F A C A – D E – L I T

Facade optimisation for visual comfort by controlled daylight distribution in high rise office buildings

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REFLECTION

Position of graduation topic in Building Technology Track

The research of this graduation topic started by looking at the current situations in the indoor environment of office workplaces, where visual comfort is one of the major issues being faced by occupants due to the non-uniform distribution of daylight, as daylight is very dynamic. So, a question on how we can use daylight, as a natural source, to increase the performance of an indoor space to achieve visual comfort for the occupants was one of the main driving elements for this research.
As building envelope is a layer between outdoor and indoor of a building, it acts as the most influenced element responsible for indoor climate comfort, including daylight. High rise office buildings are more dominant as the façade surface is huge and has more occupancy. With this, there have been many challenges in design regarding building's performances that were difficult to solve until the scope of computational design took its position in design practice. Through optimisation and performance simulations, the computational design offers many possibilities to solve highly complex challenges into the most optimal design solution that performs best for building and environment. With the use of computational design methods, this complex challenge can be made possible to investigate it for a best possible outcome as a new design solution of façade with high efficiency in performance concerning daylight.

The relation between Research and Design

The initial literature research helped to formulate the research questions and objectives. The further research helped to understand sub parts related to this topic including understanding the fundamentals of light and its dynamic behaviour; investigate various façade strategies that are related with redirecting of daylight and reducing glare responsive façade that adapts to dynamic daylighting; consideration of guidelines for daylighting design; and use of computational design methods as parametric modelling, daylight simulation and optimisation. Furthermore, the investigate case studies helped to come up with a new design idea for façade that can cope up with the requirement of this project. Few research case studies helped to decide the most influential parameters that can impact on façade design's performance. These parameters were taken as a design variable for the optimisation process through parametric modelling.
The central part of this thesis was to find an optimal solution for a façade that can perform with high efficiency in distributing daylight homogeneously throughout the depth of indoor space and should be made responsive that adapt to the dynamic behaviour of daylight throughout the year.
The use of computational methods with gained knowledge on daylight from literature research helped to achieve the result where the façade validated with the considered evaluation criteria for visual comfort. Moreover, it showed a promising result in uniform distribution of daylight along with the depth.

Process

The approach of this research was followed through a research methodology that was divided into several steps; literature, computation design, evaluation and feasibility analysis.
From the literature research, the general aspects needed for a visually comfortable space were analysed to know the factors that affect comfort. These factors were taken further to formulate evaluation criteria. The values required for criteria were studied from available design standards and design guidelines. Furthermore, the factors responsible for the dynamic nature of daylight were studied. Here, the difficulty was to choose minimum instances to gain maximum output out of facade was a task. Hence, the condition with an extreme low-high difference was taken. In total, the combination of 12-instances was selected (which includes two extreme seasons, three times of the day and two extreme sky condition) which were taken further for the analysis. The aim was to gain visual comfort criteria for all selected several cases to prove the effectiveness of the proposed façade.
Based on literature and case studies, a geometry was developed and was further taken in Grasshopper to develop design variables. The variables were developed with reference to selected case studies that are believed to be most influential in daylight performance of a facade. Hereby, the complexity of the process was reduced. The setup for the parametric modelling was made using Grasshopper and Rhino. The geometry of the room was taken to Grasshopper as fixed input to make an easy comparison of each instance. For daylight simulations, a plugin Honeybee and Ladybug (both version Legacy and Plus) were used. The daylight simulations were made to obtain illuminance distribution inside the room, DGP, and contrast to fulfil visual comfort criteria. Further, the optimisation process was carried out using a plugin called Wallacei, an evolutionary multi-objective optimisation engine for Grasshopper was used which works on NSGA II algorithm. The use of NSGA II algorithm was made due to its speed and accuracy in obtaining a solution. The optimisation for an optimal façade solution was made with an objective function to increase the daylit area by minimising over-lit and under-lit areas. The optimisation process was made for all 12-instances to get an individual solution for each scenario.
All optimised solution showed fulfilling the visual comfort criteria during the evaluation process, although few solutions went through manual adjustments. Concluding the performance, the façade was taken further, and its constructible aspects were developed. Moreover, the feasibility aspects were analysed regarding fire safety, maintenance, automation and cost.

Societal impact

The extent of applications of the results in practice

The design of the façade was made, considering its constructability and feasibility in practice with ease. Looking at existing dynamic facades that are already built, the majority of them is kept unused. The proposed façade scheme of this project is kept as easy as possible to keep it in serviceable condition along the year. The elements of façade are provided with two motion, rotation motion and folding/unfolding like an origami shape; and the adaptation of movement is based on exterior daylight conditions. These adaptation works of the facade to maintain the visual comfort criteria indoors within required values along the year. The visually comfortable space provides good health to the occupants, increase their productivity and functionality towards their work. Furthermore, the feasibility aspects based shows that the application of proposed façade can be made on both new construction and refurbishment project as well.

The extent of projected innovation achievement

This project deals with an innovative, dynamic façade scheme that adapts to exterior dynamic daylight conditions to fulfil indoor daylight requirement for visual comfort with a focus on uniform distribution along the depth. The façade is analysed for diverse factors based on daylight conditions that include two diverse seasonal days (summer solstice, winter solstice) based on highest and lowest sun's altitude; three different time of day (10h, 13h, 16h) based of three azimuths (orientation) of the sun as SE, S, SW; and two sky conditions (clear sky and overcast) based on direct sunlight and diffuse light. The performance of façade has shown the distribution of daylight in the required range of illuminance (300-2000 lux) for about 88% of the depth area as an average from all analysed instances and showed an average of 0.57 uniformity ratio. Furthermore, the façade also validates with glare and contrast criteria. Overall, the façade showed promising results, but it failed to block direct sunlight from a very low altitude of the sun, which were observed on sidewalls for cases in winter-clear sky condition.

Contribution of this project towards sustainable development (people, planet, profit)

A dynamic façade scheme as the final product of proposed research showed the potential in controlling daylight's distribution for indoor spaces throughout the depth. This can have many likely impacts on the building and users. Accomplishing visual comfort in indoor spaces will impact mainly on the user's functional efficiency, productivity, and healthy life.
Furthermore, the availability of an adequate amount of daylighting in indoor spaces will have an impact on the overall energy consumption level of the building. In these recent years, many discussions are taking place mainly on the increasing energy consumption in office buildings. Poor distribution of daylighting categorises energy consumption by:

- Over-lit room areas, due to excessive brightness and glare it results in heat gain and demands high cooling loads. Moreover, High-rise buildings tend to be more energy-intensive due to direct solar gain from radiation (Godoy-Shimizu, 2018).
- Under-lit room areas, due to low illumination it leads to the demand for using artificial lighting. The observation says that office building consumes a high level of energy due to the use of artificial lights.

Heat gain and use of artificial light due to lack of daylight, increases the energy consumption of the high-rise which accounts for 40% of energy consumption in the building sector of Europe, 26% for office building (Eurostat 2014), which further demands 44% of the energy only for lighting (Todd 2011).

The final result showed that using the proposed scheme; artificial light can be reduced to 88% of the time, which reduces concerning energy consumption related to lighting. Moreover, this can result in a high amount of energy saving on the scale of a high rise building. The reduction in energy demand will also reduce the overall carbon footprint of the building.

Contribution of this project towards architecture / the built environment

Nowadays, with the global challenges like climate change, population growth and pollution; it has become necessary for every architect to follow a performance-driven design solution that can bring better indoor comfort and reduces the energy demand. The daylight regulations are becoming of more and more importance and compulsory to be considered for all new construction. Architects and engineers will be forced to work considering the daylight regulations to compile in their new designs. This project will showcase them a developed digital workflow based on parametric modelling, daylight simulation and optimisation; which will be useful to evaluate and improve visual comfort efficiency for many alterations of design on façade, which will provide a near-optimal solution for daylight performance.

Further Research possibilities (Individual or several together)

1. Rooms at **different levels** of a high rise. As the amount of daylight illuminance could be different for different level.
2. Rooms facing in **different orientation**. Comparative analysis between S/W/E/N and/or SE, SW, NE, NW.
3. **Different Location/ Different climate.** Comparative assessment for high rise buildings in different locations and/or different climate zones.
4. With **surrounding context.** Comparative assessment between high, mid and low dense context around a high rise.
5. **Different Program/function** space with varied illuminance requirement.
6. **Different typology.** Other than high rises like residential, commercial etc.
7. **Thermal Insulation** for indoor comfort. With the optimised façade solution.
8. **Material Variations** for the façade elements.
9. **Optimising Interior Ceiling.** Shape/slope/material to enhance more light.
10. **Module/Panel size variation.Different design/geometry/Patterns**. Coping with the same concept, method and workflow.
11. **For curved faced facades**.
12. **For outdoor glare check caused by Façade and needed improvement**.
13. **Make a Tool.** Make the computational workflow smarter,

- Code it in python for generative solutions.
- Reduce runtime for optimisation.
- Machine learning. Can adapt to various parameters like regulations, climate etc.