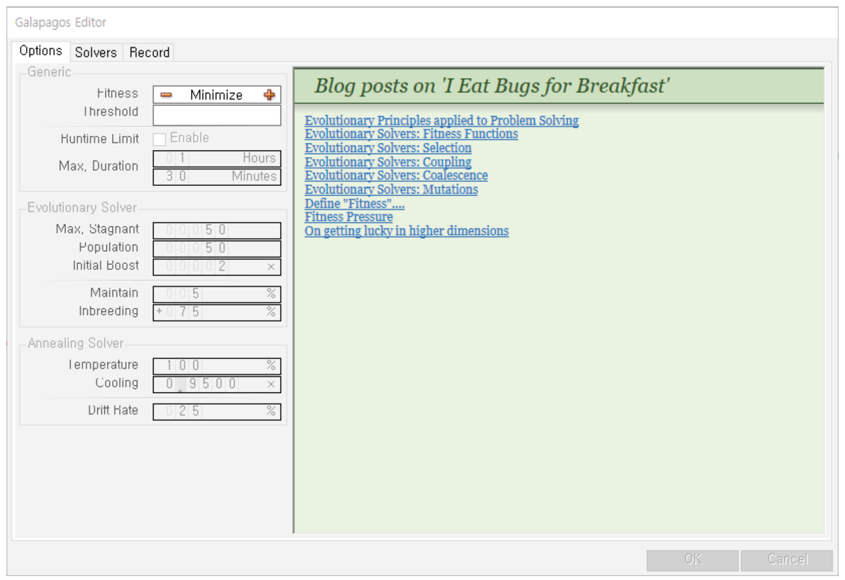
Value Return to Design

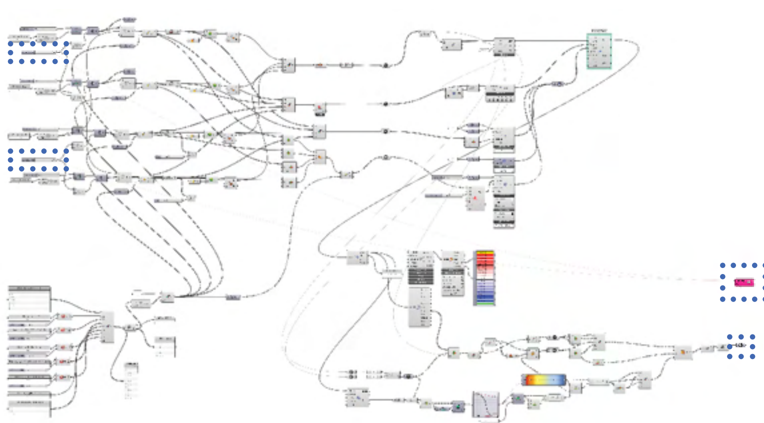
1) Disassemble the simulation result and sort out line data

2) Create mesh representation with the data

3) Generate visual setting for the mesh

4) Sort out the area data from the mesh





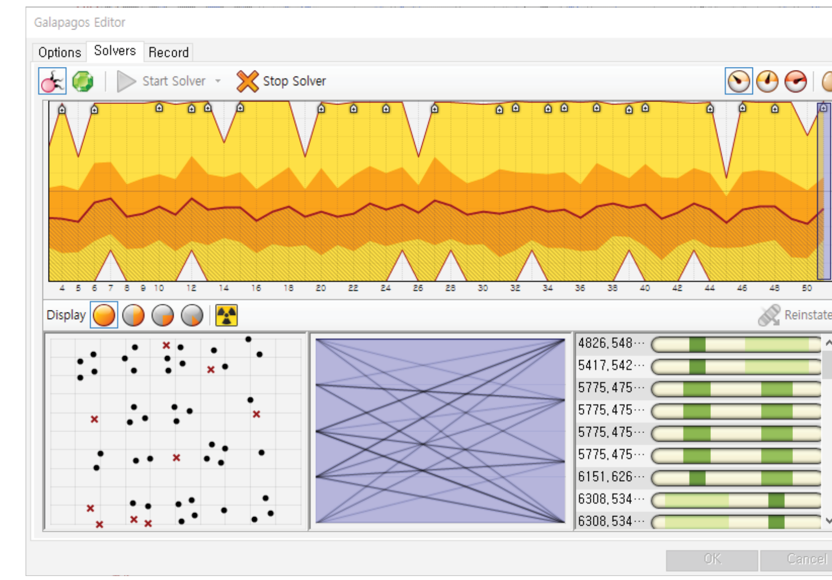
Evolutionary Optimizing

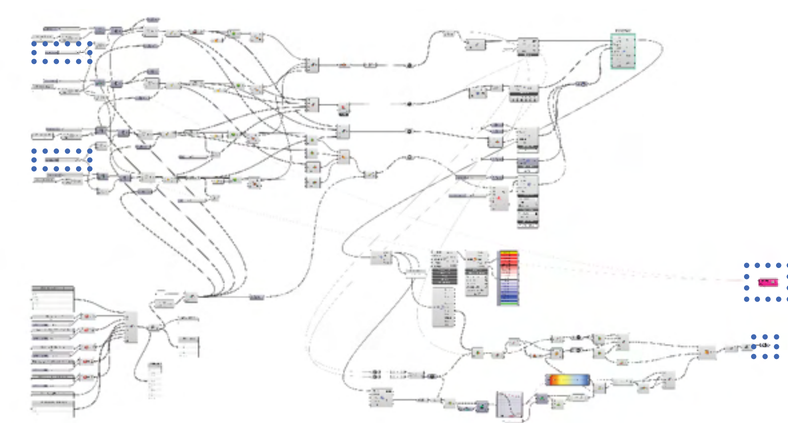
1) Connect 2 Number of the columns to Genome

2) Connect Mesh Area to Fitness

3) Set the Fitness to be minimized

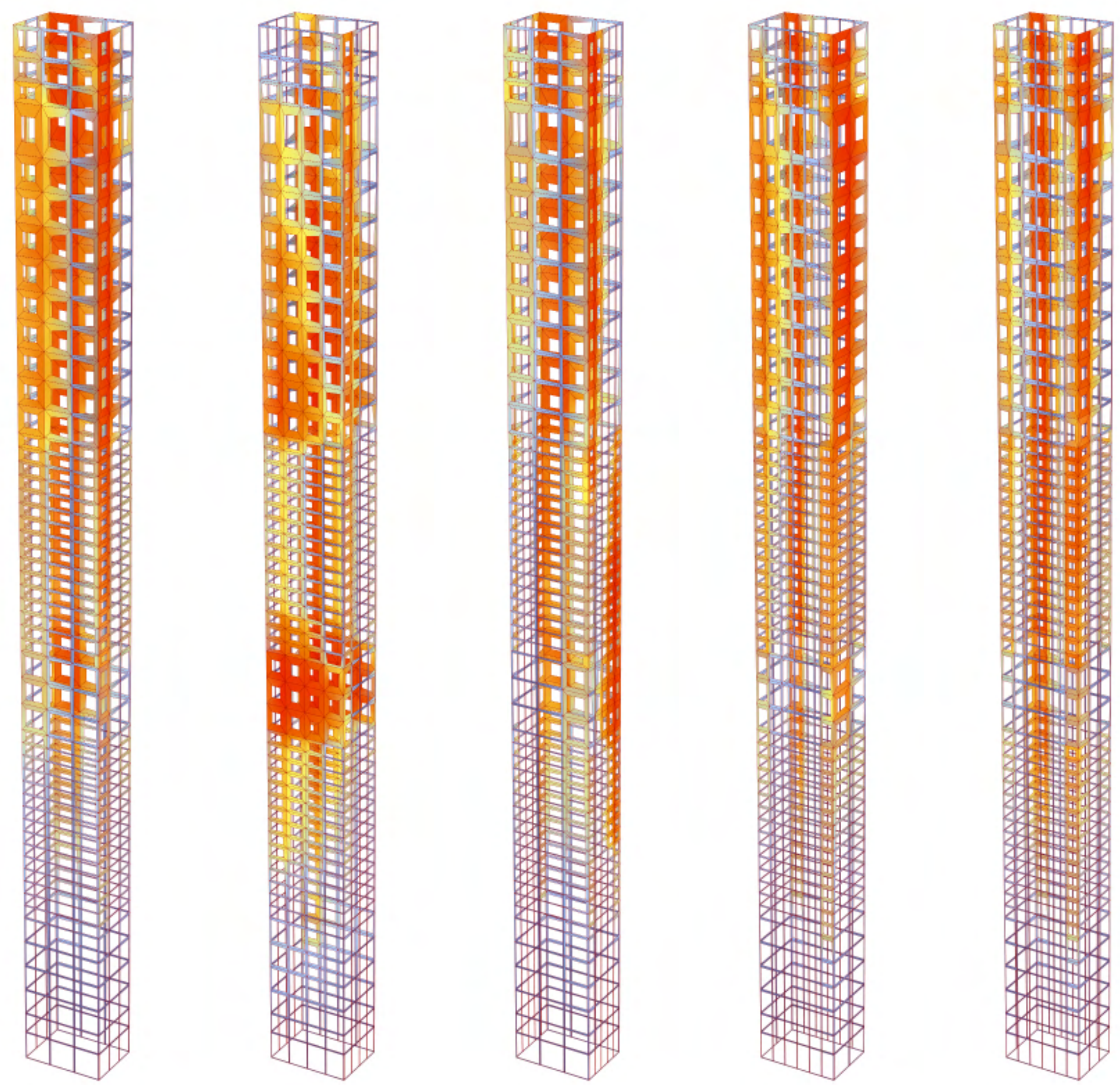
4) Move to Solvers tab

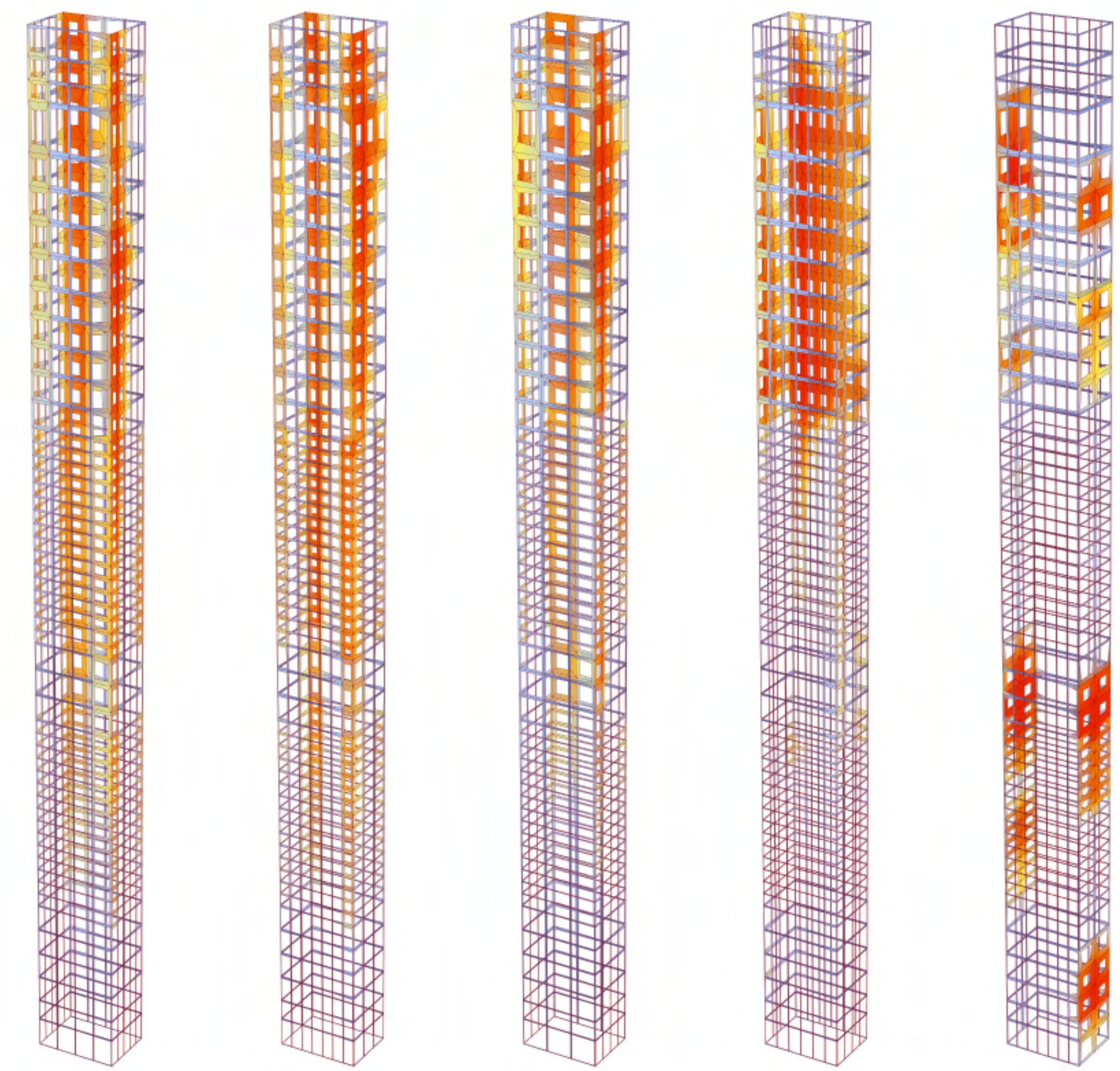


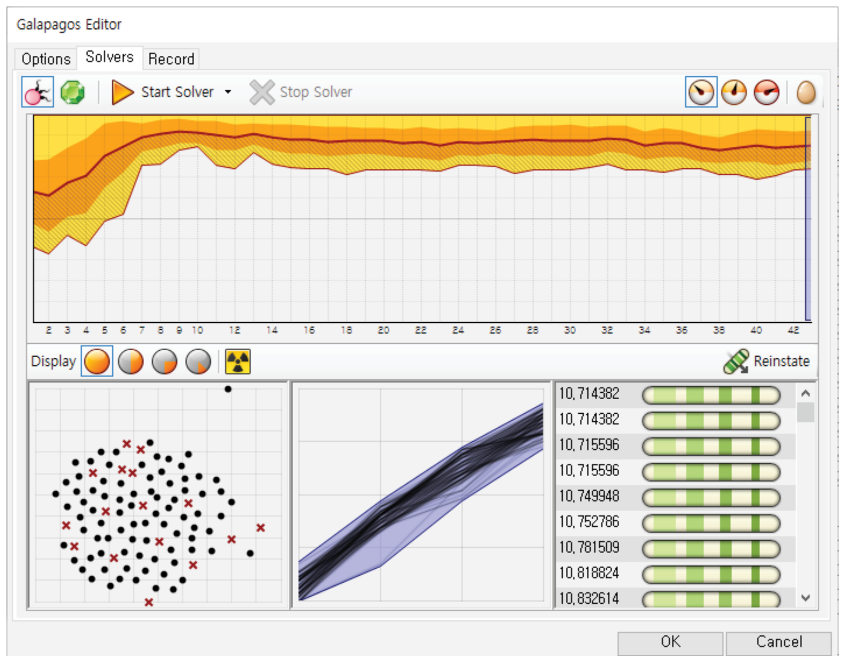


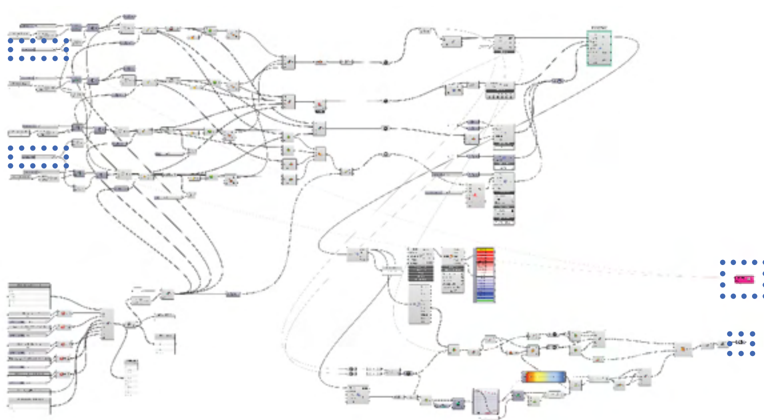
1) Check evolutionary solver

2) Start by clicking start solver







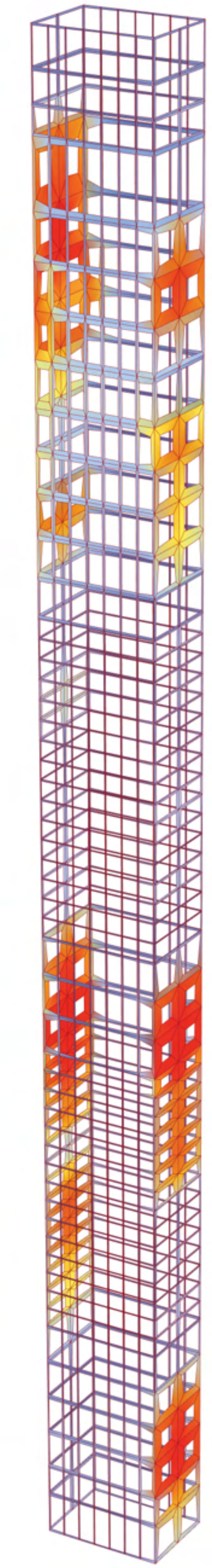


Pick the best

1) Click the top item from the list

2) Click reinstate button

3) Gene-pool will be adjusted in accordance with the step 2



CONCLUSION & FUTURE STUDY

Conclusion & Future Study

Parametric design allows architects, designers and engineers, to specify the key parameters of a project and make changes interactively. Parametric design has been dominantly used as a formal expression, but it also can be used to make more efficient designs, explore better options and optimized buildings.

The creative collaboration between architects and engineers leads to take full advantage of parametric design. By defining the right input parameters and geometrical logic, a design professional is able to develop a challenging aesthetic shape and an efficient design. This procedure has been developed in engineering practice, but it is now available for designers and architects due to the new technology.

Will this make designers rely too heavily on computers or produce shapes that are unnecessarily complex and full of waste? It is not true, if they are used as an aid to, rather than a replacement for, design innovation in architectural and structural design. As a design professional, one must still use one's design judgment, experience and professional standards to define reasonable design parameters and understand their relative importance to the safety and quality of the building. This approach not only applies to geometrical parameters, but to all the design assumptions engineers make to plan for the uncertainties and possible variations of the design environment during the building life cycle.

We expect this research to initiate the integrated design approach between different design professionals. First volume of this research has been focused on size and shape optimization in regards with each structural member sizes based on the direction of forces and location of reinforcing elements. Seconds volume will explore more on shape and topology optimization through referred projects.

References

Wonoto, N. (2017). Integrating Parametric Structural Analysis and Optimization in the Architectural Schematic Design Phase. Clemson University.

Ali, M. M., & Moon, K. (2007). Structural developments in tall buildings: Current trends and future prospects. Architecture Science Review, 50(3), 205-223.

Bucci, F., & Mulazzani, M. (2002). Luigi moretti works and writings Princeton Architectural Press.

Buelow, V., Falk, A., & Turrin, M. (2010). Optimization of structural form using a enetic algorithm to search associative parametric geometry. Proceedings of the International Conference on Structures Architecture, , 1 195-196. doi:10.1201/b10428-93

Burry, J., & Burry, M. (2010). The new mathematics of architecture (1st ed.) Thames & Hudson.

Charleson, A., W., & Pirie, S. (2009). An investigation of structural engineer-architect collaboration. Journal of the Structural Engineering Society, 22(1)

Christensen, P. W., & Klarbring, A. (2009). An introduction to structural optimization (1st ed.). Netherlands: Springer. doi:10.1007/978-1-4020-8666-3

Davison, J., Popovic, O., & Tyas, A. (1998). A new degree program in structural engineering and architecture. Proceedings of the International Conference on Engineering Education,

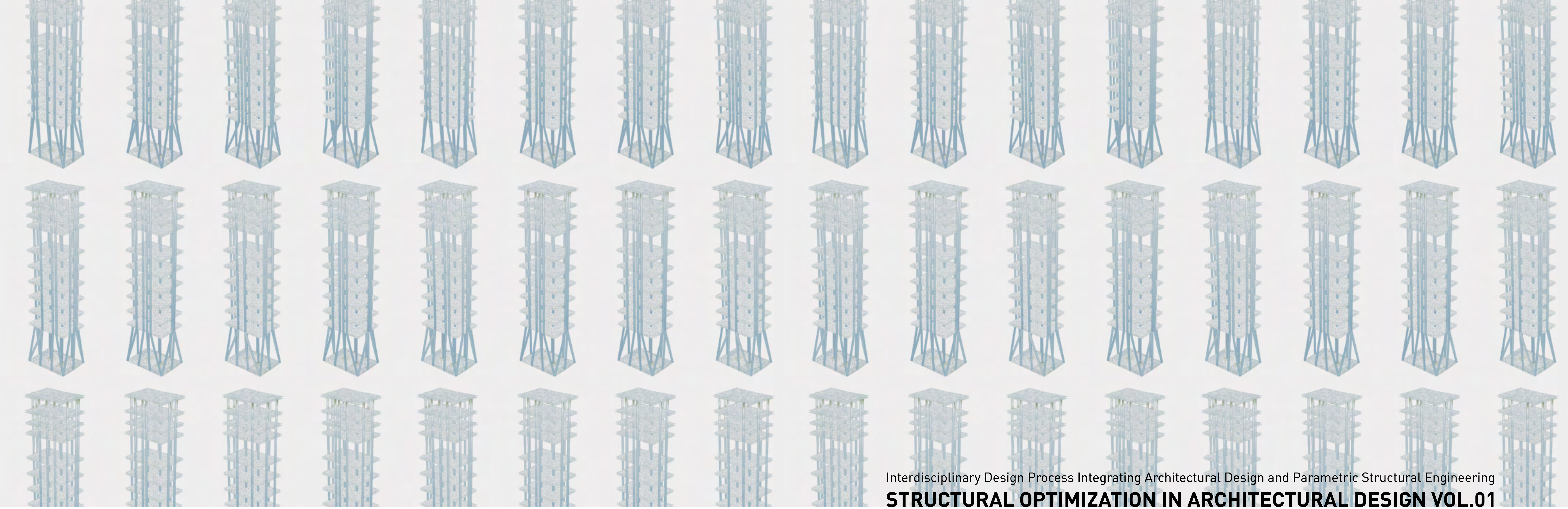
Faridah, A., Sani, A., & Ismail, R. (2004). Bridging the gap: Architecture and structural engineering. Conference on Engineering Education (CEE 2004), Kuala Lumpur.

Felkner, J., Chatzi, E., & Kotnik, T. (2013). Architectural feedback in the structural optimization process. Structures and Architecture: Concepts, Applications, and Challenges, , 676-684.

Gerber, D. (2007). Parametric practices: Models for design exploration in architecture (Doctor of Design).271

Larena, A. (2009). Shape design methods based on the optimization of the structure. historical background and application to contemporary architecture. Proceedings of the Third International Congress on Construction History, Cottbus.

Peters, T. F. (1991). Bridging the gap: Rethinking the relationship of architect and engineer. New York: the Relationship of Architect and Engineer", Van Nostrand Reinhold.



Interdisciplinary Design Process Integrating Architectural Design and Parametric Structural Engineering

STRUCTURAL OPTIMIZATION IN ARCHITECTURAL DESIGN VOL.01

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This research paper was written by Dongil Kim and Jaekyung Jake Han at H Architecture, 2019.

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