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Design Optimization Using Conflicting Building Information - A case Study Focused on the View and Structure in High-Rise Building Design

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Abstract Within residential high-rise market there are many value determining factors. Site condition, view, program, units and structure are important parameters that are directly related to the financial aspect of the project. However, most of the studies of high-rise building design focus on the façade and the shape strategies from an esthetic point of view without considering these factors. The objective of this study is to investigate new design approach that incorporates site, program and structural information at an early stage as a generator of building form and explore a wide range of strategies to negotiate these factors in the process of design/decision making. Not being based on designer's subjective preference or style, architects still can create interesting building design through integration and negotiation of various building information. Since this form is based on real data, not just play of abstract form, we can expect that this form has great potential to be developed into real one at the later design phase.

Keywords: Pragmatism, Parametric, Computation, Building Information, Optimization

1. INTRODUCTION

1.1 Background

Since the advent of 'computation' in architecture, designers have leveraged the power of advanced digital tools for a wide range of purposes. Especially in designing High-rise Towers, computers have been playing critical role in every design phase. However, many investigations trend towards one of two directions: the search for new and exciting forms and BIM (Building Information Modeling), seeking to facilitate design and construction processes. Many designers still use an intuitive design process and switch to BIM for production, or they collect optimization data for several factors at the front end of the design process and try to rationalize the often divergent result cerebrally (Ottchen, 2009) The new availability of massive amounts of data combined with computation power offers a whole new way of understanding the world. As projects become increasingly complex, the level of information integrated into the project grow rapidly. But How does one decide which has more priority than the others? How can data work for the design process rather than limit? How does one surpass mere data collection and technical optimization?

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1.2 Objective and the Method of the Study

Within residential high-rise market there are many value determining factors. Site condition, view, program, units and structure are important parameters that are directly related to the financial aspect of the project. However, most of the studies of high-rise building design focus on the façade and the shape strategies from an esthetic point of view without considering these factors. For example, Kim & Yang (2012) in their study on the BIM-based Automation of Envelope Form Generation implemented the study to develop an automation system for the envelop form generation which could be linked up with other parametric digital tools. (In-Han Kim and Jung-Im Yang, 2012) Even though this system could generate various envelop forms, this study focuses on the form control at the pre-schematic phase using abstract parameters. Vollers also proposed study about the morphological scheme of non-orthogonal high-rises, but his study is mainly based on software manipulations to describe shaping in general.(Vollers, 2009)

The objective of this paper is to investigate new design approach that incorporates site, program and structural information at an early stage as a generator of building form and explore a wide range of strategies to negotiate these factors in the process of design/decision making. Not being based on designer's subjective preference or style, architects still can create interesting building design through integration and negotiation of various building information. Since this form is based on real data, not just play of abstract form, we can expect that this form has great potential to be developed into real one at the later design phase.

Site / program/ environment information are collected and analyzed to set up relationships between seemingly unrelated data as an architectural form. Specifically, views are used as main parameters for driving the initial building form. The views from the 4 sides of the each floor are calculated and each floor is rotated and extruded to get the best view. It is tested against structural rationale using an evolutionary solver to optimize/maximize its performance. For this optimization process to control the profile of the tower, Galapagos adjusts a matching set of conflicting outputs which are minimizing structural deviation and maximizing total views, thus ensuring that more units have windows oriented toward good views while it works within structural rationale.

2. DESIGN PROCESS

2.1 Project Context

The site is located in downtown Chicago, which is directly on Michigan Ave. and across from the 'magnificent mile'. The site is a bit dull and lifeless compared with the area toward the north of the site. The Hard Rock Hotel which is occupying the current site is quite high (500ft), but the building itself seemed to disappear between the other buildings around. However, this prime location dictates a certain focus on the exposure and visibility of the building. On the lower floors one has framed views (mostly by other buildings) which only give a glimpse of the entire view. As one continues upward, the views continue to expand until the length of the Chicago river and the vast cityscape from a distance. The programs for the building are mixed use development including residential, office and commercial spaces which are organized as commercial space on the bottom floors, office on the middle floors and residential on the upper levels.

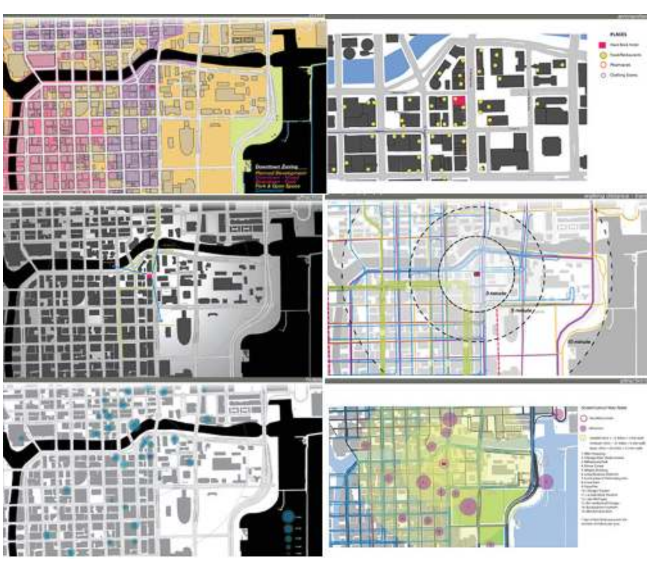

Figure 1. Site Analysis Diagrams: Views, Zoning, Transportation, Walkability, Demographics, Retail and Residential Programs around the site. This information is used to set up the parametric massing model on the site.

2.2 Initial Parametric Massing

The process begins by making a parametric massing 3D model with core architectural elements. This is done by taking the limits of the site and extruding them upwards. This establishes the floor to floor heights, the basic floor plates, the cores, reasonable column grid (25') and loosely defined programs, which also reflecting zoning ordinances that pertain to setbacks and heights. This massing is a systematic relational diagram that has all the core architectural elements as basic project parameters. The initial programs for the base are retail and public, and office and residential are for the upper portion. Each program has its own requirements and therefore needs different design strategy.

Figure 2. Views from the Site: To the northeast, navy pear, to the south Millennium park, to the southwest, Willis tower and to the northwest, riverfront with high rise buildings as backdrops.

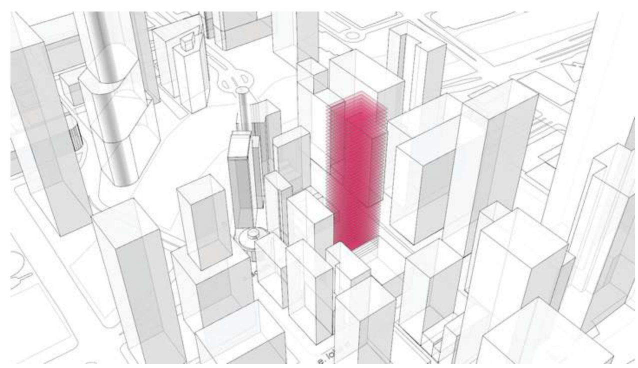

Figure 3. Parametric massing on the site: The entire downtown of Chicago is modeled in 3D and a parametric massing 3D model is placed to test the view.

2.3 View

As the site is located within downtown Chicago, it has amazing views from all of the sides. To the northeast, navy pear, to the south Millennium park, to the southwest, Willis tower and to the northwest, riverfront with high rise buildings as backdrops.(marina tower, trump tower etc.) However, as the site is located within dense urban environment, one doesn't have much view except from the small view corridor between buildings until 100ft high. The entire Chicago downtown is modeled in 3D to gain an accurate knowledge about heights, views and proximities and analyzed the views around the site using 'View fields', which are essentially fields of points contained within certain areas around the site that are established as "good views". First, the four different sides of each of the floor plates are taken individually and the midpoint of each is found. Separately, different viewing fields are established. The four views that are established are.

1. Millennium park
2. East River,
3. The Cityscape toward the west River,
4. The Cityscape toward the North Lake.

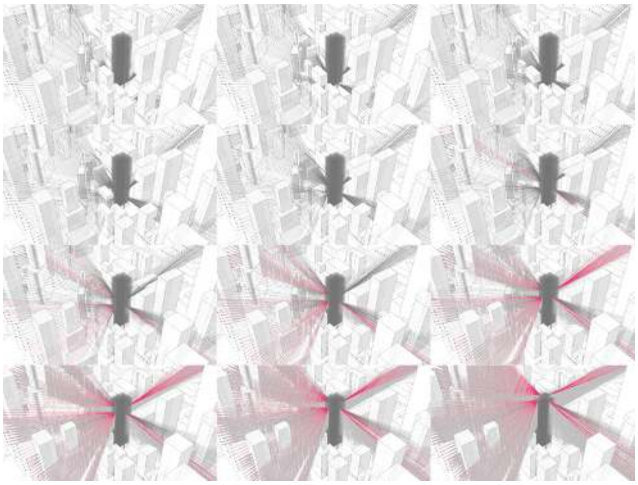

Figure 4. View Field Matrix: From Top left to Bottom right(0, 40', 80', 120', 160', 200', 240', 280', 360', 400' 440', 480'): On the lower floors one has framed views (mostly by other buildings). As one continues upward, the views continue to expand until the length of the Chicago river and the vast cityscape from a distance.

Each view field is established with 20' grid of points which would serve as control points to define the density of the views. Then an elaborate parametric algorithm was developed in Grasshopper, which allowed us to test each view field from each floor whether they are blocked by other building around the site. The extents of these views are measured and a point field is distributed within the area of viewing. This establishes destination points to test whether or not the views from the building on the site make it to their destination without being blocked. The goal is to optimize the view for every floor of the building and every side of the floors. So using the midpoint of every side of every floor, a line of view rays is drawn between each midpoint to every point in the viewing field. For example, there are 80 view rays each side per floor on a 45 story building, which has four sides per floor that means there are 14,400 view rays that are being tested. These rays were placed within the site to test whether or not each and every view ray is obstructed by the surrounding buildings. If the view ray is blocked, it returns a false value and is removed from the view fields. If the view ray makes it to the viewing field without any obstructions, it returns a true value.

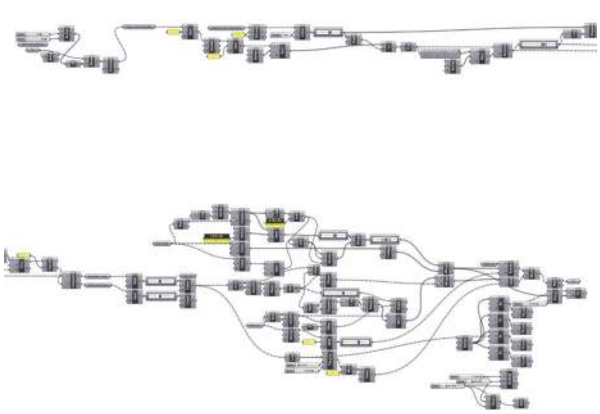

Figure 5. Grasshopper script to test each view field from each floor

FLOOR #	SIDE 1	SIDE 2	SIDE 3	SIDE 4	FLOOR #	SIDE 1	SIDE 2	SIDE 3	SIDE 4
0	0.0%	0.0%	0.0%	0.0%	23	16.0%	16.0%	0.0%	0.0%
1	0.0%	0.0%	0.0%	0.0%	24	16.0%	22.2%	0.0%	7.4%
2	0.0%	0.0%	0.0%	0.0%	25	16.0%	24.7%	0.0%	19.8%
3	0.0%	0.0%	0.0%	0.0%	26	16.0%	28.4%	0.0%	32.1%
4	0.0%	0.0%	0.0%	0.0%	27	16.0%	32.1%	0.0%	40.7%
5	0.0%	0.0%	0.0%	0.0%	28	16.0%	33.3%	0.0%	50.6%
6	0.0%	0.0%	0.0%	0.0%	29	17.3%	35.8%	0.0%	55.6%
7	0.0%	0.0%	0.0%	0.0%	30	23.5%	37.0%	0.0%	58.0%
8	0.0%	0.0%	0.0%	0.0%	31	25.9%	40.7%	47.9%	58.0%
9	0.0%	0.0%	0.0%	0.0%	32	32.1%	40.7%	75.0%	60.5%
10	13.6%	0.0%	0.0%	0.0%	33	32.1%	42.0%	100.0%	63.0%
11	16.0%	0.0%	0.0%	0.0%	34	32.1%	43.2%	100.0%	63.0%
12	16.0%	0.0%	0.0%	0.0%	35	32.1%	44.4%	100.0%	66.7%
13	16.0%	0.0%	0.0%	0.0%	36	32.1%	46.9%	100.0%	66.7%
14	16.0%	0.0%	0.0%	0.0%	37	32.1%	46.9%	100.0%	66.7%
15	16.0%	0.0%	0.0%	0.0%	38	32.1%	46.9%	100.0%	66.7%
16	16.0%	0.0%	0.0%	0.0%	39	32.1%	46.9%	100.0%	66.7%
17	16.0%	0.0%	0.0%	0.0%	40	35.8%	49.4%	100.0%	66.7%
18	16.0%	0.0%	0.0%	0.0%	41	35.8%	50.6%	100.0%	66.7%
19	16.0%	0.0%	0.0%	0.0%	42	40.7%	50.6%	100.0%	66.7%
20	16.0%	0.0%	0.0%	0.0%	43	43.2%	50.6%	100.0%	66.7%
21	16.0%	2.5%	0.0%	0.0%	44	44.4%	50.6%	100.0%	66.7%

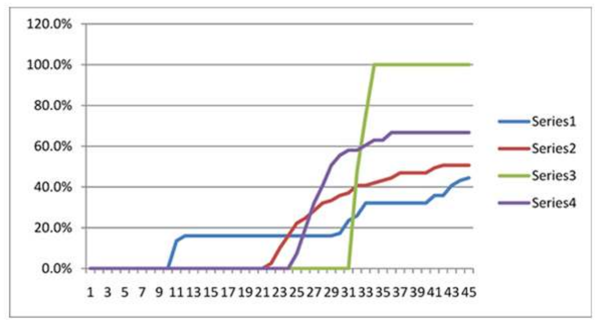

Figure 6. View Percentages of each side for each floor (from ground to 44th floor)

The side of each floor is rotated to align with the average view. This is done by taking the previous list mentioned above and separating out the true and false values for each side of each floor. For example, if the south side of 40th floor has 80 total view rays and only 41 of the view rays are not obstructed then those 41 vectors are separated out and the average vector out of the 41 is found. The side of the floor is then rotated about its midpoint to become perpendicular to the average vector. In another word, you can call this vector as the best view ray. This results in each side of the building to optimize its orientation for the best view. Programmatic breakdowns and the emphasis on particular relationships become the main determinant of how the massing will be extruded. The program of the high-rise is determined based on views as well. It would be seen as a pixelated transition from the bottom to the top of the building being WORK / LIVE-WORK / LIVE. This allows for the bottom part of the tower and the part with more limited views to be for office space, as the views get better the program begins to change from WORK to LIVE. The LIVE portion begins with smaller units and as it gets higher (and the views get better) the units get bigger. This is a result of previous section which is the extrusion to increase the wall area as the views get better. This matches better views with larger area resulting in more profit. As far as the division of units, each floor is divided into a certain number of units which allows for the smooth transition from WORK to LIVE as one moves upward. Corner units would be combined into the adjacent units to form larger units. This follows the hypothesis that as the views get better the square footage should also get larger to match the increase in price. Outdoor space for a majority of the units is also created by pushing and pulling the individual units either 5', 6', 8', or 10'. The distance is based on the view and as it gets better, the below unit is pushed further out creating a larger balcony for the unit above. Also, this extrusion will allow for the units to move outward and inward without blocking natural light from other units.

FLOOR #	ROTATION SIDE 1	ROTATION SIDE 2	ROTATION SIDE 3	ROTATION SIDE 4
0	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00
9	0.05	0.05	0.00	0.00
10	0.06	0.06	0.00	0.00
11	0.07	0.07	0.00	0.00
12	0.08	0.08	0.00	0.00
13	0.09	0.09	0.00	0.00
14	0.10	0.10	0.00	0.00
15	0.11	0.11	0.00	0.00
16	0.12	0.12	0.00	0.00
17	0.13	0.13	0.00	0.00
18	0.15	0.15	0.00	0.00
19	0.16	0.16	0.00	0.00
20	0.17	0.17	0.05	0.00
21	0.18	0.18	0.07	0.00
22	0.19	0.19	0.05	0.00
23	0.20	0.20	0.05	0.00
24	0.22	0.22	0.05	0.00
25	0.23	0.23	0.06	0.00
26	0.24	0.24	0.03	0.00
27	0.25	0.25	0.01	0.00
28	0.26	0.26	0.00	0.00
29	0.25	0.25	0.00	0.00
30	0.25	0.25	0.00	0.05
31	0.28	0.28	0.01	-0.02
32	0.29	0.29	0.01	-0.02
33	0.30	0.30	0.03	-0.01
34	0.32	0.32	0.04	0.01
35	0.33	0.33	0.05	0.03
36	0.34	0.34	0.06	0.04
37	0.36	0.36	0.07	0.06
38	0.37	0.37	0.08	0.08
39	0.39	0.39	0.09	0.09
40	0.40	0.40	0.10	0.11
41	0.42	0.42	0.11	0.13
42	0.43	0.43	0.12	0.14
43	0.45	0.45	0.13	0.16
44	0.45	0.45	0.13	0.16

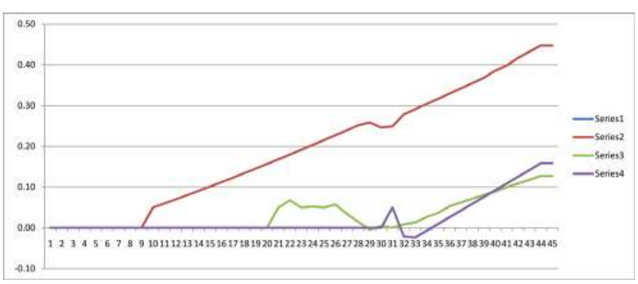

Figure 7. Rotation of each side for each floor(from ground to 44th floor)

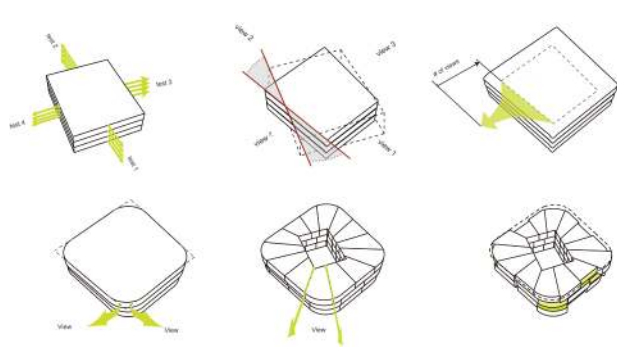

Figure 8. Process Diagram of rotation and extrusion. The side of each floor is rotated to align with the average view and extruded to maximize the view.

FLOOR #	EXTRUSION-SIDE 1	EXTRUSION-SIDE 2	EXTRUSION-SIDE 3	EXTRUSION-SIDE 4
0	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00
7	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00
9	5.00	0.00	0.00	0.00
10	5.74	0.00	0.00	0.00
11	6.47	0.00	0.00	0.00
12	7.21	0.00	0.00	0.00
13	7.94	0.00	0.00	0.00
14	8.68	0.00	0.00	0.00
15	9.41	0.00	0.00	0.00
16	10.15	0.00	0.00	0.00
17	10.88	0.00	0.00	0.00
18	11.62	0.00	0.00	0.00
19	12.35	0.00	0.00	0.00
20	13.09	0.00	5.00	0.00
21	13.82	0.00	10.00	0.00
22	14.56	0.00	10.77	0.00
23	15.29	5.00	11.55	0.00
24	16.03	6.25	12.32	0.00
25	16.76	7.50	13.09	0.00
26	17.50	8.75	13.86	0.00
27	18.24	10.00	14.64	0.00
28	18.97	11.25	15.41	0.00
29	19.71	12.50	16.18	0.00
30	20.44	13.75	16.95	5.00
31	21.18	15.00	17.73	6.92
32	21.91	16.25	18.50	8.85
33	22.65	17.50	19.27	10.77
34	23.38	18.75	20.05	12.69
35	24.12	20.00	20.82	14.62
36	24.85	21.25	21.59	16.54
37	25.59	22.50	22.36	18.46
38	26.32	23.75	23.14	20.38
39	27.06	25.00	23.91	22.31
40	27.79	26.25	24.68	24.23
41	28.53	27.50	25.45	26.15
42	29.26	28.75	26.23	28.08
43	30.00	30.00	27.00	30.00
44	30.00	30.00	27.00	30.00

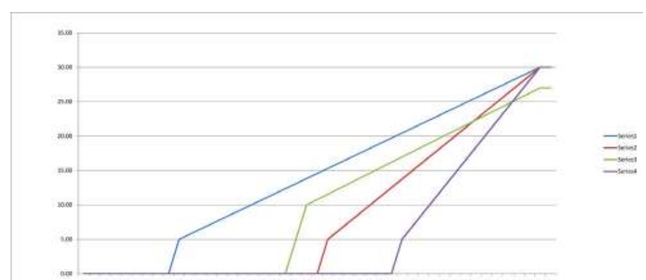

Figure 9. Extrusion of each side for each floor(from ground to 44th floor)

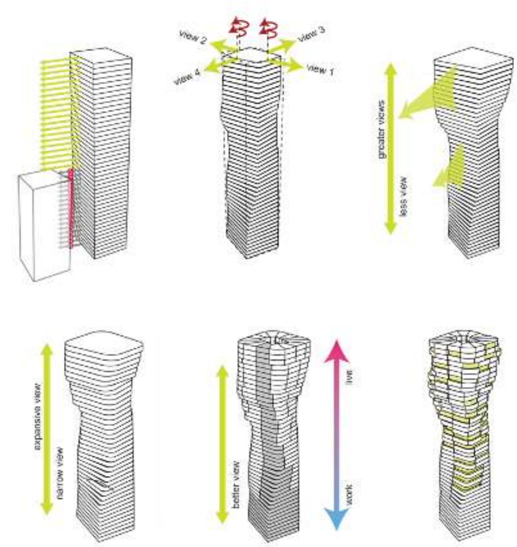

Figure 10. Design Process Diagram

3. TESTING

Through the process discussed above, a base model established with the constraints of the site and program produced a theoretical form. While this form is composed purely of necessity to fulfill the specified requirements, it is still a virtual form because it has yet to be tested to be actualized. The hypotheses for our project are;

1. Rotating the face of each side so that it is perpendicular to the best view in that direction, which allows for better and more views.

2. Extruding the face of each side depending on the number of views and vastness of the views which increases the surface area of each exterior wall allowing for more floor area as the views get better. (Views get vaster as one moves up the tower).

These hypotheses are tested by taking the base model, dividing it into generic units, and testing the views from each unit to the specified viewing field. The point of view from each unit starts 7 feet back from the exterior wall. This tests whether or not the viewing field can be seen from within the room not just at the facade. The 7 feet back means that all views counted from the units are easily viewed from within the room. After testing the base model for views, the theoretical form is taken and divided into units, the same process is followed by starting the point of view from each unit 7 feet back from the exterior wall. The views are counted in the same way and compared. The testing shows that the theories are correct allowing for 32% more total views than the original model. The views are also more direct and thus better because of the rotation.

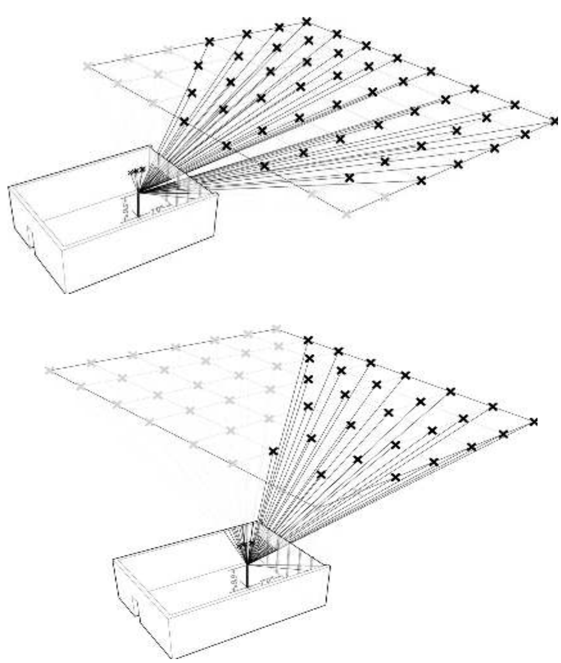

Figure 11. View field testing within individual unit

4 .OPTIMIZATION

This optimization process is usually the manual and most tedious part of performance based design. The system that is setup is used to get close to the optimized geometry, but like most problems there are some user defined variables that are just guesses. In this study, these variables are things like the maximum amount of extrusion, the ratio that determines how far each wall is extruded, and the completeness of each side rotation. We can maximize our chosen result which is the total number of views, by changing and manipulating each of these variables. But without a counterbalance, these variables have no limit. Theoretically, there is nothing wrong with each wall being extruded 1,000 feet to bring it as close to each of the viewing fields as it can be. But in reality, there are other parameters we need to ensure if this is feasible as a building.

Conventionally, structural issue is once secondary concerns. Even though it is directly related to the financial aspect of the project, it is considered after the initial design is finished. In this paper, structure is used as one of the primary players for the optimization process through Galapagos. Galapagos, which is Grasshopper plug-in, is an evolutionary solver that takes variables and tests for “fit” or optimum values. Simply put, the solver adjusts the variables within domains to maximize/minimize the output. The process continues breeding successful iterations until it narrows in one a maximized result. This, applied to architecture, is a way of performance based design that takes the guess and check method out of the equation.

Previously, geometry would be analyzed, and then manually adjusted, only to analyze again and manually adjust again. This guess and check method of performance based design is highly inefficient even with the advent of BIM software which allows for quicker changes, the geometry still needs to be adjusted manually. Thus begins a long and tedious process to reach a supposed optimum geometry, where in reality the end success along with failed trials were really just scratching the surface of possible iterations. Galapagos along with other evolutionary solvers takes this inefficient process and makes it almost instant, with a result that is more accurate than the manual method could ever be. With Galapagos views are compromised according to structural rationale which is directly related to constructional and economic issues. For example, if we find forms that operate more efficiently from a structural point of view, then we can use fewer materials and easier construction methodology. This will allow us to find a balance between what is structurally feasible and what provides the best and maximum views.

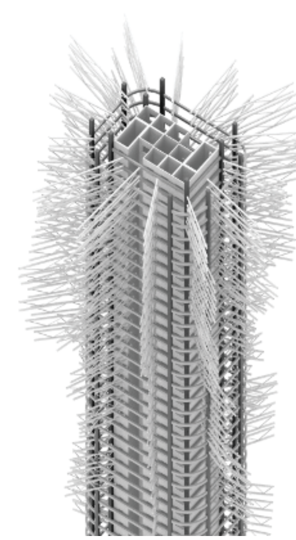

Figure 12. Structural Diagram_views are compromised according to structural rationale

In Galapagos, we set up the output for 2 categories (Structure and View) as below;

To minimize structure deviation;

To maximize total views;

But since Galapagos is only able to optimize a single numeric output, the two outputs that need to be optimized, structure and views, need to be combined into a single number. This is done by first getting both outputs into numbers that are of the same scale. For example, the maximum number that the views output can result in is 14,020 where the structural output number is infinite. This is because the calculation for the structural members is exponentially based on the amount of cantilever and rotation. Meaning as the sides are cantilevered outward, the size and cost of the structural members are growing exponentially. Thus it begins with a relatively low number and soon turns into an incredibly large number. The method of getting these numbers to be of the same scale is to first find the maximum values of each number. As there can only possibly be 14,020 views that can be completed, the maximum value for the views is 14,020. And after a few calculations we established a maximum value for the structure to be 3,000, which is equivalent to the edge of reality in constructability.

Now knowing the minimum and maximum's of each value, we can now convert the outputs to percent numbers so that they are on the same scale. So for example if the output of views is 10,094, the scaled number is 0.72. This means that this is 72% of the maximum number 14,020. The amount for the structural output is based on the extrusion and rotation of the building and the raw value is 1,253 which can be scaled to 0.42 which is 42% of the maximum number 3,000.

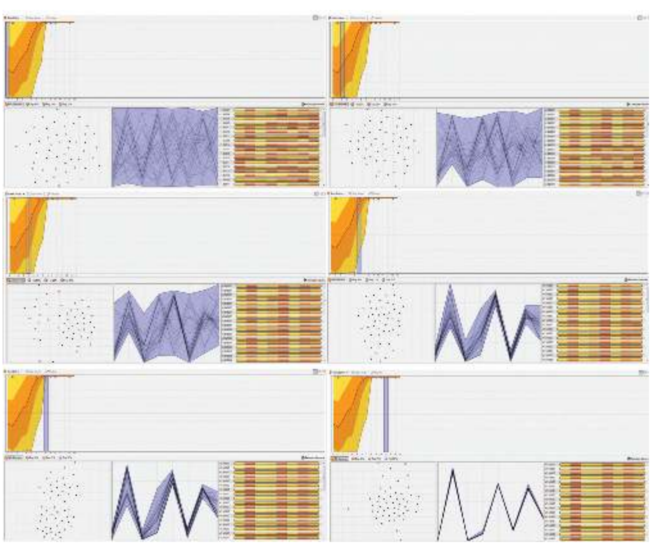

Figure 13. Optimization through Galapagos. It will begin justing all of the variables within each of their domains to try to increase that final output number

At this point, we need to remember that these are counteracting values and they are going in opposite directions. We want to maximize views while minimizing structure. Therefore, we need to invert the structural output so it can compete with the views output. This works by taking structural output number and subtracting it from 1. (ex) 1-0.42 = 0.58) So as our initial structural value gets larger the revised value gets smaller.

Figure 14. Final Building shape

The final step is to give priority to one output or the other. Once the numbers have been scaled, they can then be given priority by multiplying both numbers by the predetermined percentage. Since the premise of our project is to maximize views, a little extra cost in the structure is reasonable. But it also needs to be realistic. 60% priority for the maximization of views and 40% priority for the lower cost of structure are given for them. We can now multiply views output value of 0.72 by 60% which gives us 0.432 and the structural output which is 0.58 by 40% which is 0.232. These numbers are then added to get 0.664. This represents final singular output for which to maximize. Now, Galapagos can optimize the output. So if it begins at the point discussed previously, the single output will be 0.664. It will begin adjusting all of the variables within each of their domains to try to increase that final output number of 0.664.

5. CONCLUSION

In this study, a new method to develop building form using real information at the pre-schematic design phase was proposed. Specifically, view and structure are used as main parameters which are directly related to the financial aspect of the project. The views from the 4 sides of the each floor are calculated and each floor is rotated and extruded to get the best view. Structure is used for the optimization process through Galapagos. Each parameter has its own requirements and therefore results in opposing design strategies which the computer is able to balance appropriately to find an optimal design solution.

According to the values and parameters of the views and structure, this process can produce multiple building forms which are optimized for different parameters. The result in this study strikes an optimum balance between structural feasibility, and the maximum amount of views from each unit, condensing at the very least, days of optimization and at the most hundreds of thousands of years of computations, down to a relatively instant accurate result. Using only building information without architect's preference or style, I was able to create interesting and meaningful building form. Through this process, the concept and design are much more integrated to the existing conditions of the site, the user needs, and architects' intention. It means "freedom from being forced into either the formal indulgence or signature architecture or a hyper-rational mode of performative justification".(Ottchen, 2009)

It is fair to say that if this process was done manually one would be able to rule out most of those solutions and approach the correct answer just using intuition. But that can only get so far. It may approach the most optimum value, but it will never reach it. Galapagos arranges all of the variables randomly as the first generation. Then fitness or strength is measured and genomes are mated with others to form the offspring which are the next generation. Basically it is finding clues to suggest the best possible answer lies within a certain direction, and that direction is explored and tested, and if correct it continues, gaining confidence that it is approaching correct answer. Eventually the results are narrow enough that the program is confident in its answer and it returns a result.

This study shows alternatives through the parametric solutions found in emerging tool and algorithms, providing an opportunity to experiment in new direction. Since only some specific parameters from the site have been utilized and implemented, it is necessary to implement more information from the site to create more accurately calculated building form. However, the optimization of multiple parameters will not automatically produce single ideal form. The architect still must take full responsibility in design and should look at the big picture to decide which factors to parameterize, to give boundaries to the parameters, assign a weight to each factor etc. As architects, we have to maximize our responsiveness to each design challenge, we must work incrementally, adaptively, and openly, without a fixed and dictatorial idea. (Saunders, 2007) Our next endeavor is to study the application of more complex building information into the project on a larger architectural scale. I believe by using computation in a comprehensive manner, we can achieve this goal sooner than later.

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