IMPACT OF KINETIC FAÇADE DESIGN TO ENHANCE DAYLIGHT PERFORMANCE FOR OFFICE BUILDING IN CYBERJAYA MALAYSIA

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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Some critical directions of building facade are highly exposed to the sun and it requires a smarter shading device than conventional shading devices that fail to adapt with nature of sun motion may occur during day, month and seasons.

In this study, parametric scripts were written to propose six Kinetic facades design to enhance daylight performance followed by theoretical comparison. The case study was selected to be on Stare Central office building in Cyberjaya, Malaysia to be as virtual model which was built in Rhino for the daylight simulation and to conduct physical daylight measurement by Lux meter device to validate the simulation through a comparison between the physical daylighting measurement with the virtual simulation.

Parametric Daylight simulation was performed on Rotating Facade design through Rhino software using plugins Grasshopper and Diva with a Radiance interface based on LEED V4.1 criteria. The daylight simulation was divided into four phases, starting with annual simulation for benchmark (the actual existing facade) and different glaze materials followed by simulations for facade parameters (size & rotation angle) ending with the hourly daylight simulation. The annual simulation was conducted using Daylight Dynamic Performance Metrics specifically; Spatial-Daylight-Autonomy (sDA300/50%) and Annual-Sunlight-Exposure (ASE1000/250hr). While the Hourly simulation depend on modified metric which is Hourly Spatial daylight Autonomy HsDA and Hourly sun exposure HSE from 8AM to 6PM in four days that represent the equinox and solstice days.

From the results obtained, benchmark cases illustrate the need of high-performance facade to decrease the recorded dangerous values caused by direct sun radiation. none of the glaze materials achieved credit of LEED standards except Generic Translucent panel 20% with 1 credit. The rotation angle 20˚ and 30˚ of rotating façade have achieved three credits of LEED in east and west respectively as a static system. Finally, the study proposed two optimized dynamic systems able to adapt hourly according to the sun position and achieve higher performance than optimum static configure based on comparison.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

MENEROKA REKA BENTUK KINETIK FAÇADE UNTUK MENINGKATKAN PRESTASI SIANG BAGI BANGUNAN PEJABAT DI CYBERJAYA MALAYSIA

Oleh

OMRAN MOESAS SUBHI

Jun 2021

Pengerusi : Nor Azlina binti Alias, PhD
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Beberapa arah kritikal muka bangunan sangat terdedah kepada matahari dan ia memerlukan peranti teduhan yang lebih pintar daripada peranti teduhan konvensional yang gagal menyesuaikan diri dengan sifat pergerakan matahari mungkin berlaku pada siang hari, bulan dan musim.

Dalam kajian ini, skrip parametrik ditulis untuk mengusulkan 6 jenis reka bentuk muka bagunan untuk meningkatkan prestasi cahaya siang diikuti dengan perbandingan teori. Kajian kes telah dipilih untuk berada di bangunan pejabat Stare Central di Cyberjaya, Malaysia sebagai model maya yang dibina di Rhino untuk simulasi siang hari dan untuk menjalankan pengukuran siang hari fizikal oleh peranti Lux meter untuk mengesahkan simulasi melalui perbandingan antara fizikal. pengukuran siang hari dengan simulasi maya.

Simulasi Parametrik Daylight dilakukan pada reka bentuk muka bangunan yang berputar melalui perisian Rhino menggunakan plugin Grasshopper dan Diva dengan antara muka Radiance berdasarkan kriteria LEED V4.1. Simulasi siang hari dibahagikan kepada empat fasa, bermula dengan simulasi tahunan untuk penanda aras (fasad sedia ada sebenar) dan bahan sayu yang berbeza diikuti dengan simulasi untuk parameter muka bagunan (saiz & sudut putaran) berakhir dengan simulasi siang setiap jam. Simulasi tahunan telah dijalankan menggunakan Metrik Prestasi Dinamik Siang secara khusus; Spatial-Daylight-Autonomi (sDA300/50%) dan Annual-Sunlight-Exposure (ASE1000/250hr). Manakala simulasi Setiap Jam bergantung pada metrik yang diubah suai iaitu Autonomi siang Hari Spatial HsDA dan HSE pendedahan matahari Setiap Jam dari 8 pagi hingga 6 petang dalam empat hari yang mewakili hari ekuinoks dan solstis.

Daripada keputusan yang diperoleh, kes penanda aras menggambarkan keperluan fasad berprestasi tinggi untuk mengurangkan nilai berbahaya yang direkodkan yang disebabkan oleh sinaran matahari langsung. tiada bahan sayu mencapai kredit piawaian LEED kecuali panel Lutsinar Generik 20% dengan 1 kredit. Sudut putaran 20 ˚ dan 30˚ bahagian hadapan berputar telah mencapai tiga kredit dalam LEED di timur dan barat masing-masing sebagai satu sistem statik. Akhir sekali, kajian itu mencadangkan dua sistem dinamik yang dioptimumkan yang dapat menyesuaikan setiap jam mengikut kedudukan matahari dan mencapai prestasi yang lebih tinggi daripada konfigurasi statik optimum berdasarkan perbandingan.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ASE	Annual Sunlight Exposure
sDA	Spatial Daylight Autonomy
CHPS	Collaborative for High Performance Schools
CAD	Computer-aided design
BS	British Standard
MIDA	Malaysian Investment Development Authority
MS	Malaysian standards
GH	Grasshopper
DA	Daylight Autonomy
IES	Illuminating Engineering Society
DAmax	Maximum Daylight Autonomy
GAs	Genetic Algorithms
DAcon	Continuous Daylight Autonomy
DF	Daylight Factor
LEED	Leadership in Energy and Environmental Design
EPW	EnergyPlus Weather files
RAD	Solar Radiation
ASHRAE	American Society of Heating, Refrigerating and Air conditioning Engineers
USGBC	The U.S. Green Building Council
WWR	Window-to wall ratio
UDI	Useful Daylight Illuminances

CHAPTER 1

INTRODUCTION

1.1 Introduction

Daylight is a crucial resource for office spaces as it can contribute to illuminance levels that assist to improve indoor environmental quality, reduce the need for artificial lighting and provide user comfort. An important role for facade openings is to provide daylight, since daylight is considered the best type of light because it matches human visual response and color requirements. For managing the indoor environment conditions, façades must often perform contradictory functions (Y. K. Yi, 2019). The conditions of the climate that provide its environmental context in any given geographical location vary from morning to afternoon, from night to day, and from season to season. (Shi et al., 2020) The building facade has the ability to receive or reject free energy from the outside environment, thus, it reduces the quantity of artificial energy required to attain suitable indoor conditions. More recently, new approaches for using daylight simulation as a design tool have been evolved, proving the advantages of a parametrically driven façade to achieve optimal daylight performance. In this study, daylighting will be a crucial performance criterion for design kinetic facades for office spaces using parametric design and optimization methods.

1.2 Research Background

Building serves as a shelter or protection for humans to safeguard from external circumstances like the hot and cold weather. In this essence, the outer part of a building becomes the physical barrier between internal and external surroundings. It is also considered as the shell that maintains the comfort of indoor space that aids the climate control. The implementation of more advanced building services applications through lighting, air-conditioning and ventilation heating has been made for the sake of enhancing the indoor environment along with the thermal comfort. Following that, building outer part has started losing its role in administrating energy and comfort. Additionally, large glass facades are being widely used particularly in office buildings without consideration being made to the tropical climate. Hence, the building exerts a large load for energy to keep up with the building interior condition (Sharaidin, 2014).

Emphasis should be given in designing the outer envelope which resolves issues related to appearance, energy consumption and occupant thermal and visual discomfort. These days, as there are global energy crises, energy consumption has now been placed among the crucial aspects to be considered when designing a building (Wagdy et al., 2016).

The form of the façade has a significant effect on the amount of useful daylight that can be admitted into the interior. Due to the fact that the sun has dynamic characteristics, such as direction, direct and indirect rays and intensity various methods for controlling and filtering daylight have been developed. These include fixed devices, kinetic devices, amorphous geometric systems, and different glazing materials. In addition, the intensity of incident solar radiation is significantly dependent on the angle of the receiving surface in relation to the sun's direction (Badarnah, 2017). Thus, in the earliest phases of the design, finding an ideal form was a transitory process driven by the dynamic within daylight. in the course of time, the comfort concept has been developed which led to the idea of changing the façade configurations over time is one way to improve visual comfort. (Hosseini et al., 2019). Today, the optimizing approach is used through parametric design tools to design geometric complex shapes and determine it by specific parameters which serve architects and engineers to design complex geometries. The geometry form can be altering whenever those parameters such as the proportions or curvatures are modified. Consequently, when it is necessary to modify the model, it is not necessary to recreate it each time. More precisely, the geometry attributes that are interconnected automatically change their features according to the defined parameters modification.

1.2.1 Malaysia Solar Radiation

In terms of geographical location, the position of Malaysia is at 1°-7° latitude, and 100°-120° longitude, which supports that it has ample solar (Ministry of Science, Technology and Innovation). The annual average of level of solar radiation in cities of Malaysia is shown in Figure 1.1.

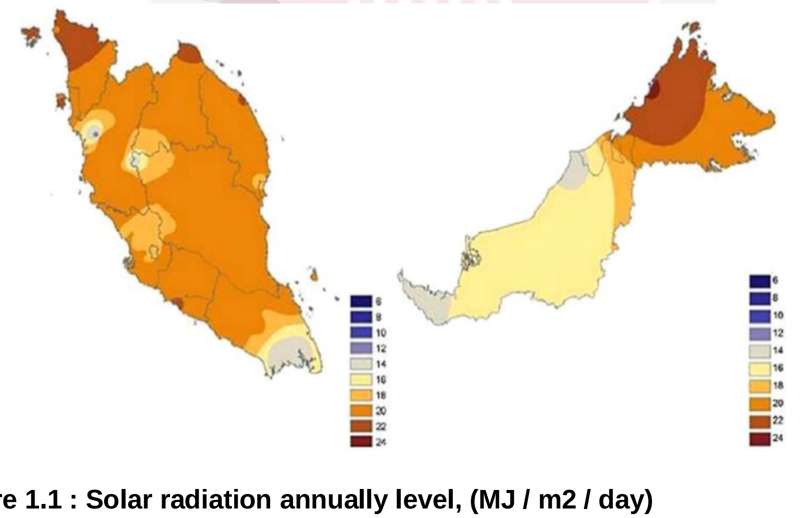

Figure 1.1 : Solar radiation annually level, (MJ / m2 / day)
(Source : Siang et al., 2020)

Solar irradiation per day in Malaysia makes up about 4.7 to 5.8 kWh/m^2 (it could reach 6.8 kWh/m^2 in November and August), with the value per year is around 1596.5 to 1643 kWh/m^2/year and 133.0 kWh/m2 per month. High solar radiation is recorded in the states located in the north region of Malaysia and a number of cities located in east Malaysia every year. Solar radiation slightly decreases from north to south states. In southern Peninsular Malaysia and a few regions in Sarawak recorded the lowest amount of solar radiation (Pheng et al., 2016).

1.2.2 Responding Environmental Changes

These days, it is a must for architectural design to be performance-based so as to enable the users to experience the comfort, saving the electricity and daylight efficiency besides other aspects that have to be put into consideration so that the building can get adapted with environment (El Sheikh, 2011; Soudian & Berardi, 2021) Several office buildings in Malaysia use an entire glass facade without considering the need of adapting the building with the tropical climate, thus, causing an over-lit area and glare, and affect the social sustainability of user comfort (Al-Masrani et al., 2018). After isolating building facade from its role which represents an administrator of energy saving, a huge responsibility lies on office buildings in using the energy to maintain the comfort of interior condition. Therefore, the utilization of facade must be reinforced for adaptation with the climate to achieve specific targets by the means of adjusting itself to enhance daylight performance and improve user comfort leading to reduced consumption of electrical system (Wagdy et al., 2016). However, initial design process rarely evaluates the performance of dynamic interfaces because of the challenge of its qualitative and quantitative assessment in contrast with static devices that are easily evaluated.

The simulation of kinetic facades becomes possible currently through design programs which are able to connect the building and environment (Hosseini et al., 2020). Such simulation will allow façade to have more flexibility, and easily adapted and change the shape following what the future expects it besides allowing more amendments to be made with surrounding environment and hence ensuring greater performance as opposed to static interfaces when compared (Wagdy et al., 2016). A smart kinetic façade which is programmable in response to climate change and changes in surrounding environment involves unified daylight control, proper lighting, and glare control which depends on the task in this space in the time of working hours (Hosseini et al, 2020; El Sheikh, 2011)

1.3 Problem Statement

In Malaysia, many office buildings practice large glass facades without considering the tropical climate. During the day, direct sunlight may cause negative effect on internal space. Solar behavior that keeps changing during the day, month and year causes another problem of determining the constant rate of daylight in a space.

Many studies have dealt with office building façades using conventional shading device such as louvers, egg crate, fins and overhang in tropical climate, these devices only perform their task at few day hours and fail at others. Since the dynamic movement of the sun requires an intelligent device that trace the sun position and its angle.

In the early design stage, it is rare to measure dynamic system in term of its performance due to the long time consuming and the difficulty of identify the algorithm to assess its quantitative and qualitative performance. As opposed It is much easier to evaluate the performance of static devices (Hosseini et al., 2021; Reinhart & Wienold, 2011). Therefore, the researchers should test more complex façades geometry on tropical regions to have initial idea about the most proper façade shape that adapt with climate conditions.

The main research question is:

How can kinetic facades and motion algorithms help architects in achieving the best daylight performance and optimum daylight availability?

Sub research questions:

Sub RQ1<HOW>: How can dynamic or parametric design systems generate and explore different design alternatives for specific target performance?

Sub RQ2<How>: How can kinetic façade system achieves better performance in comparison with static façade system?

Sub RQ3<which>: Which parametric modelling tools and strategies that can be followed for architectural performance-based-design approach to enhance daylight performance for office spaces?

1.4 Research gap

In tropical countries, it is rare for research on kinetic external shading devices to be carried out, especially with regard to office buildings' facades. Moreover, the exploration on dynamic complex geometries shading systems' performances has not been made yet. In consequence, it is crucial for research to make assessment on their performances and adaptation when in tropical weather (Al-Masrani et al., 2018).

East and west orientations of building facades in Malaysia causes a significant increase in heat as a result of facing the movement of the sun throughout the year (Lau et al., 2016a). These directions require kinetic shading devices to respond immediately to the sun position.

1.5 Objectives of Research

The study aimed to examine kinetic façade application in working towards the enhancement of daylight performance in office buildings. In achieving the aim, the targeted objectives were demonstrated as the following:

1. To propose different kinetic façade designs to enhance natural lighting performance and compare between them based on theoretical assessment.
2. To evaluate the daylight performance of the proposed façade design annually to determine the optimum configuration of kinetic façade as a static system and compare it with different glaze materials.
3. To evaluate the façade performance hourly in term of daylight to determine the optimal façade configure for each hour to achieve predictive dynamic shading system and compare it with the optimum static configure.

1.6 Scope of Research

The study focuses on parametric design in configuring kinetic facades. The study evaluates the daylight performance through deducing and testing the facade configurations needed for office space in Cyberjaya, Malaysia.

Listed below are the specific tasks to achieve the research objectives:

1. Reviewing the available kinetic façade applications. Thoroughly review the standards criteria, and provide comprehensive literature in the research area.
2. Identifying and proposing a suitable model of kinetic façade with a few operative options suggested.
3. Simulating the proposed model of kinetic façade for daylighting performance.
4. comparison in terms of daylighting performance with other systems including an existing (control or untreated) façade and different glazing systems.

1.7 Contribution and Importance of the Study

Specific contribution of this study includes:

1. Proposing a kinetic façade design to enhance daylight performance through identify the optimum configuration that achieve user's comfort in term of daylight performance.
2. The research presents a performance based-design through the complete understanding of daylight principles and conducting a parametric design concept that relies on changing parameters to achieve different results that assist to extract a dynamic shading system to adapting hourly with the tested climatic conditions.

1.8 Limitation of Study

The use of kinetic facades involves daylighting, thermal design along with a variety of façade materials. As the key performance criteria in designing kinetic façade is the daylight performance pertaining to Malaysia climate, thus case study was carried for the east and west orientation on office building. This thesis had proposed a kinetic facade design and optimize its parameters (size, rotation angle) with parametric design system as early design process to adapt with Malaysia climate so that daylight performance can be enhanced. But since the aim of this study is to look for suitable approach designing and evaluating non-conventional solar screens which are capable in achieving daylight performance thus, the proposed façade is limited to some degrees of shape and geometry.

1.9 Thesis Organization

This thesis is composed of 5 chapters including this introductory chapter and the rest is organized as follows:

Chapter 2 consists of 3 sections. This section focuses on the identification of kinetic façade patterns, evaluation of types of Kinetic facades design and shading systems while the second part focuses on Malaysia office building, climate and façade problem. The third part focuses on daylight design criteria, metric, rating system, role of daylight and assessment of works related to kinetic façade from previous studies.

Chapter 3 outlines the methodology that was used. The work stages include model development, simulation classification and computer programs utilized across the research.

Chapter 4 comprises the outcomes and analyses on the simulations and comparison of proposed façade configurations results. The elaboration is made on the outcomes to focus on the research outcomes.

Chapter 5 is the final chapter where conclusions made to reflect the earlier set objectives. Recommendations for future studies where possible are also proposed here. Figure 1.2 shows the workflow chart of the study.

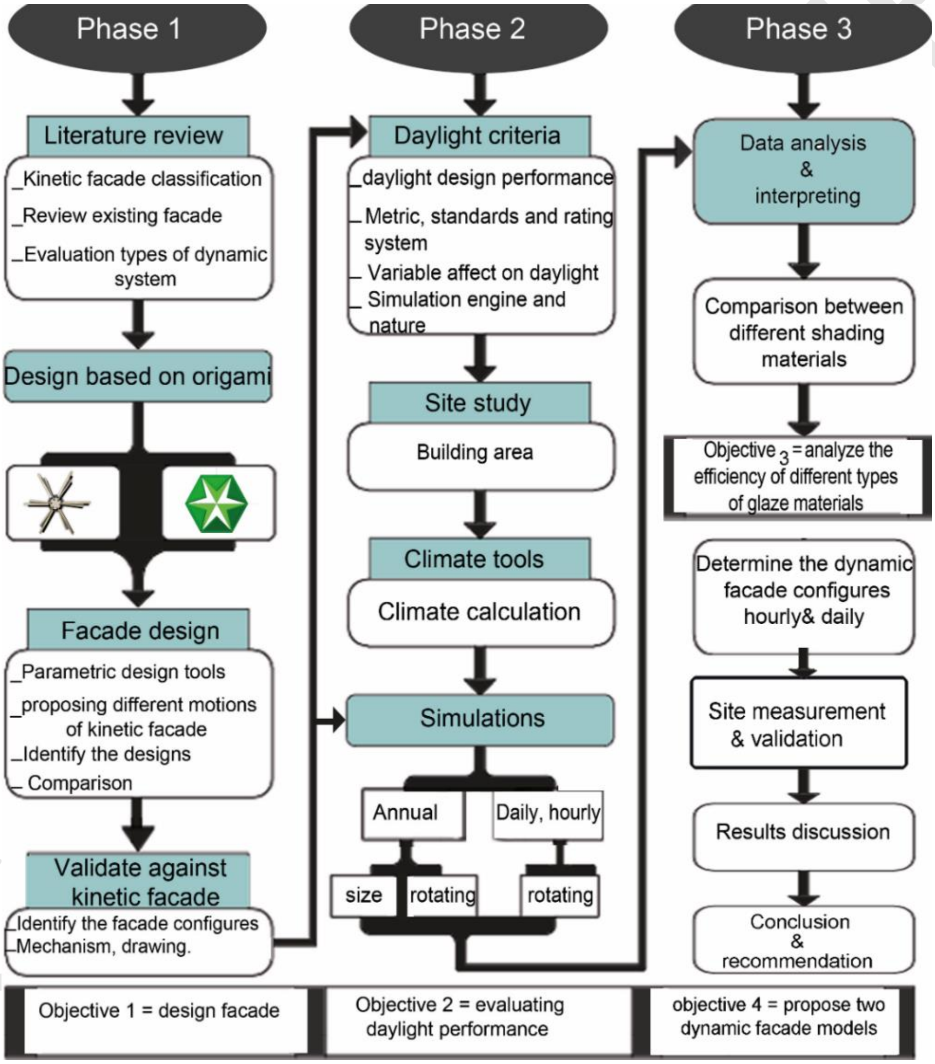

Figure 1.2 : Chart workflow

1.10 Summary

This chapter provides an overview of the research on kinetic response. this part explains how it relates to the realization of facades that respond to environmental conditions in order to enhance the efficiency of the office building in term of daylighting. It explains the motivation behind conducting this research as well as the current issues involving current building practices in the adaptation of shading devices for environmental strategies. This chapter also outlines the research questions and illustrates the importance of research methodology for framing the exploration and answering the questions. In addition to specifies the research scope and the research gap.

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