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Evaluating Energy Performance of Double Skin Facade Building

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Abstract: *BIM means Building Information Modelling Management that people are able to design, create and maintain the building throughout the whole lifecycle. BIM technology provides a new design method that overall energy performance could be simulated and evaluated and it helps to achieve the sustainability goals. Transparent facade system on modern buildings usually causes high heating or cooling consumption. The double skin facade could be used as possible solution for these problems. A student work would be simulated in BIM and its double skin facade system would be evaluated to reduce energy consumption.*

Keywords: *BIM; Double Skin Facade; Energy Performance Simulation; Parametric Study*

1. Introduction

BIM is an abbreviation that has different meanings including: Building Information Modelling/ Model Management. The CIC (Construction Industry Council) explains BIM as an innovative and collaborative way of working that people are able to design, create and maintain the built environment efficiently by using these technologies. Nowadays, BIM has been implemented in various fields from project planning, structural design, facility management, and sustainable buildings [1].

Sustainability could be activated and implemented throughout a project lifecycle using BIM technology [2]. BIM technology provides a new design method that energy efficiency performance could be analyzed and evaluated and it helps to achieve the sustainability goals.

Modern architectures are usually dominated by transparent facade system. These large glazed facades always lead to high building heating and cooling loads, as well as energy consumption and environment impacts [3]. The double skin facade is one possible solution for these problems.

This essay is based on my undergraduate studio project, which is a university conference center in Beijing, China (Figure 1). The building has two parts: the lower block is for food and beverages, and conference, the tower is for hotel and apartment. Considering the hot weather in Beijing, I would like to use double skin facade to reduce the building's energy consumption.

The paper focuses on this project to explore the implementation of BIM in a collaborative platform to reduce the solar radiation. It is difficult to simulate or analyze all the steps based on single software. Thus, I would like to work on a compatible platform- Rhino, Grasshopper, and Ladybug. They could be integrated into the entire simulation process and be a great supplement for Revit (Figure 2).

Note: Author's own drawing

Figure 1: The university conference center

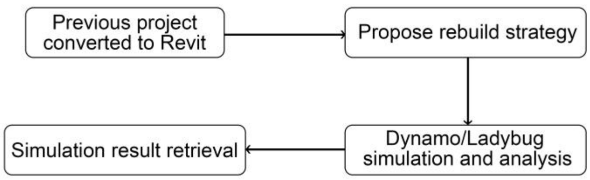

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Figure 2: The design process

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2. Literature review&case study

2.1 Literature Review

The construction process contributes the most to environmental impacts over the world [4]. Thus, the Architecture, Engineering and Construction (AEC) industry is increasingly adopting new technologies and methodologies to promote the development of sustainable constructions.

Sustainable architecture could be seen as an approach to building that reduces harmful effects on human health and the environment. Negative environmental impact of buildings should be minimized by enhancing efficiency and moderation in the use of materials, energy, and development space [5].

Integrated with BIM technology, green building becomes a hot spot gradually. Santos (2020) suggested that the environmental and economic assessment of buildings could be evaluated by the life cycle assessment (LCA) and life cycle costing (LCC) methodologies. These methods could be used to support the decision-making process at the early stage of a project. Solutions for as-built data acquisition such as laser scanning and infrared thermography, and on-site energy tests that benefit the acquisition of energy-related data are explored [1]. The weather effects are needed to be paid attention and a climate-based design method for high performance building facades is provided based on BIM software [6].

Highrises are usually dominated by glass facade systems in order to achieve high transparency. However, these large glazed facades always lead to high heating and cooling loads because of the huge solar radiation [7]. It not only results extra energy consumption and environment impacts, but also causes high construction budgets. One of possible solutions for this circumstance is using double skin facade.

Double skin facades are comprised of two layers (Figure 3), the inner layer providing the thermal skin of the building and the outer panels controlling the sunlight. The ventilated cavity between the two layers functions as a thermal buffer, which reduces undesired heat gain during the cooling season, heat loss during the heating season [8].

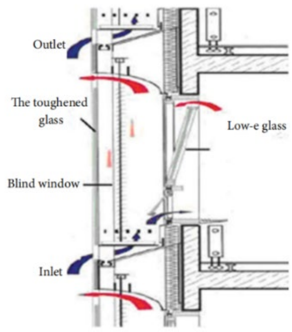

Figure 3: The structure of double skin façade [7]

2.2 Case Study

My design proposal is to rebuild the building with double skin facade as the solar shading system. Therefore, I found two precedent studies which both have double skin facade structures. They have close link with the proposal and their geometry pattern panels inspired me a lot.

Case study 1: New Campus Library of BUCEA

The project is located at the heart area of the New Campus Library of Beijing University of Civil Engineering and Architecture, Beijing, China. The bottom part of the building is punched, so that the square volume of the building turns to curved and looks like floating above the water (Figure 4).

The upper elevation of the building uses double skin. Outside part of the glass curtain wall is wrapped by GRC grid in diamond cross pattern. These diamond-grid panels change to different patterns and density according to the different orientation of sunshine.

When the sunlight becomes the strongest level, the grid layer has become an effective barrier to direct sunlight. The interior light which is filtrated by the panels becomes mottled shadows.

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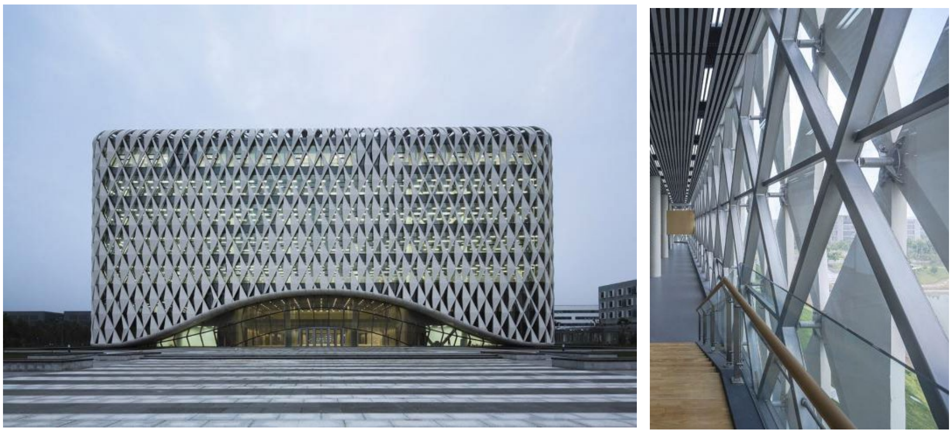
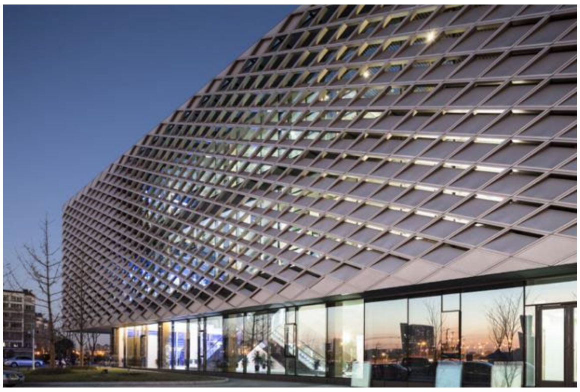


Note: from https://www.gooood.cn/new-campus-library-of-bucea-by-tjad.htm

Figure 4: The university conference center's facade and interior

Case study 2: Nantong Urban Planning Museum



Note: from https://www.gooood.cn/nantong-urban-planning-museum-by-henn.htm?lang=cn

Figure 5: The museum's facade

The urban planning museum is located in Jiangsu, China. The museum, to extent, is similar with case study 1--they both have a square volume and the ground floor set back making the upper floors appear to float (Figure 5).

The facade of the upper floors is composed of two layers: the inner facade forming the thermal skin of the building and the outer skin controlling exposure to direct sunlight. The diamond-shaped grid is comprised of seven different panels that allow for varying degrees of opening from 9%-60%. The interior light could be controlled according to the needs of different functions.

More public program and offices are located on ground floor. They get the maximum levels of natural daylight. Exhibition areas are on the upper floors and they have a predominantly closed facade with minimal openings.

3. Proposed strategies and implemention of bim

3.1 Project Proposal

The conference center I created is a tower with several podiums providing different types of functions (Figure 6). The tower has a height of 108m and has total 24 floors. The whole building is a frame-shear wall structure with a total area of about 9600 square meters. The conference rooms, activity center, and banquet hall are located from 1st to 4th floor. The hotel and apartment area are located from the 5th to 24th floor.

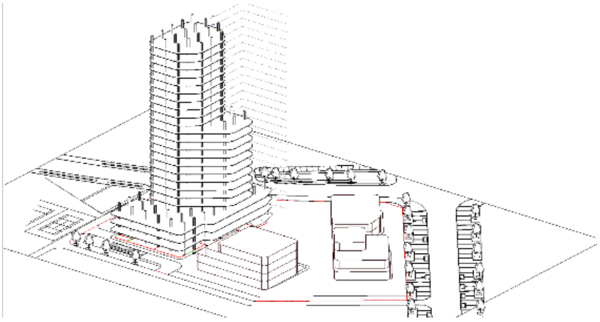


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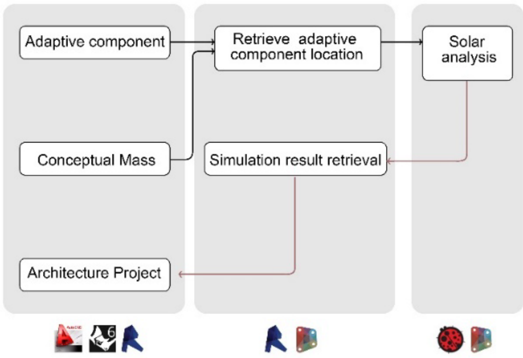
Figure 6: Revit project

Inspired by case studies, the basic proposal is to create an adaptive component covering the building envelope. It could act as the double skin facade to provide different sun shades for those hotels and apartment area according to the different solar radiation. A basic Revit architectural project with surrounding buildings as masses is constructed for analyzing and rebuilding.

The first step of design process will import CAD files and convert the original Rhino model to Revit project. Then a conceptual mass will be created and an adaptive component will be used as the pattern. Dynamo or grasshopper will be used for solar analysis in the next step. Finally, after the simulation result is retrieved, the conceptual mass will be loaded into the project. The building energy cost will be analyzed and evaluated (Figure 7).

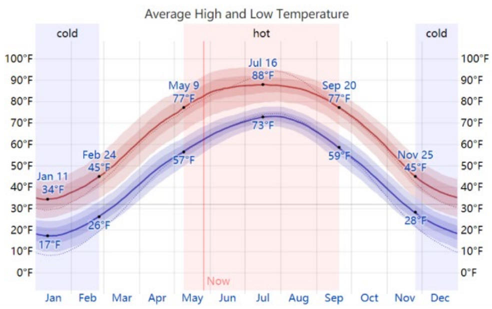


Note: Author's own drawing

Figure 7: Design workflow

3.2 Weather Condition in Beijing

It is important to analyze the weather condition before the solar analysis. Searching from website, I found that in Beijing, the hot season lasts for 4.4 months, from May 9 to September 20, with an average daily high temperature above 77°F (Figure 8). The hottest day of the year is July 16, with an average high of 88°F. The length of the day in Beijing varies significantly over the year, the longest day is June 21, with 15 hours of daylight (Figure 9). Thus, these data suggest the largest energy consumption day and I would like to choose June 21 as the day for solar analysis.



Note: from https://weatherspark.com/ y/131055/Average-Weather-in-Beijing China- Year-Round

Figure 8: Average high and low temperature

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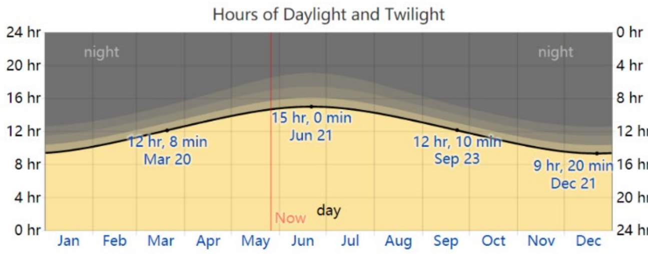

Note: from https://weatherspark.com/y/131055/Average Weather-in-Beijing-China-Year-Round

Figure 9: Hours of daylight and twilight

By using ladybug and Beijing epw file, the windrose (Figure 10) and sunpath (Figure 11) could be analyzed. The wind rose diagram reflects the directions of prevailing wind throughout the year. The sun path diagram directly shows the environment and the sun direction with my building.

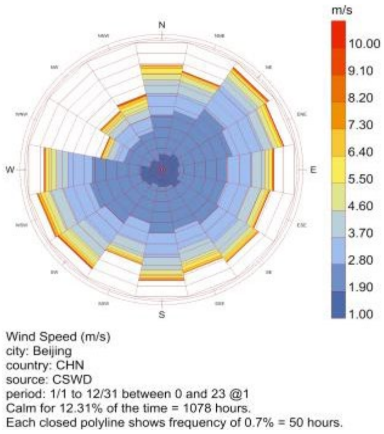

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Figure 10: Windrose of Beijing

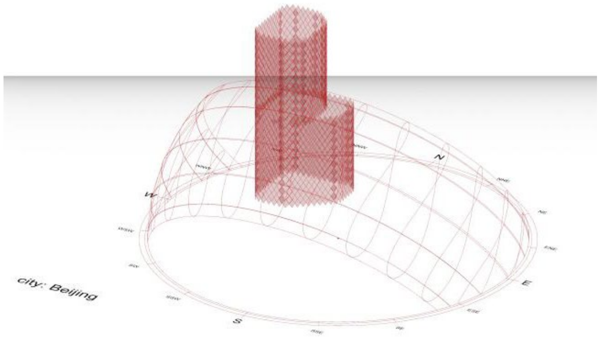

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Figure 11: Sunpath of Beijing

3.3 Creating the conceptual and adaptive component

Firstly, I converted Rhino models to Revit project as the surrounding building masses. A conceptual mass is created based on the dimension of the Revit architectural project. Then a pattern based component is created as the curtain panel. It is based on the rhomboid-grid and has three dimensions. The Height is depended on the storey height- 4.5m. The width is depended on the facade divided grid. (Figure 12).

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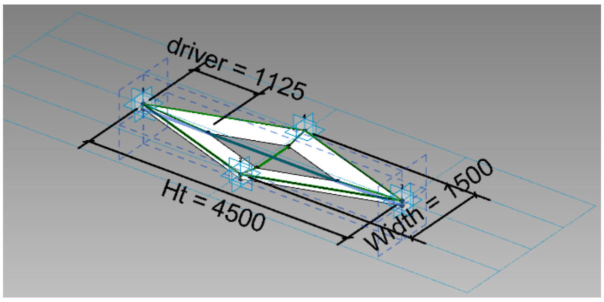
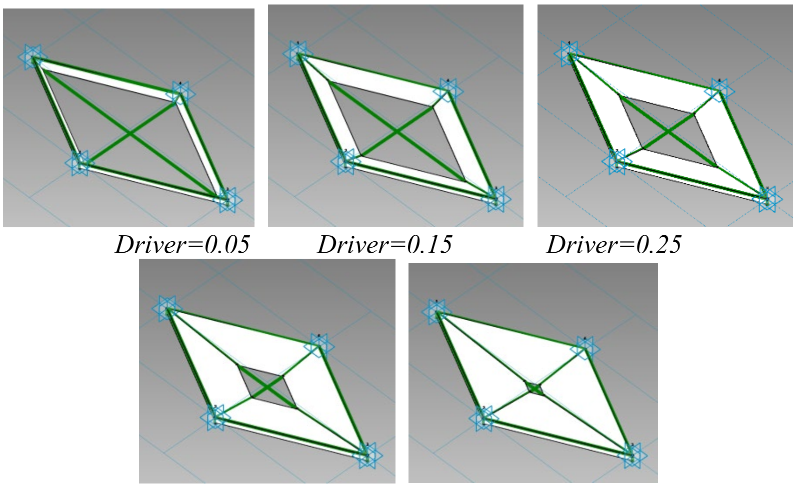


Note: Author's own drawing

Figure 12: The adaptive component and dimensions

The parameter-'Driver' is the normalized value of the reference point which means the distance between the point and the rhomboid's corresponding corner point (Figure 13). It reflects the panel's open degree and it varies from 0.05 to 0.45.0.05 means almost opened and 0.45 means closed. The 'Driver' could be changed easily and quickly by Dynamo and show the different opening degrees directly.



Driver=0.05 Driver=0.15 Driver=0.25

Driver=0.35 Driver=0.45

Note: Author's own drawing

Figure 13: Different values of Driver

3.4 Ladybug radiation analysis

Ladybug is a powerful plugin in grasshopper which specializes in handling large scale environment and conducting complex daylight simulation. This plugin could combine the workflow with this highly capable performance assessment software (for daylight, energy, airflow and thermal comfort) seamlessly. Therefore, I would try to use ladybug for the solar analysis firstly.

After loading the adaptive component into the conceptual mass, there are six steps in the analysis process:

1) Selecting all the adaptive components into Dynamo.

2) Getting components' location points, creating polygons and surfaces with center points.

3) Getting normal vectors of corresponding polygon center points, outputting surface centers and normals and writing to CSV files.

4) In ladybug, recreating points and meshes after loading the data.

5) Creating the sky matrix with Beijing epw file and conducting the solar analysis. Writing results to CSV files.

6) Loading the result into Dynamo and remapping the values into a range and setting the elements parameters by using these values.

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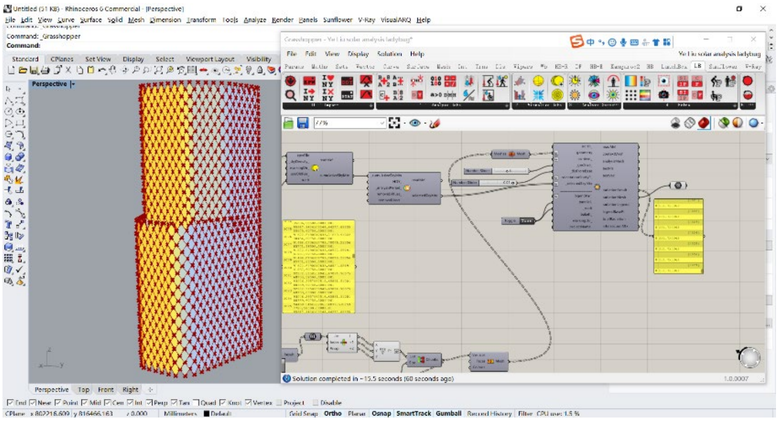

Note: Author's own drawing

Figure 14: Solar analysis based on Ladybug

In ladybug, the result of radiation result is shown precisely and directly (Figure 14). The yellow means the longer daylight hours while the blue means the shorter. However, there is something wrong when I import the data into Dynamo. Through there is no error message from nodes, the adaptive components couldn't be changed. I wonder that whether the value '0' from the data is invalid in Dynamo. Finally, I decide to change the workflow and use the Dynamo.

3.5 Dynamo radiation analysis

Due to the problems in ladybug, I turn to use Dynamo. There are five steps in the process which is similar with the ladybug working process:

1) Selecting all the adaptive components into Dynamo.

2) Getting components' location points, creating polygons and surfaces with center points.

3) Getting normal vectors of corresponding polygon center points.

4) After setting the corresponding location and time of daylight June 21, the daylight normal vectors could be got. The angles between panels and daylight could be calculated.

5) Remapping the values into a range and setting the elements parameters by using these values (Figure 15).

The angles between panels and daylight should be remapped and limited to 0.05-0.45. The bigger radiation data is, the bigger remapped value will be and the smaller open the panels will be.

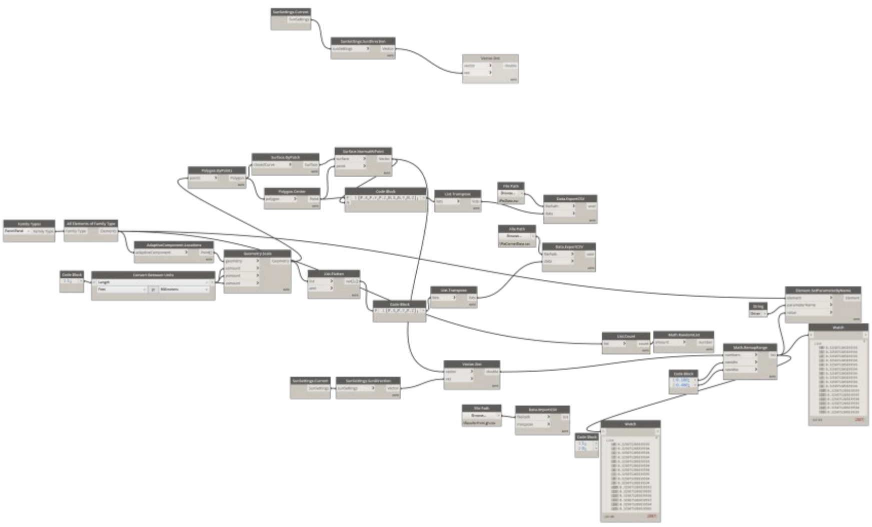

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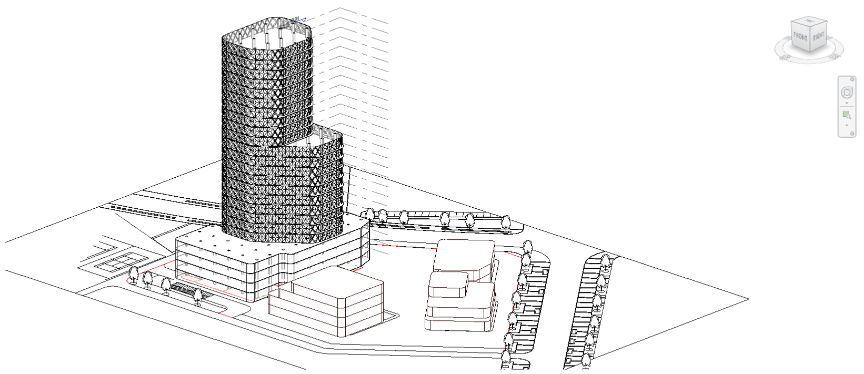
Figure 15: Dynamo nodes



Note: Author's own drawing

Figure 16: The final revit project

After setting the adaptive components parameters by using remapped values, the conceptual mass is loaded into the architecture project (Figure 16).

4. Reflection and future development

4.1 Reflection

With the help of weekly lectures and workshops, the basic knowledge, technical implementation, strategies of using BIM and practical applications are delivered to me. BIM is not just a software 'Revit' or perfect as a panacea. BIM helps people collect and manage all related project information efficiently from concept stage, developed stage, technical design and construction. Workshops show us students how to build models and evaluate our workflows in practice. Parametric modelling approaches are introduced by customizing building components parameters. It is totally different from Sketch Up or Rhino.

When I worked on this research, it really improved my competence of problem solving and independent learning. Even though I followed the tutorial step by step, I still encountered lots of different problems. The data from ladybug didn't work in Dynamo. The nodes seemed working if randomized values are applied. Thus, the result data from ladybug must be problematic. I couldn't figure it out and gave up. In another Dynamo workflow, there was an error message 'Unit type is an in valid unit type'. People on the Dynamo forum met the same problem with me.

4.2 Future development

In this essay, the building's daylight performance is evaluated. It reflected the possibility of engaging the idea of sustainability with BIM. Sustainable components could be analyzed and evaluated efficiently with BIM technology. Double skin facade system seems a feasible strategy to reduce the unwanted daylight from different location and orientation.

Due to the time limit and my capability, there are several problems. In this conference center, the hotel and apartment area are located from the 5th to 24th floor. Almost all the rooms are closed suites except for some activity space and roof garden. These suites' walls are attached to the outer curtain panels. These walls may also have an influence on the radiation so the solar analysis result is too idealized. There are some weird site design and architecture elements in my original undergraduate project. I optimized its forms in this project. Therefore, it is in lack of site design and external environment. The missing of some surroundings may lead the result to be inaccurate.

Other analysis should be taken, such as illumination analysis and CFD analysis. I choose the summer solstice as the simulation date because it has the longest daylight hour. However, when there is no sufficient daylight in winter, these solar shading panels may have an impact on interior light. Therefore, illumination analysis is necessary to test whether interior rooms have sufficient daylight. Highrise buildings usually have complex facade appurtenances such as balconies, or shading elements. These elements interact with the external climate in a complex manner and have huge impacts on heat transferring and ventilation [9]. With the help of CFD techniques, structures and shading devices could be evaluated by the wind direction and wind speed.

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