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The development of a Modular Adaptive Facade System Based on Pre - Calculated Light Values Through Parametric Models and Real - Time Light Sensors

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Abstract

The design of exhibitions often faces limitations in utilizing natural light inside the building due to the diverse and rotating nature of exhibited artworks. These objects have varying light sensitivity and prolonged exposure to excessive light can cause damage or deterioration. Therefore, in exhibition design, it is crucial to consider the direction and quantity of light that falls on the displayed objects to protect them from potential harm caused by natural light and extend their longevity. Consequently, the factor of utilizing natural light within exhibition spaces becomes a challenging element to control. The goal of this research is to develop an adaptable building envelope system to control the amount of natural light in response to the use of exhibition spaces. This was achieved by creating a parametric model using Rhinoceros software and its Grasshopper plugin for designing the building envelope. Together with the use of physical computing to create a hardware system that was programmed to develop a prototype of an adaptable building envelope we have developed a process able to optimize lighting delivery for exhibited objects. The building envelope has adjustable openings that correspond to the position of the exhibited objects and the sun. The building envelope can serve as a sunshade to prevent direct sunlight from impacting the exhibited objects while allowing the utilization of natural light in other areas within the exhibition space. The results of this research demonstrate suitable building facade designs that can be applied to exhibition spaces in various projects. The researchers evaluated the performance of the model by simulating exhibition spaces equipped with the building facade system in the southern and western directions and measured the intensity of light entering the exhibition areas. Results showed an average light intensity for the spaces ranging from 30 to 90 lux, which does not cause any damage to the exhibited objects. The researchers also tested the functionality of the building facade system with natural light and found that the control system and mechanisms worked accurately, reducing the sunlight intensity by 97.3%. This adaptable building facade system can address complex architectural design challenges and allow architects to control the amount of natural light within exhibition spaces. The design flexibility of the facade envelope system allows it to respond to different daylight periods that vary seasonally and would impact the exhibited objects.

Keywords

Adaptive Design; Facade Design; Parametric Design; Daylight

1. Introduction

Exhibition is a presentation that involves showcasing a diverse and rotating collection based on various themes. The exhibited objects are varied and have different light sensitivity. If the objects receive excessive light for extended periods, it could lead to damage or deterioration. Therefore, in the exhibition design, consideration must be given to the appropriate amount of light that interacts with each exhibited object to protect them from natural light and prolong their lifespan. Since the exhibited objects are constantly exposed to light, controlling the amount of light must be done appropriately, taking into consideration the conservation of the objects while ensuring a clear view for the visitors. Currently, building facades are designed with sun shading in areas where sunlight enters to disrupt the interior space. This helps to reduce heat and control the amount of sunlight entering the building. Additionally, it enhances the aesthetic appearance of the building. Building facades have been widely utilized for various purposes and advancements have led to the development of movable facades that can automatically respond to the sun's movement, thereby controlling the overall amount of light entering the building. But the design of exhibitions often faces limitations in utilizing natural light within the space due to the need to consider the amount of light that falls on the exhibited objects to prevent damage. Additionally, the exhibited works are constantly rotating based on various themes, which makes the factors related to using natural light in the exhibition space difficult to control.

This research aims to explore the directions, theories, and relevant technologies related to the development of "The Transformable Facade System" to control the amount of natural light in response to the usage of exhibition spaces. The objective of this research is to design a parametric model that can respond to the exhibited objects effectively. It is anticipated that the development of this system will be beneficial for architects and designers who can use this parametric modeling process for preliminary architectural design with environmental considerations. Additionally, the system aims to extend the lifespan of the exhibited objects for their respective owners. The system also can enhance visitor experience in viewing the exhibition.

2. Literature Review

We gathered projects related to the application of parametric modeling design in architecture to investigate the possibility of developing models and studying operational procedures. These project exhibit characteristics and research outcomes are described in the following section.

Research work related to parametrically designed building envelopes to control the amount of light within a building

In architectural design, considering the orientation and quantity of sunlight is crucial, as it significantly impacts both the efficiency of space utilization and functionality. For example, the research by Sanakaewthong et al. (2022) involves designing a dynamic building envelope to control the amount of light intensity, creating a suitable environment for efficient workspaces. This is particularly relevant because current building designs often incorporate large open spaces, leading to excessive and disruptive light levels in working areas. The research by Betul and Nese (2023) sought to enhance the visual comfort of building occupants and reduce heat from sunlight. Both of these forementioned research works leverage parametric building envelope design to efficiently harness natural light within the building and cater to the needs of the occupants. Furthermore, they propose valuable directions for architects to incorporate and apply parametric modelling in the design of various building types.

Research work related to building design through the creation of parametric models

Paibulkijcharoen (2018) conducted research on parametric modeling applied to the design of adaptive architecture. This study focuses on the design of an open-air library in the context of Thailand, with several primary objectives. The main goal was to identify the most suitable parameters for shaping the architecture and adapting it to the ever-changing environment, according to the natural light and indoor comfort conditions. The study applied parametric modeling combined with a genetic algorithm to achieve this goal. This research created a variety of areas, although during the day there was little change. The research also explored the connection between lighting and comfort conditions.

Research work related to the design of adaptable building envelopes using physical computing

The design of the building facade can be modified by applying physical computing to increase space utilization efficiency while considering the environment and the amount of natural light in the building. For instance, the research by Sribumrungsart (2014) proposed the design of an automatic natural light control system within the building, responding to the user's space usage behavior. This system allows the user to adjust brightness according to their space usage behavior. Similarly, research by Srinoradithlert (2017) focused on the implementation of an automated facade system in residential buildings that is controlled and commanded through a smartphone.

The above-mentioned research demonstrates that the application of physical computing in architecture can effectively regulate the amount of natural light entering the building based on appropriate lighting conditions and space usage patterns. Furthermore, this technology enhances user comfort and increases space utilization efficiency for building occupants.

3. Research Methodology

3.1 Selection of tools for creating a parametric model

From a study and research into plugins for creating parametric models, it was found that the main and popular software for parametric modeling is Autodesk Revit and Rhinoceros. Therefore, a comparison of these two programs is presented in Table 1.

Table 1 Related software comparison

Programs	**Autodesk Revit**	**Rhinoceros**
First year published	2000	1994
Operating system	Microsoft	Microsoft Windows / macOS
Developer	Autodesk Inc.	Robert Mcneel Corp
3D modeling system	Spline / Polygons	NURBS / Polygons
Parametric program	Dynamo	Grasshopper for Rhino
Generative Design add-on	Optimo / Project Fractal / Project Refinery	Galapagos / Octopus / Biomorpher / WALLACEI

From the study and comparison of related programs, it was concluded that the suitable tools for use in our research were Rhinoceros 6 and Grasshopper for Rhino. The rationale for this conclusion is as follows:

A. The flexibility in creating 3D models – 3D modeling in Grasshopper is more flexible because the main working objective involves both regular 3D modeling and parametric modeling, which differs from Dynamo that primarily focuses on Building Information Modeling (BIM).

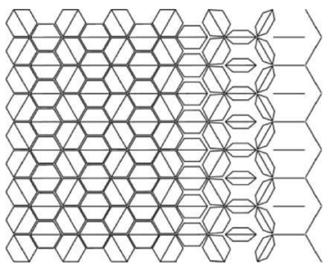
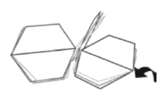
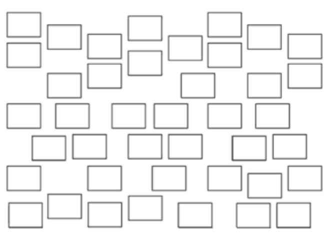
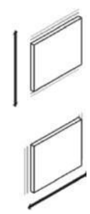
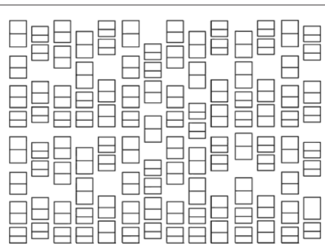
B. The size of the components and stability - The size of the components in 3D modeling using Revit is larger because creating 3D models in Revit involves a substantial amount of data, which affects the stability and resource requirements of the software.

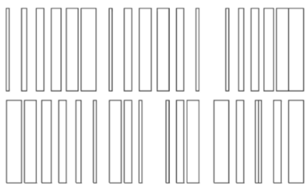
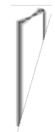
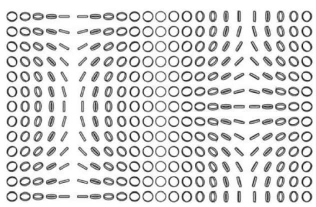
C. Broader and Longer User Base - Rhinoceros was developed several years before Revit, which has resulted in a significantly larger and more established user base. This, in turn, has led to a more significant number of plugin developers and a wider variety of add-ons for the software.Based on the aforementioned features and reasons, it can be concluded that Rhinoceros and Grasshopper for Rhino are suitable for parametric modeling design.

3.2 Selection of the building envelope modification model

In the process of designing architectural facades, the researchers studied and compared various methods of adaptive building envelopes, drawing reference from “Designing Kinetics for Architectural Facade” by Jules Moloney. The researchers specifically selected adaptive building envelope designs that allow independent and diverse movements without relying on stretching or contracting materials. These chosen designs were then used for comparison and analysis as summarized in Table 2.

Table 2 A study and summary of building envelope modifications from Designing Kinetics for Architectural Facade by Jules Moloney to be used as a model for research

Name	Character of Change	Movement appearance	Physical Appearance
The Ciudad de Justicia		 - rotation up – down.	- Mounted on the hexagonal structural axis. - Each panel moves independently of each other.
Screen Translation		 - Scrolling in the horizontal and vertical axis.	- There are independent movements in each panel. - formed an uneven opening. - unclear movement patterns.
Kiefer Technic showroom		 - Vertical axis movement with folding.	- The deformation of the square panel has independent movement. - An opening is formed between the folds of each panel.

Nordic Embassies		 - Up and down rotation in the vertical axis.	- have independent movement and an opening was formed. between the rotating square panels.
Malvern Hills Science Park		 - Left and right rotation in the horizontal axis.	- have independent movement and an opening was formed. between the rotating square panels.
Kinetic wall sculpture Battleship		 - Rotate the circular panel in the x y axis.	- Each panel moves independently of each other. - Form an irregular shape.

From the comparison presented in Table 2, it was found that each design exhibited different movements and rotation points. The researchers chose a hexagonal design, known as "The Ciudad de Justicia" because it offered the highest structural feasibility (Figure 1). Each panel had axes of rotation on the hexagonal structure, providing various rotation angles to accommodate sunlight direction and create a more dynamic experiential perception compared to other designs. This clear and independent rotational pattern of the building envelope allows it to serve its purpose of shading the displayed objects from direct sunlight.

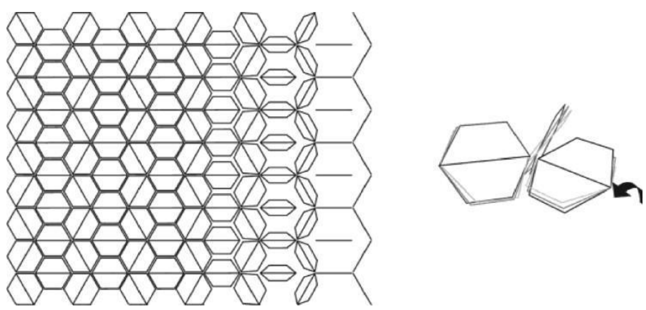


Figure 1 Hexagonal parametric building envelope and rotation characteristics.

3.3 Prototype Parametric Design

Determine the hexagonal rotation pattern of the building envelope

In determining the form of the hexagonal building envelope structure we consider that the direction of rotation up and down all 4 axes is the middle axis, the upper-bottom axis, the left diagonal axis, and the right diagonal axis as summarized in Figure 2.

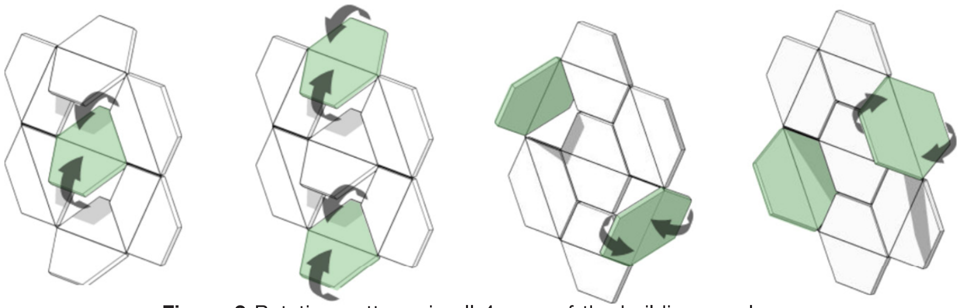


Figure 2 Rotation patterns in all 4 axes of the building envelope.

Creating a hexagonal pattern on the area of use

The Hexagon Cells (Hex) command was used to arrange hexagonal patterns within those surfaces. Next, hexagonal panel sheets were constructed along four rotational axes derived from the hexagonal structure that was previously established. Each axis had different diagonal lines for rotation and the rotation of each panel could be controlled using the Rotate Axis (RotAx) command (Figure 3).

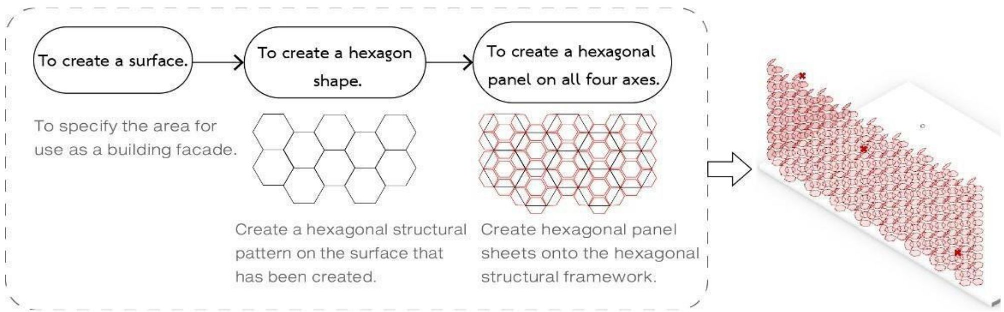


Figure 3 Creating a hexagonal pattern on the area of use.

Determine the position of the sun and the location of the objects on display

Sunlight and the path of the sun were simulated, with the sun's position set in Bangkok, Thailand. The Geometry (Geo) command was used to define the display objects and create the boundaries of each object using the Bounding Box (Box) command. Then, the Line (Ln) command was used to create lines between the position of the sun and the position of the display objects, as shown in Figure 4.

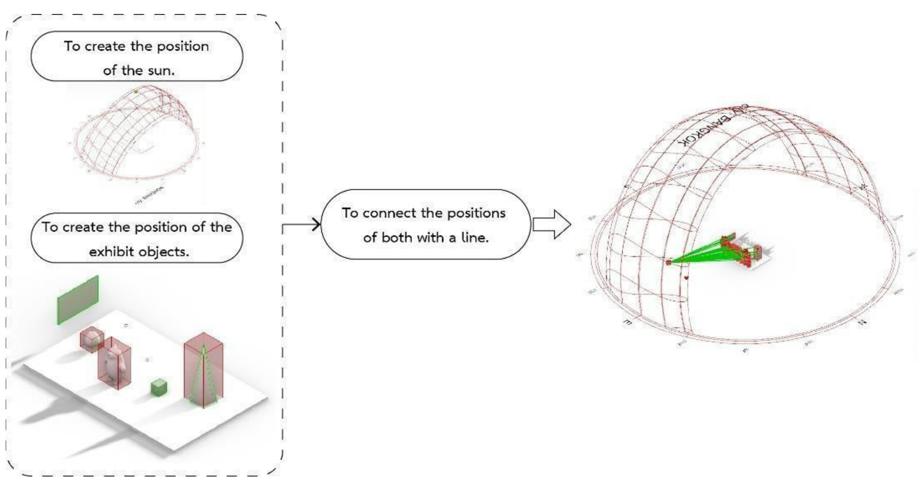


Figure 4 Determine the position of the sun and the location of the objects on display.

Control panel rotation

After obtaining the lines connecting the position of the sun and the position of the display objects, the next step was to find the points where these lines intersect with the surface of the working area. This was done using the Line I Plane (PLX) command to create these points. Then, the Surface Closest Point (Srf CP) command was used to make each hexagonal panel work with the nearest point on the surface in each axis direction (Figure 5). The minimum and maximum opening angles for each axis were specified. Panels that were closest to the point will be closed to block the light, and they will gradually open more with distance from the point.

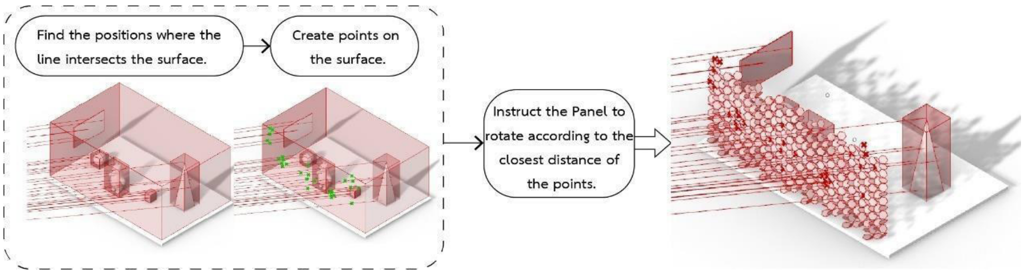


Figure 5 Control panel rotation.

Create a case where every panel is fully open to receive sunlight

For this scenario, the rotation values for all axes were fully open to receive maximum sunlight when the sunlight does not directly hit the exhibited object. This was achieved by setting the rotation angle to 90 degrees in the Rotate Axis (RotAx) command for each axis (Figure 6).

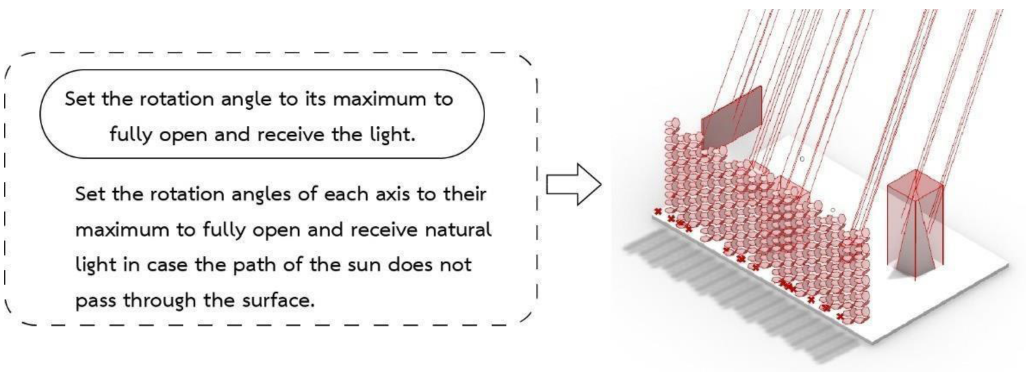


Figure 6 A case where every panel is fully open to receive sunlight.

The process of screening and displaying data

When creating this case, the panels will be closed when the object is hit by sunlight and the panels will be open to receive sunlight when the object is not hit by sunlight. This was visualized through the Stream Filter (Filter) command (Figure 7). When the connection line between the sun and the exhibited object passes through the usable area, it will display the result for case 1 under which all panels will be closed to prevent the object from receiving direct sunlight. On the other hand, when the connection line between the sun and the exhibited object does not pass through the usable area, it will display the result for case 2 under which all panels will be fully open to receive natural light.

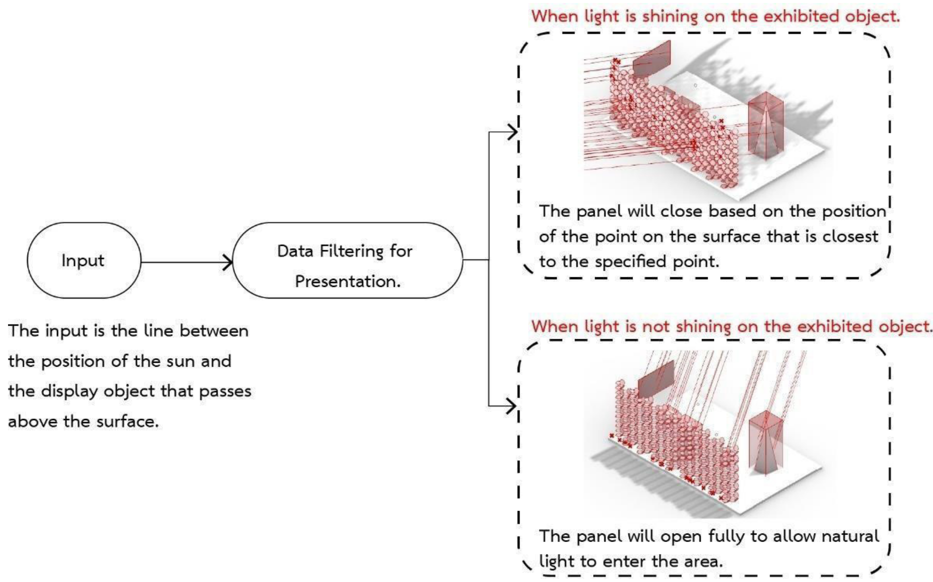


Figure 7 The process of screening and displaying data.

The process of creating a rotation pattern for all 5 sides

For this case, a rotation pattern for all 5 sides front, back, left, right and top was created to support user usage (Figure 8).

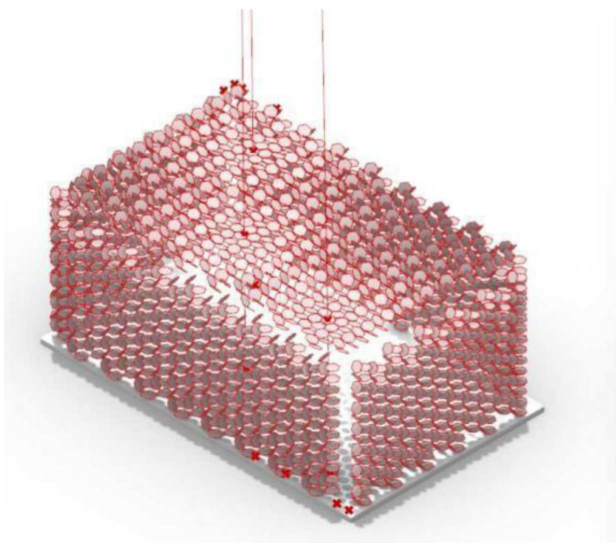


Figure 8 The process of creating a rotation pattern for all 5 sides.

3.4 Physical Computing

Work process of physical computing

Physical computing supported by Rhinoceros is accomplished by employing Firefly Design Interactively to connect between Grasshopper and microcontrollers. To command the servo motors' operations, there are two input variables, which are the rotation angles at each user-defined time interval, (day, month, and hour), for displaying the results. The servo motors will display the results based on the values obtained from the Rhino program and each panel will gradually close in case of excessive light. This adjustment is determined by measuring the light intensity using sensors. The workflow for this component of the research is summarized in Figure 9.

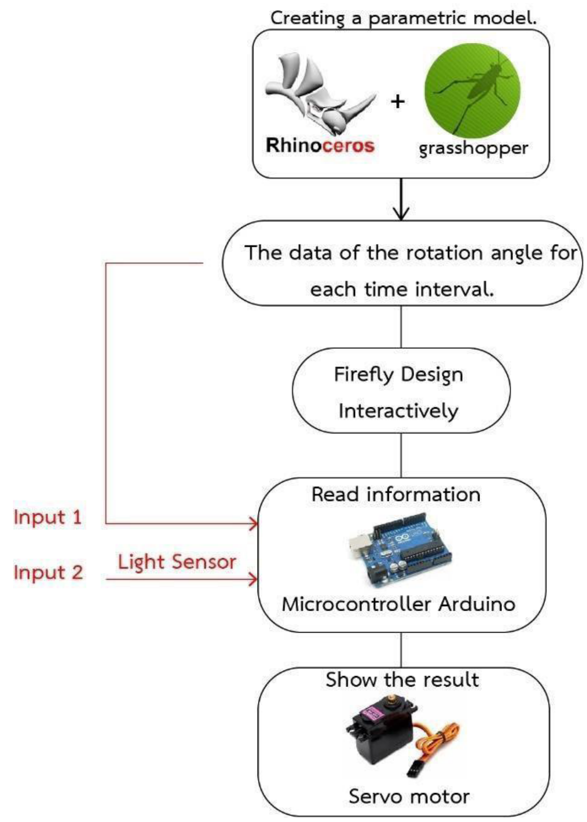


Figure 9 Workflow diagram of physical computing.

Development of an adaptive building facade prototype

After developing the system and obtaining results from the model creation, we then proceeded to develop a prototype of an adaptable building envelope that physically demonstrates its functionality. This prototype consists of the following components:

1. Structural frame and panel

The structural design is based on a parametric design that considers the installation of servos and the angular direction of the panel. The frame structure was hexagonal, measuring 35 x 39 cm, with a thickness of 2 cm (Figure 10). It included rectangular holes measuring 2 x 4 cm on all 7 axes for mounting servo motors. The panel was in the shape of a hexagon measuring 17. 30 x 15 cm, referencing the dimensions of standard hexagonal tiles available in the market. These tiles are suitable for both interior and exterior use and come in a variety of colors and materials, allowing users to choose according to their preferences and needs.

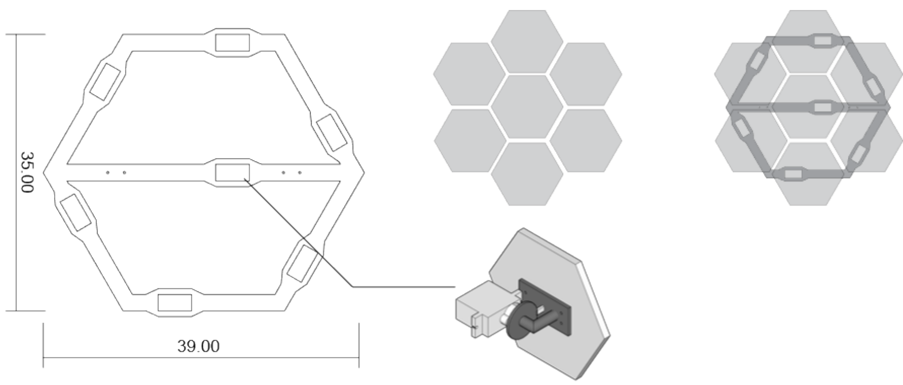


Figure 10 Structural frame.

2. Light sensor

The operation of the adaptable building envelope prototype begins by sending the rotation angle values of the panel for the selected month/day/hour from the Rhinoceros program to the Arduino microcontroller board. In cases of excessive light, additional sensor data were provided as input to the microcontroller to increase the angle at which the panels closed, as follows.

(A) The exposure value was between 0 and 499, simulating a cloudy day = The panels would close at the angle determined by the Rhinoceros program.

(B) The exposure value was between 500 and 1,200 lux, simulating a partly cloudy day = The panels would close further to 2/4 of the angle determined by the Rhinoceros program.

(C)The exposure value was between 1,201 and 2,000 lux, simulating a clear day = The panels would close further to 3/4 of the angle determined by the Rhinoceros program.

(D) The exposure value was 2,001 lux or higher, simulating a sunny day = The panels would close completely or to 0 degrees.

4. Servo motors (all 7 axes)

In this research, servo motors were used to display the adjustment of the solar shading panels. The control ranged from 0 to 90 degrees, where 90 degrees represented fully open panels to allow maximum sunlight penetration and gradually closed to 0 degrees.

For prototype 1, a total of 7 servo motors were used, installed on the hexagonal structure frame and panels. The servo motor rotations were controlled by selecting the month/day/hour from the Rhinoceros program and the light value measured by the sensors

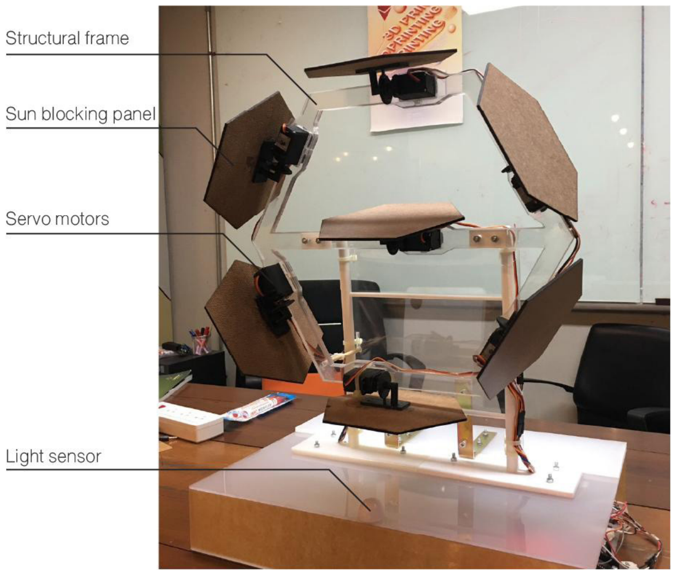


Figure 11 The adaptable building facade prototype.

In the operation of the microcontroller, after creating the parametric model from Rhinoceros and the Grasshopper plugin, we obtained the rotation angle data for each time interval. Then, we used the Firefly Design Interactively plugin to connect these data to the microcontroller board to command the servo motors to rotate according to the read angle. When the light sensor read the specified range, the microcontroller commanded the servo motors to rotate to a more closed angle than the previous angle (Figure 12).

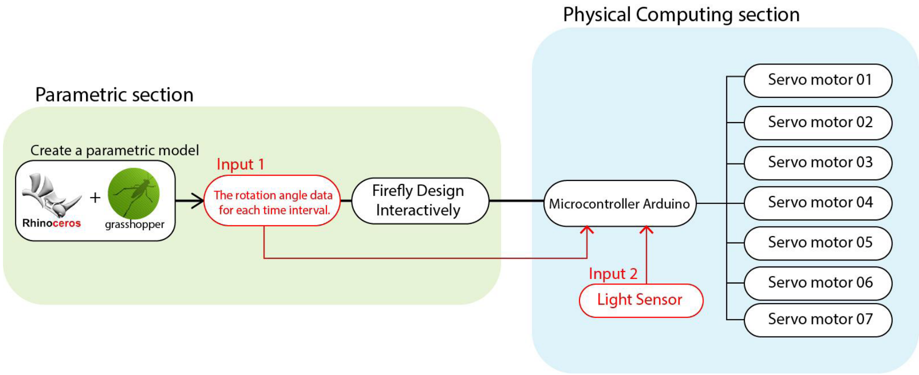


Figure 12 Diagram of the process of commanding the adjustable building facade.

5. Display of research results

5.1 Results from Rhinoceros and the Grasshopper plugin - sunlight shines directly onto the exhibited objects

The building facade will serve to block direct sunlight from hitting the exhibiting objects directly. However, at the same time, it will allow natural light to be utilized in other areas within the exhibition space, as illustrated in Figure 13.

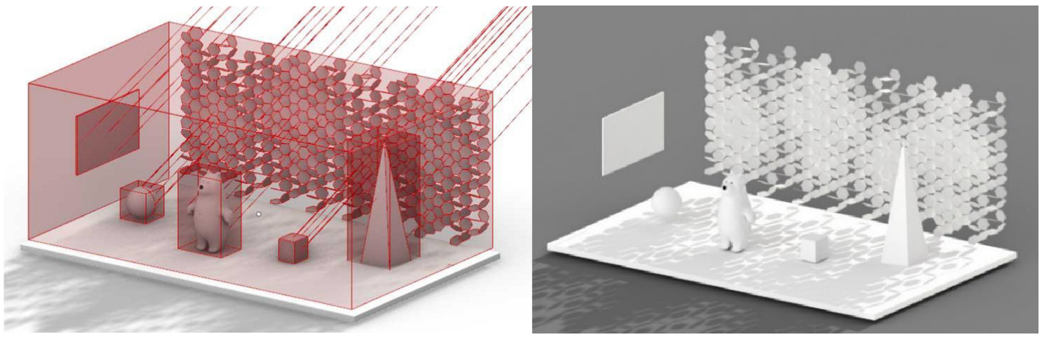


Figure 13 The result when sunlight shines directly onto the exhibited objects.

5.2 The result when sunlight does not shine directly onto the exhibited objects

When sunlight does not directly shine on the exhibited objects, the building facade will act as an opening to allow natural light to enter the exhibition space fully (Figure 14).

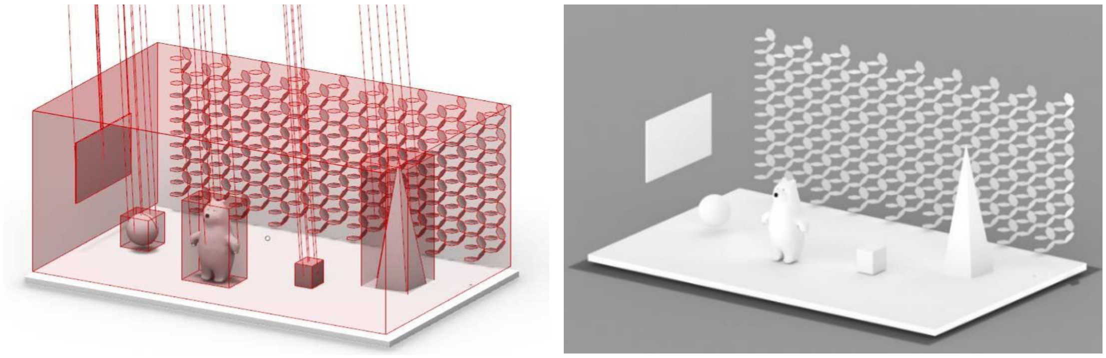


Figure 14 The result when sunlight does not shine directly onto the exhibited objects.

5.3 The results demonstrating various sizes of opening

The results presented in Figure 15 illustrate the impact of different opening sizes in the envelope structure.

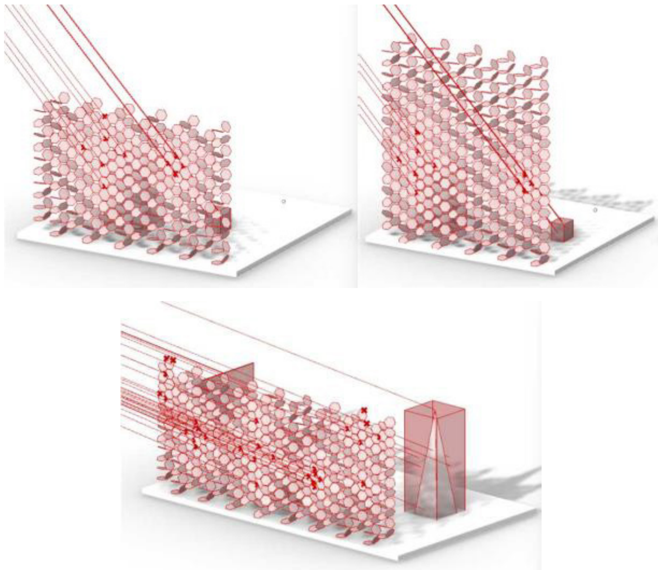


Figure 15 The results are demonstrated in various sizes of opening.

5.4 The results displayed using physical computing

The results where the input is data from the program

In the example of physical computing, the researchers selected a west-facing building facade that would receive sunlight during the time frame of 4 : 00 PM to 6 : 00 PM. Panel Module number 80 was used for the simulation, as shown in Figures 16-19.

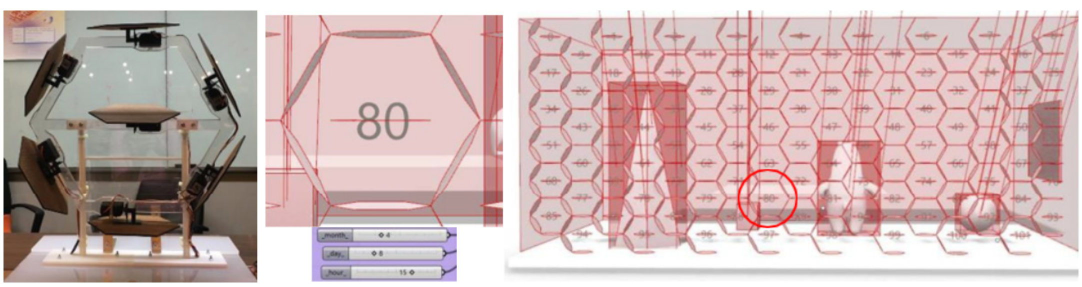


Figure 16 Display of results of physical computing at 3:00 p.m.

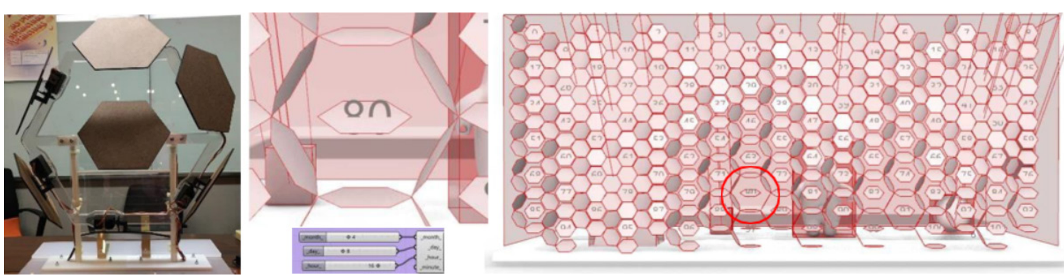


Figure 17 Display of results of physical computing at 4:00 p.m.

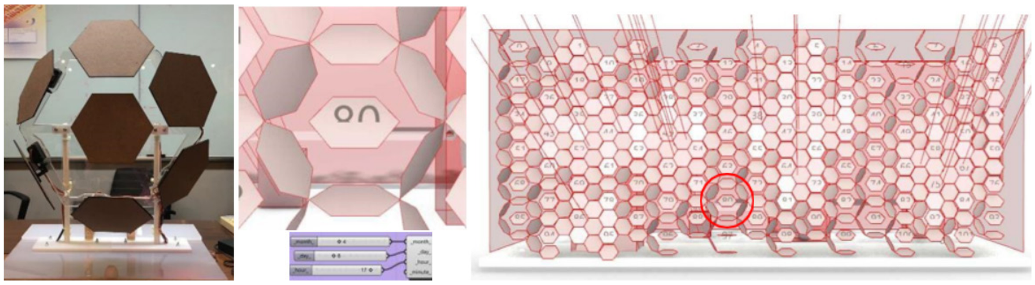


Figure 18 Display of results of physical computing at 5:00 p.m.

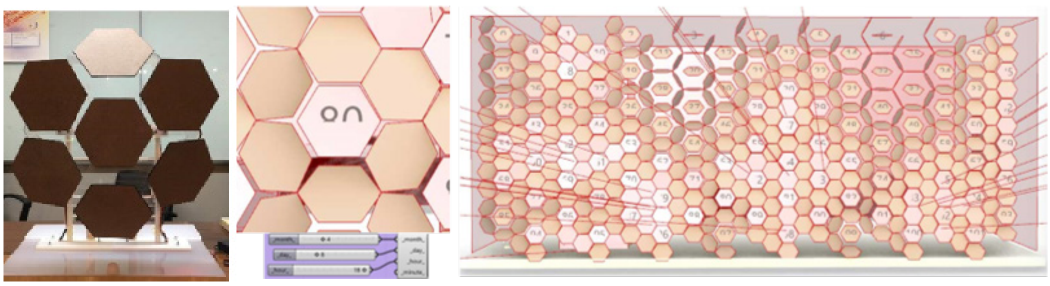


Figure 19 Display of results of physical computing at 6:00 p.m.

5.5 The results where the input involves a light intensity sensor

The sensor was responsible for measuring the light intensity to gradually close the panel in response to the increasing brightness (Figure 20).

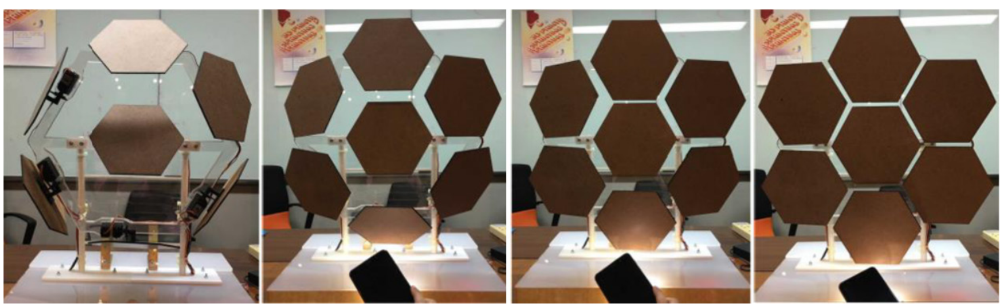


Figure 20 The results in the case where the input involves a light intensity sensor.

6. Research Evaluation

The objective of this research is to create a parametric model of an adaptable building envelope to control the amount of incident light reaching exhibition objects within the exhibition space. The evaluation methods employed are as follows.

The researchers simulated the exhibition hall area to adapt it to the developed system, where the adaptable building envelopes were installed on the west and south sides, as these are the areas that receive the most sunlight. The building size is 4.50 meters wide, 8.00 meters long, and 3.50 meters high from floor to ceiling. The area contains a total of five display objects with different sizes and shapes (Figures 21 and 22). The researchers used the results to evaluate the effectiveness of two modeling methods, which are:

(1) The effectiveness of the model will be evaluated by measuring the amount of natural light in the exhibition area using plugins

(2) The performance of the control system and the mechanism of the adaptive building facade will be assessed.

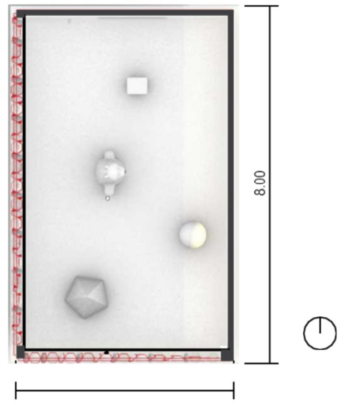


Figure 21 The floor plan of the experimental area installed with adaptive building façade.

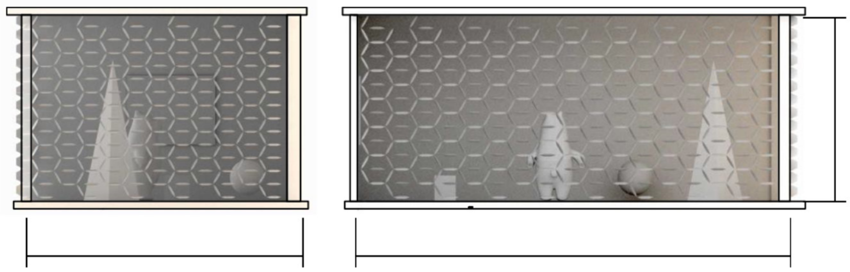


Figure 22 The front and sides of the experimental area installed with adaptive building façade.

6.1 The effectiveness of the model by measuring the amount of natural light in the exhibition area using plugin.

The performance of the control system and the mechanism of the adaptive building facade will be assessed in this section. The level of light intensity that does not cause any damage to the exhibited objects is within the standard range of 50 - 300 lux. To assess the performance of the model, we used the Ladybug and Honeybee plugins to calculate the amount of light entering the exhibition area. The plugins were used to analyze the results of opening and closing the building facade during the period of shape transformation, specifically from 1:00 to 6: 00 p.m. in all seasons. The measured light intensity in the exhibition area should not exceed 300 lux, as this is the maximum brightness level that the exhibited objects can tolerate. The results of the light intensity in the experimental area for each time period are summarized in Figures 23-26.

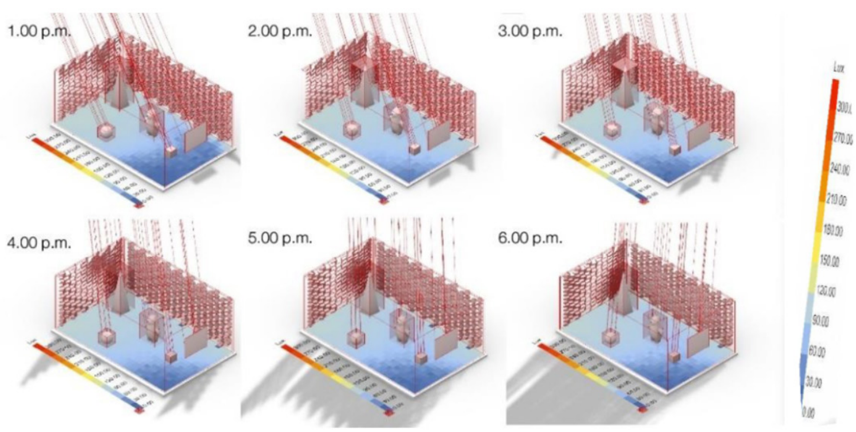


Figure 23 The light intensity in the experimental area during the time period from 1:00 to 6:00 p.m. in the month of February.

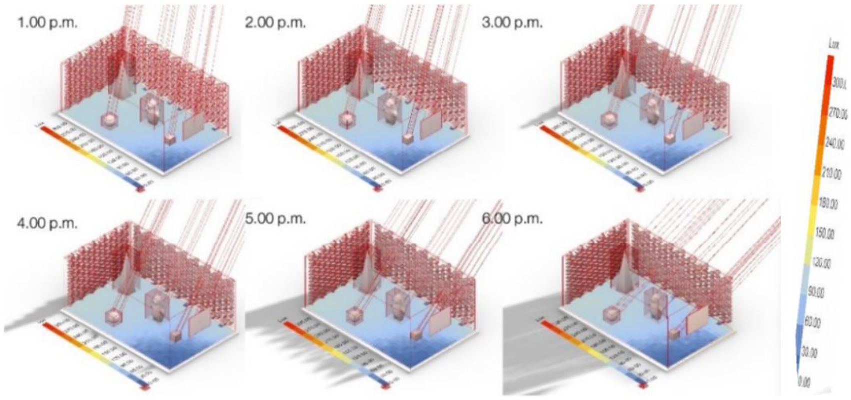


Figure 24 The light intensity in the experimental area during the time period from 1:00 to 6:00 p.m. in the month of May.

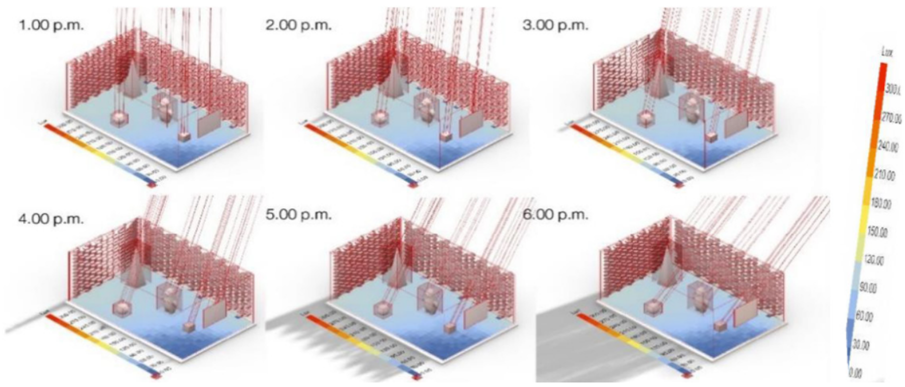


Figure 25 The light intensity in the experimental area during the time period from 1:00 to 6:00 p.m. in the month of August.

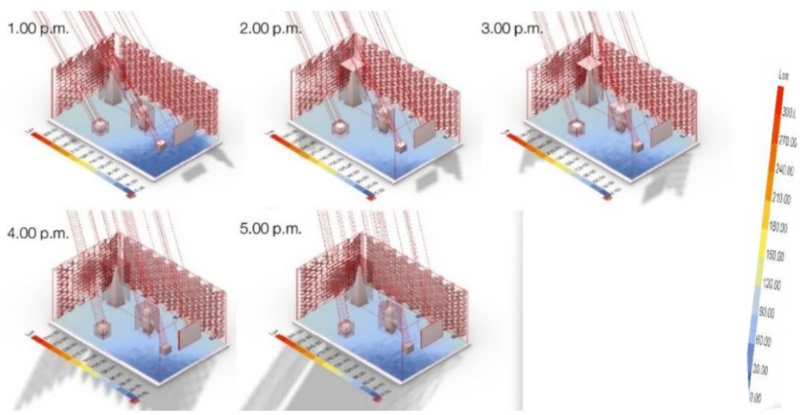


Figure 26 The light intensity in the experimental area during the time period from 1:00 to 5:00 p.m. in the month of November.

From the light intensity testing in the experimental area during each time period and season, it was found that in every season, the light intensity in the area ranged from 30 to 90 lux. This falls within the range of light intensity that does not cause damage to the exhibited objects. The maximum recorded light intensity was 90 lux, especially in the area of the open south-facing section, which does not exceed the standard light exposure value for the exhibited objects. Therefore, it can be concluded that the proposed parametric model of the adaptable building facade can effectively guide natural light management in the exhibition area without causing damage to the displayed objects.

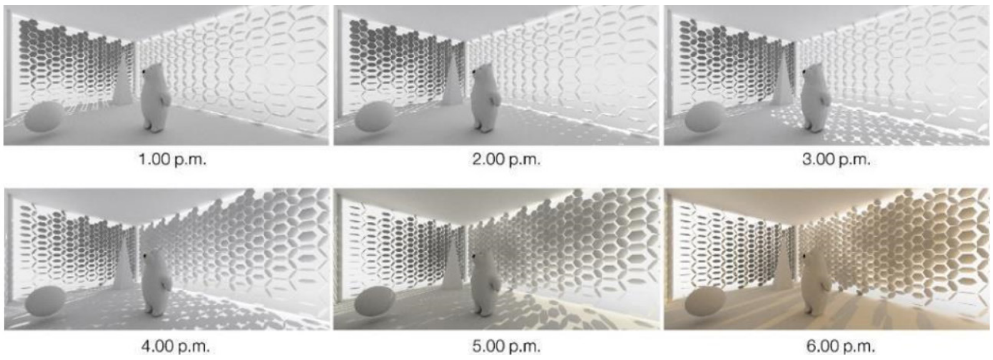


Figure 27 The interior view of the exhibition building with the adaptable building facade during the time period of 1:00 to 6:00 p.m. in the month of February.

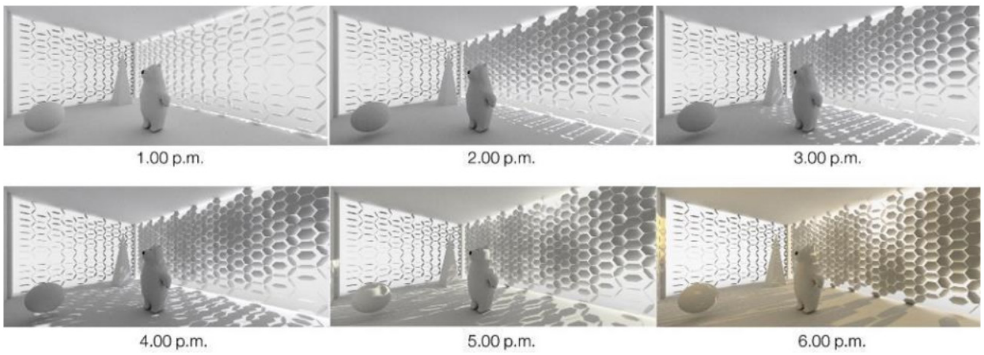


Figure 28 The interior view of the exhibition building with the adaptable building facade during the time period of 1:00 to 6:00 p.m. in the month of May.

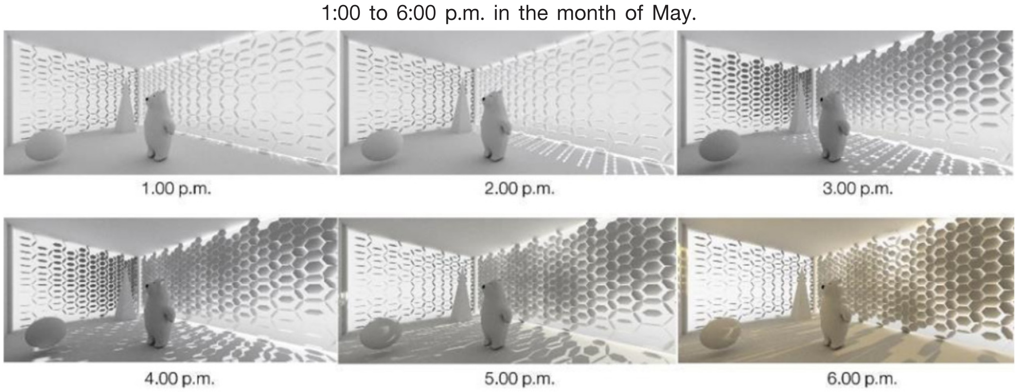


Figure 29 The interior view of the exhibition building with the adaptable building facade during the time period of 1:00 to 6:00 p.m. in the month of August.

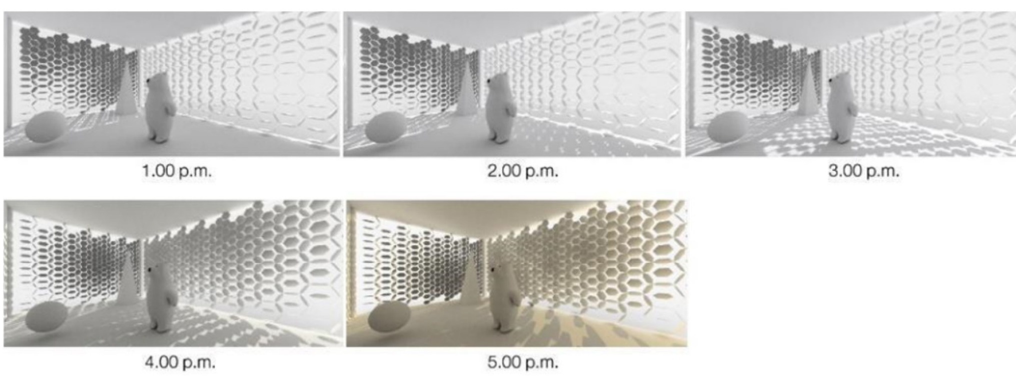
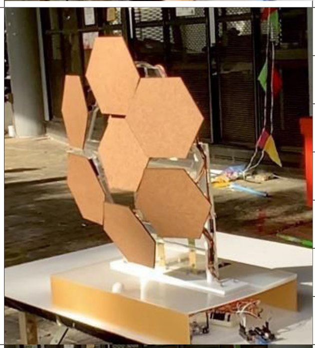


Figure 30 The interior view of the exhibition building with the adaptable building facade during the time period of 1:00 to 5:00 p.m. in the month of November.

6.2 Performance evaluation of the control system and mechanism of the adaptable building facade

The prototype of the adaptable building envelope operates both from a computer system for control commands and an electrical circuit system to drive the motor's operation. The functionality of the control system and mechanism was evaluated by the research team. We conducted tests on the operation of the control system and mechanism of the building envelope using natural sunlight on June 10th, at 4:00 p.m and the results are summarized in Table 3.

Table 3 The operation of the control system and mechanism of the adaptable building facade.

Amount of light in front of the building facade	Character of Change	Degree of Servo		Amount of light behind the building facade
4,084 lux		center	50 degree	264 lux
		top	53 degree	
		bottom	73 degree	
		top left	71 degree	
		right bottom	78 degree	
		top right	66 degree	
		top left	73 degree	
7,461 lux		center	25 degree	281 lux
		top	29 degree	
		bottom	45 degree	
		top left	35 degree	
		right bottom	39 degree	
		top right	33 degree	
		top left	36 degree	
9,967 lux		center	16 degree	293 lux
		top	17 degree	
		bottom	24 degree	
		top left	23 degree	
		right bottom	26 degree	
		top right	22 degree	
		top left	24 degree	
12,293 lux		center	0 degree	286 lux
		top	0 degree	
		bottom	0 degree	
		top left	0 degree	
		right bottom	0 degree	
		top right	0 degree	
		top left	0 degree	

The prototype of the adaptable building envelope controls the amount of light, operates using a computer system to command the electrical circuitry, and displays the motor's operation. The functionality of the control system and mechanism was evaluated based on testing the adaptable building envelope's performance when exposed to natural light. It was found that.

1. The command from the computer system to the microcontroller and the light received from the sensor to the microcontroller were accurate and precise. The operational mechanism functioned smoothly. The building envelope accurately changed its angle according to the specified time and the amount of sunlight.

2. The structure was robust and could withstand the torque of the servo motors. The servo motors could rotate at the correct angle according to the model in the program.

3. The building envelope could help shield sunlight and reduce the amount of natural light inside the building. The measured light levels behind the adaptable building envelope were significantly lower than the light levels in front of the building envelope, with a reduction of approximately 97.6%.

In conclusion, the operation of the control system and mechanism was efficient, accurate, and effectively reduced the amount of light in the building area as intended.

7. Conclusion

The limitations

1. In this research, only the amount of natural light on the exhibited objects was considered, without taking into account other external factors such as airflow and rain protection, among others. In future development, these additional external factors can be incorporated to create a more flexible and comprehensive model for practical use.

2. The control system still needs to be continuously connected to the Rhinoceros program, as it requires selecting the month/day/hour from the Rhino program to command the rotation angle of the Panel, which will change accordingly with the specified hour.

3. The developed shape is currently only a hexagonal form. However, in further development, it can be designed to have various other shapes or different rotational patterns to provide a wide range of options for users. This will allow users to choose a suitable design that matches the characteristics of the building.

Suggestion

1. Develop the system to consider a wider range of natural factors, such as rainwater management, air circulation, and thermal comfort. Additionally, providing different viewpoints may offer more options for users, allowing them to apply the system to various buildings, and enhancing its overall usefulness. To achieve this, additional plug-ins like "Butterfly," which simulates airflow and thermal comfort, may be utilized for more accurate calculations.

2. Develop the system to directly connect the database with the microcontroller, eliminating the need for constant connections and commands through the Rhino program. This can be achieved by using the latitude and longitude values of the sun and storing the panel rotation angles for each panel as data in the database, which will be connected to the microcontroller.

3. Each type of exhibited object may have different standard light sensitivity levels. It is possible to develop the system so that the opening and closing of the panel modules can be customized based on the light sensitivity of the displayed objects, which may vary. This could lead to a more diverse pattern of the building envelope, offering greater variability.

4. When implementing the system in real-world applications, consideration should be given to repair and maintenance. The building envelope system consists of four main components: the structural frame, panel modules, servo motors, and light sensors. Each of these components can be disassembled independently for repair, maintenance, or replacement of various materials, all while ensuring that the control system functions normally without any disruption.

Conclusion

The design of exhibition spaces often faces limitations in incorporating natural light due to the need to consider the amount of light that directly affects exhibited objects to prevent damage. Furthermore, the constant rotation of artworks in these spaces to accommodate various content makes it challenging to effectively control natural light. This research addresses the issue of controlling the quantity of natural light in exhibition spaces,offering architects a solution that can be applied to various building types facing similar challenges in regulating natural light within their spaces. The adaptable building facade design developed in this study can be customized to suit the requirements of different building spaces. This facade design is flexible and capable of reducing damage caused by sunlight. Therefore, buildings encountering difficulties in controlling the amount of natural light within their spaces can benefit from the adaptable building facade design.

This research demonstrates that applying technology in architectural design can greatly benefit the field of architecture. It leads to the development of new architectural paradigms that cater to diverse human needs and usage patterns, making architecture more adaptable and responsive to changing environmental conditions. This enables architecture to evolve and transform, driven by computer-controlled systems, while still accommodating natural variations. Thus, architectural work can adjust to and meet a wide range of requirements.

At present, the parametric system can effectively prevent direct sunlight from impacting objects on display during different time intervals. This is achieved in conjunction with physical computing, which enables the adaptable and highly precise control of light quantities affecting objects on display. It allows for the selective shading of specific areas within the building and it can be applied to other building types facing challenges related to natural light control or specific sun-shading needs.

Author Contributions

Conceptualization, Nassareen.A.; Methodology, Nassareen.A and Chawee.B.; Validation, Nassareen.A.; Formal analysis, Nassareen.A. and Chawee.B.; Investigation, Nassareen.A.; Resources, Nassareen.A.; Data Curation, Nassareen.A. and Chawee.B.; Writing - Review & Editing, Nassareen.A. and Chawee.B; Visualization Preparation, Nassareen.A.; Supervision, Chawee.B.; Project administration, Nassareen.A.; Funding acquisition, Chawee.B. All authors have read and agreed to the published version of the manuscript.

References

Betul, K., & Nese, C. (2023). *Enhancing visual comfort with Miura-ori-based responsive facade model* [Master's thesis]. Department of Architecture, Kocaeli University.

Hosseini, S.M., Mohammadi, M., Rosemann, A., Schröder, T., & Lichtenberg, J. (2019). *A morphological approach for kinetic façade design process to improve visual and thermal comfort: Review. Smart Architectural Technologies* [Master's thesis]. Department of the Built Environment, Eindhoven, the Netherlands.

Jules, M. (2011). *Designing kinetics for architectural facades: State change.* Pindar NZ.

Karen, C. (2011). *Galleria centercity / UNStudio*. Archdaily. https://www.archdaily.com/125125/galleria-centercity-unstudio

Lilly, C. (2019). *What are kinetic facades in architecture?*. Archdaily. https://www.archdaily.com/922930/what-are-kinetic-facades-in-architecture

Paibulkijcharoen, T. (2018). *Multi-objective genetic algorithm for transformable architectural design* [Master's thesis]. Faculty of Architecture and Planning, Thammasat University.

Srinoradithlert, K. (2017). *Design guideline for automatic facade controlled by smartphone application* [Master's thesis]. Faculty of Architecture and Planning, Thammasat University.

Sribumrungsart, P. (2014). *Automatic daylight control systems in architecture based on interaction of human behaviour* [Master's thesis]. Faculty of Architecture and Planning, Thammasat University.

Sanakaewthong, S., Miyata, K., Horanont, T., Xie, H., & Karnjana, J. (2022). *Kinetic facade design with Eshelby Twist for sunlight exposure reduction* [Master's thesis]. Japan Advanced Institute of Science and Technology.

Shivam, A (2021). *Kinetic facade: Evolution and design process.* ArcAce. https://arcace.ca/kinetic-facade-evolution-and-design-process

Zhang, A., Bokel, R., Dobbelsteen, A. van den., Sun, Y., Huang, Q., & Zhang, Q. (2017). *Optimization of thermal and daylight performance of school buildings based on a multi-objective genetic algorithm in the cold climate of China* [Master's thesis]. School of Architecture, Tianjin University.