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Article

Using Biomimicry Science in the Design of a Kinetic Façade to Regulate the Amount of Daylight Entering a Working Space

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Abstract: Today, buildings are increasingly designed with transparent materials, with glass paneling being especially popular as an installation material for its architectural allure. However, its major drawback is admitting impractical amounts of sunlight to interior spaces. Office buildings with excessive sunlight in indoor areas result in worker inefficiency. This article studied kinetic façades as means to providing suitable sunlight for interior spaces integrated with a triple identity of DNA structure, photosynthetic behavior, and the twist used, which was divided into generation and evaluation. The generating phase first used an evolutionary engine to produce potential strip patterns. The kinetic façade was subsequently evaluated by Climate Studio software to validate daylight admission in an indoor space with Leadership in Energy and Environmental Design (LEED) version 4.1 criteria. To analyze the kinetic façade system, the building envelope was divided into four types: glass panels, static façades, kinetic façade (version 1, rotating movement), and kinetic façades (version 2, twisting movement). In addition, for kinetic façades, degrees of simulation for versions 1 and 2 were 20, 50, 80, and 100 degrees, in order to ascertain potential for both façades to the same degree. Comparing all façades receiving the daylight factor (DF) into the space from more or less sunlight resulted in the decreasing order of potential as follows: entirely glass façade, kinetic façade version 2, kinetic façade version 1, and static façade. By receiving daylight factor (DF), the façade filtered appropriate amounts of daylight into the working space moderately and beneficially. Daylight simulation results indicated that the newly designed kinetic façade (version 2) had more potential than other building envelope types in terms of filtering beneficial daylight in indoor areas. This article also experimented with the kinetic façade prototype in an actual situation to test conditional environmental potential. The kinetic façade (version 2) was explored in the building envelope with varied adaptability in order to provide sunlight and for private-to-public, public-to-private, or semi-public working areas.

Keywords: kinetic façade; biomimicry; daylight factor (DF); LEED criteria; strip form

1. Introduction

Natural light is crucial to humans, having many aspects according to the following issues. Historically, it has been divided into three parts: (a) those related to humans and buildings; (b) those related to lighting and buildings; and (c) those related to interactions between humans, the workplace, and productivity.

First is the relationship between humans and buildings. Humans spend between 80% and 90% of their lives indoors [1–3]. One of the indoor spaces where humans spend much of their time is the office building. Most office work occurs during the day; thus, daylight is crucial for human activities. As Figure 1 illustrates, the Illuminating Engineering Society of the United States (IES) established illumination levels as essential for safety and

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productivity as early as 1913. In addition, illumination levels were specified for specific activities [4].

Second is the relationship between lighting and buildings. In the 1950s, daylight was the primary source of lighting in the indoor areas of buildings. Buildings were planned and in-built designed to maximize available daylight. In 1990, researchers examined the relationship between natural light and health, concluding that daylight or natural light is essential for indoor workers' health [5,6]. In 1993, several buildings were created with 50% daylight via a skylight, such as the Wal-Mart building in Oklahoma; sales tracking indicated sales pressure (sales per square foot) was much higher than in other stores with less daylight. In addition, daylight affects people's emotions within buildings, such as in terms of buying things [7].

Third is the relationship between humans, the workplace, and productivity, as people are a company's biggest asset and expense [5,6]. Employee salaries represent about 13 times the building cost [8]. Therefore, it stands to reason that these resources are managed for optimum productivity, efficiency, and sustainability. In the 20th century, window design took off in new directions to become more cutting-edge, as windows are more than functional light and air openings. They are, indeed, important architectural components that highlight fresh ideas and creativity. Moreover, they can aid several aspects of productive design, such as changing spaces more widely and assisting users in performing activities in the building more efficiently [9].

However, more windows or open, transparent elements are also disadvantageous; thus, in the 21st century, more buildings have been constructed with a concern around environmental responsibility and engagement with nature, involving the way in which to integrate nature and architecture effectively. Incorporation of natural light is the prevalent design method; for instance, learning rooms promote engagement with natural light. It has been demonstrated that incorporating natural light and greater elements of nature improves academic attainment, reduces disciplinary problems, reduces stress, promotes curiosity, and increases occupants' ability to concentrate. In the interest of environmental responsibility, schools will continue to combine the multiple benefits of nature with energy-efficient lighting options. In addition, there is a current tendency among architects and designers to design building features to improve building performance and receive the appropriate amount of natural light. For instance, using façades or building envelopes enhances daylight quality that balances the exterior and interior of buildings [10,11].

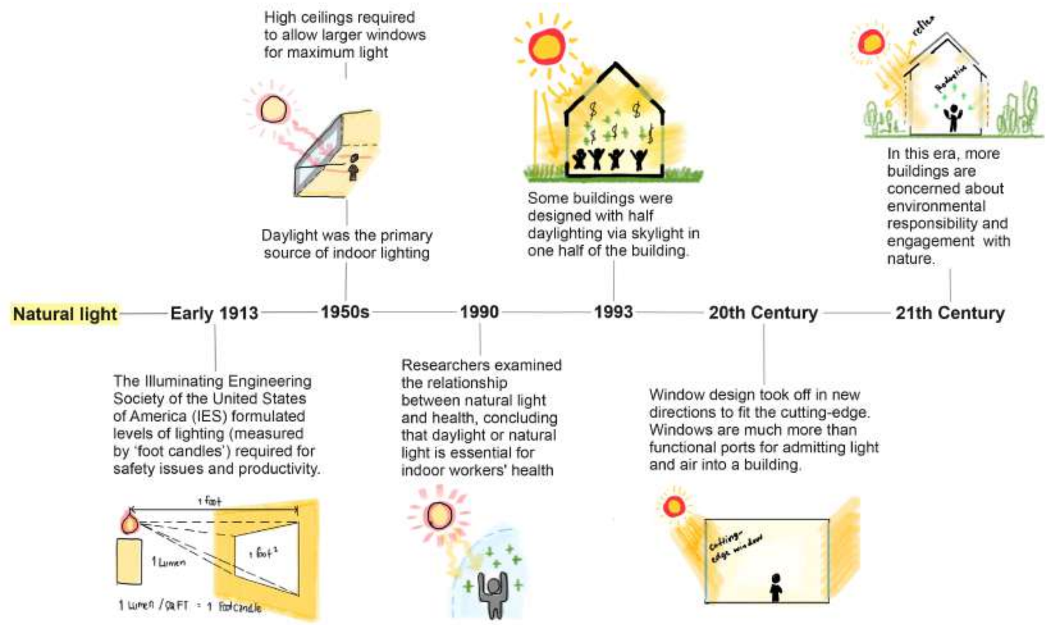

Figure 1. The timeline of how natural light is crucial in buildings.

An example case of a building that was designed with an exaggerated proportion of transparent materials or a massive amount of open building envelope space is the Suvarnabhumi International Airport, Thailand, as shown in Figure 2, which has a problem with receiving excessive sunlight into the interior space. Thus, it adversely affects users who view it as uncomfortable and a waste of space [12–14]. Furthermore, in the case of working spaces, is common that users are not uncomfortable using the space since they receive excessive sunlight [15], as shown in Figure 3. It directly affects individuals that actively use these spaces [16], especially in terms of physical wellness.

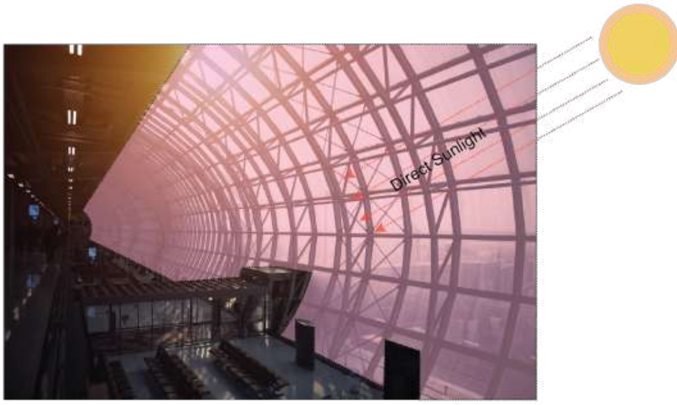

Figure 2. Suvarnabhumi International Airport in Thailand was constructed with excessive transparent materials, causing sunlight to come into the indoor space, particularly direct sunlight.

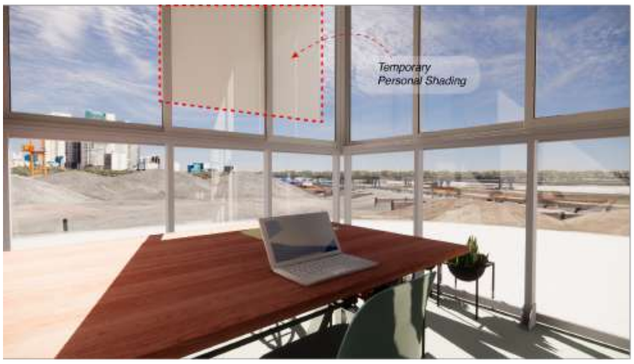

Figure 3. An over-glazed façade will cause excessive glare and overheating in interior spaces. The only option for occupants is to install protective measures in their workstations.

There was research that explored how natural light affected the performance of 278 university students in a course with three-hour weekly lectures. The study was taught six times in six consecutive years (2013–2018) [15]. The experiment separated the students into two groups: one group in an artificially lit basement classroom, and one group in a classroom with windows receiving natural light. The exam and attendance scores were compared; the group in the classroom with windows had better exam scores than the basement classroom group, respectively, at 13.17% and 7.73% [15].

Furthermore, natural light affects human health, particularly eyestrain, which is a common condition that occurs when eyes become exhausted from prolonged use, such as staring at computer displays or other digital devices, reading, or working in front of a computer [17,18]. Almost all eye discomfort is caused by insufficient illumination, both natural and artificial [19]. This issue emerges due to the inappropriate wall ratio for the climate. Therefore, it is inefficient to utilize space such that natural light remains essential to human activities. This issue motivated the researchers' interest in properly managing the environment in buildings, which is the daylight factor (DF) response to human comfort via the façade.

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This research studied the provision of appropriate natural light into the workspace by using a kinetic façade mimicking the distinctive points such as physical aspects, behavior, and movement. This research used the physical nature of DNA, the phototropism phenomenon, and the twist movement to integrate the distinctive point of each element's feature into a kinetic façade. The development of kinetic façade technology has allowed for the effective control of an interior environment defined by natural light that promotes worker productivity and human wellness [18,20]. The objectives of this research are as follows:

1. To research the suitable façade forms (forms-finding) that are effective in providing a suitable interior environment that with natural light by using science;
2. To study the optimal efficacy of the façade, namely, the daylight factor (DF);
3. To evaluate the kinetic façade in terms of LEED version 4.1 criteria;
4. To evaluate the efficacy of kinetic façade in a real-world situation.

2. Related work

2.1. Summarizing gaps, problems, and limitations of related works

Figure 4 shows the gaps in the literature review related to this study. This was divided into three parts, which are (1) technical problems, (2) usage problems, and (3) academic and research problems.

Firstly, (1) technical problems; it has been separated into two parts (1.1) controlling problems and (1.2) structural systems.

(1.1) Controlling problems have two issues, which are as follows;

(1.1.1) Delays in the movement of a system. This problem occurs when the façade system does not respond directly to stimulus factors such as environment and human control [13,21–24].

(1.1.2) A system does not to respond to human behavior. This issue links to 1.1.1 and 1.1.2 that occur from the system not being connected to the environment; thus, it affects users in terms of their use of the space in the indoor area not being satisfied [13,21–26].

(1.2) Structural problems have two gaps, which are as follows;

(1.2.1) The large system of the façade. One of the problems of the kinetic façade is that the system is not compact; thus, it makes the façade challenging to install [13,21,23,24,27].

(1.2.2) The friction problems during the operation relate to the controlling problem; therefore, when designing the overall system, the controlling elements are crucial in reducing the friction issue [21,23,24,28–30].

Secondly, (2) usage problems have an issue that concerns (2.1) user needs, wherein there is a gap in which occupants seek localized control of their specific working, living, or learning environment. This problem relates to human behavior since every person has a different purpose for using the space—not only in terms of working but in utilizing it as a multi-purpose space. In this issue, the kinetic façade should have a solution for adapting to use. For instance, users can control the kinetic façade via the application instead of automatically adjusting the sunlight intensity. Although this is a different objective in this study, we have a guideline for using the kinetic façade for various purposes in the last topic [22,23,25,31–33].

Thirdly, (3) academic and research problems have two significant issues, namely, (3.1) gaps in the forms of the façade and (3.2) lacking issues.

(3.1.1) Forms of the façade have a gap that is easy to summarize in terms of the façade forms. It does not include optimization issues; therefore, in this study, we simulated the potential of the façade in many forms for comparison with the kinetic façade in a new design in terms of daylight factor (DF).

(3.2) Lacking issues were divided into four gaps, which are as follows:

(3.2.1) Few evaluation methods in terms energy efficiency since most papers have a concept design [21,24,34,35].

(3.2.2) Few measurements or evaluation data on real-world adaptive façade (AF) system assessment [21,23,33–44].

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(3.2.3) It being rare for projects to compare the effectiveness of façades [21,24,37,39–41,43].

(3.2.4) Most of the paper only simulating modeling in the software [21,22,37,40–42].

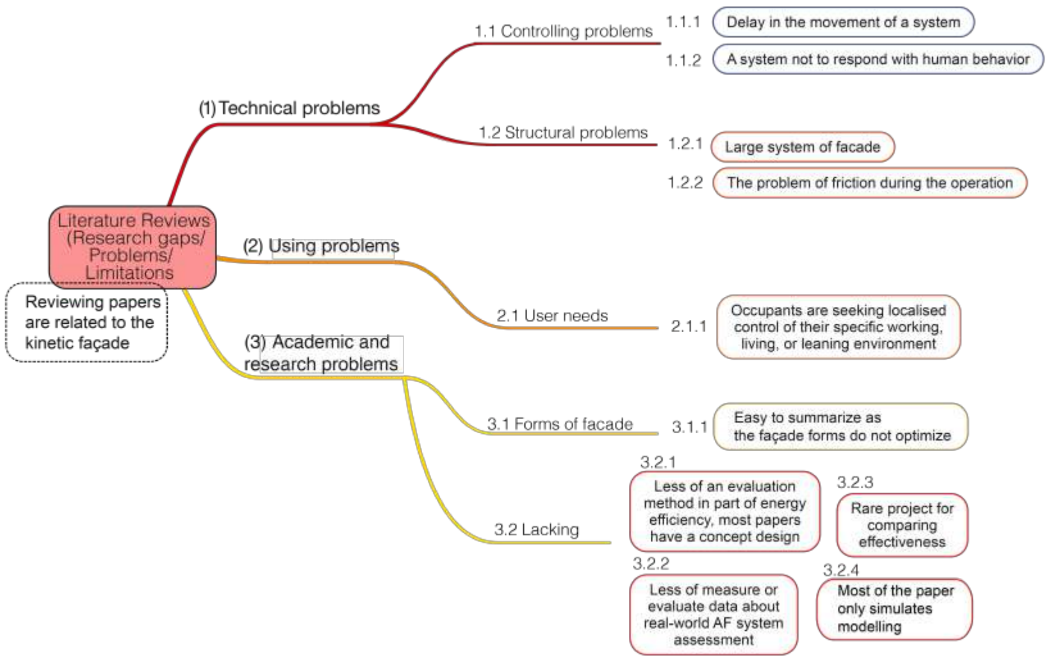

Figure 4. Summary of gaps, problems, and limitations of related works.

2.2. *Daylight factor*

In this study, the daylight factor (DF) and LEED v. 4.1 requirements were simulated by using Climate Studio; the software is the fastest and most precise form of environmental performance analysis for the architecture, engineering, and construction industries.

2.2.1. Formula expression

Daylight factor (DF) is a common and straightforward method for measuring the perceived daylight quality in a room. It is the ratio of outside illumination to interior illumination, represented as a percentage. The greater the DF, the more natural light a room receives; rooms with an average DF of 2% are considered daylit. However, a space is only supposed to have good natural lighting when the DF is greater than 5% [45–47],], as described in Table 1.

The formula is expressed as Equation (1) :

$$DF = 100 \times \frac{E_{in}}{E_{ext}} \quad (1)$$

In Equation (1)

- E_{in} is interior illumination at a fixed location;
- E_{ext} is horizontal outdoor illuminance under an overcast (CIE sky) or uniform sky.

The brightness of an overcast standard (CIE sky) varies with altitude. For example, the zenith is three times brighter than the horizon. This study used an overcast (CIE sky) to evaluate the potential of a kinetic façade to filtrate the daylight into the indoor space.

2.2.2. LEED version 4.1 criteria

LEED version 4.1 criteria is the next-generation standard for green buildings' design, construction, operations, and performance. It promotes buildings, concentrating on efficiency and leadership in order to deliver the triple bottom line returns of people, the

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Table 1. Daylight factor and appearance.

Average DF	Appearance
< 2%	Room looks gloomy.
2% to 5%	Predominantly daylit appearance, but supplementary artificial lighting is needed.
> 5%	The room appears strongly daylit; daytime electric lighting is rarely needed.

planet, and profit. LEED version 4.1 increases building standards for energy efficiency, water conservation, site selection, material selection, daylighting, and waste reduction. This study focused on the daylight factor (DF) part. The compliance options for evaluating LEED version 4.1 are separated into two measurements: daylight simulation and actual measurement [48].

Firstly, daylight simulation is divided into two options. Option 1 uses simulation to demonstrate that spatial daylight autonomy (sDA) is a measure that specifies a percentage of the area that satisfies minimum daylight illuminance levels for a specified fraction of the working hours per year; at least 55 percent of the space achieves sDA. In addition, the annual sunlight exposure (ASE) indicator reveals the possibility of visual discomfort inside work environments. For LEED version 4.1, space cannot exceed 10 percent.

Option 2 uses a simulation to demonstrate that illuminance levels between 300 and 3000 lux are achieved between 9 a.m. and 3 p.m. at the equinox.

Secondly, actual measurement (option 3) uses actual measurements to demonstrate that illuminance levels for 75% of the space are between 300 and 3000 lux. In this study, we integrated both measurements to evaluate the potential of the kinetic façade.

3. Research methodology

Figure 5 illustrates the overall diagram of the research methodology. It has four major sections: (A) biomimicry processes, (B) the kinetic façade part, (C) the validation part, and (D) the problems in the gap of the literature reviews. Firstly, the biomimicry process has three parts for integrating the distinctive part of nature into a kinetic façade, which are the physical appearance of DNA (deoxyribonucleic acid), the movement from the Eshelby twist, and behavior from the phototropism phenomenon. First, these elements are interpreted as kinetic façade forms via a computational method in part B. Secondly, part B is the kinetic façade part that inputs the data from parts A to part C to simulate the kinetic façade. This process uses a computational method for façade optimization that uses software for the simulation, namely, Rhino and Grasshopper. Rhino is used to build 3D buildings for plugging in the kinetic façade, and Grasshopper uses two plug-ins, namely, Climate studio and Wallacei. Climate studio, the most precise program for analyzing environmental performance, uses natural light analysis regarding daylight factor (DF) and LEED version 4.1 criteria. Wallacei, an evolutionary engine that enables users to simulate evolution, is used for analyzing suitable façade patterns. After that, we summarize the potential of each façade type; only glass panel, static façade, kinetic façade (version 1, rotating movement), and kinetic façade (version 2, twisting movement). After summarizing the data in the simulation, the next step is the real-world testing part, which involves fabrication, testing, and validation. This step makes the mini prototype of a kinetic façade that uses material that is of high flexibility, durability, and breathing ability (moisture-wicked), as well as being waterproof.

Furthermore, the mini prototype must have a compact system; only the top and bottom are used for controlling the façade since the target for a combination of the material and controlling system must be a lightweight and flexible structure. Thirdly, part C is the validation part; this study used the box spaces for simulation, which are sizes S (5 x 8 meters), M (10 x 8 meters), and L (15 x 8 meters), by using the different types of façades. It has only a glass panel, a static façade, and a kinetic façade (version 1) with 20 deg, 50 deg,

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80 deg, and 100 deg, as well as a kinetic façade (version 2). The kinetic façade version 2 also experiments with 20 deg, 50 deg, 80 deg, and 100 deg. All steps must respond to the problems in the gap of the literature reviews in part D, which are as follows:

1. Delay in the movement must be solved by a practical test;
2. A system does not respond to human behavior solved by a practical test;
3. A large system of a façade must be solved by a practical test;
4. The problem of friction must be solved by a practical test;
5. Occupants seek localized control of their specific working, living, or learning environment. The guideline clarified this gap for installing and using the kinetic façade since the kinetic façade can be adjusted for any purpose that the user wants. For example, if users do not want the kinetic façade to move automatically by sunlight, it will adapt the façade that adjusts by human control;
6. Easily summarize the façade forms (do not optimize) and solve by comparing numerical data in real-world testing and simulating data;
7. A rare project for comparing effectiveness, solved by comparing numerical data in real-world testing and simulation data;
8. Rarely measuring or evaluating data in a real-world kinetic façade system assessment, solved by comparing numerical data in real-world testing and simulation data;
9. Less of an evaluation method in terms of energy efficiency since most papers have a concept design, solved by comparing numerical data in real-world testing and simulation data.

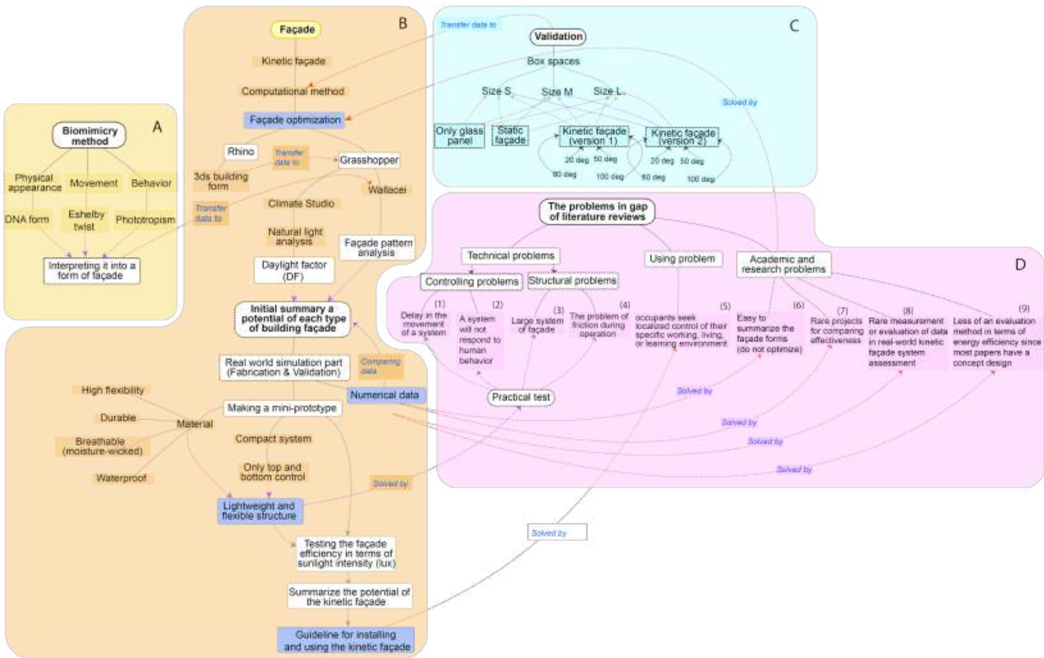

Figure 5. The overall diagram of the research methodology.

3.1. *Comparing the effectiveness of the façade*

Figure 6 shows the factor for comparing the effectiveness of each façade type; the data were collected to compare the efficacy of the façade by simulating the space in the same condition that focuses on daylight factor (DF) and LEED version 4.1 criteria. The variables are as follows:

- Independent variables:

1. Without façade (only glass panel);
2. Static façade;
3. Kinetic façade (version 1, rotating movement);

4. Kinetic façade (version 2, twisting movement).

- Dependent variables:

1. The natural light that focused on the daylight factor (DF);
2. LEED version 4.1 criteria.

- Control variables:

1. Surrounding: No existing buildings nearby, and the same zone for the simulation;
2. Location: Bangkok, Thailand;
3. Climate: Overcast sky;
4. Period: Daylight —annual period analysis, time analysis (8:00 a.m. to 6:00 p.m.).

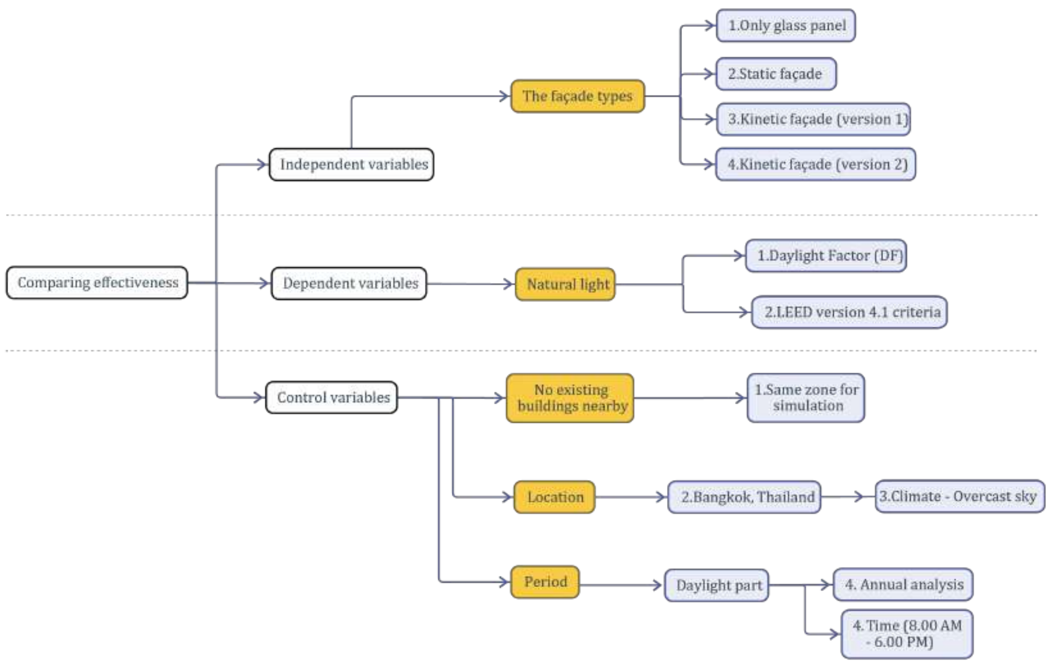

Figure 6. Variant diagram for the comparison of effectiveness.

4. Biomimicry part

4.1. Translating the biomimicry method to the kinetic façade idea

Biomimicry brings modern ideologies closer to nature by using nature as a design inspiration to tackle human problems in a sustainable manner [49]. Biomimicry connects the constructed environment to the natural world by emulating, measuring, and learning from Mother Nature. This strategy is based on the idea that "the more our environment resembles the natural world, the more likely it is that we will be accepted on this home that is ours, but not ours alone." [50]. Carl Hastrich created the biomimicry design spiral in 2005 [5,51]. It is a step-by-step process for transforming the ideas of nature into innovative and sustainable design solutions. Biomimicry processes were compounded into six processes, namely, (1) identify, (2) translate, (3) discover, (4) abstract, (5) emulate, and (6) evaluate. This process clarified each step in this study, as shown in Figure 7.

4.1.1. Identify process

An identification of the functions in design that need to be performed. For example, this study has the purpose of a kinetic façade that can adjust itself through following the sunlight intensity.

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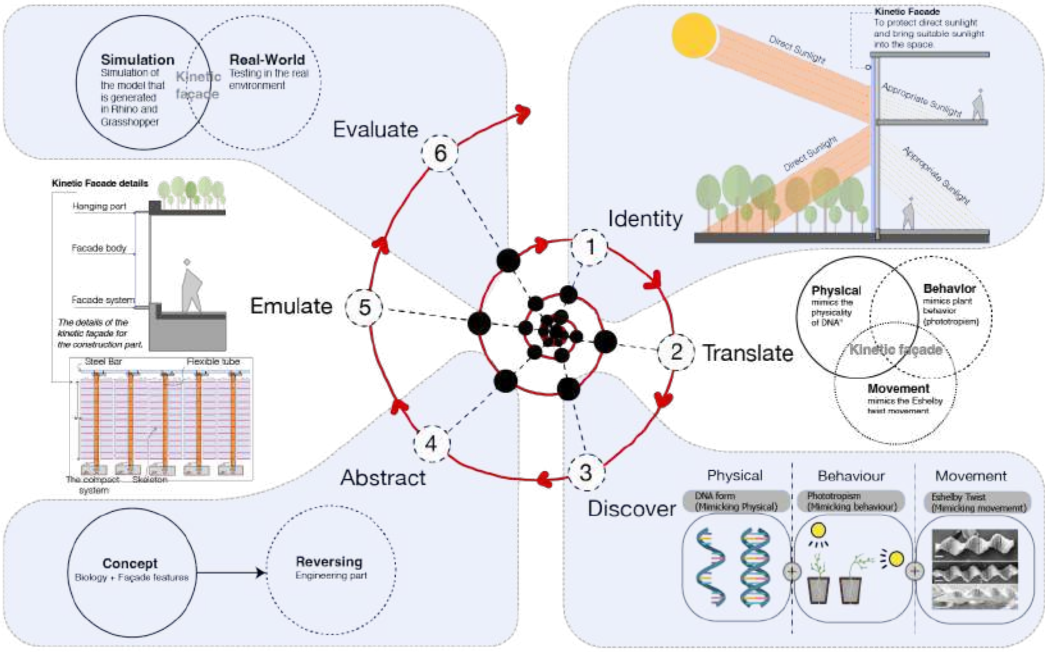


Figure 7. The biomimicry design spiral principle for integration in this study.

4.1.2. Translate process

This process is integrated between the biological ideas, namely, physical aspects, behavior, movement of nature, and the identify process, which is the main feature of the kinetic façade in terms of the suitable design solution.

4.1.3. Discover process

To find the strategies of nature. This study had three components for accomplishing the kinetic façade target: physical environment, behavior, and movement. The idea of physical aspects stems from the physical of deoxyribonucleic acid (DNA) structure. Behavior is viewed in light of the phototropism phenomenon of plants that want to receive sunlight; thus, this phenomenon is of a beneficial feature for the kinetic façade and can adjust itself to follow the sunlight intensity.

Finally, the Eshelby twist is the phenomenon of a nanowire pipe tree that has a twist; it is a fascinating movement since it can be integrated into the DNA form.

4.1.4. Abstract process

Reversing the ideas in terms of engineering has practical benefits for installation within buildings. This study must change the integration ideas between nature and kinetic façade identity to a suitable process that can work in an actual situation.

4.1.5. Emulate process

Exploring the kinetic façade components in construction that respond to the façade features in process one (the identify process).

4.1.6. Evaluate process

Compare the kinetic façade performance between simulations and real-world testing to know the performance of the kinetic façade using the biomimicry science method.

4.2. Analysis of the probability of façade forms (Phase 1)

This section analyzes the likelihood of façade patterns influenced by the physical DNA, phototropism behavior, and Eshelby twist to design the strip form. Wallacei, an evolutionary algorithm software for producing algorithm forms, was used to generate this.

Evolving algorithms are a collection of optimization algorithms that mimic the mechanisms of natural evolution [52].

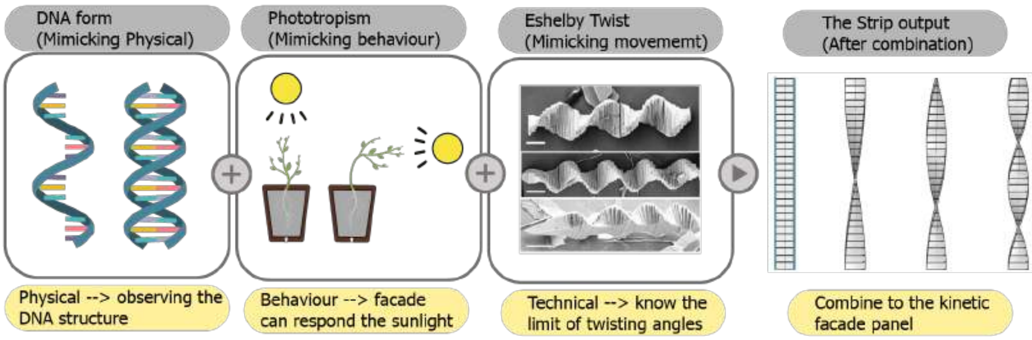
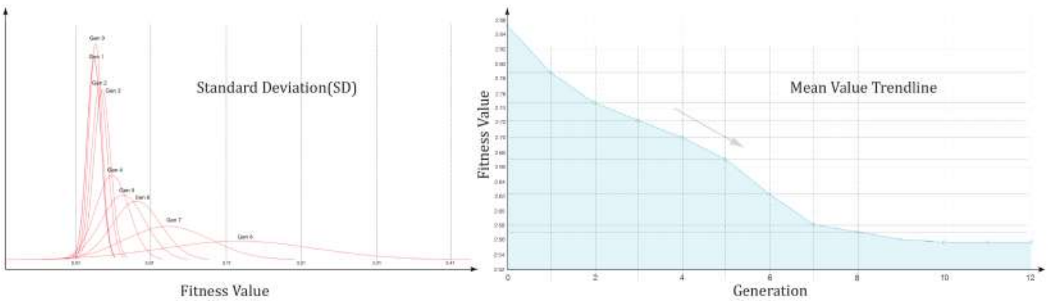


Figure 8. An inspiration for a façade merging physical DNA and phototropism behavior.

Figure 8 shows the process of generating the strip, which has three components: the physical DNA structure, phototropism behavior, and the Eshelby twist. Firstly is the DNA form; this study mimicked the physical DNA form, namely, its structure. Secondly is the phototropism phenomenon, found through observing the phototropism behavior of plants. The purpose is that plants adjust their trunk to sunlight for photosynthesis. It is stimulated by photoreceptors related to signaling mechanisms. In addition, plants modify their development characteristics in response to environmental influences, such as the amount of available sunshine [53]. Thirdly is the Eshelby twist, understood through studying the movement of nanowires that can twist themselves according to the environment, which is a benefit for a technical application that can know the limit of twisting angles, being effective for preventing sunlight. These factors are crucial for interpreting the façade strip mechanism since every component has a dominant feature to prevent sunlight, making the building effectively unique.



(a) the trend of SD in eight generations (b) the mean value trendline of the strip forms

Figure 9. Overall generation of the strip phenotype in 450 solutions and the trend of SD.

Figure 9a depicts the strip phenotype probability patterns in the standard deviation (SD) graph, resulting in 450 solutions from generations 0 to 8. When compared to other generations, each generation differs and repeats patterns. For example, generation 0 and generation 5 share some strip patterns. However, the strip patterns that result from the phenotype are distinct, resulting in a range of strip phenotypes that are shown in the slope of each generation. For example, generation 0 is a higher slope than generation 8, meaning generation 0 is more diverse in terms of strip forms than generation 8. The strip pattern diversity also relates to the image shown in Figure 9b, the mean value trendline illustrated in the slope pattern; it has a declining graph, which means the strip forms have less diversity in the latest generation. The strip phenotype is produced by simulating the DNA structure, phototropism phenomenon, and Eshelby twist movement to reproduce the characteristics of strip patterns for use in the kinetic façade model. Phenotypes are the observable characteristics of an individual that result from the interaction between its genotype (total genetic inheritance) and its environment. Observable characteristics include behavior, biological qualities, color, shape, and size [54]; for instance, the same bird species has a different physical appearance (phenotype) in a different region [55]. Therefore, the phenotype is the simple indicator for observing the strip forms of the façade. For instance, Figures 10 and 11 show the probability output in 50 solutions of a strip phenotype in generation 3; it has different and the same strip forms in the generation, with 10 patterns (phenotype) related to sunlight. The overall result in 450 solutions paused for generating the phenotype in Wallacei software since when looking at the trend of SD in eight generations, as shown in Figure 9a, the slope of the last generation is less than the first generation. It indicates that the strip phenotype is repeated in the same patterns—this serves no purpose for generating for the next generation. A low standard deviation indicates that most results are comparable (less variation within the population). On the other hand, a high standard deviation indicates that the results are further from the mean, with more variation within the population [56]. When the SD graph is examined, the earlier generation displays a greater variety of strip patterns than the most recent generation.

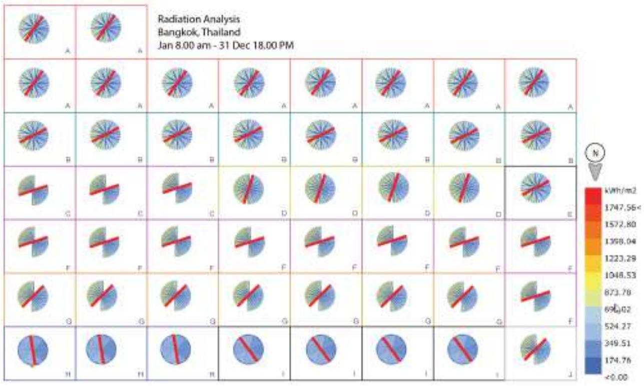


Figure 10. The probability of the strip phenotype in generation 3 (50 solutions); top view.

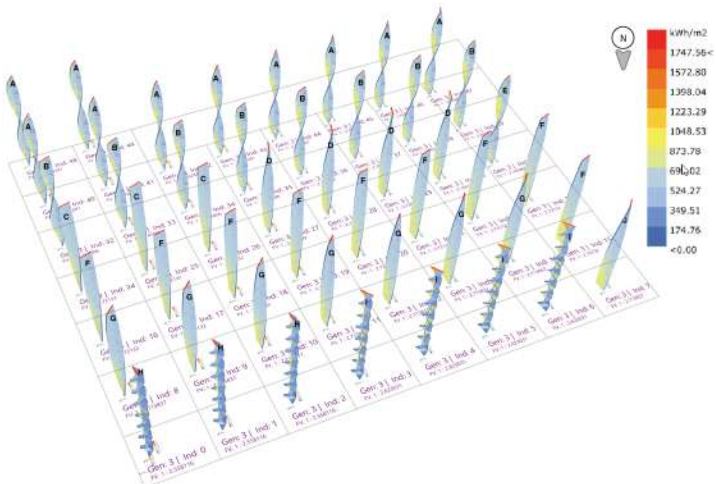


Figure 11. The probability of the strip phenotype in generation 3 (50 solutions); isometric view.

Figure 12 summarizes generation 0 through to generation 8, the strip patterns applicable to the kinetic façade concept. These patterns were chosen because they each respond to sunshine differently, much like phototropism behaviors. The potential to shield the sun at various times depends on the varying strip pattern angles. Thus, adapting to user needs in various conditions when living in a space is advantageous since the strip will twist more when the light intensity is as low as a strip 3.

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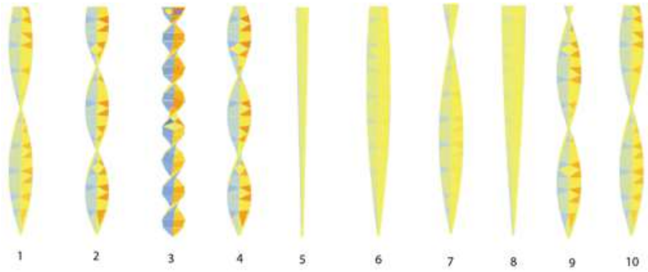

Figure 12. The strip form summaries of the different characteristics and potential after the simulation with sunlight.

4.3. Analysis of natural light ambience (Phase 2)

Figure 13 shows the setting-up node for the simulation in the box spaces. The node is crucial for simulating the daylight factor. Therefore, we set the node position close to the human eye, approximately 1.10 meters high, which is a very sensitive distance to simulate the daylight factor [57] when performing work activities. This node level uses every size of the box. If we know the daylight level in this position, we will compare and develop the façade in future issues.

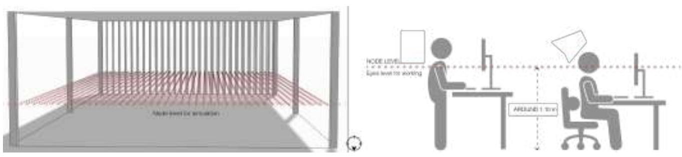

Figure 13. Set-up of the model for simulation in terms of daylight factor.

5. The validation of the façade

*5.1. **Simulation processes***

Figure 14 illustrates the box spaces for the simulation in terms of daylight factor (DF) and LEED version 4.1 criteria in terms of the different sizes of boxes that must be installed into the façade in different types for the simulation, including:

1. Only a glass panel;
2. Static façade, which is 90 deg (fix angle);
3. Kinetic façade (version 1; rotating), which 20 deg, 50 deg, 80 deg, and 100 deg;
4. Kinetic façade (version 2; twisting), which 20 deg, 50 deg, 80 deg, and 100 deg; this type of façade was explored efficiently in this study, particularly in terms of natural light into the space.

The reason for simulating the boxes in different sizes is to know the effects of sunlight entering the area and how much of a difference there is when simulating the difference between the façade and area sizes. The box sizes refer to the dimensions of the home office, with sizes S, M, and L. The approximate capacities of people in the space of sizes S, M, and L are 16, 32, and 48 people, respectively. This study varied only in terms of the width dimension; the depth was fixed since the depth affects the accessibility of sunlight. Furthermore, it was beneficial to simulate the criteria for a green building in terms of LEED version 4.1. Therefore, each space was assumed as the office in different sizes, being of benefit for initial prediction in order to pass or fail the criteria.

5.2. Results of the daylight simulation

5.2.1. Comparing a façade in all types

Figure 15 summarizes the simulated daylight factor (DF) that is referred to in Figures A27, A28, A29, A30, A31, A32, A33, A34 and A35, and Figure A36. The bar graph was split by size and degree when comparing all façade types. First, the glass panel alone

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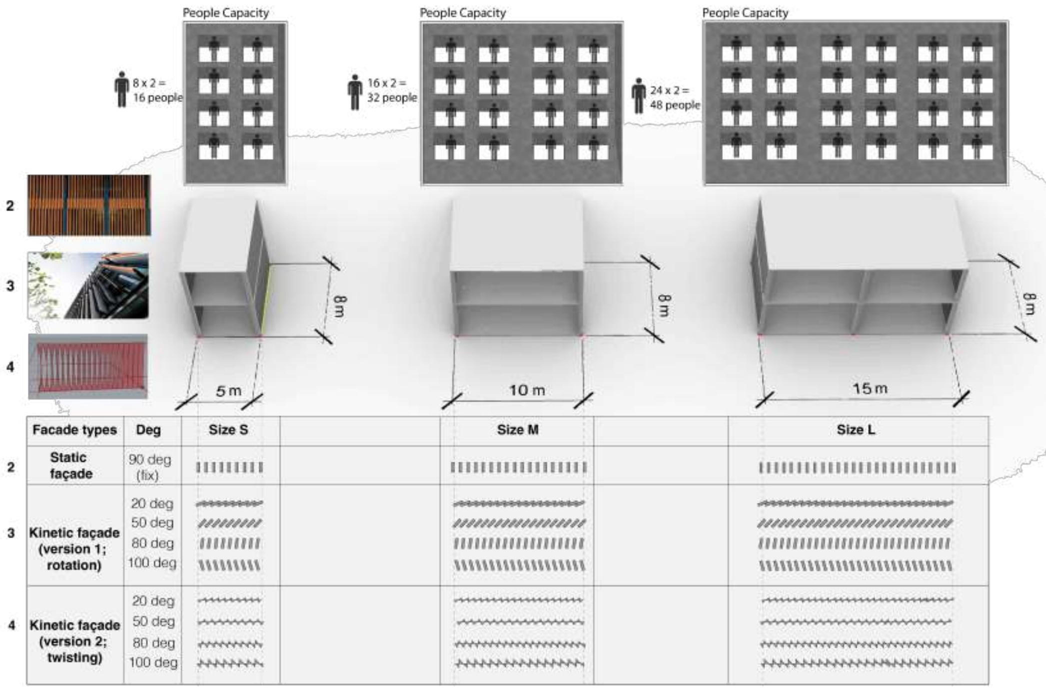

Figure 14. The box spaces for simulation in terms of daylight factor (DF).

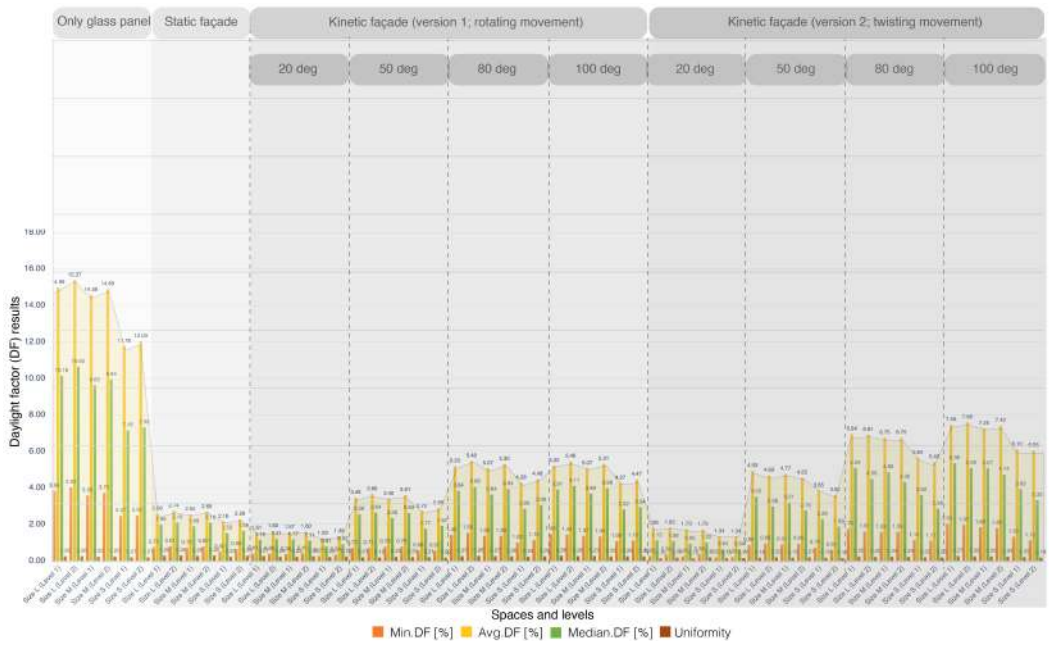

Figure 15. Comparing a façade in terms of daylight factors.

had the maximum daylight factor (DF) compared to the other building envelopes at 50 deg, 80 deg, and 100 deg. The static façade had a lower DF than the kinetic façades version 1 and 2. Excluding 20 degrees for both kinetic façades, the kinetic façade version 1 in 20 degrees had the lowest DF, followed by the kinetic façade version 2 in 20 degrees. When concentrating on the kinetic façades version 1 and 2, it was clear that kinetic façade version 2 had a somewhat greater average daylight factor (DF) than the kinetic façade version 1. This indicates that the kinetic façade version 2 can bring about more natural light into areas of any size in comparison with the kinetic façade version 1.

5.3. The results of LEED version 4.1 criteria

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Table 2. The results after the simulation of the glass panel alone, the static façade, and the kinetic façade (version 1) in terms of LEED version 4.1 criteria.

Façade Type	Size, Level	Area (ft^2)	sDA (%)	ASE (%)
Only glass panel	Large, level 1 (L1)	1211	100	35
	Medium, level 1 (M1)	807	100	33.33
	Small, level 1 (S1)	404	100	26.04
	Large, level 2 (L2)	1211	100	36
	Medium, level 2 (M2)	807	100	33.33
	Small, level 2 (S2)	404	100	32.29
	Total	4844	100	33.72
Static façade	L1	1211	100	0.00
	M1	807	100	0.00
	S1	404	97.92	0.00
	L2	1211	100	0.00
	M2	807	100	0.00
	S2	404	100	0.00
	Total	4844	98.83	0.00
Kinetic façade (Version 1, 20 deg)	L1	1211	84.00	0.00
	M1	807	83.82	0.00
	S1	404	52.08	0.00
	L2	1211	92.33	0.00
	M2	807	84.31	0.00
	S2	404	57.29	0.00
	Total	4844	81.22	0.00
Kinetic façade (Version 1, 50 deg)	L1	1211	100	0.67
	M1	807	100	2.45
	S1	404	95.83	1.04
	L2	1211	100	1.00
	M2	807	100	3.43
	S2	404	97.92	1.04
	Total	4844	99.48	1.57
Kinetic façade (Version 1, 80 deg)	L1	1211	100	0.00
	M1	807	100	1.47
	S1	404	100	0.00
	L2	1211	100	0.00
	M2	807	100	4.41
	S2	404	100	0.00
	Total	4844	100	0.98
Kinetic façade (Version 1, 100 deg)	L1	1211	100	0.00
	M1	807	100	0.98
	S1	404	100	0.00
	L2	1211	100	0.00
	M2	807	100	2.45
	S2	404	100	0.00
	Total	4844	100	0.57

Table 3. The results after the simulation of the kinetic façade (version 2) in terms of LEED version 4.1 criteria

Façade Type	Size, Level	Area (ft^2)	sDA (%)	ASE (%)
Kinetic façade (Version 2, 20 deg)	L1	1211	84.33	3.67
	M1	807	72.06	3.92
	S1	404	53.13	3.13
	L2	1211	93.33	4.00
	M2	807	83.33	5.88
	S2	404	54.17	2.08
	Total	4844	79.26	3.98
Kinetic façade (Version 2, 50 deg)	L1	1211	100	15.33
	M1	807	100	16.67
	S1	404	100	13.54
	L2	1211	100	13.00
	M2	807	100	13.24
	S2	404	100	10.42
	Total	4844	100	14.06
Kinetic façade (Version 2, 80 deg)	L1	1211	100	11.33
	M1	807	100	11.76
	S1	404	100	10.42
	L2	1211	100	16.00
	M2	807	100	15.20
	S2	404	100	13.54
	Total	4844	100	13.32
Kinetic façade (Version 2, 100 deg)	L1	1211	100	11.00
	M1	807	100	11.27
	S1	404	100	9.38
	L2	1211	100	16.00
	M2	807	100	15.69
	S2	404	100	15.63
	Total	4844	100	13.33

sDA—spatial daylight autonomy, a measure that specifies a percentage of area that satisfies minimum daylight illuminance levels for a specified fraction of the working hours per year.
ASE—the annual sunlight exposure: an indicator revealing the possibility for visual discomfort in inside work environments.

Table 2 illustrates the result of LEED version 4.1 criteria in terms of the glass panel alone, the static façade, and the kinetic façade (version 1). First, the glass panel alone exceeded daylight in spaces of every size; the easy factor for analysis of ASE is that standard daylight for human comfort in daylight in a space should not exceed 10% in the area. Second, in contrast, the static façade makes it challenging to let natural light into the room since this façade design is too compact; thus, artificial light must be installed into the space instead. Third, the kinetic façade (version 1) is 20 deg, 50 deg, 80 deg, and 100 deg. The output is that ASE can accept users to work in the space; however, some areas are too dark for a person to perform in. For instance, the 20 deg of the kinetic façade (version 1) in every space's ASE was 0%, being too dark to use natural light to work in, or in some areas was 100 deg, being too dark in terms of natural light in the large level 1 (L1), small level 1 (S1), large level 2 (L2), and small level 2 (S2).

Table 3 illustrates the result of the kinetic façade (version 2) in terms of LEED version 4.1 criteria, wherein the difference in degree represents the dynamic of the kinetic façade. It shows some degrees exceeded the standard criteria in ASE since the excellent condition should not exceed 10% in the space because it makes users uncomfortable when working. Thus, we solved this problem by changing the movement of the kinetic façade from moving with the same angle in one panel to moving with a different angle in one panel, as shown in

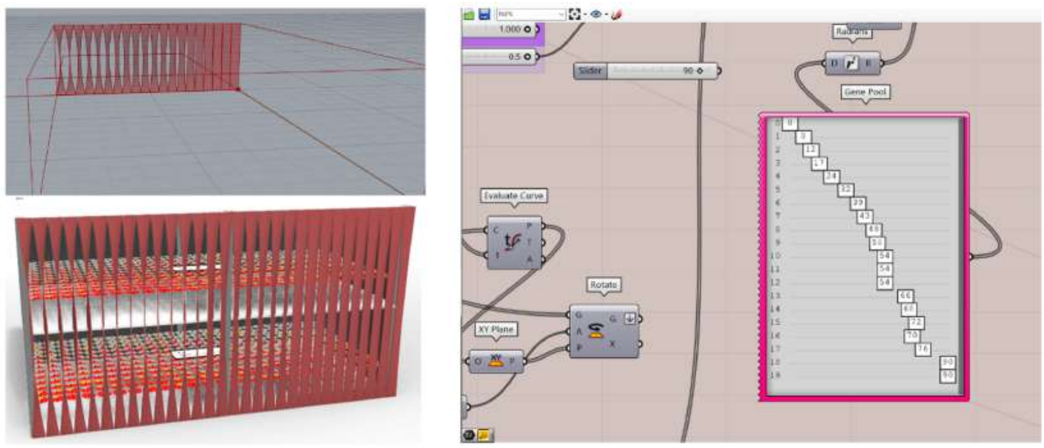
Figure 17. In other words, each strip of the kinetic façade freely moves to provide suitable sunlight.

Figure 16. Summary of all of the façades in terms of LEED version 4.1 criteria.

Figure 16 summarizes all the façade types in LEED version 4.1, along with the simulation results for each façade type: glass panels only, a static façade, a kinetic façade (version 1), and a kinetic façade (version 2). It met the LEED version 4.1 criterion for the lowest amount of daylight that can enter a space. In addition, all façades met the LEED version 4.1 requirements for a natural light reception. This criterion benefitted the kinetic façade design that sought to shield the sun, as demonstrated by this study. If the kinetic version 2 passes the LEED version 4.1 measures, it will obtain the minimal amount of sunlight required by the criterion, which makes human activities in the spaces more efficient. However, the ASE could be concerned with the next step, as a standard should not exceed 10% of the spaces.

5.3.1. Improving the potential of the kinetic façade version 2

Figure 17 shows the improvement potential for providing suitable sunlight in a space in terms of the kinetic façade version 2. It focuses on the movement of the façade from the same degree in one panel to different degrees in one panel for freely moving in each strip with regard to sunlight intensity.



(a) The facade movement pattern after improving (b) Freely move of facade degree in Grasshopper

Figure 17. The improvement of the potential of the kinetic façade version 2.

Figure 18 illustrates the results of improving the kinetic façade (version 2) in terms of LEED version 4.1, which shows sDA, ASE, and average lux. Evidently, improving the strip movement by freely moving to each strip is better in terms of output in order to provide

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suitable sunlight into the space as opposed to moving with the same pattern in one panel, and since the first factor of concern in this step is ASE, it should not exceed 10% in the space; this output ASE is 8.0% of all areas, being acceptable for the users in the space.

Figure 18. Improving the result of the kinetic façade version 2.

6. The Fabrication process

Figure 19 illustrates the kinetic façade model for fabrication in the 3D model. It has three major components: (A) head, (B) body, and (C) box system. The minor component compounds with fifth elements are as follows: (a) The main structure for installation into existing windows, which is a part of the head of the whole system. (b) The skeleton for supporting the fabric and (c) flexible fabric that uses polyester fabric since it has a material property that is fixed in the methodology, having high flexibility and durability, and being breathable (moisture-wicked) and waterproof. In addition, there is (d) a flexible tube that is a significant element for changing the degree of the façade; these parts are a part of the body of the whole system. Finally, the last part (e) is the bottom part; this part compounds with the box system of the façade, which is the crucial part for controlling the body.

6.1. Façade ideas for installation

Figure 20 shows the kinetic façade (version 2) elements that have five components for controlling the body in twisting, namely, (a) flexible tube, (b) skeleton (cable tile), (c) handle, (d) polyester fabric, and (e) system box (controller). We designed the kinetic façade as a module system that is easy to install and can easily have its elements changed. Firstly, in terms of installation purposes, each user has various needs, such as only one window panel for personal shading or a whole panel of the building, and this façade can respond to the user's need. Secondly, for the purpose of changing the façade elements, one of the problems with architecture components is the difficulty in replacing parts when they expire. Thus, this façade is designed to be easily changed in terms of its material, especially the fabric, in order to protect the short-life product from sunlight.

7. Results and Discussion

Table 4 shows the standard EN 12464 light and lighting [58]. Depending on the activity, the recommended light level for office work in indoor workspaces is between 500 and 1000

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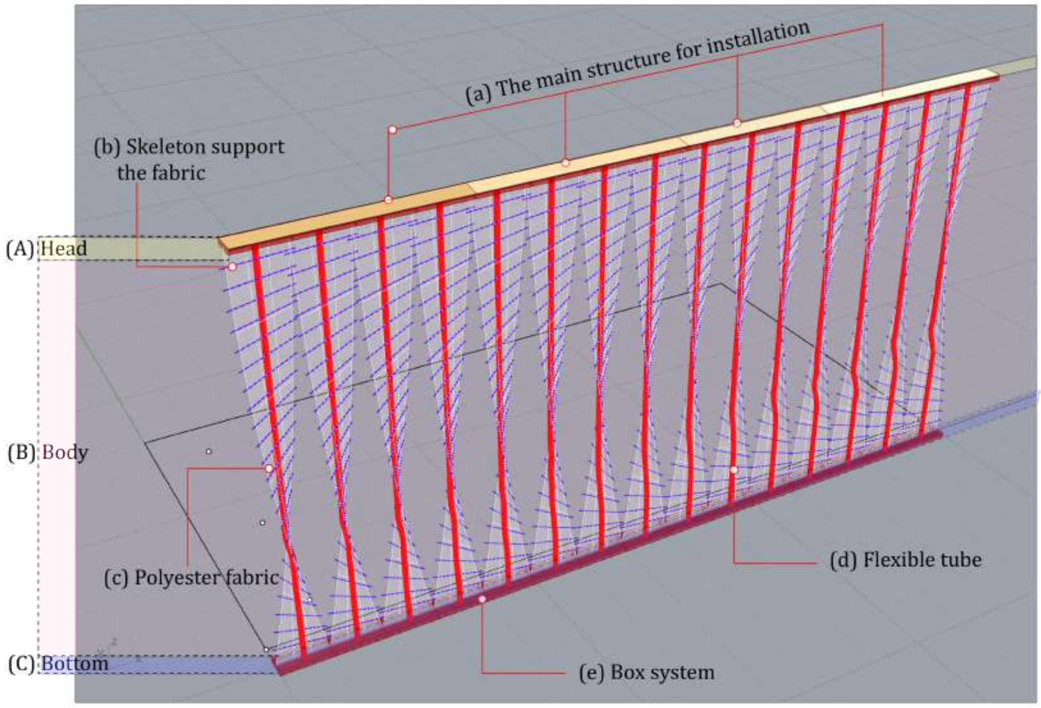

Figure 19. The model for the new design of kinetic façade fabrication.

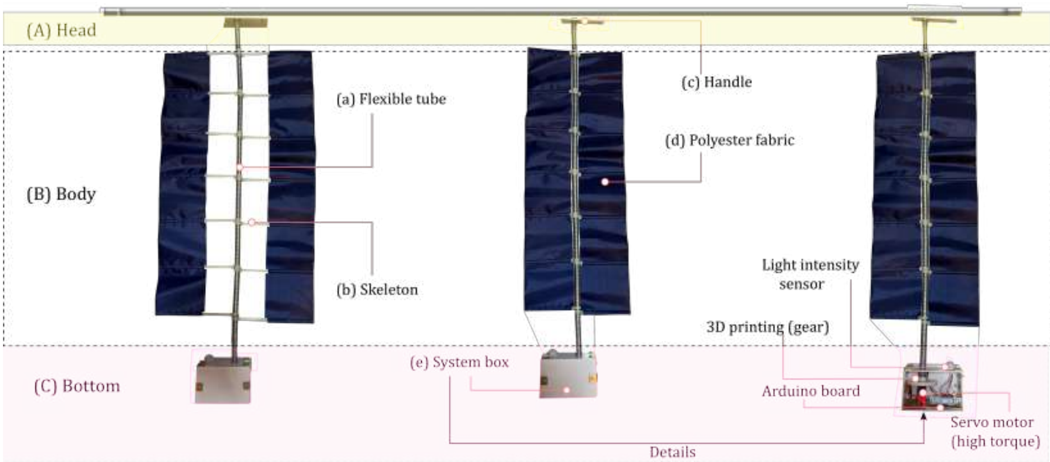

Figure 20. The kinetic façade (version 2) elements.

lux. The light level may reach up to 1500-2000 lux for precise and thorough work. However, in this study, the lux level with a lux range between 500 and 2000 lux was acceptable since it has a range of work scopes in different tasks, as highlighted in the table.

7.1. The results of the kinetic façade version 2 before and after installation

Figure 21 shows the testing results in the actual space situation without the kinetic façade. The result is an excess of daylight in the space, particularly in the morning period between 8:00 a.m. and 11:00 p.m.; at 8 a.m., it reached a peak of 26,104 lux. This harms human health, especially eye health, and affects work efficiency.

Figure 22 shows the results for testing the actual situation of the space after installing the kinetic façade. The result effectively reduced the daylight in the area, especially in the morning period that peaks at 8:00 a.m., at approximately 26,104 lux. It was reduced to 800 lux, suitable for the users in the space.

Figure 23 illustrates the kinetic façade version 2 at a record of movement at different times of the day between 8.00 a.m. and 6.00 p.m. with a time-lapse technique for observing

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Table 4. The light levels for each activity

Activity	Lux $/m^2$
Public areas with dark surroundings	20 – 50
Simple orientation for short visits	50 – 100
Areas with traffic and corridors: stairways, escalators, and travelators; lifts; storage spaces	100
Working areas where visual tasks are only occasionally performed	100 – 150
Warehouses, homes, theaters, archives, loading bays	150
Coffee break room, technical facilities, ball-mill areas, pulp plants, waiting rooms	200
Easy office work	250
Classrooms	300
Normal office work, PC work, study library, groceries, show rooms, laboratories, check-out areas, kitchens, auditoriums	500
Supermarkets, mechanical workshops, office landscapes	750
Normal drawing work, detailed mechanical workshops, operation theaters	1000
Detailed drawing work, very detailed mechanical works, electronic workshops, testing and adjustments	1500 – 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 – 5000
Performance of very prolonged and exacting visual tasks	5000 – 10,000
Performance of very special visual tasks of extremely low contrast and small size	10,000 – 20,000

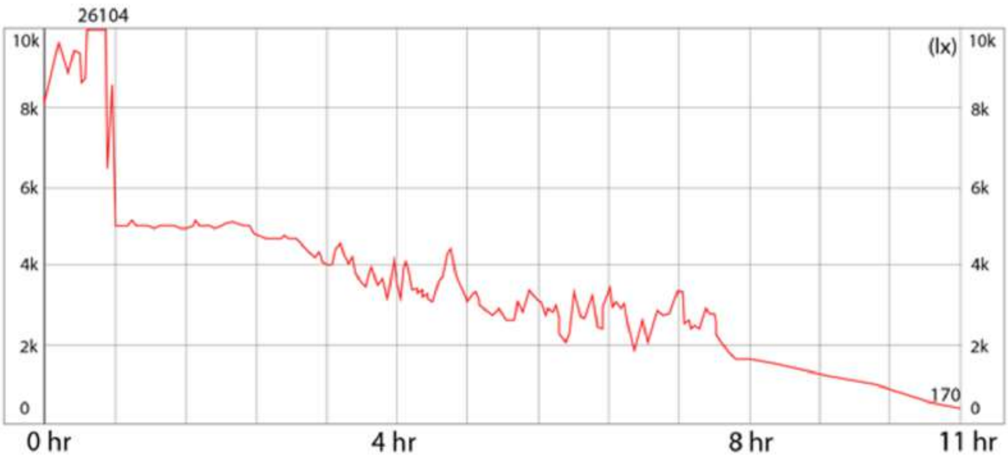

Figure 21. Testing the actual situation (before installing the kinetic façade).

the kinetic façade behavior. The result is that the kinetic façade was able to respond to the sunlight at different angles related to sunlight intensity on the testing day.

Figure 24 illustrates the comparison line graph for both the space without the kinetic façade and the space with the kinetic façade. The space with the kinetic façade version 2 was dramatically decreased. Moreover, the lux values were suitable for working areas with an average range of 500–2000 lux for working activity areas, as shown in Table 4. In contrast, compared with the space without a kinetic façade, it had excessive daylight through in the space, particularly from 8:00 a.m. to 2:00 p.m.; this was over sunlight for working activity areas.

Referring to LEED version 4.1 criteria in option 3, which is actual measurement, the illuminance level for passing the requirements is 75% of the space between 300 and 3000 lux. Table 5 illustrates the approximate lux values after installing the kinetic façade (version

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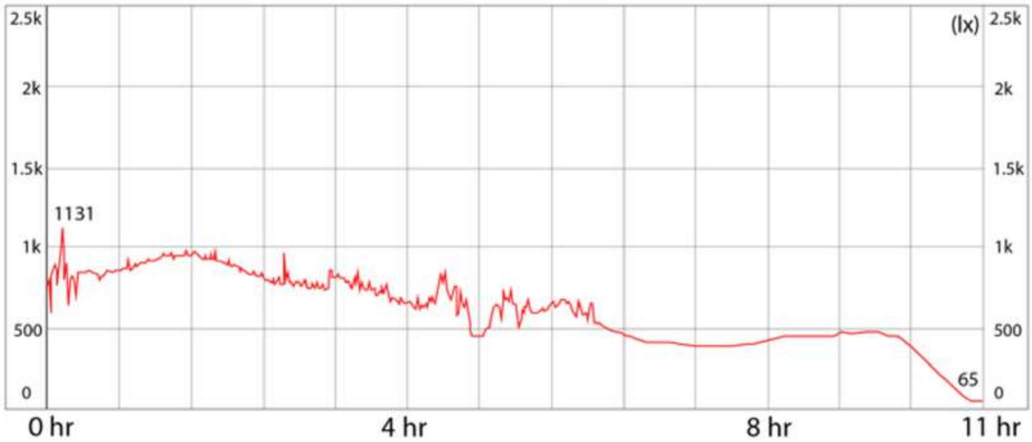

Figure 22. Testing the actual situation (after installing the kinetic façade).

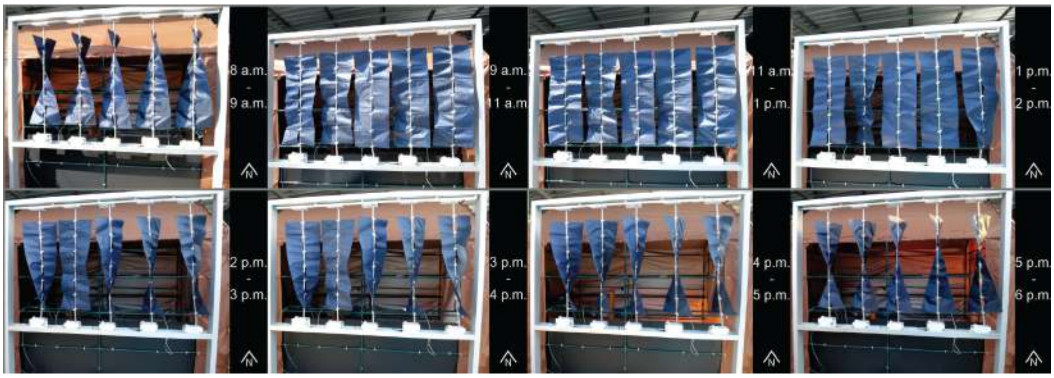

Figure 23. The kinetic façade movement in different time periods.

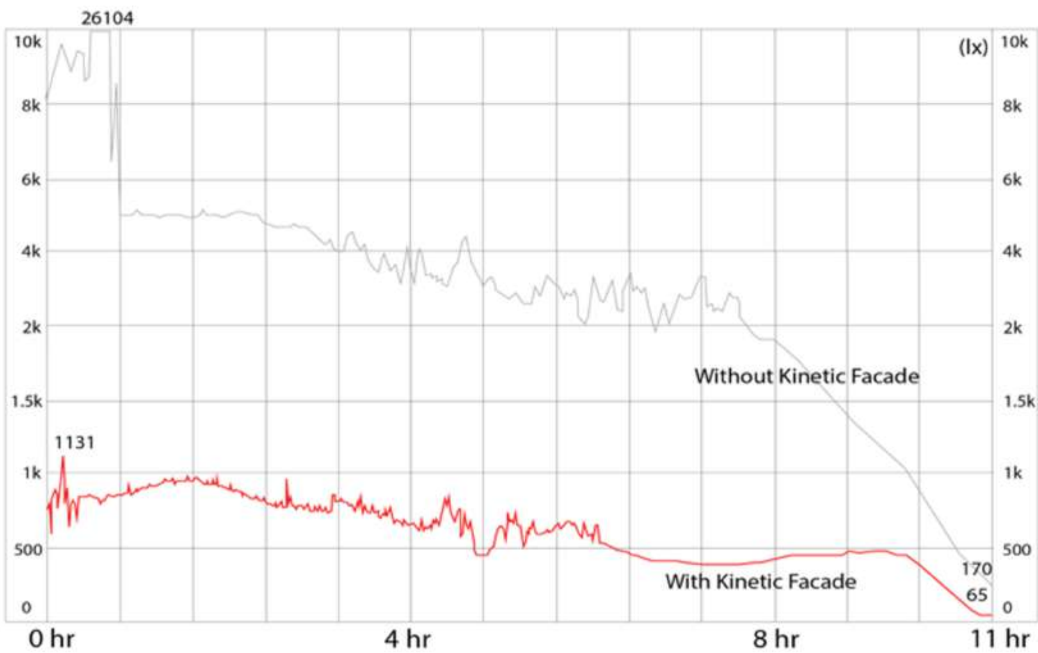

Figure 24. Testing in the actual situation (comparing graph trends between before and after installation of the kinetic façade version 2).

2). It passed the LEED version 4.1 criteria since the space can receive between 300 and 3000 lux levels during office hours, approximately 8:00 a.m. to 5:00 p.m.

Table 5. Comparing approximate lux value trends between before and after installation of the kinetic façade version 2.

Time	Hours	Lux Values (Before Installing Kinetic Façade)	Lux Values (After Installing Kinetic Façade)
8:00 a.m.	1	26104	800
9:00 a.m.	2	5000	950
10:00 a.m.	3	4300	700
11:00 a.m.	4	4200	650
12:00 p.m.	5	3500	500
1:00 p.m.	6	3000	650
2:00 p.m.	7	3000	450
3:00 p.m.	8	1900	450
4:00 p.m.	9	1500	490
5:00 p.m.	10	1000	430
6:00 p.m.	11	170	65
Average		4879.45	557.72

7.2. *Guideline for installing the kinetic façade version 2*

(a) The kinetic façade installation (view from outside) (b) The kinetic façade installation (view from inside)

Figure 25. The kinetic façade installation views from outside and inside.

Figure 25 demonstrates a prototype of the kinetic façade (version 2) installation with the window areas. However, this is just one approach for installing the kinetic façade with the windows. In this paper, the we designed an approach for adapting the kinetic façade in various solutions in terms of a human-made object.

Figure 26 shows the guideline for applying the various solutions. This study was illustrated in terms of five solutions, as follows: (A) the rooftop kinetic shading, (B) the kinetic parasol, (C) the kinetic partition, (D) the interior kinetic curtain shading, and (E) the kinetic façade (prominent for development in this study).

First to consider is (A) rooftop shading for providing shade to users. It serves the same purpose as installing a façade plug-in with a building envelope that offers adequate sunlight. Secondly is a façade that moves and plugs into a parasol. Unfortunately, because it cannot alter the shading to follow the sunshine for humans when using it, the original parasol does not respond to human use. However, this invention can address this issue by adjusting the shade to correspond with the intensity of the sunlight. Thirdly is a working station in the interior space with a kinetic partition. The distinctive of this innovation further filtrates the sunlight intensity through the working area.

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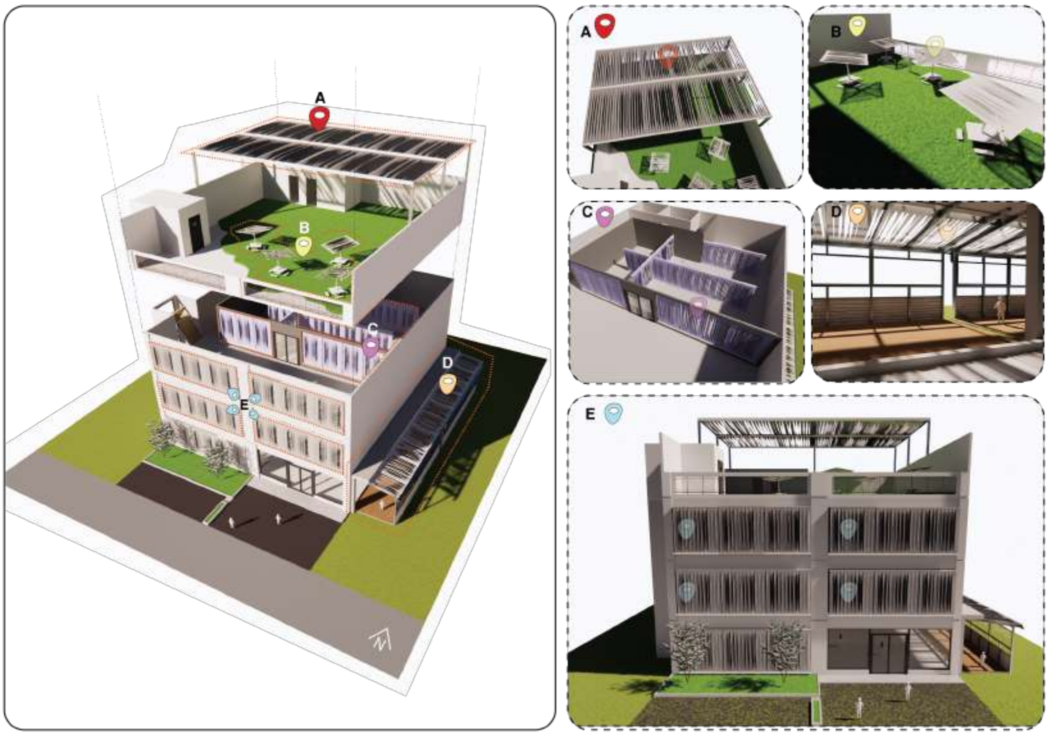

Figure 26. The kinetic façade guideline for installation cases.

Furthermore, it can provide private space for users in the working place since it can adjust the degree of the strip. These benefits can provide users in the working area with more productivity. Fourthly is the interior kinetic curtain shading, a solution that has the same function as the rooftop shading but its differences are with regards to the position for installation. This solution is located inside the space; thus, the function is similar to a curtain. The different places for installing a kinetic façade can alter the materials for use; for example, the interior kinetic curtain shading can use a sophisticated fabric that cannot be waterproof. Finally, there is (E) the kinetic façade, which is the main innovation and solution focused on in terms of development in this study, which demonstrated the fabrication processes and was tested in the actual situation. The result was that it can provide adequate sunlight through the spaces. Thus, this benefit can allow for adjustment of the kinetic shading in any solution users want.

8. Conclusion and future work

This research has proposed mimicry of the identity of natural phenomena to provide a kinetic façade innovation for filtrating sunlight into the working space. It has three components for analysis of the natural phenomena: the physical DNA, phototropism behavior, and Eshelby twist movement through the use of the biomimicry science method for interpreting it in terms of strip forms, which are a part of the main component of the kinetic façade. The technical process for implementing it involves using Rhino and Grasshopper software for generating the possible strip forms and evaluating the potential of the kinetic façade system in terms of daylight factor (DF), including the sunlight intensity through the spaces and LEED version 4.1 criteria. The results after both simulations showed the possible strips and the evaluation of the kinetic façade potential for providing suitable sunlight. Firstly, in the simulation of the possible strip forms, there were eight generations of the standard deviation (SD) trend graph. The overall number of strips was 450 solutions; however, most of the strip forms in each generation were repetitive forms, shown in Figure 9a,b illustrating the trend of SD in eight generations and the mean value trendline of the strip forms. Evidently, both graphs continued to decrease in the latest generation, which meant they had less strip form (phenotype) diversity. Therefore, the researcher would

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stop generating the strip phenotype in generation eight. For the strip form selection, the potential for bringing daylight suitably through the space is crucial. Therefore, we chose 10 patterns with different degrees of twisting to obtain sunlight for each period into the space appropriately. The degree of evaluation, which can be converted to degrees, is 0 deg to 100 deg.

For evaluating the entire kinetic façade system in terms of daylight factor (DF) and LEED version 4.1 criteria in two parts, we used a simulation and real-world testing. In the simulation section, the type of building envelope was divided into four types, which are (a) glass panel alone, (b) static façade, (c) kinetic façade (version 1), and (d) kinetic façade (version 2). In addition, for kinetic façades, versions 1 and 2 were defined as the same degrees for simulation: 20 deg, 50 deg, 80 deg, and 100 deg. In the real-world testing section, the lux value of the room was measured to determine the potential of the kinetic façade (version 2) in the actual situation.

Firstly was the daylight factor (DF) part. The bar graph was separated by sizes and degrees for simulation daylight factor (DF) when comparing all façade types, as shown in Figure 15. Firstly, the glass panel alone had the highest daylight factor (DF) through the space compared with the others. In contrast, the static façade had lower DF than the kinetic façade of versions 1 and 2 at 50 deg, 80 deg, and 100 deg. Exclusive for 20 deg for both kinetic façades was the kinetic façade (version 1) in 20 deg with the lowest DF, followed by the kinetic (version 2) in 20 deg. Next, we focused on the kinetic façade versions1 and 2. Evidently, the kinetic façade (version 2) had a slightly higher average daylight factor (DF) than the kinetic façade (version 1). This means the kinetic façade (version 2) can bring more daylight through spaces of every size. The amount of sunlight to access the area should be at a medium level. It does not receive too little sunlight into the area or too much since the appropriate DF benefits human activities in the spaces, particularly the proper daylight in the workplace; it can encourage people in the area to have more work efficiency.

Secondly, the LEED version 4.1 criteria part is shown in Table 2, displaying the result after simulation of each type of façade. There were glass panels only, static façade, kinetic façade (version 1), and kinetic façade (version 2) in terms of LEED version 4.1 criteria concerning the minimum daylight that can access the space. Moreover, all of the façades passed the LEED version 4.1 criteria for receiving natural light. This criterion benefits the kinetic façade design that aims to protect from the sunlight in this research. If the kinetic façade version 2 passes the LEED version 4.1 measures, it will tend to receive minimum sunlight as the standard of the criteria, which helps human activities in the spaces more effectively.

Thirdly, real-world testing was crucial in this study since it can validate the kinetic façade (version 2) potential after simulation and whether it is practical for use in an actual situation. Therefore, the results were divided into two parts: the potential for providing suitable sunlight and the technical issue during the operation. First, the kinetic façade (version 2) had the potential to provide suitable sunlight into the space, as referred to in the standard EN 12464 light and lighting. It has a suitable average lux for working, namely, 557.72 lux; this is in comparison to before the installation of the kinetic façade, wherein the lux exceeded for working was 4879.45 lux. Second, the technical issue from the literature review gaps was separated into four parts. First was the large system issue; this prototype in this study was design as a compact system since if it is a large system, it will affect various aspects such as delay in movement, external appearance, and installation. As for the second delay in the movement, this prototype did not delay the movement for reacting to the sunlight since we designed the controlling system as simply as possible. Thirdly was the issue of friction during the operation; this prototype produced no friction. In contrast, it was smooth to change the degree when reacting with the sunlight since it reflexed with the compact system of the façade. Finally, there is the issue of systems not responding to human behavior; on this, the kinetic façade can respond to the suitability of human work, but not human need, since the façade prototype reacts with the sunlight to provide suitable sunlight in the working space with no human control. However, this issue can be improved in terms of the two systems, environmental control and human control, since every aspect is of benefit in a different situation. For further suggestions regarding the façade after testing in a real situation, one potential drawback of a kinetic façade is that it cannot hold up under all kinds of weather. Circumstances such as heavy rain and too much sunshine might cause the sensor to act erratically, making the device perform unpredictably.

Finally, the kinetic façade was employed not only alongside the building exterior but also with other artificial elements such as roofs, working partitions, parasols, and pavilions that users desire to protect from direct sunlight or instead allow adequate sunlight into the areas. For future work on this topic, we will create a dynamic façade (version 2) system that can be utilized for any installation purpose; for example, the system can install both horizontal and vertical components. In addition, the system should adapt to an environmental factor that may automatically respond to the environment, similar to this study, and respond to user requirements by regulation via the application platform. These characteristics make this idea more suitable for commercialization.

Author Contributions: This paper represents the results of teamwork. Conceptualization, S.S., T.H., and K.M; methodology, investigation, resources, and data curation, S.S., T.H., K.M., J.K., C.B., and H.X.; writing—original draft preparation, S.S.; writing—review and editing, S.S., T.H., K.M., J.K., C.B., and H.X. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

yes

Appendix I Appendix

Appendix I.1 Glass panel alone

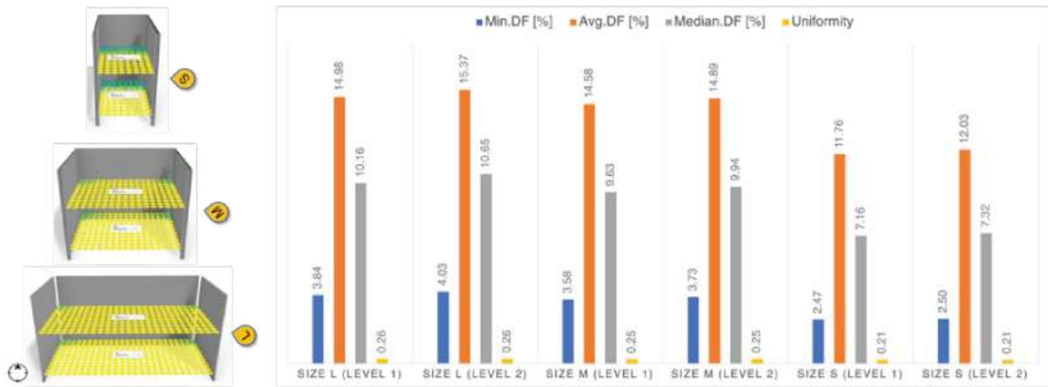

Figure A27. The results of daylight factor simulation in terms of a glass panel alone.

The results of the daylight simulation illustrate the crucial factor for evaluation, namely, daylight factor (DF).

Figure A27 shows the results of glass panels alone in terms of daylight factor (DF) analysis, with 27% of all illuminance sensors having a daylight factor of 2% or higher. Therefore, assuming the room exceeds daylight in the space, it should be improved in order to filtrate daylight into the area. However, the benefit of this level of daylight is that artificial lighting is not required.

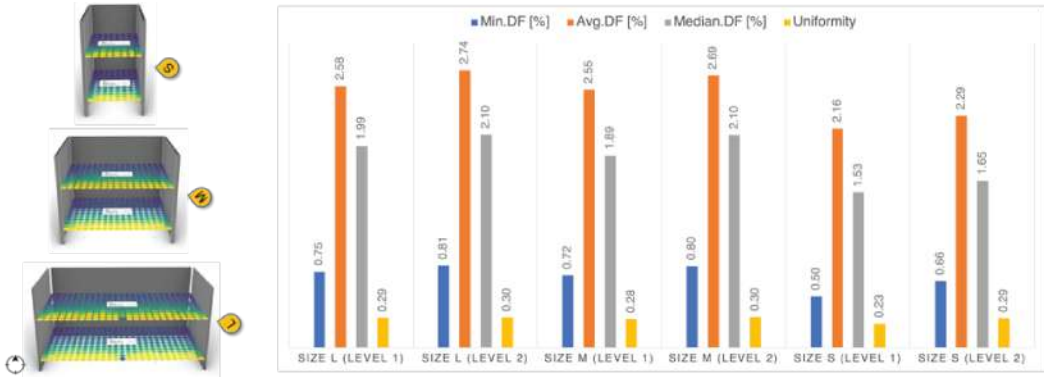

Figure A28. The results of daylight factor simulation in terms of a static façade.

Appendix I.2 Static façade

Figure A28 shows the results of the daylight factor (DF) analysis of a static façade, with 9% of all illuminance sensors having a daylight factor of 2% or higher. It means the room has a strong daylit presence that provides users the ability to perform activities in the space since at this level of daylight, electric lighting is rarely required.

Appendix I.3 Kinetic façade (version 1)

Appendix I.3.1 Kinetic façade (version 1, 20 deg)

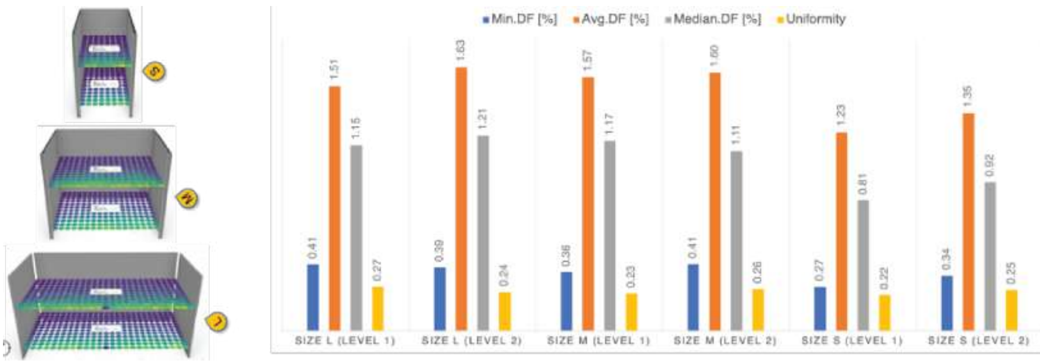

Figure A29. The results of daylight factor simulation in terms of a kinetic façade (version 1, 20 deg).

Figure A29 shows the results of the daylight factor (DF) analysis of a kinetic façade (version 1, 20 deg), with 0% of all illuminance sensors having a daylight factor of 2% or higher. It means the room is gloomy since the façade makes daylight hard to access the area. Thus, in this case, it must be improved with artificial lighting.

Appendix I.3.2 Kinetic façade (version 1, 50 deg)

Figure A30 shows the results of the daylight factor (DF) analysis of a kinetic façade (version 1, 50 deg), wherein 4% of all illuminance sensors had a daylight factor of 2% or higher. Thus, it means a predominantly daylit appearance: daylight can be accessed at some periods. However, artificial lighting is also mandatory in this condition since natural light alone is not adequate for user activities in the space, mainly working activities.

Appendix I.3.3 Kinetic façade (version 1, 80 deg)

Figure A31 shows the results of daylight factor (DF) analysis of a kinetic façade (version 1, 80 deg), wherein 8% of all illuminance sensors had a daylight factor of 2% or higher. Thus, it means the room has a strong daylight level that provides users with the ability to perform activities in the space since at this level of daylight, electric lighting is not crucial in terms of its installation.

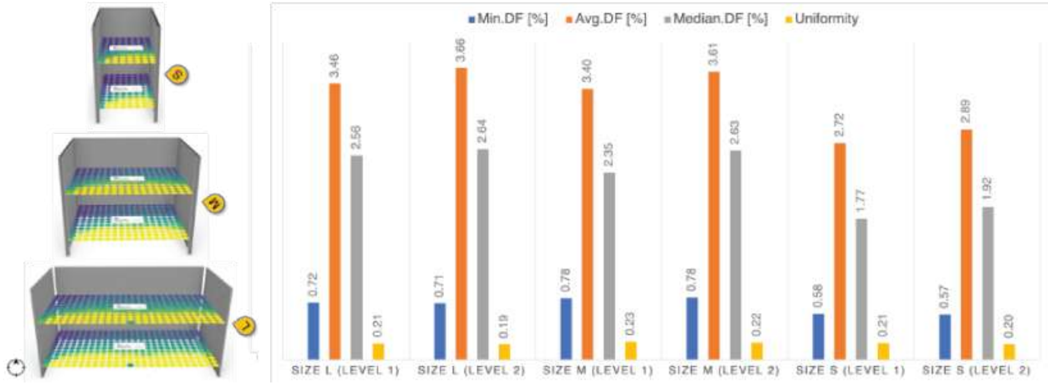

Figure A30. The results of daylight factor simulation in terms of a kinetic façade (version 1, 50 deg).

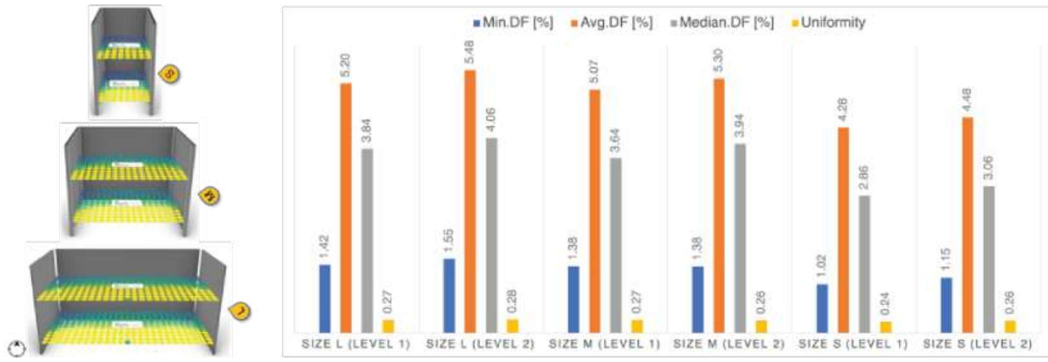

Figure A31. The results of daylight factor simulation in terms of a kinetic façade (version 1, 80 deg).

Appendix I.3.4 Kinetic façade (version 1, 100 deg)

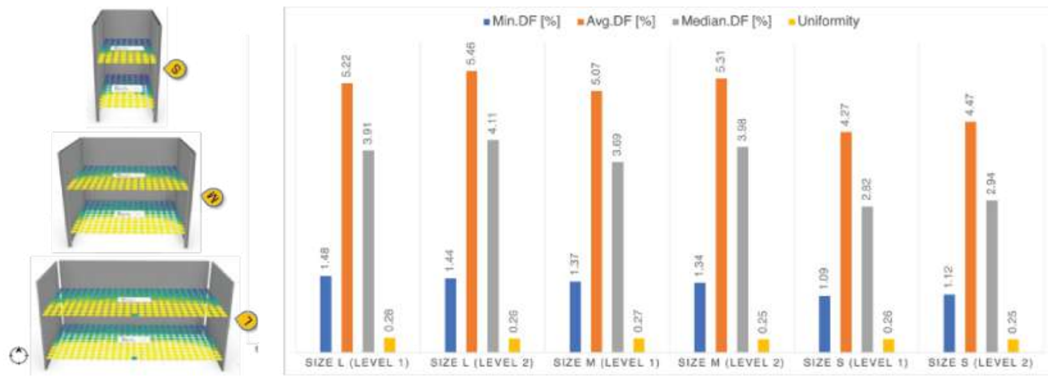

Figure A32. The results of daylight factor simulation in terms of a kinetic façade (version 1, 100 deg).

Figure A32 shows the results of daylight factor (DF) analysis of a kinetic façade (version 1, 100 deg), wherein 8% of all illuminance sensors had a daylight factor of 2% or higher. Therefore, it means the room has a strong level of daylight that provides users with the ability to perform activities in the space all day long in the working period since at this level of daylight, electric lighting is not crucial in terms of its installation.

Appendix I.4 Kinetic façade (version 2)

Appendix I.4.1 Kinetic façade (version 2, 20 deg)

Figure A33 shows the results of daylight factor (DF) analysis of a kinetic façade (version 2, 20 deg), wherein 4% of all illuminance sensors had a daylight factor of 2% or higher. This means a predominantly daylit appearance: daylight can be accessed at some periods. However, artificial lighting is also mandatory in this condition since natural light is not adequate for user activities in the space, particularly working activities.

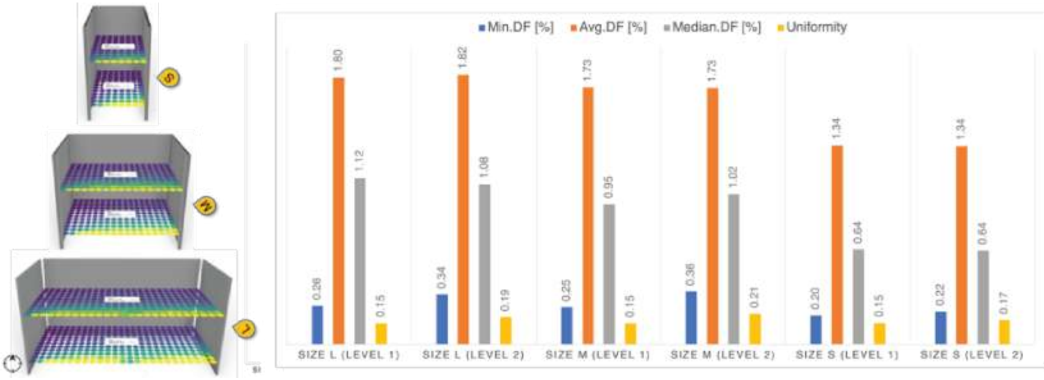

Figure A33. The results of daylight factor simulation in terms of a kinetic façade (version 2, 20 deg).

Appendix I.4.2 Kinetic façade (version 2, 50 deg)

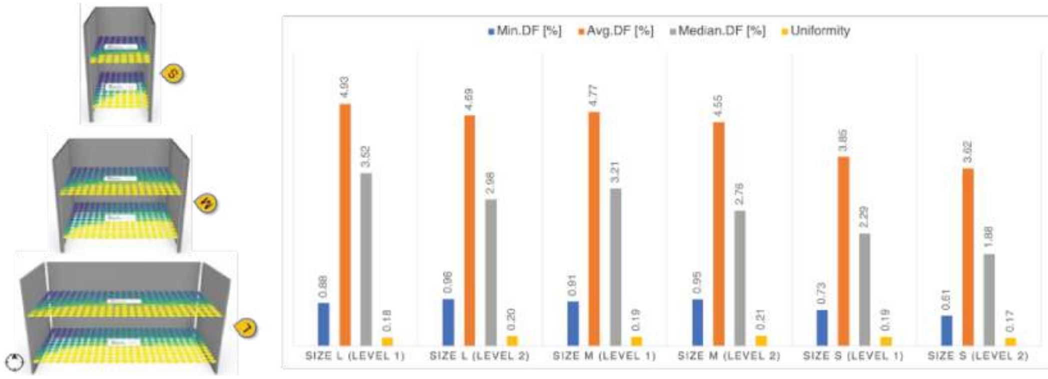

Figure A34. The results of daylight factor simulation in terms of a kinetic façade (version 2, 50 deg).

Figure A34 shows the results of daylight factor (DF) analysis of a kinetic façade (version 2, 50 deg), wherein 9% of all illuminance sensors had a daylight factor of 2% or higher. Thus, it means the room has a strong level of daylight that provides users with the ability to perform activities in the space all day in the working time since at this level of daylight, electric lighting is not crucial in terms of its installation.

Appendix I.4.3 Kinetic façade (version 2, 80 deg)

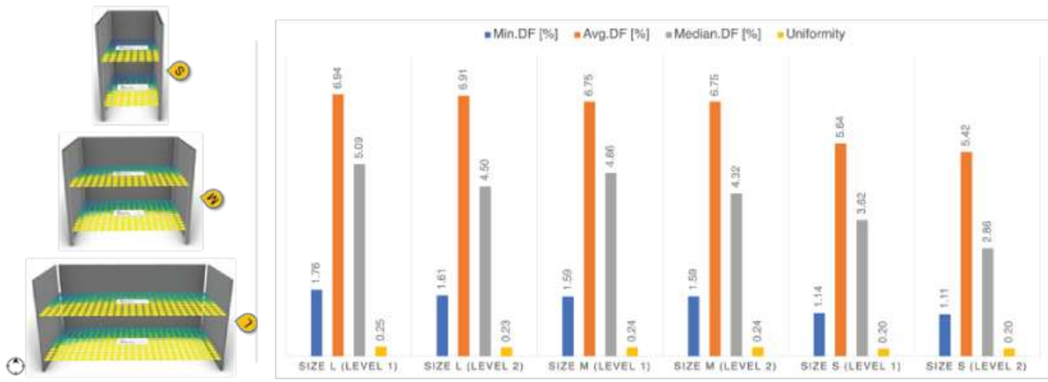

Figure A35. The results of daylight factor simulation in terms of a kinetic façade (version 2, 80 deg).

Figure A35 shows the results of daylight factor (DF) analysis of a kinetic façade (version 2, 80 deg), wherein 13% of all illuminance sensors had a daylight factor of 2% or higher. Thus, it means the room had a strong level of daylight that provides users with the ability to perform activities in the space all day in the working period since at this level of daylight, electric lighting is not crucial in terms of its installation.

Appendix I.4.4 Kinetic façade (version 2, 100 deg)

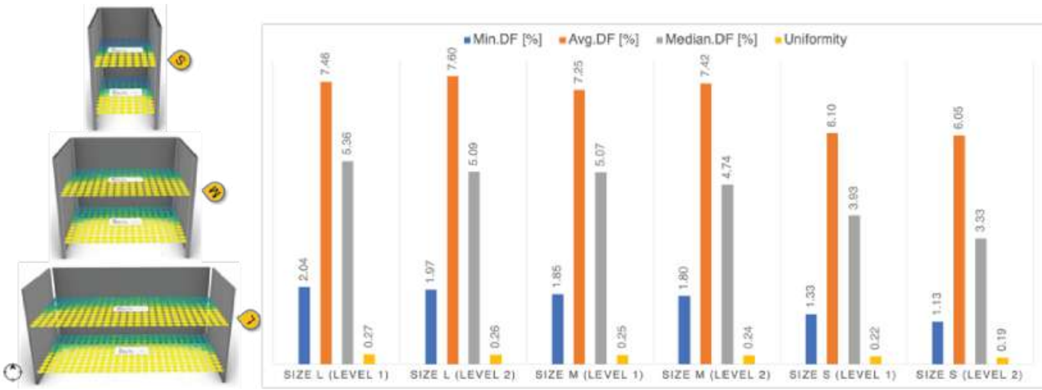

Figure A36. The results of daylight factor simulation in terms of a kinetic façade (version 2, 100 deg).

Figure A36 shows the results of daylight factor (DF) analysis of a kinetic façade (version 2, 100 deg), wherein 16% of all illuminance sensors had a daylight factor of 2% or higher. Thus, it means the room has a strong level of daylight that provides users with the ability to perform activities in the space all day in the working period since at this level of daylight, electric lighting is not crucial in terms of its installation.

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