Journal of Advanced Research in Applied Sciences and Engineering Technology 29, Issue 3 (2023) 62-76

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Solar Responsive Facade as Siamese Cultural Aesthetic Frontage in Malaysia

Nur Shararath Bunjarat Seng Chuan[1], Farhana Mohd Razif[1,*], Md Azree Othuman Mydin[1], Hazrina Haja Bava Mohidin[2], Leng Pau Chung[3]

[1] School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, USM, Penang, Malaysia
[2] SUPRE, Faculty of Built Environment, University of Malaya, 50603 Kuala Lumpur, Malaysia
[3] Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Skudai 81310, Malaysia

ARTICLE INFO

Article history:
Received 30 November 2022
Received in revised form 22 December 2022
Accepted 13 January 2023
Available online 5 February 2023

Keywords:
Responsive architecture; Kinetic façade; Building identity; Siamese pattern; Energy efficiency

ABSTRACT

A kinetic façade, also referred to as a solar responsive façade (SRF), is a movable façade that responds to the amount of light received. The mechanism prevents excessive light from entering while allowing the ideal amount of natural lighting into buildings. Following the green building movement, SRF usage increased because it can both lower heat gain and improve the aesthetics of a building's design. Even though the SRF has many advantages, the façade pattern has become uniform across all cultures, regions, and climates, which results in a lack of identity in building design. This essay will focus on SRF designs that were inspired by Malaysia's Siamese culture. Examining the daylight factor (DF) of three particular Siamese patterns from cultural art, religious art, and cultural craft is the main objective. The designs were then mounted on a wall measuring 5.3 x 6.0 metres with a window-to-wall ratio of 70%. (WWR). Using VELUX Daylight Visualizer 3, the potential Siamese patterns were built as a three-dimensional model and the DF at nine different folding techniques were examined. Based on the percentage of achieving a 1.0 to 3.5 daylight factor in all kinetic folding techniques, the result reveals that the religiously inspired pattern is the best among the three selected Siamese patterns. While the pattern helps to ensure that buildings receive the most natural light possible, the study shows that the folding technique also has a significant impact by reflecting light into the structure.

1. Introduction

These days, thanks to technological advancements, the exterior of a building can be dynamic and adaptable to its surroundings. A structure's facade is its outward appearance and, as such, greatly affects how people view the building [1-2]. Due to its role in controlling the amount of heat from the daylight and providing daylight, ventilation, and sun shading [3-4], the façade's form becomes quite important in conserving energy. Romano *et al.,* [5] found that a comprehensive analysis of a building's behaviour reveals that the ability to bend rather than break under a sudden force is preferable. This concept forms the base for Solar Responsive Façade (SRF), which are adaptable entities that respond

[*] *Corresponding author.*
E-mail address: farhanarazif@usm.my

https://doi.org/10.37934/araset.29.3.6276

to varying environmental conditions on a continual basis. The optimum design for a kinetic façade is designed in a geometric form such as the Al-Bahar Towers. Hosseini *et al.,* [6] stated that for Al-Bahar Towers, significant emphasis was placed on the regulating capabilities of the façade when designing moveable petals for managing daylight. The regulatory duty of the facade includes adapting, regulating, and reacting. Dynamic responses to environmental stimuli are used to execute these in accordance with predetermined criteria in order to achieve desired outcomes. In accordance with the functionality of the façade, the design of the façade pattern has become similar, which lacks identity. From an architectural standpoint, the building envelope, or facade, is in essence the building's public face and as a result, greatly affects how people perceive the structure. The envelope serves as a mediator or buffer between the interior and exterior environments from an energetic standpoint as shown in Figure 1. The envelope can reduce solar insolation, resulting in lower heating and cooling demands and better daylight distribution. In order to balance energy performance with architectural expression, fine-tune the various functions, generate electricity, and more, PV modules can be integrated into a dynamic shading system [7].

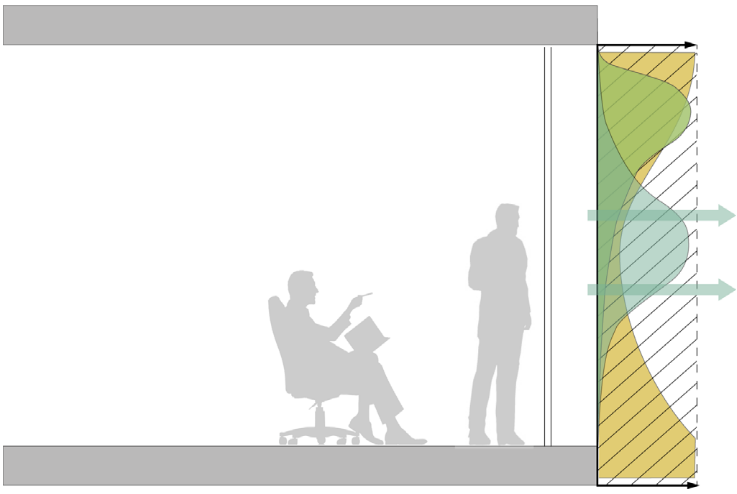


Fig. 1. The facade mediates the interior-exterior environment and serves many purposes [7]

The use of daylight is an efficient method to reduce the artificial lighting requirements of non-domestic buildings. To provide ample daylighting in spaces, daylight performance metrics are the primary standards used to assist building design or to compare one building to another in terms of daylighting in a room. The most widely used daylight performance parameter is daylight factor [8].

1.1 Solar Responsive Façade (SRF)

Solar responsive façade (SRF) or also known as kinetic façade, is the skin of a building and is exposed to light, heat, and wind. The basic function of SRF is to provide shading and daylight distribution throughout the building. Building a façade is considered high performance when it can reduce the amount of heat gain from solar while optimizing natural lighting which leads to higher energy efficiency rates [9]. Nowadays, there are several functions, materials, and layers in façade to meet environmental changes and the need of becoming responsive, multifunction, and dynamic. The movement of SRF can be set to autonomous and the design can be clustered into multiple groups installed on building façades [10]. A comprehensive literature review on the implication of solar responsive façade on energy efficiency or visual and thermal comfort is done. The main keyword for the article search is ‘solar responsive façade’ with synonyms of ‘kinetic façade’, ‘responsive façade’, 'adaptive façade', and 'smart façade', and the search limits to articles published between 2015 and 2022. Table 1 shows the 20 articles that met the criteria and are chosen for the literature studies. Most of the façade designs are in a hot and humid climate, tropical climate, and region that has hot summer focus more on shading to filter the direct sunlight into the building. Some of the façades integrated with photovoltaics are located at a location that receives the maximum sun rays without obstruction during the day.

Table 1
Research on the implication of solar responsive façade on energy efficiency, visual or thermal comfort

Author	Location	Method Used	Type	Findings		
				Energy Efficiency	Visual	Thermal Comfort
Flor *et al.* [11]	United Kingdom (temperate)	Experimental Study & Simulation	Switchable Material in Double-Skin Façades		✓	✓
Mangkuto *et al.,* [12]	Indonesia (hot and humid)	Experimental Study & Simulation	Adaptive Shading Devices			✓
Bui *et al.,* [13]	Australia (desert or semi-arid)	Experimental Study & Simulation	Adaptive Façade	✓		
Di Salvo [14]	Mediterranean (mild wet winters and hot, dry summers)	Literature Review & Case Study	Building Envelopes with Smart Façade Skins			✓
Tabadkani *et al.,* [15]	Australia (desert)	Literature Review & Case Study	Adaptive Façade	✓	✓	✓
Frattolillo *et al.,* [16]	Italy (hot, dry summers and cool, wet winters)	Simulation	Solar Thermal Collectors Integrated Facade	✓ *Photovoltaic - integrated*		✓
Sheikh& Asghar [3]	Pakistan (temperate)	Experimental Study & Simulation	Adaptive Biomimetic Facade	✓	✓	✓
Babu *et al.,* [17]	Singapore (tropical climate)	Experimental Study	Interior Venetian Blinds		✓	✓
Hosseini *et al.,* [6]	Netherlands (moderate maritime climate)	Literature Review	Kinetic Façade		✓	✓
Tabadkani *et al.,* [18]	Iran (hot, dry climate)	Experimental Study & Simulation	Adaptive Solar Façade (ASF)		✓	✓
Schieber *et al.,* [19]	Germany (Continental climate)	Experimental Study	Adaptive Innovative System		✓	
Badarnah [20]	Massachusetts (humid continental climate)	Literature Review & Case Study	Adaptive Innovative System	✓ Photovoltaic -integrated	✓	
López *et al.,* [21]	Spain (temperate)	Experimental Study	Responsive Innovative System	✓	✓	

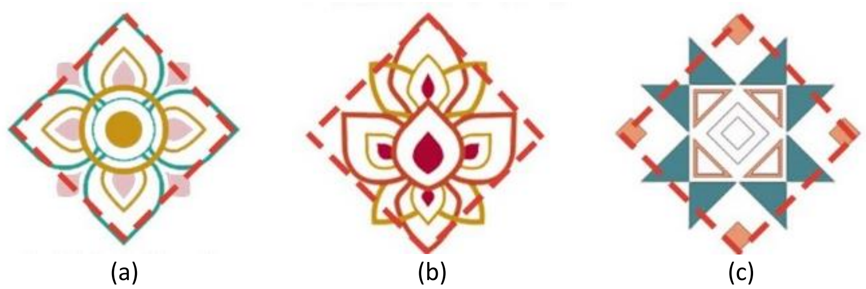
Grobman *et al.,* [22]	Mediterranean Climate	Experimental Study & Simulation	Kinetic Façade		✓
Sugár *et al.,* [23]	Hungary (continental)	Literature Review & Case Study	Responsive Innovative System	✓	
Nagy *et al.,* [1]	Switzerland (no excessive heat, cold or humidity)	Experimental Study & Simulation	Adaptive Solar Facade	✓ Photovoltaic -integrated	
Mahmoud & Elghazi [24]	Egypt (dry, hot- desert)	Experimental Study & Simulation	Kinetic Façade		✓

1.2 Thai Architecture and Siamese Patterns

Thai architecture is a multidisciplinary field that includes history, language and literature, philosophy and religion, social and cultural history, folklore, and art [25]. Thai architecture is linked to symbolism which exemplifies Siam's strength and culture. Horayangkura [26] stated that as symbolic aspects of Siamese culture, prominent distinctive traits such as high-pitched gable roofs, spired roof structures, lotus-shaped motifs, and sources of water are used.

From the past to the present, Thai architecture portrays the Siamese or Thai people's livelihood through creativity, ideal imagination, and national identity. The circular bell-shaped style of Singhalese stupas, the square columnar form of Sirivijaya stupas, the Sukhothai period's lotus bud summit style, and the Ayutthaya and Bangkok period's square base with corners style are some of the Thai architecture [27].

Siamese pattern designs are inspired by the culture of Siamese daily life, beliefs, and craft items which are derived from art, religion, and craft (refer to Figure 2). For cultural art, Lai Thai or Traditional Thai Patterns, mainly consists of lines and decorative patterns. For religious-inspired patterns, it is mostly Buddhist-inspired forms that can be seen in temple columns that are commonly shaped at the tip into lotus buds, jasmine garlands, incense smoke, as well as candle flame. Cultural craft-inspired patterns are derived from traditional Thai textiles that have distinctive geometric patterns and plant motifs. According to Sawasdee *et al.,* [28], everyday items have a significant influence on the patterns. The outline of the Siamese patterns is extracted to form the simplest form of façade. The façade is then adjusted to fits the functionality of sun shading.



(a) (b) (c)

Fig. 2. Patterns that are inspired by Siamese (a) Art, (b) Religion and (c) Craft

1.3 Kinetics Façades

Through innovation, new opportunities are emerging, such as the use of programmable origami-based features that enable mechanical unfolding, metamaterials, and the use of Building Information Modeling (BIM) in conjunction with digitalization and the Internet of Things (IoT). Using programmable origami-based features to generate outstanding geometry in roof elements is no longer the only application; mobility and automatization for energetic and functional goals are also taken into consideration. As a result, the new design ideas frequently emphasize responding to changing climatic conditions and the environment to gain a competitive edge [29]. According to Le-Thanh *et al.,* [30], the folding method frequently utilized in origami is the most efficient way to produce more intricate and imaginative creations. The well-known traditional Japanese art of origami is noted for its ability to offer a great degree of kinetic complexity in the creation of various paper shapes of objects. The kinetic shading devices' ability to adaptably modify their shapes is made possible by the Origami folding techniques, which allowed designers to make considerably more inventive designs. The indoor environment of the building can be improved, uncomfortable consequences such as glare, warmth, and direct sunshine can be lessened, and the energy cost for cool loading can be reduced by using these flexible shading systems.

The first stage in maximising the benefits offered by a certain place, according to Malaysian Standard [31], is designing well within the contextual climate and site. The main strategies for ensuring thermal and visual comfort in building structures in a hot, humid climate are to orient, insulate, shade, collect daylighting, and ventilate. A properly planned building envelope can enhance thermal comfort and daylight. The external wall should be built to provide a view and regulate daylight while minimising solar heat gain. The daylight factor (DF) was intended to quantify daylighting performance irrespective of the real, instantaneous sky conditions. As a result, it was defined as the ratio of internal horizontal illuminance E_{in} at any position in space to unobstructed (external) horizontal illuminance E_{out} from a globe of the sky [32]. Table 2 shows how different level of daylight factor affects human comfort in terms of lighting, glare and thermal comfort. DF 1.0 to 3.5 are acceptable in terms of daylight received and thermal comfort.

Table 2
Daylight factor (DF) and impact on human comfort

Daylight Factor (%)	Lighting	Glare	Thermal Comfort
> 6.0	Intolerable	Intolerable	Uncomfortable
3.5 – 6.0	Tolerable	Uncomfortable	Tolerable
1.0 – 3.5	Acceptable	Acceptable	Acceptable
<1.0	Perceptible	Imperceptible	Acceptable

Glare, heat discomfort and visual discomfort are brought on by illuminations greater than 2000 lux. It is well documented that excessive levels of daylight illumination are strongly related to occupant discomfort. Too little daylight illumination may not help the perception of the visual world or the performance of visual tasks in any practical sense (i.e., below a minimum). Table 3 shows the range of useful daylight illuminance where the useful range is from 100 to 2000.

Table 3
Useful daylight illuminance (UDI) range

Description	Lux
Exceed the useful range	> 2 000
Within the range defined as useful	100 to 2 000
Below the useful range	<100

300 lux, or what is referred to as a "well-daylit space," is what a substantial majority of building users perceive to be sufficient [34]. A design illuminance of 500 lux is actually common throughout most of the developed world. Electric lighting is therefore often made to evenly provide 500 lux of (artificial) illumination throughout the work plane. When facing a computer workstation at a straight

angle to the window, the visual environment was rather acceptable when the work plane illuminance was less than 1800 lux [33].

2. Methodology

2.1 Derivation of Pattern

The design of the patterns is inspired by Siamese patterns of art, religious and craft. The pattern is outlined by studying the form of patterns on art pieces, religious items, and traditional silk. In Figure 3, selected patterns are simplified and adjusted to achieve maximum shade coverage. Each pattern is then finalized on a 1m x 1m frame structure.

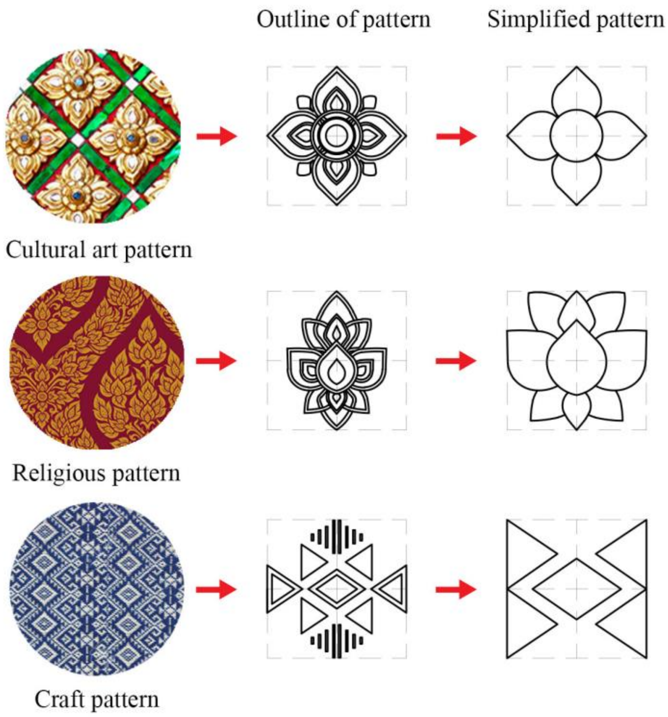
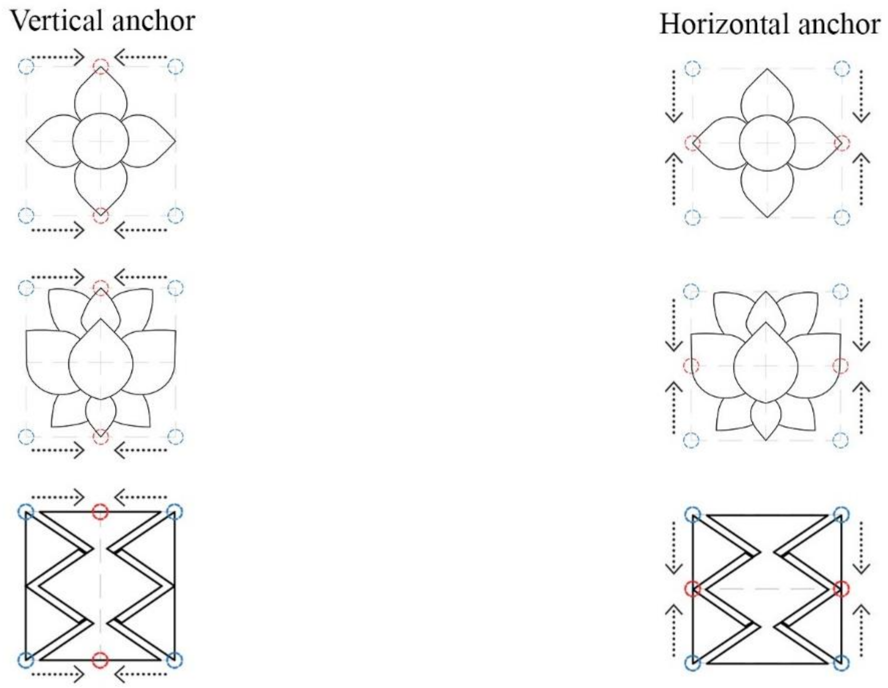


Fig. 3. Derivation of Siamese patterns into kinetic facade module

2.2 Kinetics Façade Patterns

Fixed anchor points determine the movement's constraints which can define different shapes and highlight the kinetics pattern of the module [35]. The module is designed with blue anchor points (Figure 4) that are attached to either the horizontal support or vertical support. The red anchor points indicate the folded part of the module.



(a) (b)

Fig. 4. Anchor points marked with blue circles are attached to (a) Vertical support (b) Horizontal support marked in red circles

The module can be manipulated into nine kinetics in accordance with vertical position or horizontal position. Figure 5 shows the nine-kinetics produced based on the folding technique. For modules in the vertical position, the module folds the x-axis to the left or to the right side of the wall, whereas for the horizontal position modules, the pattern folds along the y-axis to the top or to the bottom of the façade. The anchor point constrains the kinetics pattern as the module cannot fold simultaneously on both axes.

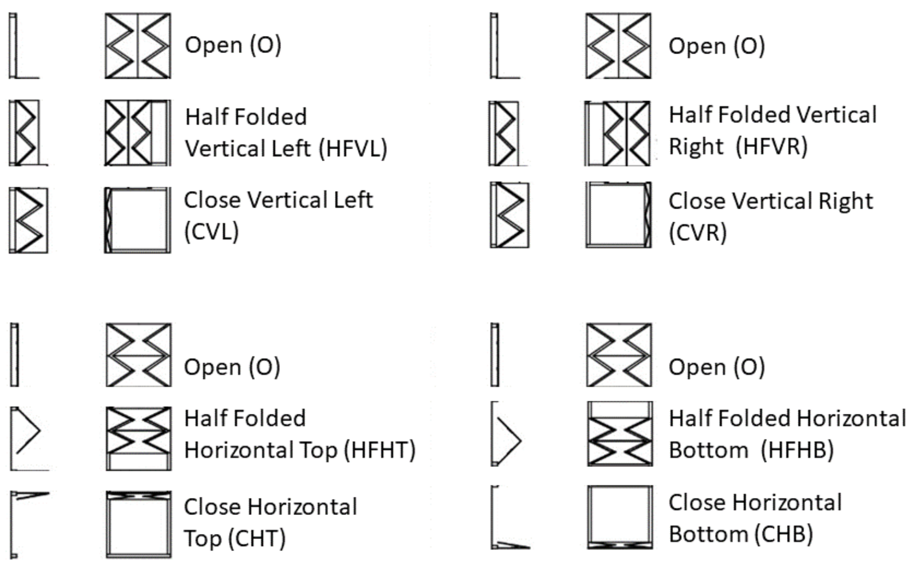


Fig. 5. Example of kinetic pattern folding techniques from side view and front view

2.3 Modelling

The base model is built with a size of 5.3m x 6m x 4m (h) of which the WWR is 70%. The WWR is then distributed to 1m x 1m for façade module structure system installation. The support structure system is decided on the folding motion along x or y axes as shown in Figure 6.

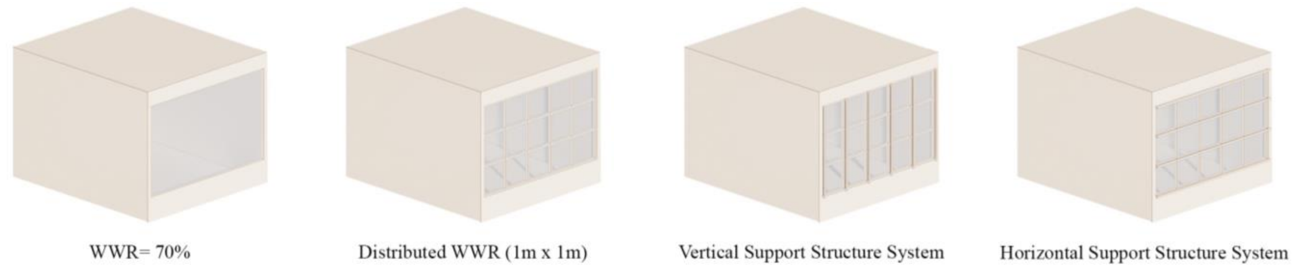
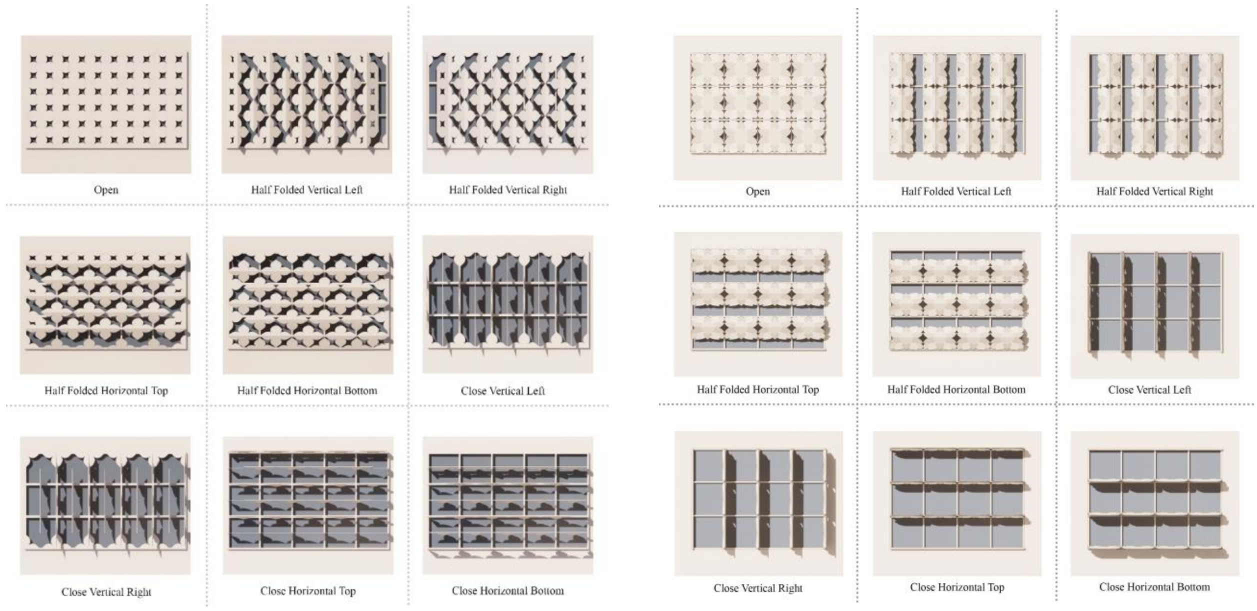
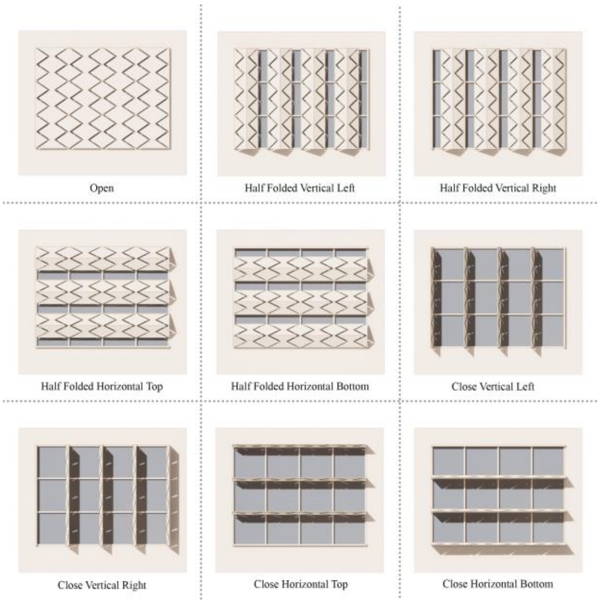


Fig. 6. Modelling process

The fundamental folding technique generated folding patterns that resulted in a set of geometric deployments. All folds can be manipulated to compact the design into a flat shape. The pattern module is folded in the form of symmetry, and when folded, it remains in a plan. The flow of kinetic movement in the cultural art pattern (Figure 7(a)), religious pattern (Figure 7(b)), and craft pattern (Figure 7(c)) are individually simulated using VELUX Daylight Visualizer 3 software.



(a) (b)



(c)

Fig. 7. Different opening methods for (a) Art-inspired kinetic pattern (b) Religious-inspired kinetic pattern (c) Craft-inspired kinetic pattern

4. Result & Discussion

The numerical outcome of the simulation analysis generated daylight factor data for all nine kinetics of three patterns. Table 8 compares the percentage of DF in nine kinetics of cultural art patterns, with Half Folded Vertical Left, Half Folded Vertical Right and Close kinetics patterns having the highest proportion of DF ranging from 25.02 % to 44.98 %. Half Folded Horizontal Top has the lowest percentage at 14.00 %. Daylighting can only reach up to 2.7m depth of the rooms during the Close Horizontal Bottom kinetics pattern. Table 9 shows that for religious patterns, the DF varies significantly between half-folded kinetics pattern and Closed kinetics pattern which has a difference of approximately 17.34% and can be up to 31.78%. In this case, the daylight entering the space varies about 1.29m - 1.63 difference in both kinetics pattern. Craft and religious art patterns produced almost similar findings, where the harvest of daylighting into the room resulted in a difference of only 0.02m in most of the kinetics pattern except for the Half Folded Horizontal Top where craft patterns differ in about 1.18m with the religious pattern as shown in Table 6, 7, 8 and 9.

Table 6
Daylight Factor (DF) of base model

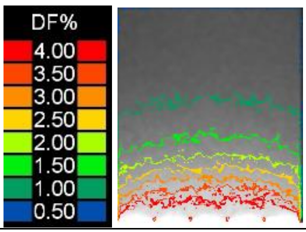
	Daylight Factor		
	<1	1-3.5	>3.5
Measurement log (pixels)	232700	218337	59339
Percentage (%)	45.59	42.78	11.63
Depth (m)	2.7	4.6	0.7
Image			

Table 7
DF comparisons based on kinetics patterns of cultural art pattern

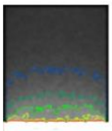
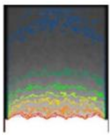
	O	HFVL	HFVR	HFHT	HFHB	CVL	CVR	CHT	CHB
									
					Daylight Factor <1.0				
Measurement log (pixels)	503663	345445	342544	399767	368885	273722	274170	281077	229691
Percentage (%)	96.29%	74.30%	73.87%	84.03%	79.44%	62.13%	62.51%	63.99%	54.06%
Depth (m)	5.78m	4.46m	4.43m	5.04m	4.77m	3.73m	3.75m	3.84m	3.24m
					Daylight Factor 1.0 – 3.5				
Measurement log (pixels)	12469	116312	117897	66590	92150	157539	156794	154097	191115
Percentage (%)	2.39%	25.02%	25.42%	14.00%	19.85%	35.76%	35.75%	35.08%	44.98%
Depth (m)	0.14m	1.50m	1.53m	0.84m	1.19m	2.15m	2.14m	2.10m	2.70m
					Daylight Factor >3.5				
Measurement log (pixels)	6904	3201	3301	9381	3299	9307	7638	4079	4054
Percentage (%)	1.32%	0.69%	0.71%	1.97%	0.71%	2.11%	1.74%	0.93%	0.95%
Depth (m)	0.08m	0.04m	0.04m	0.12m	0.04m	0.13m	0.10m	0.06m	0.06m

Table 8
DF comparisons based on kinetics patterns of religious-inspired pattern

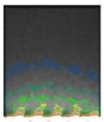
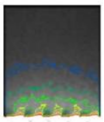
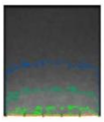
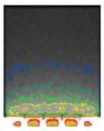
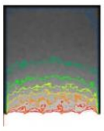
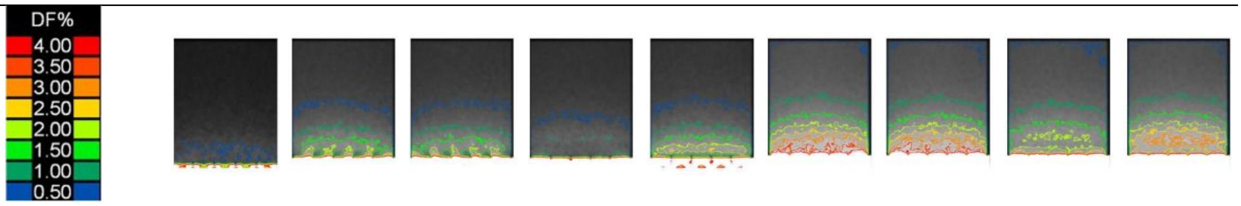
	O	HFVL	HFVR	HFHT	HFHB	CVL	CVR	CHT	CHB
									
					Daylight Factor <1.0				
Measurement log (pixels)	507353	362508	358384	365125	352722	228199	227935	240176	218931
Percentage (%)	96.56%	77.20%	76.67%	77.95%	72.23%	53.19%	52.38%	56.41%	50.62%
Depth (m)	5.79m	4.63m	4.60m	4.68m	4.33m	3.19m	3.14m	3.38m	3.04m
					Daylight Factor 1.0 – 3.5				
Measurement log (pixels)	13241	103593	105447	99984	124502	185798	186521	182393	209815
Percentage (%)	2.52%	16.73%	22.56%	21.35%	25.50%	43.31%	42.86%	42.84%	48.51%
Depth (m)	0.15m	1.32m	1.35m	1.28m	1.53m	2.60m	2.57m	2.57m	2.91m
					Daylight Factor >3.5				
Measurement log (pixels)	4852	3470	3579	3275	11111	15005	20712	3212	3746
Percentage (%)	0.92%	0.74%	0.77%	0.79%	2.28%	3.50%	4.76%	0.75%	0.87%
Depth (m)	0.06m	0.04m	0.05m	0.04m	0.14m	0.21m	0.29m	0.05m	0.05m

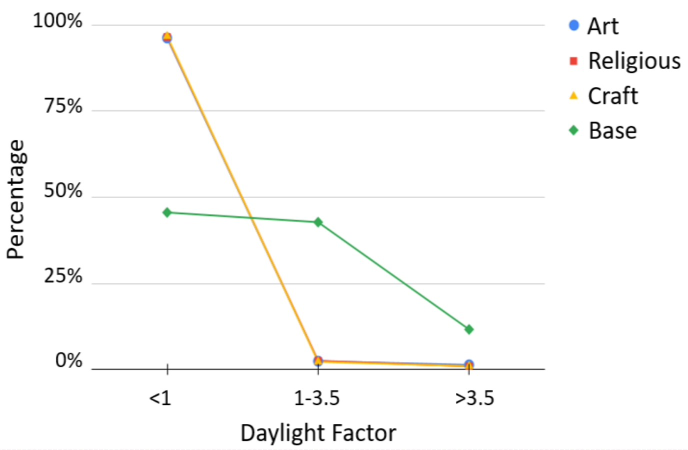
Table 9
DF Comparisons based on kinetics patterns of craft-inspired pattern



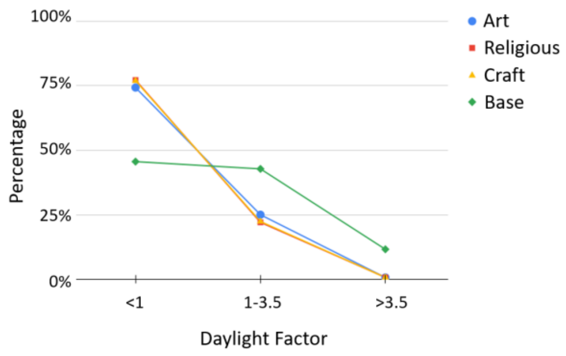
	O	HFVL	HFVR	HFHT	HFHB	CVL	CVR	CHT	CHB
					Daylight Factor <1.0				
Measurement log (pixels)	498921	359655	353836	453693	351075	225019	229420	242548	219695
Percentage (%)	96.76%	76.90%	76.38%	96.30%	74.05%	52.12%	53.32%	57.42%	50.98%
Depth (m)	5.81m	4.61m	4.60m	5.78m	4.44m	3.13m	3.20m	3.44m	3.06m
					Daylight Factor 1.0 – 3.5				
Measurement log (pixels)	11521	104769	106155	13780	117306	189522	186669	176565	207650
Percentage (%)	2.24%	22.40%	22.92%	2.93%	24.74%	43.90%	43.39%	41.80%	48.19%
Depth (m)	0.13m	1.34m	1.35m	0.18m	1.48m	2.63m	2.60m	2.51m	2.89m
					Daylight Factor >3.5				
Measurement log (pixels)	5028	3252	3264	3633	5753	17158	14172	3322	3581
Percentage (%)	0.98%	0.70%	0.77%	0.77%	1.21%	3.97%	3.29%	0.79%	0.83%
Depth (m)	0.06m	0.04m	0.05m	0.05m	0.07m	0.24m	0.20m	0.05m	0.05m

4.1 Performance of Nine Kinetics Patterns of Each Cultural Patterns

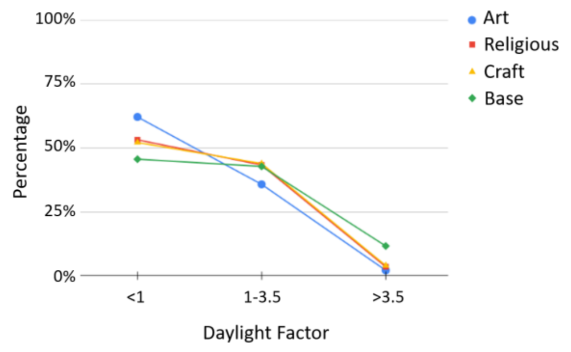
Figure 8 depicts the recommended daylight factor range, which is between 1.0% and 3.5%. Less than 1.0% is considered dark, whereas 3.5% to 6.0% is considered bright. The graph reveals that the maximum percentage of daylight factor occurs during the kinetics patterns of Close Vertical Left (CVL), Close Vertical Right (CVR), Close Horizontal Top (CHT), and Close Horizontal Bottom (CHB), which range from 35.08% to 48.51%, whilst the base model with 70% glazed façade recorded 42.78% of daylight factor of 1.0% - 3.5%.



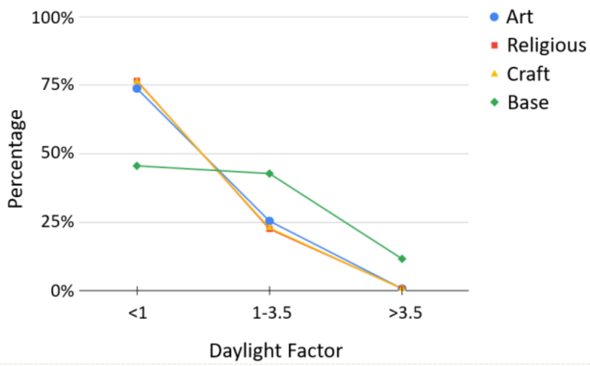
(a) Open



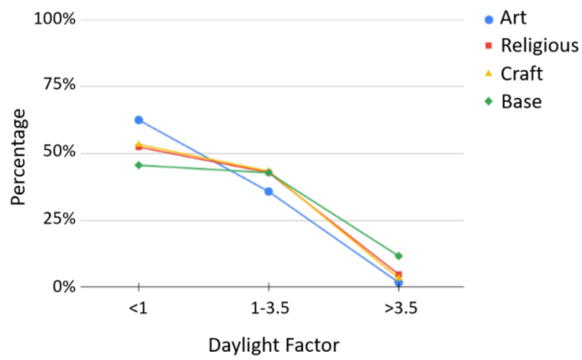
(b) Half Folded Vertical Left (HFVL)



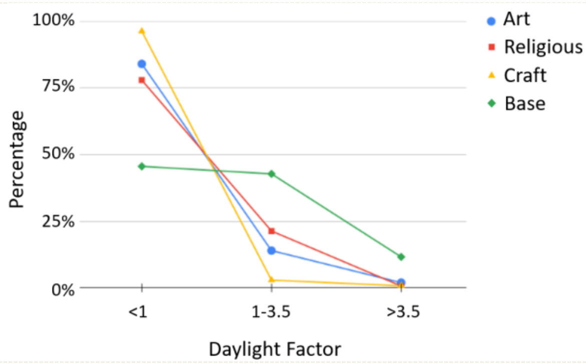
(c) Close Vertical Left (CVL)



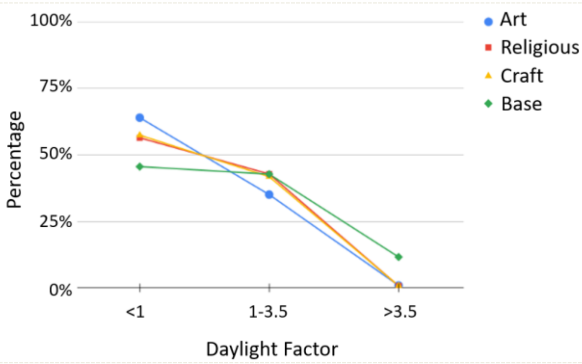
(d) Half Folded Vertical Right (HFVR)



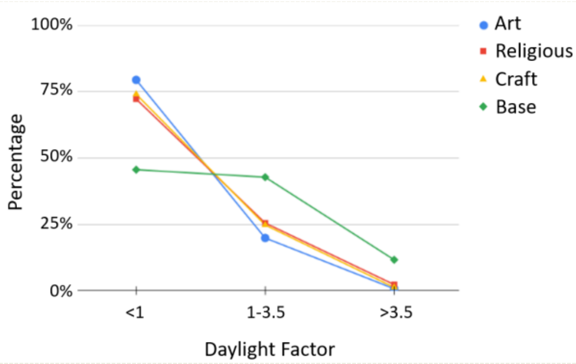
(e) Close Vertical Right (CVR)



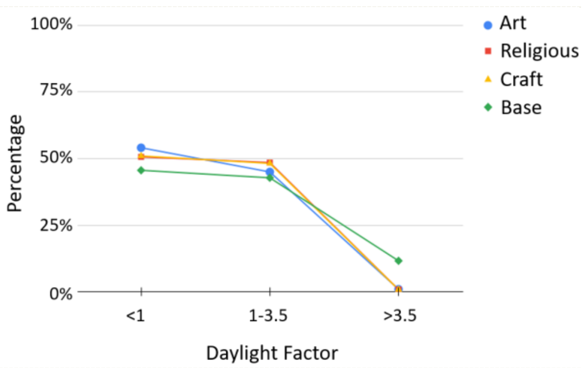
(f) Half Folded Horizontal Top (HFHT)



(g) Close Horizontal Top (CHT)



(h) Half Folded Horizontal Bottom (HFHB)



(i) Close Horizontal Bottom (CHB)

Fig. 8. Daylight factor for each kinetic pattern

The most noticeable variation between each pattern is at the kinetics pattern of Half Folded Horizontal Top (HFHT), where religious pattern recorded the closest to the base model, 25.50%, as compared to art pattern and craft pattern. During the Half Folded Vertical Left (HFVL) and Half Folded Vertical Right (HFVR) kinetics pattern, the cultural art pattern recorded the closest to the base model, which is 25.02% and 25.42% respectively, compared to the religious pattern (22.06% and 22.56%) and craft pattern (22.40% and 22.92%). The three cultural patterns show comparable results of providing shade and very low to minimal daylight contribution during the Open (O) kinetic pattern. Despite the differences in pattern, Half Folded Vertical Left (HFVL) and Half Folded Vertical Right (HFVR) produce identical results for the vertical shading position. The simulation research revealed that the religious pattern outperformed the base model in the majority of the kinetics patterns. The craft pattern had the lowest performance, with a significant difference in some of the daylight factors when compared to the other patterns (refer to Figure 9)

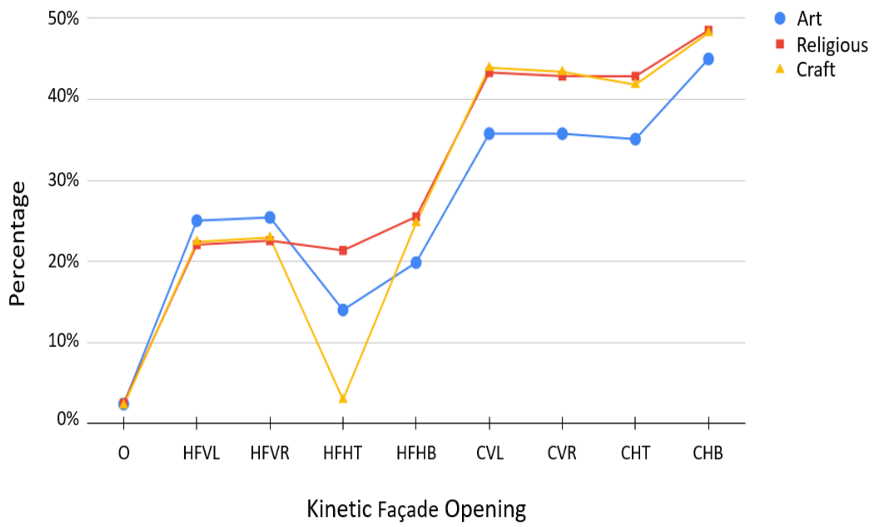


Fig. 9. Percentage of having 1.0 – 3.5 daylight factor in each Kinetic Pattern

5. Conclusion

For architects and developers, the issue of daylight is crucial. It influences the practical layout of the occupant's comfort, structure, and space. The folding technique utilized to design the SRF can improve the form of the façade, making it more adaptive to its surroundings. Simulation studies on each of the kinetics patterns help in the early stages of building design. This paper concludes that the design and kinetics patterns of the façade pattern have a significant impact on daylight contribution. According to the findings, the design of patterns and the use of kinetics pattern is able to harvest daylight into the rooms in response to the external environment at any time of the day. A suitable daylight factor of 1% - 3.5% is recommended for more in-depth of the room as it provides tolerable lighting, glare, and thermal comfort for the user of the space. This study's comparative numerical simulation analysis of the pattern difference in response to daylight factor (1.0%-3.5%) will aid in the identification of the most effective pattern design that embodies the cultural cue for the community.

Acknowledgment
The author would like to acknowledge research funding from Short Term Research Grant, Universiti Sains Malaysia (304/PPBGN/6315299).

References

[1] Nagy, Zoltan, Bratislav Svetozarevic, Prageeth Jayathissa, Moritz Begle, Johannes Hofer, Gearoid Lydon, Anja Willmann, and Arno Schlueter. "The adaptive solar facade: from concept to prototypes." *Frontiers of Architectural Research* 5, no. 2 (2016): 143-156. https://doi.org/10.1016/j.foar.2016.03.002

[2] Nasir, Muhammad Hafeez Abdul, Ahmad Sanusi Hassan, Mohd Nasrun Mohd Nawi, and Aimi Salihah Abdul Nasir. "Analysis of Hotel Façade Thermal Performance with a Special Reference to the City Hotels in George Town, Penang." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 3 (2022): 199-208. https://doi.org/10.37934/araset.28.3.199208

[3] Sheikh, Wajiha Tariq, and Quratulain Asghar. "Adaptive biomimetic facades: Enhancing energy efficiency of highly glazed buildings." *Frontiers of Architectural Research* 8, no. 3 (2019): 319-331. https://doi.org/10.1016/j.foar.2019.06.001

[4] Salim, Nuzaihan Aras Agus, and Ahmad Sanusi Hassan. "Simulation on Building Envelope Design using Biomimicry Conceptual of Palm Leaf Pattern for Self Cleaning Maintenance." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 3 (2022): 376-392. https://doi.org/10.37934/araset.28.3.376392

[5] Romano, Rosa, Laura Aelenei, Daniel Aelenei, and Enrico Sergio Mazzucchelli. "What is an adaptive façade? Analysis of Recent Terms and definitions from an international perspective." *Journal of Facade Design and Engineering* 6, no. 3 (2018): 65-76.

[6] Hosseini, Seyed Morteza, Masi Mohammadi, Alexander Rosemann, Torsten Schröder, and Jos Lichtenberg. "A morphological approach for kinetic façade design process to improve visual and thermal comfort." *Building and Environment* 153 (2019): 186-204. https://doi.org/10.1016/j.buildenv.2019.02.040

[7] Nagy, Zoltan, Bratislav Svetozarevic, Prageeth Jayathissa, Moritz Begle, Johannes Hofer, Gearoid Lydon, Anja Willmann, and Arno Schlueter. "The adaptive solar facade: from concept to prototypes." *Frontiers of Architectural Research* 5, no. 2 (2016): 143-156. https://doi.org/10.1016/j.foar.2016.03.002

[8] Bian, Yu, and Yuan Ma. "Analysis of daylight metrics of side-lit room in Canton, south China: A comparison between daylight autonomy and daylight factor." *Energy and Buildings* 138 (2017): 347-354. https://doi.org/10.1016/j.enbuild.2016.12.059

[9] Meagher, Mark. "Designing for change: The poetic potential of responsive architecture." *Frontiers of architectural Research* 4, no. 2 (2015): 159-165. https://doi.org/10.1016/j.foar.2015.03.002

[10] Rossi, Dino, Zoltán Nagy, and Arno Schlueter. "Adaptive distributed robotics for environmental performance, occupant comfort and architectural expression." *International Journal of Architectural Computing* 10, no. 3 (2012): 341-359. https://doi.org/10.1260/1478-0771.10.3.341

[11] Flor, Jan-Frederik, Xiao Liu, Yanyi Sun, Paolo Beccarelli, John Chilton, and Yupeng Wu. "Switching daylight: Performance prediction of climate adaptive ETFE foil façades." *Building and Environment* 209 (2022): 108650. https://doi.org/10.1016/j.buildenv.2021.108650

[12] Mangkuto, Rizki A., Mochamad Donny Koerniawan, Sri Rahma Apriliyanthi, Irma Handayani Lubis, Jan LM Hensen, and Beta Paramita. "Design optimisation of fixed and adaptive shading devices on four façade orientations of a high-rise office building in the tropics." *Buildings* 12, no. 1 (2022): 25. https://doi.org/10.3390/buildings12010025

[13] Bui, Dac-Khuong, Tuan Ngoc Nguyen, Abdallah Ghazlan, Ngoc-Tri Ngo, and Tuan Duc Ngo. "Enhancing building energy efficiency by adaptive façade: A computational optimization approach." *Applied energy* 265 (2020): 114797. https://doi.org/10.1016/j.apenergy.2020.114797

[14] Di Salvo, Santina. "Façade Solar Control and Shading Strategies for Buildings in the Mediterranean Region." *International Journal of Environmental Science & Sustainable Development* 5, no. 2 (2020): 32-47. https://doi.org/10.21625/essd.v5i2.758

[15] Tabadkani, Amir, Masoud Valinejad Shoubi, Farzaneh Soflaei, and Saeed Banihashemi. "Integrated parametric design of adaptive facades for user's visual comfort." *Automation in Construction* 106 (2019): 102857. https://doi.org/10.1016/j.autcon.2019.102857

[16] Frattolillo, Andrea, Laura Canale, Giorgio Ficco, Costantino C. Mastino, and Marco Dell'Isola. "Potential for building façade-integrated solar thermal collectors in a highly urbanized context." *Energies* 13, no. 21 (2020): 5801. https://doi.org/10.3390/en13215801

[17] Babu, Sushanth, Jian Zhou, Man Pun Wan, Adrian S. Lamano, Jatin N. Sarvaiya, Zhe Zhang, DEVS Kiran Kumar et al. "Investigation of an integrated automated blinds and dimmable lighting system for tropical climate in a rotatable testbed facility." *Energy and Buildings* 183 (2019): 356-376. https://doi.org/10.1016/j.enbuild.2018.11.007

[18] Tabadkani, Amir, Astrid Roetzel, Hong Xian Li, and Aris Tsangrassoulis. "A review of automatic control strategies based on simulations for adaptive facades." *Building and Environment* 175 (2020): 106801. https://doi.org/10.1016/j.buildenv.2020.106801

[19] Schieber, G., L. Born, P. Bergmann, A. Körner, A. Mader, S. Saffarian, O. Betz, M. Milwich, G. T. Gresser, and J. Knippers. "Hindwings of insects as concept generator for hingeless foldable shading systems." *Bioinspiration & Biomimetics* 13, no. 1 (2017): 016012. https://doi.org/10.1088/1748-3190/aa979c
[20] Badarnah, Lidia. "Form follows environment: Biomimetic approaches to building envelope design for environmental adaptation." *Buildings* 7, no. 2 (2017): 40. https://doi.org/10.3390/buildings7020040
[21] López, Marlén, Ramón Rubio, Santiago Martín, and Ben Croxford. "How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes." *Renewable and Sustainable Energy Reviews* 67 (2017): 692-703. https://doi.org/10.1016/j.rser.2016.09.018
[22] Grobman, Yasha Jacob, Isaac Guedi Capeluto, and Guy Austern. "External shading in buildings: comparative analysis of daylighting performance in static and kinetic operation scenarios." *Architectural science review* 60, no. 2 (2017): 126-136. https://doi.org/10.1080/00038628.2016.1266991
[23] Sugár, Viktória, Péter Leczovics, and András Horkai. "Bionics in architecture." *YBL Journal of built environment* 5, no. 1 (2017): 31-42. https://doi.org/10.1515/jbe-2017-0003
[24] Mahmoud, Ayman Hassaan Ahmed, and Yomna Elghazi. "Parametric-based designs for kinetic facades to optimize daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns." *Solar Energy* 126 (2016): 111-127. https://doi.org/10.1016/j.solener.2015.12.039
[25] Verapreyagura, Pornphan. "The Transition of the Research Methodology for Thai Study of Architecture in Transationalized World." (2010).
[26] Horayangkura, Vimolsiddhi. "In search of fundamentals of Thai architectural identity: A reflection of contemporary transformation." *Athens Journal of Architecture [Internet]* 3, no. 1 (2017): 21-40. https://doi.org/10.30958/aja.3-1-2
[27] Klinchan, Nilratana. "Thai culture that ASIAN students should know." *Mahachula Academic Journal* 4, no. 1 (2017): 188-203.
[28] Sawasdee, Kasinee, Boonsom Yodmalee, and Kosit Phaengsoi. "Silk Patterns: Conservation and Development of Traditional Thai silk Production for Added Commercial Value in Khon Kaen Province." *Asian Culture and History* 7, no. 1 (2015): 41. https://doi.org/10.5539/ach.v7n1p41
[29] Pavón, Rubén Muñoz, Ángela Moreno Bazán, Jorge Jerez Cepa, Antonio A. Arcos Álvarez, Jesús María Alonso Trigueros, Marcos García Alberti, and Jaime Reinoso Tellaeche. "New Use of BIM-Origami-Based Techniques for Energy Optimisation of Buildings." *Applied Sciences* 12, no. 3 (2022): 1496. https://doi.org/10.3390/app12031496
[30] Le-Thanh, Luan, Thang Le-Duc, Hung Ngo-Minh, Quoc-Hung Nguyen, and H. Nguyen-Xuan. "Optimal design of an Origami-inspired kinetic façade by balancing composite motion optimization for improving daylight performance and energy efficiency." *Energy* 219 (2021): 119557. https://doi.org/10.1016/j.energy.2020.119557
[31] Malaysian Standard: Energy efficiency and use of renewable energy for residential buildings - Code of practice. MS2680:2017
[32] Mardaljevic, John, and J. Christoffersen. "'Climate connectivity'in the daylight factor basis of building standards." *Building and Environment* 113 (2017): 200-209. https://doi.org/10.1016/j.buildenv.2016.08.009
[33] Tregenza, R. "W'arers, LM.(1983)." *Daylight coefficients. Lighting Research and chnnalogy* 15, no. 2 (81): 65-71. https://doi.org/10.1177/096032718301500201
[34] Pesenti, Marco, Gabriele Masera, Francesco Fiorito, and Michele Sauchelli. "Kinetic solar skin: a responsive folding technique." *Energy Procedia* 70 (2015): 661-672. https://doi.org/10.1016/j.egypro.2015.02.174
[35] Ahmad, Asim, Om Prakash, Anil Kumar, SM Mozammil Hasnain, Puneet Verma, Ali Zare, Gaurav Dwivedi, and Anukul Pandey. "Dynamic analysis of daylight factor, thermal comfort and energy performance under clear sky conditions for building: An experimental validation." *Materials Science for Energy Technologies* 5 (2022): 52-65. https://doi.org/10.1016/j.mset.2021.11.003