Designing a facade by biomimicry science to effectively control natural light in buildings (Glare analysis)

Sukhum Şankaewthong*1, Teerayut Horanont1, Kazunori miyata2 and Jessada Karnjana3

1School of Information, Computer and Communication Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand
2 School of knowledge science, Japan Advanced Institute of Science and Technology, Ishikawa, Japan
3 National Electronics and Computer Technology Centre (NECTEC), Thailand
*Sukhumphed@gmail.com

Abstract. The increasingly popular design trend of glazed facades using daylight in buildings has made it essential for innovations to eliminate the unnecessary intrusion of sunlight in spaces. This study aims to create a kinetic façade pattern by referring DNA structure and photosynthetic behaviour to mimic biomimicry science characteristics in Wallacci evolutionary software for generating possible patterns. Daylight glare thresholds were determined as an essential factor for user productive work. Comparison of three-building envelope potential was made for preparing spaces (zones A, B) in Bangkok condition; without a façade, with a static facade, and with a kinetic facade. DIVA software was used to analyse glare in terms of daylight glare probability (DGP). First, DGP (without façade) for zones A and B were 100% and 55%, or intolerable glare. Second, DGP (static façade) for zones A and B were 59%, 30%; zone A was intolerable, and B imperceptible. Third, DGP (kinetic façade) for zones A and B were 28% (imperceptible glare). Therefore, a kinetic façade has a high potential for protecting against unsuitable glare. These findings may serve as preliminary evidence for understanding kinetic façade potential for self-adjustment by light intensity to improve quality of life for occupant use of spaces.

1. Introduction
Buildings are now designed with either exaggerated proportions of transparent materials or large open spaces within a building envelope [1], [2]. For instance, in the images of Suvarnabhumi International Airport (Figure 1) and a working space (Figure 2), there are various issues that can occur from excessive natural light, one of which is "intolerable glare". Glare directly affects human activities that use spaces such as these as working spaces, creation spaces, and relaxing spaces, yet this is particularly so in working spaces since people must focus their eyesight [3]. Natural light is crucial since it can make work more effective. In 2011, a poll was conducted among 135 architects, lighting designers, and consultants, which found that over 80 percent of participants deemed natural light to be either an important or extremely important design factor (Figure 3). Glare factor from daylight was simulated for participants in various fields, while the simulations were integrated with luminance contrast measurements and direct sunlight identification in the users' proximity in a workspace [4]. Natural light is related to human health, especially eyestrain which is a common condition that occurs when the eyes get tired from intense use, such as staring at computer screens and other digital devices,
reading books, or working. Almost all such problems occur as a consequence of unsuitable light, including natural and artificial light that can result in eye discomfort [5]. These issues arise since open areas of wall are unsuitable for a controlled climate. Therefore, the use of spaces are inefficient to ensure that natural light remains suitable for human activities in such spaces. This issue prompted the researcher's interest to suitably control the atmosphere in buildings, specifically the glare factor which affects human comfort, by using the façade to control this problem.

**Figure 1.** Suvarnabhumi International Airport, Thailand has an exaggerated proportion of transparent materials.

**Figure 2.** Over glazed façades lead to spaces with excessive glare or overheating. Occupants have no choice but to install personal shade equipment.

**Figure 3.** Poll of 135 architects, lighting designers, and consultants on the importance of glare (Mogri 2011).

**Figure 4.** The problem uses of unsuitable glazed panels in the building envelope.

Figure 4 presents the significant problem posed by inappropriate light. Figure 4 separates this into two issues, insufficient light and inappropriate glare. First, an insufficient light issue affects both the use of spaces and human health aspects. The muse of space aspect is then divided into three issues: (1) unusable space; (2) accidents such as falling, tripping, and slipping; and (3) ineffective working including non-creativity, poor concentration, and reduced working speed. The human health aspect is then separated into two further issues: (1) mental health such as stress, depressive disorder, and
anxiety disorder; and (2) physical health, including eye strain or eye discomfort, and headache. Second, problematic glare issues also affect both aspects [6]. Nevertheless, some minor issues are not included, namely the accidental and mental health aspects.

2. Study purpose

The research studies and mimics natural form and movement. This study focuses on DNA structure and the phototropism phenomenon to find a distinctive point by interpreting its physical appearance. Kinetic façade technology is developed to effectively controlled a suitable interior atmosphere that has natural light in indoor spaces in order to encourage work efficiency and human health. The purposes of this study are as follows:

2.1. To research potential façade patterns (form-finding) that effectively provides a suitable interior environment that has natural light, with a focus on the glare factor.

2.2. To study natural movement (biomimicry) to interpret a suitable façade movement.

2.3. To analyse the effectiveness of the kinetic façade in terms of glare.

3. Research methodology

Figure 5 presents the overall research methodology to determine how a façade directly affects the glare factor. The method is divided into two phases, the façade design phase and the natural light analysis phase. The façade is validated in three types of building envelope, that is, kinetic façade, static façade, and building without a façade (only glazed façade) through testing with the DIVA software that analyses in terms of natural light. This research focuses on glare analysis to improve visual quality in the space. Rhino and Grasshopper computational methods were used to design façade optimisations for the simulation. Rhino software is used to build 3D forms while Grasshopper software uses two plug-ins - DIVA to analyse natural light and Wallacei to generate façade patterns. The kinetic façade integrates with biomimicry science to design the physical and behavioural components. The physical component uses characteristics of DNA structure to generate probability patterns and phototropism behaviours of plants, and is applied in the façade movement to respond to sunlight. Then, both inspirations are interpreted into façade patterns to generate probability patterns in Wallacei software and the potential of each façade type is analysed in DIVA software to optimise for the glare factor.

3.1. Comparing effectiveness
Data was collected to compare the effectiveness of building envelopes with a static façade, kinetic façade, and without a façade to simulate the use of space in the same zone by focusing on the glare factor. From Figure 5, the variables are as follows:

3.1.1. Independent variables
- The building envelope:
  1. Without façade (only glazed panels).
  2. Static façade.
  3. Kinetic façade.

3.1.2. Dependent variables
- Natural light, focused on the glare factor.

3.1.3. Control variables
- No existing buildings nearby, same zone for simulation.
- Location (Bangkok, Thailand), climate (clear sky), period (Winter Solstice – 22 December), time (7.00 AM – 5.00 PM).

4. Results and discussion

4.1. Analyse potential façade patterns (Phase 1)
This section analyses potential façade patterns inspired by physical DNA and phototropism behaviour to construct the strip form. Wallacei is used to generate potential façade patterns, which is an evolutionary algorithm software to generate algorithms forms. Evolving algorithms are a series of optimisation algorithms that imitate the mechanisms of natural evolution [7].

Figure 6. A façade inspiration that integrates physical DNA and phototropism behaviour.

Figure 7. The environment affects the faces of birds of the same species. Photograph: Ann Ronan Pictures/Getty Image

Figure 6 shows the processes that mimic strip DNA. This study mimics two parts for a flexible movement purpose; the physical DNA structure and phototropism behaviour. Phototropism is most commonly found in plants and involves the development of an organism in response to a light stimulus (external factor) by photoreceptors related to signalling mechanisms. According to external factors, plants adaptively change their growth characteristics according to the amount of accessible sunlight [8]. This mechanism is crucial for interpreting the façade strip mechanism since it must adjust itself to the sunlight, similar to plants.

Phenotypes are measurable traits of an individual that derive from the association of its genotype (total genetic inheritance) with the environment. Features that may be observed include behaviour, biochemical properties, colour, shape, and size, for example the bird species depicted in Figure 7 [9]. Thus, the phenotype's simple definition are external appearances or characteristics that are easy to observe.
Figure 8(a) shows the strip phenotype probability patterns, resulting in 450 solutions from generation 0 to generation 8. Each generation has different and repetitive patterns compared to other generations. For instance, generation 0 and generation 5 have some strips with the same patterns. The strip patterns that occur from the phenotype are different, resulting in various strip phenotypes. The strip phenotype occurs from mimicking DNA strip and phototropism phenomenon to simulate the characteristic of strip patterns for application in the kinetic façade model. The generation of new solutions was stopped after 450 solutions had been generated, since when looking at the standard deviation trend graphs (Figure 8[b]), the final generation had a smaller slope than the first generation. This means that the strip phenotype repeated the same patterns and has no benefit for the purpose of this research. Thus, the final generation at which the generation process was paused was generation 8. A low standard deviation factor indicates that most values are similar to each other (less variation within the population). In contrast, a high standard deviation means that the values are farther from the mean (greater variation within the population) [10]. When looking at the standard deviation graph, early generations had more varied strip patterns than the final generation, as Figure 9 shows the probability output in 50 solutions of strip phenotype in generation 3, indicating greater repetition of strip patterns than the early generation. However, it can be seen that this generation has various strip phenotypes when observing the twist angle characteristics that respond to sunlight.

**Figure 8.** Overall generation of the strip phenotype in 450 solutions and the standard deviation trend.

**Figure 9.** The probability of strip phenotype in generation 3 into 50 solutions.

**Figure 10.** DNA strip patterns summarise the different characteristics and potential after simulating with sunlight.

Figure 10 summarises the strip patterns from generation 0 to generation 8 that were applied in the kinetic façade model. These patterns were selected since they respond to sunlight differently, similar to phototropism behaviours. The various angles of the strip patterns have differing potential to block sunlight at different times. Thus, it is beneficial for adapting to user needs in various situations when living in spaces. When there is less light intensity, the strip will be more twisted than the high light intensity, similar to a strip 7 as in Figure 10.
Figure 11 presents the probability of façade patterns in generation 0. The solutions that the researcher exported is 50 out of 1150 solutions. Indeed, the phenotype generates into 23 generations, including generation 0 to generation 22. When comparing the kinetic façade from generation 0 to generation 22, the results are similar to generating DNA strips when considering standard deviation, fitness values, and standard deviation value trendline which are consistent. Therefore, this output can predict that the kinetic façade can twist or adjust to sunlight, similar to the strips in Figure 10.

Figure 12 shows the graph trend that can predict the possibility of the kinetic façade characteristic. First, standard deviation represents the distribution of a set of values from the mean [11]. The chart's objective is to present and analyse the levels of variation and convergence for each generation in the population. Increased variation is represented through a 'flat' curve, while increased convergence is represented through a 'narrow' curve. Thus, it can predict that each generation's façade patterns are independent since each generation's curve is similar. Nevertheless, each generated façade has a range of patterns, for instance the early generation's façade patterns have various phenotypes when compared to the last generation. Second, the fitness values chart analyses the fitness values for each fitness objective independently across the entire population. The aim is to visualise how the solutions perform in relation to one another, both within each generation and across the population. When analysing the graph, most of the generation is independent since most line graphs are relatively stable. However, the early generation has a fluctuating line which means that the phenotypes or external appearance are more diverse than the stable line. Third, the standard deviation trendline chart presents the standard deviation value for each fitness objective independently, and for each generation across the entire simulation from start to finish. The aim is to highlight specific trends in the variation and convergence of each generation across the population. Thus, after analysis, the graph has a similar meaning to the standard deviation graph. This illustrates that the early generated patterns were more varied than the last generation or the early generation has greater diversity than the last generation.

Figure 11. Phenotype of façade generation in generation 0 (50 out of 1150 solutions).

Figure 12. Trend of façade characteristics.

4.2. Analysis of natural light ambient (Phase 2)
This part analyses the building envelope in working spaces with a static façade, kinetic façade, and only glazed panels (without façade). The kinetic façade refers to cases generated in phase 1 to simulate effective glare protection. Figure 13(a) illustrates the setting model, which is the working space for simulation by the node. The node or dot is crucial for calculating the glare factor, hence the researcher
set the node position close to the human eye at a distance of approximately 1.10 metres when doing work activities as in Figure 13(b).

![Figure 13](image_url)

**Figure 13.** Model setting to simulate the glare factor using the node.

4.3. Glare analysis

**Table 1.** Identification of occupant sensations of discomfort.

| DGP classification       | Glare range values       |
|--------------------------|----------------------------|
| Intolerable Glare        | DGP ≥ .45                 |
| Disturbing Glare         | .45 > DGP ≥ .4            |
| Perceptible Glare        | .4 > DGP ≥ .35            |
| Imperceptible Glare      | .35 > DGP                 |

![Figure 14](image_url)

**Figure 14.** Building model without a façade and the zone to simulate both views A and B.

![Figure 15](image_url)

**Figure 15.** Glare analysis with a building model (without a façade).

Glare occurs when part of an interior space is significantly brighter than the room's luminosity. Harm can occur when the eyes are exposed to a more intense light than they are normally adapted to. The most prevalent cause of glare arises from the light source and window being in the same visual area, either directly, through reflections, or both simultaneously [12]. Daylight glare probability (DGP) was established in a new glare prediction model since existing glare indices did not accurately estimate the degree of daylight glare irritation in a working atmosphere with regular work practices and diverse non-uniform sources of glare, such as the Venetian blind system [13], [14]. GDP was derived from laboratory results in private office spaces containing human test subjects. Table 1 shows a sensation of discomfort for users of such spaces, including DGP classification and glare range values. The glare
classifications are as follows: intolerable glare; disturbing glare; perceptible glare; and imperceptible glare [15]. Glare types that negatively affect humans are intolerable glare and disturbing glare. Thus, designers should avoid and protect against these types of DGP since they will occur if spaces have an exaggerated open space or glazed façade.

Figure 14 shows the 3D model and zoning for simulating the glare factor for views A and B. These zones were selected since they have different light intensity, with view A receiving greater light intensity than view B which is a narrow space. The simulation must control the input data as follows: location; climate; and period. This study is based in Bangkok, Thailand, with clear skies and during the Winter Solstice period (22 December) between 7.00 AM and 5.00 PM. During the Winter Solstice period in Thailand, the building can receive more direct sun than during other periods, making it suitable for testing.

Figure 15 illustrates a glare analysis with a building model without a façade. For View A, the result is intolerable glare and the daylight glare index versus the percentage of persons disturbed (DGP) is 100%. View B shows the glare analysis in another area, which resulted in intolerable glare with a DGP of 55%.

Figure 16 shows the model and the zone of both views A and B to simulate the glare factor. In Figure 17, view A shows the glare analysis with the static façade building model. The result is intolerable glare and a DGP of 59%. View B shows glare analysis, with the result being imperceptible glare and a DGP of 30%. Thus, the potential of a static façade is useful for some areas that are far from glazed panels.
Thus, these views B subject to imperceptible glare, indicating that the space is suitable for working spaces. A and B were 100% and 55%, indicating intolerable glare and unsuitability for use as a space. Second, the DGP of a building with a static façade from views A and B was 59% and 30%, with view A having intolerable glare and view B subject to imperceptible glare, indicating that the space is suitable for users only from view B (narrow space). Third, the DGP of a building with a kinetic façade from views A and B was 28%, with both views subject to imperceptible glare. Hence, both areas are suitable as working spaces. The building with a kinetic façade has the potential to protect against glare. Furthermore, if the façade receives less natural light, it will twist itself to receive outdoor light following the same pattern as the seventh strip in Figure 10. Thus, the kinetic façade is a crucial element that should be installed in buildings with exaggerated proportions of open spaces and glazed panels.

Figure 19. Glare analysis with a building model (kinetic façade).

Figure 18 shows the model and the zone of views A and B to simulate the glare factor. In Figure 19, view A shows the glare analysis with the kinetic façade building model, which indicates imperceptible glare and a DGP of 28%. View B illustrates glare analysis with the result of imperceptible glare and a DGP of 28%. Figure 20 illustrates a comparison of the three-building envelopes in terms of glare factor. The result is that a kinetic façade can better protect against the glare factor than a static façade, which is useful in some areas and inappropriate glare in some periods (not stable glare factor – view B).

Figure 20. Comparing the potential of the three-building envelopes in terms of glare factor.

5. Conclusion
One crucial factor to encourage users to work effectively in working spaces is the suitable glare factor, since this can negatively affect people and reduce their working effectiveness. Thus, this study focused on simulating the potential of a kinetic façade by comparing it with a static façade and a building without a façade (only glazed panels). The kinetic façade uses biomimicry science to attain a façade pattern by mimicking nature, both in physical appearance and behaviour. The kinetic façade was inspired by nature, including DNA structure and the phototropism behaviour of plants. Thus, these inspirations must interpret a physical appearance for simulation in the evolution stage to discover the potential façade patterns by using *Wallacei*. After simulating the façade patterns, the next process simulated each building envelope’s effectiveness in the preparing space, from views A and B (Figure 15, Figure 17, and Figure 19). First, the DGP of the building without a façade from views A and B was 100% and 55%, indicating intolerable glare and unsuitability for use as a space. Second, the DGP of a building with a static façade from views A and B was 59% and 30%, with view A having intolerable glare and view B subject to imperceptible glare, indicating that the space is suitable for users only from view B (narrow space). Third, the DGP of a building with a kinetic façade from views A and B was 28%, with both views subject to imperceptible glare. Hence, both areas are suitable as working spaces. The building with a kinetic façade has the potential to protect against glare.
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