Design Optimization in a Hotel and Office Tower Through Intuitive Design Procedures and Advanced Computational Design Methodologies

Façade design optimization by computational methods

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Abstract. *The research topic of this paper exemplifies design optimization techniques of a hotel/office tower in Central China (Nanjing city), which faces subtropical humid climate throughout the year. The main intent of the project is to find optimized design solution with the aid of parametric design tools and Visual Basic Scripting techniques (in Rhino Script and Grasshopper) combined with intuitive design process. In any urban context, we firmly believe that architectural design is a responsive phenomenon, which faces diverse interaction with the user and the local climate. The building design of the proposed tower acknowledges these responsive factors of the design with the environment along with building users or residents. Consequently, we strive to develop a sustainable design solution, which is ecologically efficient and psychologically conducive to the wellbeing of the user. We developed our intuitive design product with complex computational design toolsets to leverage design and energy efficiency. In this procedure, we draw major design concepts and geometrical typologies from natural systems in the form of bio mimicry or biologically inspired design process. Overall, this research paper outlines the significance and relevant benefits of the combination of intuitive design (from experience, expertise and architects skills) with parametric scripting tools.*
Keywords. *Sustainable Building Façade; Parametric Architecture; Intelligent building skin; Solar Architecture.*

AIMS

1. To study the site and neighbouring ecological conditions with local data and 3d energy analysis platforms.
2. To form conceptual design strategies with intuition and experience.
3. To develop the conceptual design with design computing methods and scripting techniques, considering the intent to develop a sustainable design solution to enhance building performance.
4. To analyse the computational framework's result with quantitative tools.
5. Combine the results with design intuition to make innovative design strategies.

SITE RESEARCH

Site location

The site is in Central Business District of an upcoming major city in China, called Nanjing. It is considered to be one of the largest economic zones of China. It is 300 kilometers (190 mi) west-northwest of Shanghai and 1,200 kilometers (750 mi) south-southeast of Beijing. Building program usage is mixed type having an office cum hotel tower as one of the primary spatial requirements of the client. The location of the site is of highest importance for both the client and city government due to its landmark nature and strategic position at the corner of two major retail streets having high density traffic flow. As per Government's urban planning report for the city, the proposed tower is expected to have a landmark hotel cum office tower in the site, which not only would be an aesthetic pride to the historic city of Nanjing, but shall also be an exemplary model in performance driven sustainable architectural design for other major projects in the region.

Site ecology and climate

Relevant inferences from all of the ecological studies of the site could be enumerated as below:

1. Summer south east winds should be welcomed inside the building and hence a mixed mode ventilation system would be more apt in these conditions considering the high potential of the tower to harness the incoming comfortable summer breeze.
2. During winter, extremely cold and chilly breezes from north east direction should be essentially neutralized and the building should be adequately insulated or the form should be such that it protects the user from these cold breezes.
3. As Nanjing is considered one of the most hot destinations in China from May till Sep each year, adequate measures needs to be adapted in building design to minimize solar direct radiation and insolation gains on its façade especially towards the south and west direction from 11 30am till 3 30pm in the afternoon.

DESIGN

Concept design

The initial program requirement from the client and the local rules of Nanjing municipality fixed the tower height to be of 100m each floor spanning 4m (comfortable habitable height for an office building). The first four floors were occupied by hotel and office podium with entry lobby, retail shops of big brands to add revenue to the project. Initial concept design included tower form and shape analysis as its one of the rigid design move, which would control the subsequent building performance for energy efficiency and indoor comfort conditions. Keeping in mind the aforementioned interpretations from the ecological analysis of the site and the region, the tower shape formed was a L shape building mass set little towards back of the site (leaving site frontage for retail podium and public plaza). Refer Fig. 2 and 3.

The building form achieved constituted of two longer faces facing towards the south and north side respectably. Intuitively with experience and

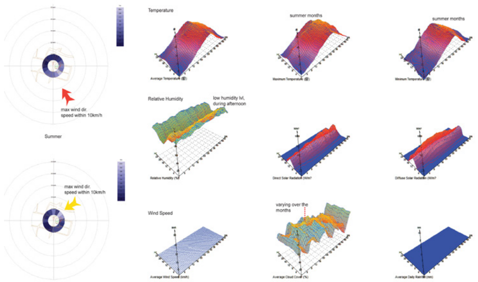


Figure 1
The above diagram explains the results obtained from Ecotect weather analysis of Nanjing showing wind flow direction, pressure, relative humidity annually.

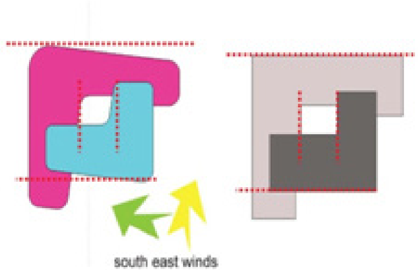
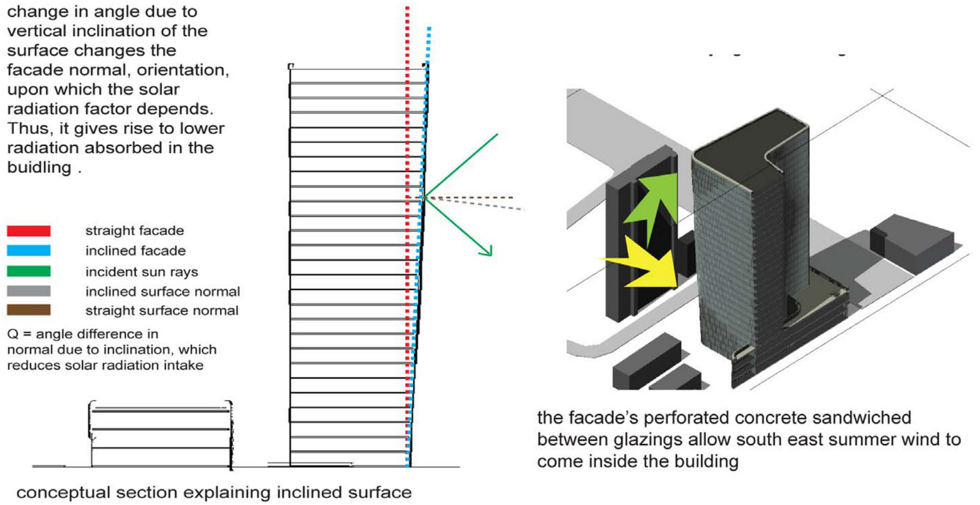


Figure 2
The conceptual design form obtained of the tower and the 3-floor height podium in front of the site. The blue form represents 100m office tower. The edges are rounded to impart smooth flow and continuity to the building facade.

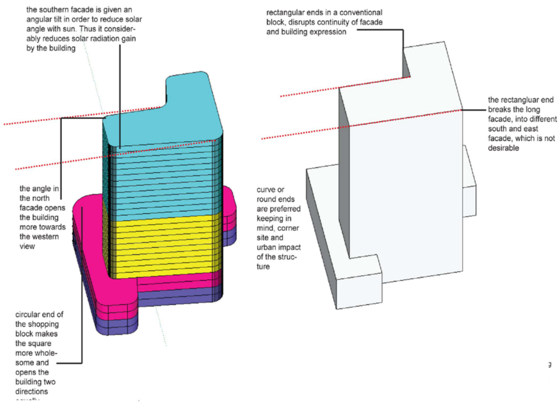
Figure 3
The section explains the inclined façade on the south and west direction which reduces solar insolation level. The computer model on the right shows the south and west façade facing a 70m residential building on the back.



knowledge, west and east facades of the sites are minimized as much as possible to grossly cut down on building incident solar insolation level, which essentially is the major component in adding to the building cooling load during summer months (Schittich, 2004). The tower corner conditions or edges were filleted/ rounded to leverage the possibility of smoother wind flow in and around the building. It also accentuated the desired aesthetics to the tower.

With a little research on scientific principles in building solar incident insolation level, it is established that this value predominantly depends on the building angle from the tested point or façade or object under consideration to the current location of the sun. With research and probe on solar insolation formulae, it was confirmed that more the building is at 90 degree to the sun, more would be the subsequent value of the building solar gains. This is very

Figure 4
The colored building block diagram shows the design changes adapted from conventional building mass. The L shaped form screens the tower from North East winter wind.
Figure 5
It shows the comparative study of an animal skin study and proposed building façade. It reflects how the building façade simulates the behavior with the help of smaller façade panels.



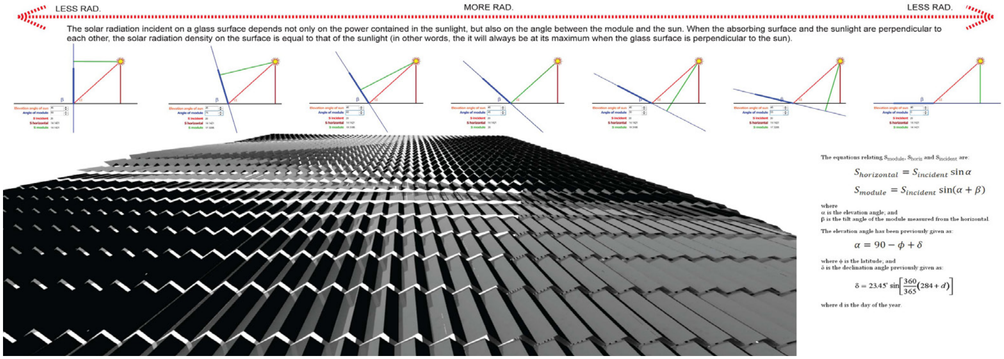


Figure 6
The diagram above shows the variably rotated panels and how their aggregation together generates a fabric of smart components as the façade design.

much explained by the projection effect, which outlines that the insolation into a surface is maximum when it directly faces the solar object or sun. Quoting from Wikipedia, "*As the angle increases between the direction at a right angle to the surface and the direction of the rays of sunlight, the insolation is reduced in proportion to the cosine of the angle*." Thus in response to adverse summer conditions in Nanjing, the façade of the tower facing towards the south and west is tapered outwards towards the top most point, which reduces the angle of the panels of the facade towards the sun. Refer Fig. 3.

To sum up, the building volume has a straight geometrical wall on the north and east façade, while the south and west façade reflects inclined wall which is tapered outside to reduce the solar insolation value incident on the south and west panels. The cause of this effect can be deduced from the idea that the panels are now less directly facing the sun, which is very much conducive to attain more efficient energy consumption. Adding to this, the L shaped tower form where the L projection is towards the North East direction helps protect the tower from extremely cold wind flow from North East direction in to the site. Refer Fig. 4.

Advanced design

The first phase of the project as described above essentially comprised of conceptual design of the form and shape of the proposed building. This process of design was largely based upon design expertise, design intuition, quantitative information of site condition (from Ecotect) and design experience. After setting up the preliminary form into the site, the next phase comprised of design development of the tower in advanced digital modeling, simulation and computational platform to apply advanced sustainable design procedures exemplifying innovative design strategies. The conceptual form model was analyzed in Autodesk Ecotect and tested for preliminary incident solar insolation gains on the site both with the tower and without. One stark observation revealed exceptional potent of the south and west façade to mitigate energy consumption in summer months. The observation was supported by the recording of very high values of solar gains on these facades. Towards the south adjoining the site, is a 70m high residential tower, which provided some relief from its shadow during the late mornings and early afternoons, but this was more towards the ground floor reaching not more 3 floors. The remaining 20 floors of our building were exposed to the extremely hot and glaring sun radiation. So to optimize the glare and solar insolation levels, essential design objective was to add significant protection to the tower against south side solar gains without compromising on building aesthetic levels.

DESIGN DEVELOPMENT

Bio mimicry and design intuition

The design intent to save relevant cooling load on the building by minimizing incident solar gains while preserving porous visual accessibility from the building to the outside, was the next challenge for us. In depth research, study was conducted where animal skins of various species were the focus of study (Benyus, 1997; Wright,Young and Hobbs, 2009). This study was very conducive for the sustainable development of the project as it delineated the following logic and design principle in these natural systems:

1. The skin system of each of these organisms, were composed of much smaller subdivided units or components, which integrated coherently to form a whole system, which we observe as the skin.
2. These components add flexibility and porosity to the skin while maintaining relevant insulation levels from the exterior adverse climate and ecological conditions. Refer Fig. 5.
3. The components enhanced the aesthetics of the species manifolds and thus provide intriguing and ambiguous visual sensation to the beholder. We understood that subdivision of the skin into intelligent components (which aggregates and self organizes), leverages the functional behavior of the animal skin. The skin is remarkable to protect itself against all external conditions. Its efficient performance is crucial for the organism's survival among many others over the years of evolution.
4. These intelligent components depicted individual transformation potential at local level, giving rise to diverse possibilities in flexibility and elasticity at the same time maintaining their design logistics with the whole part and geometry, to preserve integrity and structure.
5. These design patterns of vivid shape, size and color composition, were unique and organic in aesthetic quality.

From the research observation following major conclusions and desired design objectives were set, which further was evaluated with the aid of scientific performance simulation and computational methods to add credibility and feasibility to the design process- The preliminary building block is treated as one long continuous building façade having edge conditions rounded for smoother flow. The façade of our tower is treated as north, west, south and east faces respectively.

1. The model has to be setup with the simulation of real sun as a component in computational framework to govern behavioral response from the skin with the respective gradual change in the sun as an external attractor.
2. Each face of the skin would behave unique performance behavior with respect to the external weather condition and internal space usage and program behavior.
3. The façades in each direction are subdivided into rectangular panels of 4m by 1.5m (4m is floor-to-floor height). This is established to enable optimized construction workability and apparent cost reduction.
4. Each of the subdivided panels holds the potential to be trans-formed, scaled and rotated independently while being connected to the overall façade system, thus enabling parametric design intent. Refer Fig. 6.
5. Considering cost and client limitations, each of the façade panels would be completely static or fixed and would not in any way depict transformational changes by any induced kinetic system. The idea is to test different pattern and behavior of their transformation by programing a simulated environment with embedded logics and behaviors having sun act as an external attractor.
6. The façade panel's centroid is calculated to know its precise coordinates. It essentially acts as the key point for making further calculations especially with the simulated sun component and other relevant assertions to escalate behavior significantly. The behavior of the panel

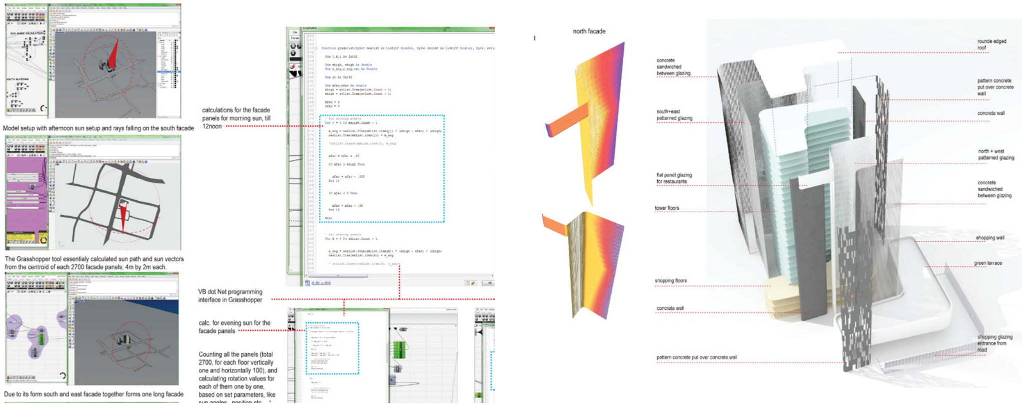


Figure 7
The screenshot above explains the VB Script interface and Grasshopper Sun component depicting the basic script framework. Axonometric Diagram of the tower shows different building material used to minimize use of glass. East and west façade are shielded with concrete wall, which are considered as thick thermal mass.

with respect to the sun is obtained, by calculating the angle, between the lines from the centroid to the sun with the surface normal of the panel itself. This is a crucial quantitative value which further provides inter related ecological performance parameters derived with scientific formulae and logistics.

7. The sun is assumed as a point in the 3D space and its behavior is simulated by coding the mechanism in computational framework.
8. Grasshopper, VB script component in grasshopper and Rhino script is chosen as the computational platform. Rhino 3d nurbs modeling platform provided extensive digital modeling tools and scope for the parametric design of the tower.
9. After the simulation, different results from the script were tested quantitatively with the help of Solar Insolation analysis, indoor CFD modeling to measure efficiency achieved in wind flow and Shadow Analysis indoor and outdoor to test the potential of the skin as a sunscreen.
10. Design Algorithm

The algorithm was very basic yet followed precise functions and procedures to enable accurate results. This essentially formed rightful decision making in design and performance domain. The key steps followed were as below:

1. Each of the subdivided facade panels were connected to the sun point with their respective centroid.
2. The line of connection between the centroid and the sun was compared with the surface normal of the subdivided panel facing outwards. The angle between the connected line and surface normal was recorded in radian for each of the facade panels.
3. This angle changed in value as the sun starts to move in its trajectory over the course of the day from morning until evening for each façade panel respectively. This angle also changed over the course of different season and months in a year, i.e. it also changed annually
4. This angle is the key component to calculate incident solar insolation value. The formula used to calculate the desired result is obtained from research data.
5. The respective values of solar insolation levels of each panels are recorded in an excel sheet (by exporting the data from the VB Script interface to the excel chart).Moreover, it was further coded to display the data in a RGB color diagram from blue (showing lowest values) to yellow (showing highest solar gains areas overlaying on the panel itself.
6. This graphic color distribution diagram on the panels clearly marked the key areas on the facade with uncomfortable solar gains value,

which should be minimized. It also clearly outlined the sun position and time of the day, which are most uncomfortable due to excessive solar gains incident on the façade panel (Hermannsdorfer and Rub, 2006).

Time: From 12noon until 2 30pm or 3 pm, the sun showed extreme solar gains on the façade.

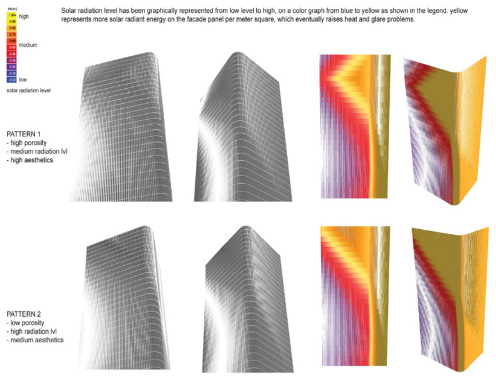
Location: The façade panels in the center between south and west direction facing most directly to the sun highlighted very high solar gains which needed to be neutralized (Koster, 2004).

Thus, the color diagram reflected the objective to maximize blue or green zones on the façade while neutralizing areas of yellow or orange on the graphical overlay of solar gain values. Refer Fig. 7.

7. As established beforehand the panels showing higher solar gain values in a day were directly facing the sun during afternoons. Therefore, the key idea to reduce the solar gains was to identify key panels whose orientation could be changed, enabling them facing away from the sun to reduce the insolation values. However, this also needed to coordinate with the visual connectivity desired from the inside space to outside, so the change in the orientation was an optimization between all of the following interconnected agendas:

- Solar gains.
- Visual connectivity.
- Construction feasibility.
- Wind protection from North East in winter.
- Wind harnessing from South East in summer.
- Aesthetic quality achieved due to change in panel orientation.
- Construction Cost and local building fenestration rules.
- Construction techniques known to local construction engineers.

8. Custom written script in Visual Basic component in grasshopper created angular values with respect to each of the key identified panels. The values were restricted in number keeping in consideration above core issues of construction and project viability. For Example the panels at the corner, where the façade is changing in topology is restricted to rotate within 15 degree, to protect excessive overhang and vision impairment from the inside of the tower to outside. These design intuitions clubbed with computational scripting potential gave rise to a generative architectural design syntax which is performance based and achieved unique aesthetic quality, local to the specific site and ecological conditions.
9. While calculating the rotational values, the time duration from morning 6am until evening 7pm was divided into three distinct zones (Morning – 6 am to 11:30 am, Afternoon - 11:30 am to 4 pm and Evening - 4 pm to 7pm). After the Boolean confirmation which time zone of the day, the sun is currently at, the for loop in VB script runs through each of the façade panel and creates rotational values based on custom written function to calculate desired solar insolation levels restricted within feasible panel orientation level. Thus, the script gives credibility to the time zone of the sun and takes active decision to set the panel at the desired orientation. It is of utmost importance to note that these dynamic rotational arrangements of each panel are not changing on site, but rather a continuous simulation system. Out of the simulation, each frame or moment could be a viable design solution and can be installed as the building skin. Therefore, all these different frames or static points in the simulation are analyzed and compared before choosing the final option. The most optimized output with reference to afore-mentioned priorities is picked as the most viable building skin for the tower. Since the entire setup of the computational model and VB Script is written in parametric form, thus the end output obtained can be grossly changed by change in parameters and variables. Thus vivid combinations of variables and constants gave rise to vivid possibilities and output façade topography. Each of the options so achieved are having same log-



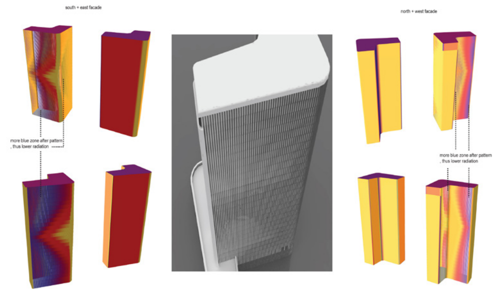


Figure 8
Solar Insolation Analysis done in Ecotect. Also shows different design option obtained and their comparative study The results were compared showing blue color as the low insolation level, while yellow reflects very high insolation.
Figure 9
Solar Insolation analysis results of another design scheme on all facades.

ics but varied panel rotational orientation and minimized solar gains level from conventional benchmark model.

10. Glass is considered highly non-sustainable building material used in landmark high-rise high performance buildings, especially if used without adequate protection and screening systems from the sun. However, at the same time, in a rapidly developing economy of china conventional design procedures believes that modern landmark office or hotel building must be designed with high content of glass and steel. General impress ion of a glass cladded building is accepted to be modern and iconic. Thus the intent and objective was to minimize and re-strict usage of glass in the building if not it can be negated completely (Knaack et al, 2007). The following were practiced to obtain the result:

- West and East façade were completely blocked from solar gain by providing fly ash enriched concrete. This acted as a strong thermal mass for thermal insulation. For the winter, the strong thermal mass enabled heat storage during day hours which could be used at nighttime.
- The pockets of space so created on the façade due to panel rotation is blocked with perforated masonry wall, which selectively allows wind flow but insulates solar gain and heat radiation significantly. Thus, it caused substantial reduction of the percentage use of glass in the building.
- Considering the north to be free of significant solar gains and having possible dissipation of diffused day lighting(which is very much welcomed in an office work environment), the subdivided panels on this zone are kept free of rotation and thus remains unchanged. The glass used in the North façade is clear and transparent to accentuate desirable visual and ventilation possibilities from both inside out and outside in.

DESIGN OPTIMIZATION

As established and mentioned beforehand from Ecotect climate analysis of Nanjing, cold wind from North East direction in the winter should be blocked to insulate the building from extreme winter breeze. The subdivided panels in the northeast direction are variably rotated away from the northeast winter breeze. Consequently it enabled placement of masonry wall (with operable perforations) sandwiched between panel-to-panel open space (Zaretsky, 2009). This cuts down incoming winter cold breeze significantly and enhances building indoor air quality and flow rate specific to season. For the summer the same has been practiced towards the southeast direction, but this time the panels are positioned facing southeast (instead of facing away). Thus, the above arrangement of selective façade panel treatment made indoor spatial conditions comfortable in all seasons annually.

However that being said, the above selective façade re-arrangement was achieved parametrically by selective façade panel recognition in a customized and manually calibrated VB script. The script placed two attractor points respectively in southeast and northeast zone of the façade on each floor. Each of those attractor points have a threshold distance which was parametrically calibrated for each simulation run , to observe effect on the whole façade. Those façade panels on the same floor, whose distance was lesser than the threshold distance, were transformed to a desired rotational value to achieve the aforementioned façade panel positioning.

CONCLUSION/ DISCUSSION

The research paper clearly outlines the objectives of a practical office cum hotel tower project. In that process, new technologies in the form of parametric design tools and programming capability in VB script proved to be instrumental in asserting hypothesis and testing their credibility and feasibility in real life construction scenario. The following important conclusions were drawn:

1. Intuitive design skills and expertise is still of exceptional potency and value to frame the solution in the form of early design conceptualization. The intuitive solutions could be very well tested with parametric and building information modeling tools for their scientific and mathematical viability.
2. After fixing the building form or shape, building façade/ skin should be analyzed to reduce building energy usage and enhance indoor and outdoor user comfort level.
3. At these stage new tools like grasshopper parametric components, rhino script and VB Scripting component in grasshopper is instrumental in testing façade design performance and construction feasibility, with the aid of simulation techniques.
4. Solar insolation values on the façade should be calculated to understand what geometrical form changes and modifications could be adapted to escalate significant reduction in solar gains specifically on the south and west façade.

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