MSA UNIVERSITY ENGINEERING JOURNAL

Origami-inspired interactive kinetic façades design: Using different interaction areas of students' positions to improve visual comfort in schools in Egypt

Yasmeen Sayed Mahmoud [1,a,*], Mourad Abdel Kader Abdel Mohsen [2,b], Ashraf Ali Nessim [3,c]

1 Department of Architecture, Faculty of Engineering, Ain Shams University, Cairo, Egypt
2 Prof. Dr., Department of Architecture, Faculty of Engineering, Ain Shams University, Cairo, Egypt
3 Associate. Prof., Department of Architecture, Faculty of Engineering, Ain Shams University, Cairo, Egypt

E-mail: [a,*]yasmeen.sayed19@eng.asu.edu.eg, [b]morad_abdelkader@eng.asu.edu.eg, [c]a.nessim@eng.asu.edu.eg

Abstract

Nowadays, we are faced with multi-sustainability challenges in the existing buildings in different sectors. Especially in the educational sector, this is a result of the disregard for their orientations and location and changes in the education system, which leads to the possibility of developing the functions and needs of these buildings. Thus, dealing with and monitoring educational buildings, especially schools, and changing them to sustainable and smart buildings are the main approach in recent days. Besides using Kinetic and interactive building envelopes is the main factor of building sustainability as referred by the literature and occupants' preferences involvement in the façade design, it provides more efficiency of the environmental performance, especially in visual comfort and improving the users' comfort. Enhancing visual performance and decreasing energy consumption leads to improvement in occupants' well-being and productivity and

ENGINEERING JOURNAL Volume 2 Issue 2
Received Date January 2023
Accepted Date March 2023
Published Date March 2023
DOI: 10.21608/MSAENG.2023.291914

a healthy learning environment in schools. This research discusses what is the suitable proposed geometrical approach of modular interactive façade design, and how it is simple to modulate, apply and adapt to external and internal changes. The main aim of this research is to study and apply adaptive and 3D modular interactive kinetic origami-based façade (IKF) and the development of form proportions of its modulation to improve the quality of daylighting performance for all orientations using climate studio software according to specific parameters to meet the standard daylight level in public schools in Egypt according to daylight and students' positions. The results show that the proposed IKF prevents visual discomfort and improves daylight performance.

Keywords: Interactive kinetic façade, Occupants' positions, Visual Comfort, Origami-inspired, Façade optimization

1. Introduction

We Natural daylight inside space is one of the most important affairs because of its importance in saving energy consumption and its ability to provide a comfortable environment inside space for occupants [1]. Hot arid areas are endowed with an abundance of clear skies, Thus, the solar energy available can significantly raise the temperature and daylight levels of interior spaces and result in an uncomfortable visual environment. Nowadays, we are facing multi-sustainability challenges in the existing buildings in different sectors which have led to the reconsideration of the development of the functions in these buildings, in addition, to the increase of energy problems in recent times [2]. Especially in the educational sector because of the changes that affect the educational process, slackness, and the less occupation of these buildings, this is a result of changing the education system, which leads to the possibility of developing the functions and needs of these buildings, saving of energy consumption and improving quality in these buildings. Attention to a new trend of architectural technologies in buildings envelopes and existing facades, especially in the case of public schools in Egypt. Due to discomfort glare and poor uniformity ratios in daylight performance, it is important to try solving these issues. To address the educational problems, several initiatives have instigated a quantitative expansion approach, rather than a qualitative one which would focus on the quality of educational spaces and the occupant's comfort. Within a study on the 1200 existing public and private school buildings in Cairo in 25 centers in it, this study was about what is the direction and orientation of these buildings and if it conforms to standards or not. As a result of this study, it was found that about 50% to 60% of these buildings have bad orientations rather than a north orientation.

The buildings’ envelopes are the systems capable of changing their properties and configuration differ from transparent to opaque, changing color, and varying optical and geometric properties. This change is due to climate changes or the indoor environment. According to these sentences, architectural skins transform over time from two-dimensional and unidirectional systems to three-dimensional forms and configurations [3]. The trend in recent decades has been to develop sustainable adaptive facades, as this development was tending to make the building modern and integrate with its external environment, so it turned to transparent glass facades, which in turn improve the mental health of users due to exposure to sunlight and views of the landscape [4]. The design of interactive kinetic facades using kinetic patterns and their movements has a major role in improving the responses of the façade and the interaction with the external environment to achieve the comfort of the occupants. Designing these shapes as simple, flexible, foldable self-shading shapes made of smart materials is essential. Also, other aspects of aesthetics, privacy, and connection to the outside are essential in the design [5]. Therefore, the design and movement of such configurations and patterns are not an easy matter to choose because it is related to the process of implementing these facades [6]. Based on studies and research that studied kinetic facades and their types of movement, five types of geometry deformations were identified which are used in most buildings with kinetic interactions. Expanding, Retracting, Folding, Sliding, and Transforming [7].

The gap is finding the performance of 3-Dimensional modular interactive kinetic facades for meeting all occupants’ comfort positions and daylight simultaneously in existing school buildings. And these modular elements which form the façade have inspirations for creating geometry and be simple to modulate, apply and adapt to external and internal changes. The statement of the problem is the existing schools have uncomfortable visual performance and Undesirable psychological environments for their occupants because of increasing daylighting, which causes glare and direct sunlight exposure in school spaces. This problem is one of the challenges which faces the existing buildings and makes them unsustainable and inefficient. The aim to overcome the problems is to study and apply an adaptive and modular interactive kinetic façade and the development of form proportions of its modulation to improve the quality of daylighting performance, adapt to daylight and occupants' positions, and be applied to meet the standard daylight level in schools in Egypt.

2. Structure

2.1. Design workflows toward innovative adaptive facades

The main function of a building with an adaptive facade is the ability to change its functions or behavior over time by continuously responding to changes and limitations in order to improve its overall environmental performance. Active and passive systems are integrated into different types of movement in order to improve energy consumption and internal comfort. These systems can be identified by whether energy is being used or not. According to [8] adaptive facades Afs were classified based on their motion typologies into two main groups: (1) simple motion type and (2) complex motion type. Simple motions are divided into two types, the first type is a type that controls the basic simple shapes with simple movements, they are movements that deal with traditional architectural solutions such as roller blinds and metal blinds and rods and the second type is the active type by using initial energy, whether electrical or mechanical. These systems can either be dealt with automatically without user interactions as in [9] where the study proved the ability of automated Venetian blinds to improve the performance of the building and the comfort of users better instead of using manual Venetian blinds. Or a comprehensive centralized transaction by entering the user and his preferences into the design process as in [10] where the impact of the automated façade process on user satisfaction was studied by knowing their preferences and different control strategies [8]. Complex motions: They are complex three-dimensional individual movements that can control and adapt unconventional adaptive facades and make them more responsive and achieve indoor environmental comfort, through the aid of parametric design and the use of advanced sensors and actuators. These movements are divided into three types: basic movements [11]- folding structure [12] - biomimetic skins [13].

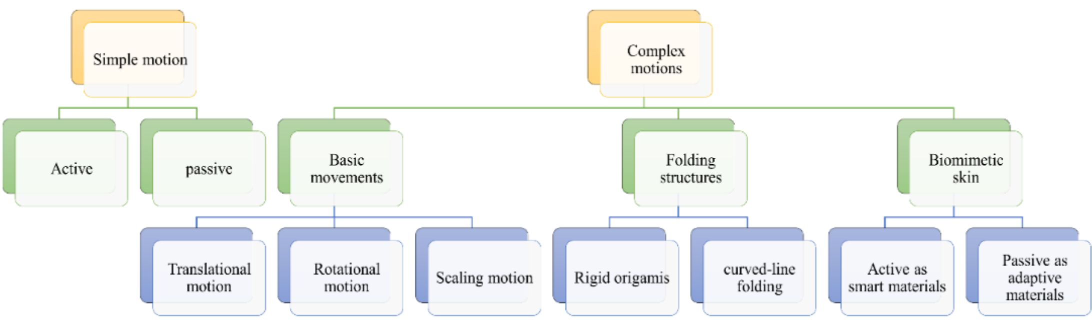
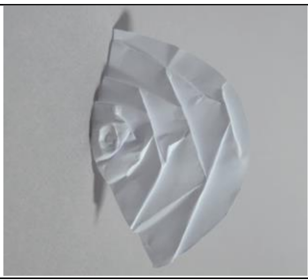
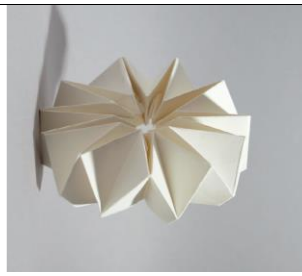


Fig. 1. Adaptive façade motion types. Source: the researchers

2.2. Origami concept and material selection of the interactive pattern

The design based on origami folding art enables us to transform two-dimensional objects and surfaces into three-dimensional elements with many advantages, including self-shading and kinetic. It is a technique that results in forms that follow the folding method with rotational and scaling movements, as we mentioned previously, so we can follow this method in the design of facades. The origami techniques are divided into three pattern types: Flat static tessellation origami, Volumetric dynamic tessellation origami that unfolds along axes, and Volumetric dynamic tessellation origami that rotates on itself [14]. In this research, the pattern will be into the second type.

Table 1. Types of origami shapes. Source: [14].

		
Flat static tessellation origami	Volumetric dynamic tessellation origami that unfolds along axes	Volumetric dynamic tessellation origami that rotates on themselves

Given the different shapes and characteristics of origami, as well as the complex movements, these complex movements must be reduced. Think also about integrating these shapes with smart micro-actuators such as the shape memory alloy (SMA) to control the change of shape in direct response to incoming solar radiation, which reduces the energy used in the shading system. It was chosen due to several features and characteristics that make it a basis for our design and thinking in the interactive shading unit [15].

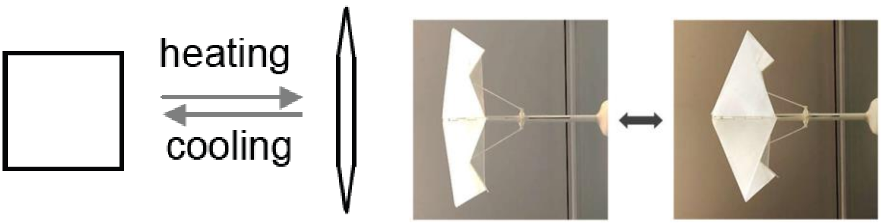
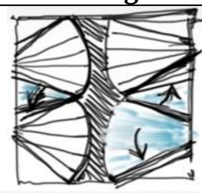
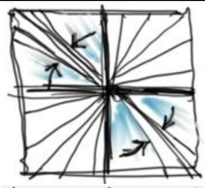
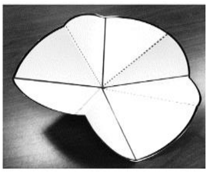
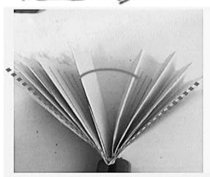
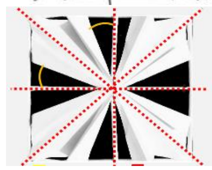
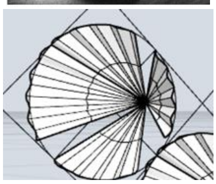
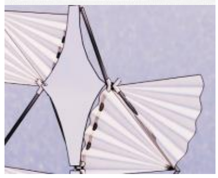
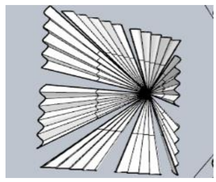


Fig. 2. Two-phase shapes and desired deformation. Source: [16], [17]

2.3. Criteria of proposals selection

The aim of the study is to analyze the simple geometric shapes in movement and implementation, and the most appropriate in their use in the facades of buildings. Therefore, three different geometric shapes were chosen: in order to compare them according to clear criteria according to the literature and other special criteria [18] which are as follows: simplicity, aesthetics, rigidity, fit, economy, functions, and minimum displacement, and by a scale from 0 to 1.

Table 2. Kinetic model. Source: the researchers

	Pai-Pai	**Triangle**	**Quadrangular**
Sketches			
Physical model			
Computer model			
Simplicity	0.6	0.8	0.9
Aesthetic	0.7	0.8	1.0
Rigidity	0.9	0.8	0.8
Fit	0.4	0.8	0.9
Economic	0.6	0.8	0.8
Functionalities	0.5	0.8	0.8
Alignment	X	0.5	0.9
Material	0.5	0.8	0.8
Displacement	1.0	0.9	0.9
Total	0.55	0.77	0.83

As in the previous table, it is clear that the most suitable form in design and control is Quadrangular, which obtained the highest percentage in the evaluation by 83%, and it is the design that will be used in this study.

2.4. Daylight evaluation criteria & optimization goals

The four metrics of sDA, SPT, ASE, and DGP will be utilized to improve classroom daylight performance after applying the skin. In the optimization phase, as suggested by LEED V4 and IES only sDA and ASE will be evaluated. The goal is to achieve sDA to be more than 75% up to 100% and minimize ASE to be less than 10% down to 0% [19]. This research is concerned with the study of classrooms, so the appropriate lighting intensity for the classroom is from 300: 500 lux, depending on the criteria of Illuminating Engineering

Society (LES), and given that the main activity of the classroom is reading and writing, so the target lighting intensity is 500 lux.

3. Methodology

The research is a quantitative simulation study and is divided into three main sections: The first section is to collect data about the case study, such as the location, climate, dimensions, and materials used. The second section explains how to design and operate the kinetic facade and what are the parameters. The third section explains how the simulation process and analyzes the information to be used in improving the performance of the interactive facade.

3.1. Case study

It is an educational building (school) with a height of five floors and consists of two adjacent buildings. In the phase of study and exploration, Cairo will be the location, given that it is the largest governorate with several schools for public education, as it contains more than 39,000 classrooms, 10% of the classrooms in Egypt. Sky conditions is a Clear Sky, the Period of simulation is to run the simulation in the classroom, the simulation period can be divided into two periods, morning, and evening, where the (first) morning period is from 8 am - to 12 pm, and the (second) evening period is from 12 pm - to 5 pm.

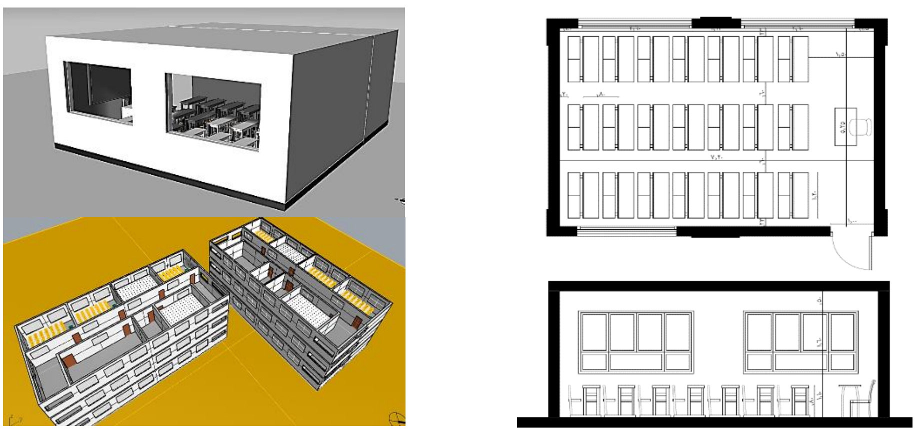


Fig. 3. Classroom configuration as the base case. Source: the researchers

Table 3. Parameters of the simulated classroom. Source: the researchers

space parameters	
Floor Level	Second floor
Room Dimensions	525*720*320cm
Surfaces materials and reflectance	
Floors	Mosaic Tiles - 20% – Generic Floors – Diffuse Reflectance
Walls	Off-White color paint - 50% - Generic Interior wall

Ceiling	White color paint - - 80% - Generic ceiling – Diffuse Reflectance.
Window Glass	Double glazing - 80% Glazing – Double panel- clear-Transmit
Window Mullions	Metal Diffuse
Outside Ground Floor	20% outside Ground- Diffuse Reflectance
Whiteboard	90% Diffuse Reflectance
Base Case Window parameters	
Window Dimensions	160*260*110 (sill)cm
Orientation	All orientations
Working plan	
Module	50*50 cm
Height	80 cm
Location and climate parameters	
Location	Cairo, clear sky
Time	From 8 am to 5 pm - From 1 Oct. to 1 Jun
Simulation model	
Material	Mesh: steel railing, Pattern: Beige fabric
WWR	70%

The school building consists of five floors, with a total height of approximately 18 meters, and each floor has a height of 3.20 m and contains multiple rooms on both sides of the building, separated by a long corridor that reaches the stairs, and the classroom dimension is 5.25*7.20 m. It contains two windows whose dimensions are 1.6*2.60 m, and another window overlooks the corridor, and its dimension is 2.30*0.95 m, The classroom also contains three rows of seats, each seat containing three students.

3.2. Skin design procedure

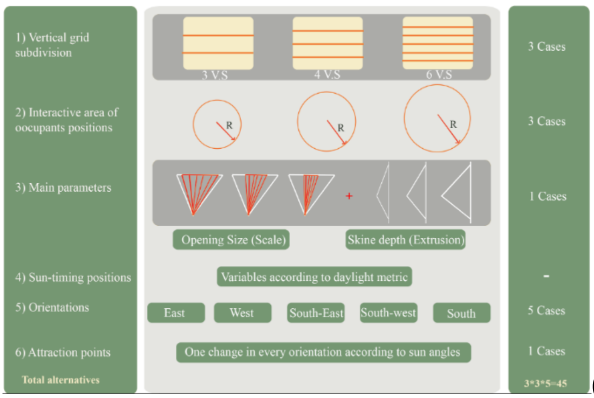
3.2.1. Parameters

When choosing the interactive kinetic facade with a three-dimensional prism shape, allows sufficient daylight to enter and diffuse in the space in a great balance, because it is self-shading and moves according to daylight and the positions of the occupants. From a morphological aspect, this facade performs the desired function in the individual kinetic modular units with several transformations based on four main variables as shown in Table 4.

Table 4. Skin parameters. Source: the researchers

Skin parameters		**Values**		**Alternatives Values**
		Minimum	Maximum	
Parameter 1	Vertical subdivision	3	6	3
Parameter 2	Opening size (scaling)	0.02 X	0.5 X	3
Parameter 3	Skin depth (extrusion)	0.3 X	0.9 X	3
Parameter 4	Interaction area radius	0.5	1.00	3
Total number of possible used values				81

The facade consists of a unit that is repeated on a rectangular grid, where the grid is built on the front of the classroom, and it is divided into two parts that encase each window opening and is 30 cm away from the original facade. The first variable is the number of vertical divisions that allow the creation of different sizes of grid rectangles and units. Whereas the recurring unit consists of 4 triangular planes and is made and implemented through the diameter of the rectangular grid. The second variable is the opening ratio of the unit, as is determined by the ratio in the width of the greater hypotenuse of the triangular flat, as the unit shrinks and folds around this side, the opening ratio is determined from 0.02 to 0.5 width. The third basic variable, which is the depth of the unit and its height perpendicular to the surface of the facade, which the moving unit as a shading element on the facade, as it represents a self-shading element, which increases the efficiency of the facade, and the aspect ratio is determined from 0.3X to 0.9X cm. The fourth parameter is the interaction field which varies according to the radius of the spot area.

(a) 

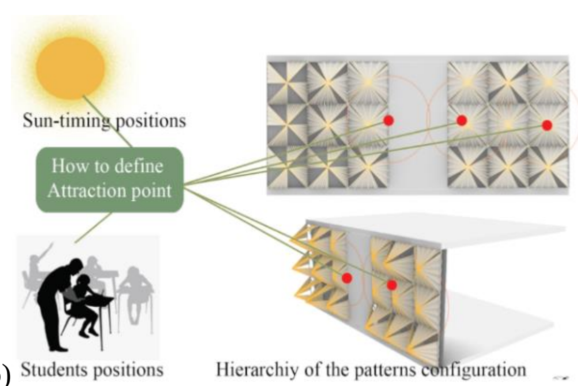
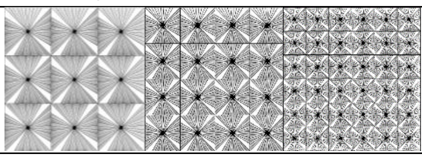
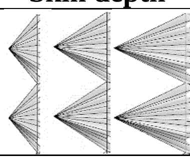
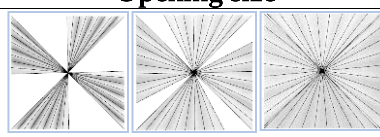
(b) 

Fig. 4(a) parameters for generating origami-inspired IKF alternatives, Fig. 4(b) generating the multi movements of kinetic units by attraction points. Source: the researchers

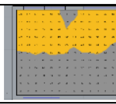
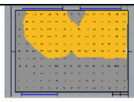
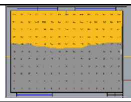
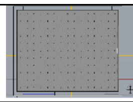
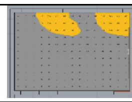
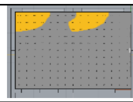
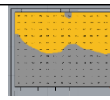
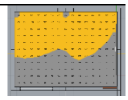
Table 5. The parameters formation. Source: the researchers

Vertical subdivision	**Skin depth**	**Opening size**
		

3.3. Daylight Analysis Logic

The simulation process in the climate studio program will be based on successive stages and aims to know the steps and mechanisms of designing and evaluating an interactive kinetic facade with the changing environmental conditions internally and externally in the classroom. In this study, we propose some steps to analyze daylight performance in the case study as follows: first determining the facades that need environmental solutions by monitoring the values of the ASE scale, second determining the hour when the intensity of the light is as high as possible for using the kinetic facades, third to determine the occupants' positions and attraction points in the façade layer, and then we can do the simulation process to improve the indoor visual comfort. The first stage shows that not all facades provide visual comfort to users in the classroom, except for the northern facade, which is ideal. In the second stage, 36 selections of the positions of the sun at the specified time points at every period were carried out on the first day of all months of the academic year for this hour and took the average of the highest and lowest sun angles, in the first period from 8 am to 10 am and the second period from 3 pm to 5 pm that these hours are the most effective in the direct daylight.

Table 6. Stage one result. Source: the researchers

Orientation	**East**	**West**	**South**	**North**	**North – West**	**North – East**	**South – East**	**South – West**
								
ASE	40.6%	46.1%	35.8%	0.0%	12.7%	14.5%	45.5%	49.7%
Acceptance	X	X	X	√	X	X	X	X
No. of students of 63	30	27	24	0	9	12	29	34
Ratio of students	47.8%	42.9%	38.1%	0%	14%	19%	46%	54%

According to the first stage results, all orientations have an unsatisfactory visual comfort level and many affected students as they have a high percentage of ASE results as shown in Table 6.

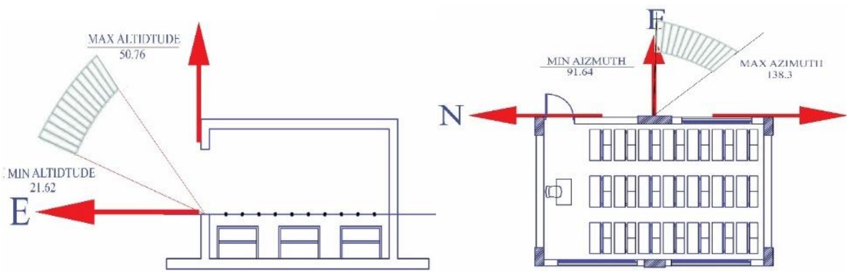


Fig. 5. The minimum and maximum values of the azimuth and altitude angles during the first period of the day in the study year. Source: the researchers

According to the analysis of the results of the second stage, it is possible to determine the maximum and minimum values of the altitude and azimuth angles for two hours in every period and take the average of these values as shown in Table 7.

Table 7. Sun angles. Source: the researchers

	Altitude		**Azimuth**		**Altitude**	**Azimuth**
	First period	Second period	First period	Second period	South orientation	

	(East/South-East)	(West/South-West)	(East/South-East)	(West/South-West)		
Maximum	(57.23+44.26)/2= 50.75	(40.90+28)/2= 34.45	(95.64+87.63)/2= 91.64	(280.6+274.2)/2= 277.4	-	-
Minimum	(17.13+26.11)/2= 21.62	(3.87+14.7)/2= 9.27	(144.33+132.31)/2= 138.3	(230.06+239.11)/2= 243.59	(36.19+21.9) /2	(114.97+260.465)/2
Average	36.19	21.9	114.97	260.465	29	187.7

3.4. The concept of occupants' movement and their positions in the simulation process

Including the users' positions and preferences in the design process and its realistic simulation methodology has become a necessity to ensure the efficiency of the facade that interacts externally and internally. In the modular units of the kinetic façade, they respond with each other to improve the quality of the internal environment for the users. As shown in Fig. 6 the methodology that affects the kinetic unit's hierarchical movements, as the simulation process is based on a change in the shape of the units depending on the mentioned variables, all of this is a result of determining the points and area of influence depending on the position of the sun and the location of the students.

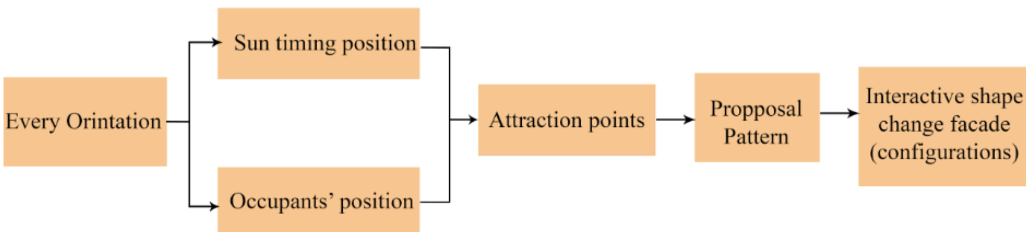


Fig. 6. The Methodology that affects the movement of the Kinetic Modular Units. Source: the researchers

3.5. The affected students' positions and attraction points in every orientation according to ASE metric

After we determined the angles of Altitude and Azimuth of the sun during the period of study months at the beginning of each month, and also through the most hours of solar radiation within the semester, they are located on the horizontal floor plan and section of the classroom, and then we determined the centers of the daylight spots that most affect the students and their seats in the classroom with the help of an ASE metric study of direct exposure to sunlight. Then they are located on the facade as interaction points for the modular units in the simulation process.

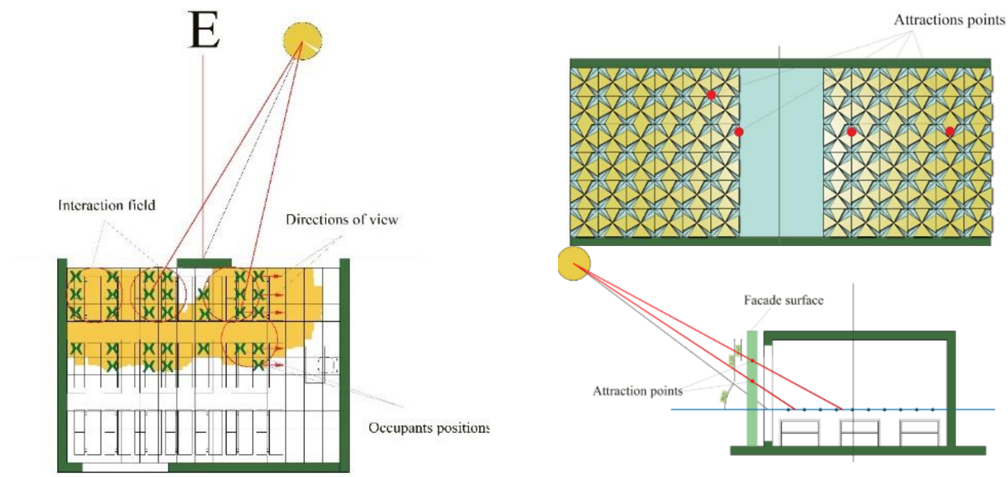
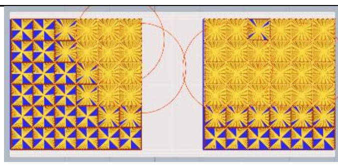
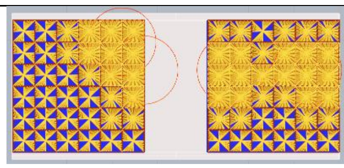
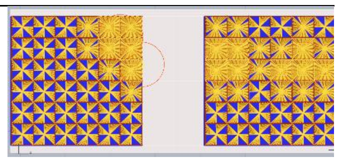
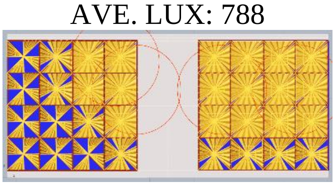
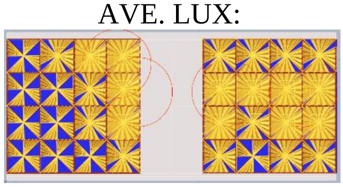
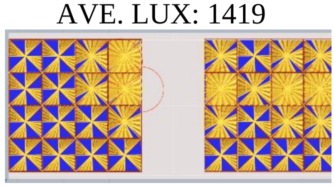


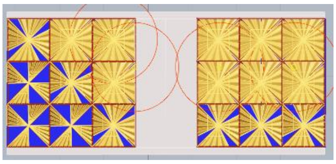
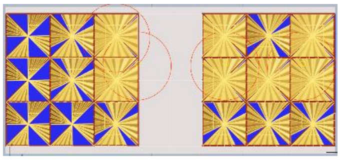
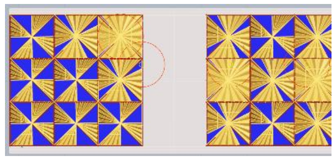
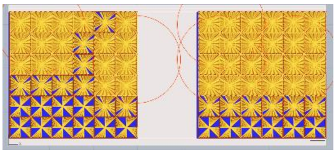
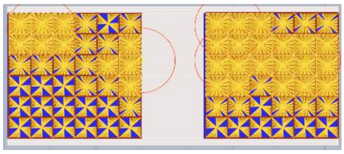
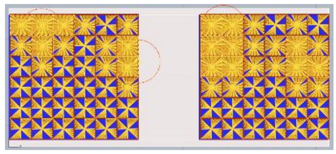
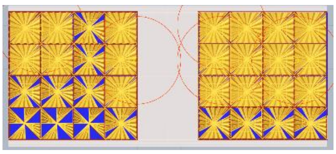
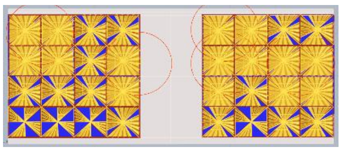
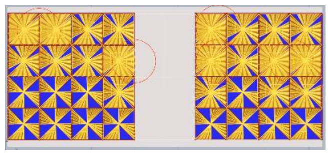
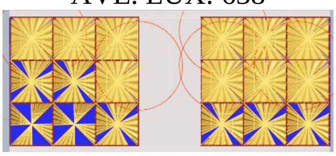
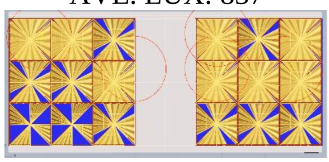
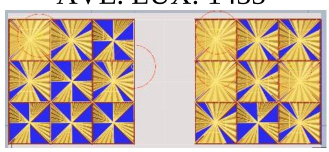
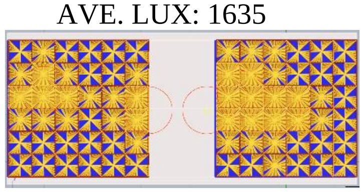
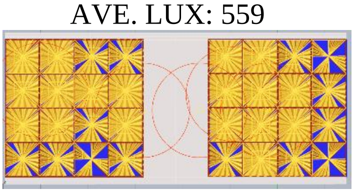
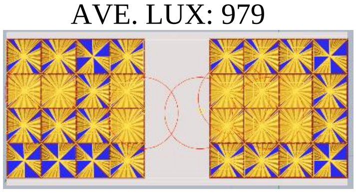
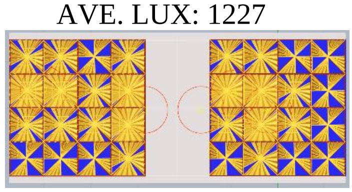
Fig. 7. Occupants’ positions, sun altitude angles in two periods of study, and the attraction points in a specific façade. Source: the researchers

4. Optimization logic and the simulation result

The improvement process is based on LEED V4 and IES ratings based on the SDA and ASE metrics. Where it is based on testing 45 different alternatives of the interactive facade configurations to find out the skin design that achieves the environment improvement in the classroom, where four basic parameters are tested in the five façade orientations with a 70% window-to wall ratio these orientations have the largest percentage of visual discomfort. Table 8 refers to the recorded results of Annual sunlight exposure (ASE), Spatial daylight autonomy (sDA), and Average lux; by simulating the hours in studying months of every orientation within the grid sizes and different radius for the interaction areas.

Table 8. ASE and sDA results of every orientation according to grid size and radius of interaction area. Source: the researchers

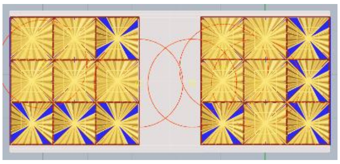
	Grid size	Radius (1)	Radius (2)	Radius (3)
	50*50 cm			
EAST		ASE: 1.2% sDA: 83% AVE. LUX: 788	ASE: 2.4% sDA: 99.4% AVE. LUX:	ASE: 3% sDA: 100% AVE. LUX: 1419
	75*75 cm			

	100*100 cm	ASE: 1.6% sDA: 86% AVE. LUX: 815 	ASE: 1.8% sDA: 98% AVE. LUX: 986 	ASE: 4.6% sDA: 100% AVE. LUX: 1493 
	50*50 cm	ASE: 2.4% sDA: 82.4% AVE. LUX: 730 	ASE: 3.6% sDA: 99.5% AVE. LUX: 991 	ASE: 7.3% sDA: 100% AVE. LUX: 1560 
	75*75 cm	ASE: 0% sDA: 75.2% AVE. LUX: 523 	ASE: 1.8% sDA: 98.8% AVE. LUX: 870 	ASE: 6.7% sDA: 100% AVE. LUX: 1474 
SOUTH -EAST	100*100 cm	ASE: 0% sDA: 81.8% AVE. LUX: 638 	ASE: 0.6% sDA: 99.4% AVE. LUX: 837 	ASE: 6.1% sDA: 100% AVE. LUX: 1435 
	50*50 cm	ASE: 1.2% sDA: 92.7% AVE. LUX: 677 	ASE: 1.4% sDA: 100% AVE. LUX: 906 	ASE: 6.7% sDA: 100% AVE. LUX: 1635 
WEST	75*75 cm	ASE: 0% sDA: 58.9% AVE. LUX: 559 	ASE: 1.2% sDA: 100% AVE. LUX: 979 	ASE: 3% sDA: 100% AVE. LUX: 1227 

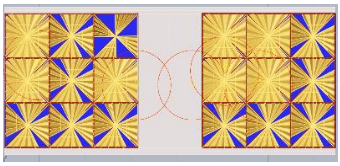
SOUTH - WEST

100*100 cm

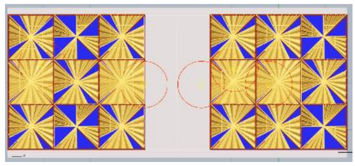
ASE: 0%
sDA: 75.81%
AVE. LUX: 651



ASE: 0%
sDA: 100%
AVE. LUX: 1001

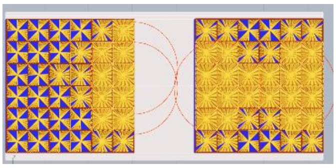


ASE: 1.8%
sDA: 100%
AVE. LUX: 1278

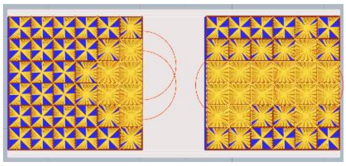


50*50 cm

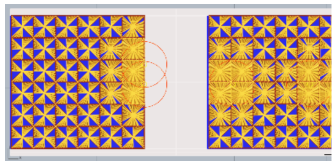
ASE: 0%
sDA: 65.5%
AVE. LUX: 595



ASE: 0%
sDA: 96%
AVE. LUX: 913

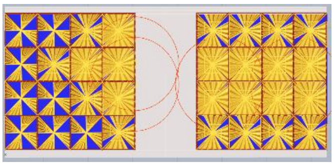


ASE: 0.8%
sDA: 100%
AVE. LUX: 1292

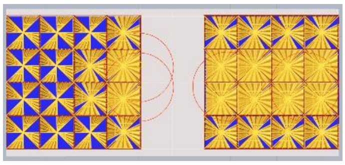


75*75 cm

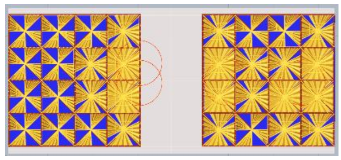
ASE: 4.2%
sDA: 100%
AVE. LUX: 1190



ASE: 5.5%
sDA: 100%
AVE. LUX: 1470



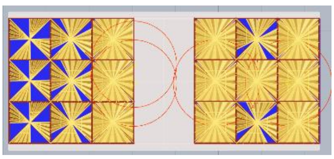
ASE: 7.9%
sDA: 100%
AVE. LUX: 1850



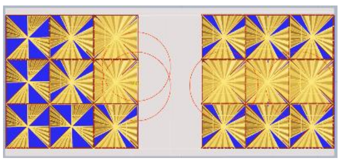
SOUTH

100*100 cm

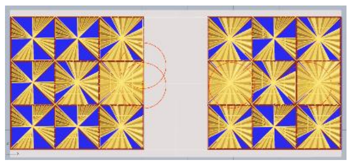
ASE: 3.6%
sDA: 100%
AVE. LUX: 1265



ASE: 7.9%
sDA: 100%
AVE. LUX: 1466

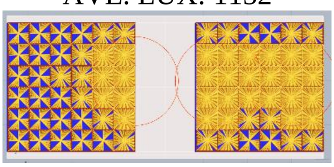


ASE: 7.3%
sDA: 100%
AVE. LUX: 1773

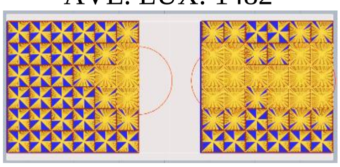


50*50 cm

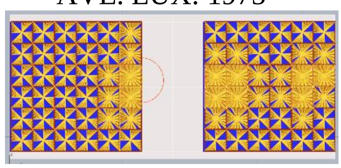
ASE: 4.5%
sDA: 99.4%
AVE. LUX: 1152



ASE: 5.5%
sDA: 100%
AVE. LUX: 1482

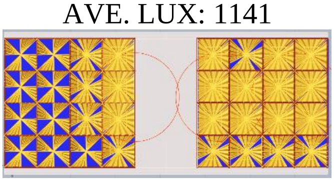


ASE: 9.1%
sDA: 100%
AVE. LUX: 1975

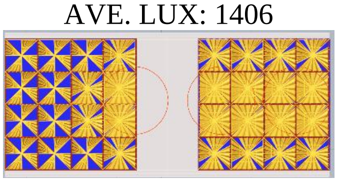


75*75 cm

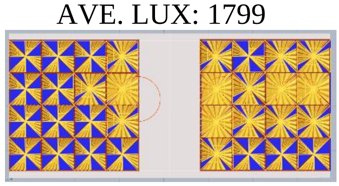
ASE: 1.2%
sDA: 100%
AVE. LUX: 1141

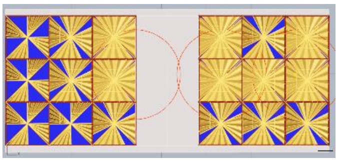
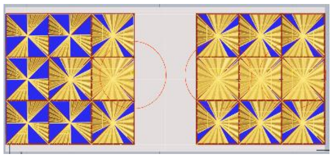
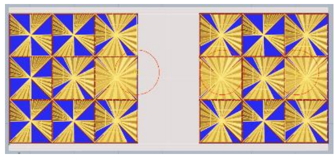


ASE: 2.4%
sDA: 100%
AVE. LUX: 1406



ASE: 3%
sDA: 100%
AVE. LUX: 1799



100*100 cm	ASE: 4.2% sDA: 100% AVE. LUX: 1207  ASE: 4.2% sDA: 100% AVE. LUX: 1240	ASE: 4.6% sDA: 100% AVE. LUX: 1467  ASE: 4.8% sDA: 100% AVE. LUX: 1676	ASE: 5.5% sDA: 100% AVE. LUX: 1852  ASE: 6.7% sDA: 100% AVE. LUX: 1942

4.1. For East façade

According to the results of measuring the ASE and sDA metrics in Fig. 8, units G2-R1 and G2-R2 have the best percentages in visual comfort, while G2-R3 and G3-R3 have the least percentages in visual comfort.

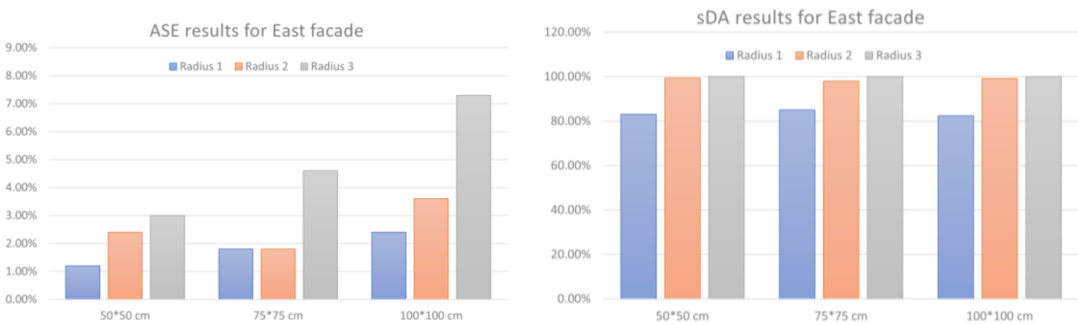


Fig. 8. Comparison of ASE and sDA for the East facade of the three simulation grids size. Source: the researchers

4.2. For South-East façade

According to the results of measuring the ASE and sDA metrics in Fig. 9, units G2-R2 and G2-R2 have the best percentages in visual comfort, while G1-R3 and G3-R3 have the least percentages in visual comfort.

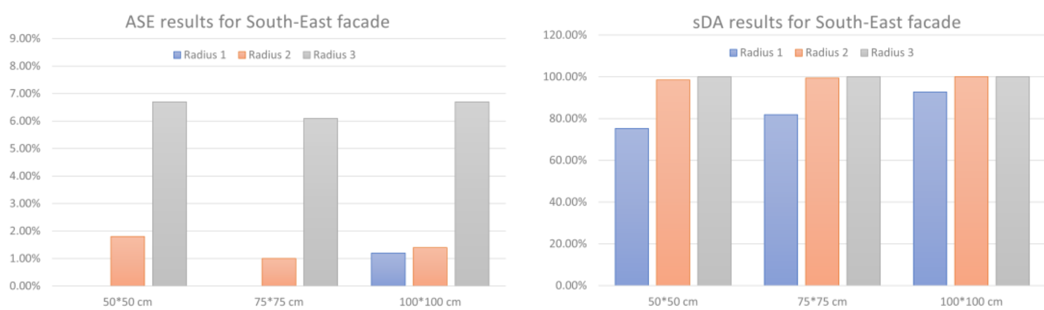


Fig. 9. Comparison of ASE and sDA for the South-East facade of the three simulation grids size. Source: the researchers

4.3. For West façade

According to the results of measuring the ASE and sDA metrics in Fig. 10, units G3-R2 and G2-R2 have the best percentages in visual comfort, while G1-R1 and G3-R1 have the least percentages in visual comfort.

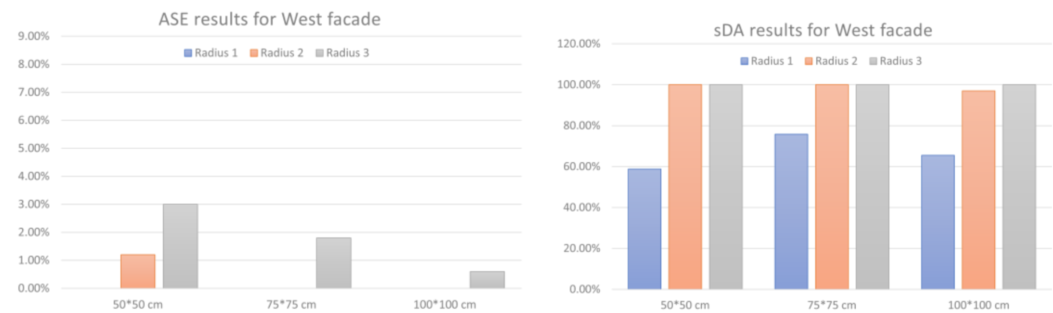


Fig. 10. Comparison of ASE and sDA for the West facade of the three simulation grids size. Source: the researchers

4.4. For South-West façade

According to the results of measuring the ASE and sDA metrics in Fig. 11, units G2-R1 and G1-R1 have the best percentages in visual comfort, while G1-R3 and G3-R3 have the least percentages in visual comfort.

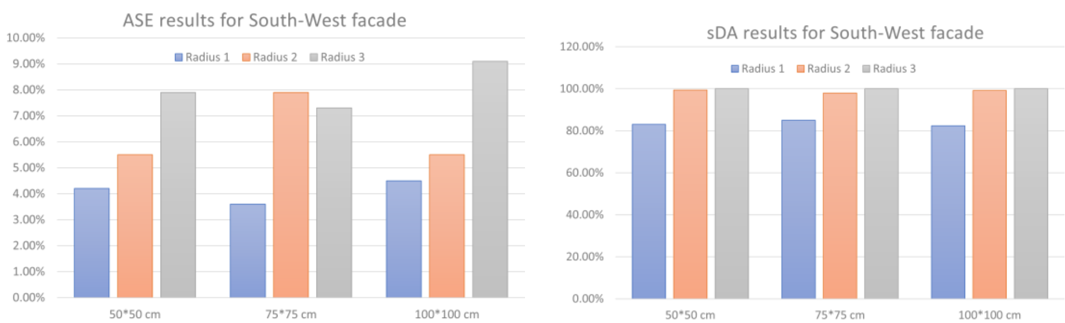
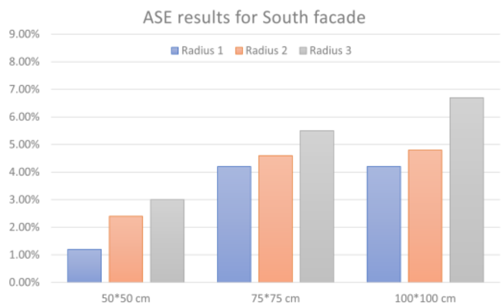


Fig. 11. Comparison of ASE and sDA for the South-West facade of the three simulation grids size. Source: the researchers

4.5. For South façade

According to the results of measuring the ASE and sDA metrics in Fig. 12, units G1-R1 and G1-R2 have the best percentages in visual comfort, while G3-R2 and G3-R3 have the least percentages in visual comfort.



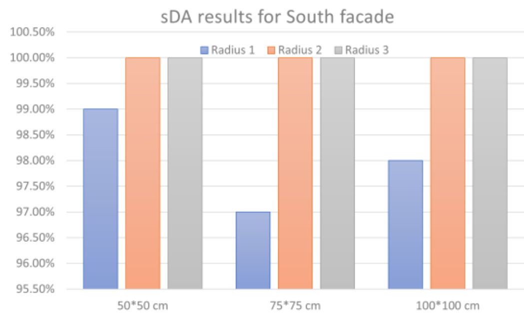


Fig. 12. Comparison of ASE and sDA for the South facade of the three simulation grids size. Source: the researchers

The comparative analysis in Table 9, represents all solutions weighted from the highest (1) highlighted with light blue to the lowest (9) highlighted with light orange. Thus, the scenario G2-R2 is the most acceptable one in the East and South-East façade, G3-R2 in the West façade, G2-R1 in the South-West façade, and G1-R1in the South façade.

Table 9. Comparative analysis of all solutions. Source: the researchers.

	Grid .1			**Grid .2**			**Grid .3**		
Orientation	R .1	R .2	R .3	R .1	R .2	R .3	R .1	R .2	R .3
East	4	3	6	2	1	8	5	7	9
South-East	3	6	8	2	1	7	4	5	9
West	9	4	7	3	2	6	8	1	5
South-West	2	4	8	1	6	7	3	5	9
South	1	2	3	4	7	6	5	8	9

5. Evaluation of the performance of the proposed interactive façade model

Evaluating the performance of the proposed interactive facade model is based on recording the size of the problem in the classroom in each orientation and at certain hours, as in the first period of the school day the calculation is made at 9 am and in the second period it will be at 3 pm and in the southern orientation it will be at 12 pm on the first day of the school months. The number of students who suffer from visual problems is calculated by recording the values of the daylight intensity for each student before and after using the facade model as shown in Table 10, using single-point-in time metric (SPT), as well as calculating the glare values as shown in Table 11, using (DGP) metric.

Table 10. No. of students affected by exceeded illuminance (>1000 Lux) before and after the interactive façade. Source: the researchers

Month	Day	Hour	East 9 am Lux	East 9 am No. of students	South-East 9 am Lux	South-East 9 am No. of students	West 3 pm Lux	West 3 pm No. of students	South-West 3 pm Lux	South-West 3 pm No. of students	South 12 pm Lux	South 12 pm No. of students
JAN	1	Before	5561	61	10735	63	5741	54	10410	63	10405	58
		After	1712	11	2325	7	925	4	3528	10	4910	6
FEB	1	Before	6913	63	11777	63	6776	57	10991	61	9316	57
		After	1749	12	2015	2	1568	6	3270	7	857	6
MAR	1	Before	8806	63	11309	63	7455	58	10450	60	7635	55
		After	1938	12	1674	3	1800	4	2941	8	823	3
APR	1	Before	10077	62	8979	61	9336	59	8880	56	4735	50
		After	2300	13	1780	3	1822	6	1122	10	2440	4
MAY	1	Before	9118	60	7073	60	10025	58	8934	54	1689	48
		After	1967	12	632	1	1955	8	1787	8	2015	3
JUN	1	Before	8790	60	6592	57	9910	59	6400	55	1740	47
		After	2822	10	857	0	2551	9	1957	7	605	0
OCT	1	Before	9131	62	9080	61	9386	58	9560	61	7742	59
		After	1558	14	1307	3	1431	5	2504	9	2792	3
NOV	1	Before	6561	62	10734	62	8154	56	11246	63	10110	61
		After	2172	12	1996	4	1501	8	2820	9	4294	9
DEC	1	Before	5687	63	11547	63	6808	55	11454	63	8960	62
		After	1522	10	2153	5	1277	4	2750	9	2522	4

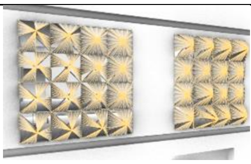
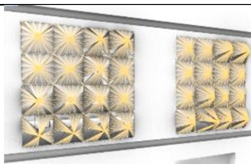
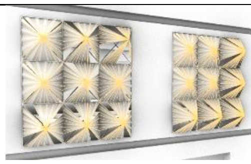
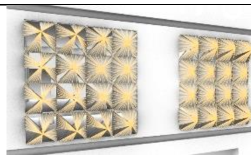
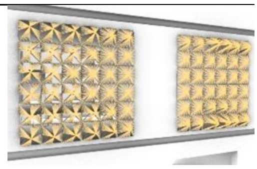
Table 11. DGP values. Source: the researcher

		East	South-East	West	South-West	South
Month	Hour	9 am No. of students	9 am No. of students	3 pm No. of students	3 pm No. of students	12 pm No. of students
21 Mar	Before	45%	44%	27%	41%	37%
	After	37%	38%	14%	37%	22%
21 June	Before	35%	23%	23%	17%	12%
	After	30%	10%	11%	10%	3%
21 Dec	Before	43%	65%	25%	60%	68%
	After	7%	3%	9%	56%	52%

6. Discussion

Studying the values of ASE and sDA facilitated understanding and knowing the change in the condition inside the classroom in terms of natural lighting levels and knowing the optimal solution from the set of simulated solutions. As shown in Table 12, Different configurations of facades pattern according to the comparative analysis in Table 9, by grading the solutions from 1 to 9 as 1 is the best one. Where the results showed that improvement can be achieved for both measures together.

Table 12. Best skin configurations in each orientation. Source: the researchers

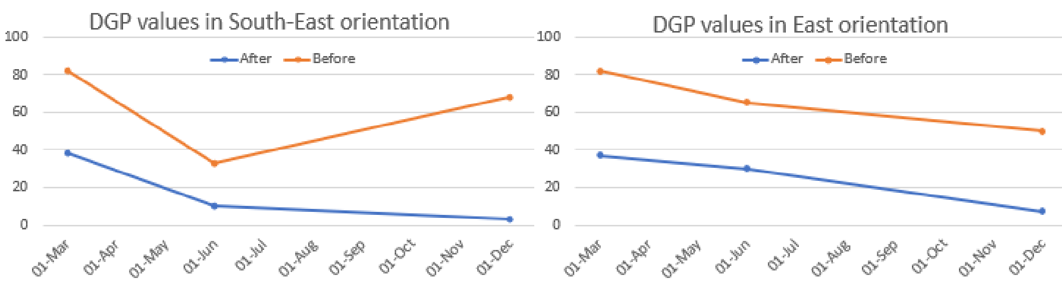
East	South-east	West	South-west	South
				
ASE: 1.8% sDA: 98%	ASE: 0.6% sDA: 99.4%	ASE: 0% sDA: 96%	ASE: 3.6% sDA: 100%	ASE: 1.2% sDA: 100%
Grid=75*75 cm Radius= 75 cm	Grid=75*75 cm Radius= 75 cm	Grid=100*100 cm Radius= 75 cm	Grid=75*75 cm Radius= 100 cm	Grid=50*50 cm Radius= 100 cm

The result of the evaluation process for the proposed solutions in terms of the intensity of illumination that exceeds 1000 lux is an improvement in the treatment ratio before and after the facade test. Where the percentage of the number of students whose performance improved was between 80% and 90%, as shown in Table 13.

Table 13. Ratios of improvement of visual comfort after using interactive façade at the critical hour in the two periods. Source: the researchers

		East	South-East	West	South-West	South
Month	Hour	9 am	9 am	3 pm	3 pm	12 pm
		No. of students	No. of students	No. of students	No. of students	No. of students
AVE.	Before	62	61	57	60	55
	After	12	3	6	9	4
Ratio		81%	95%	90%	85%	93%

As shown in Fig. 13, according to the results of the DGP metric in Table 11, as the simulation carried out on 21 o June, Mar., and Dec. in two periods of the study day the noticed reduction of the values before and after using the proposed facades in all orientations improves the quality of the visual comfort of the students.



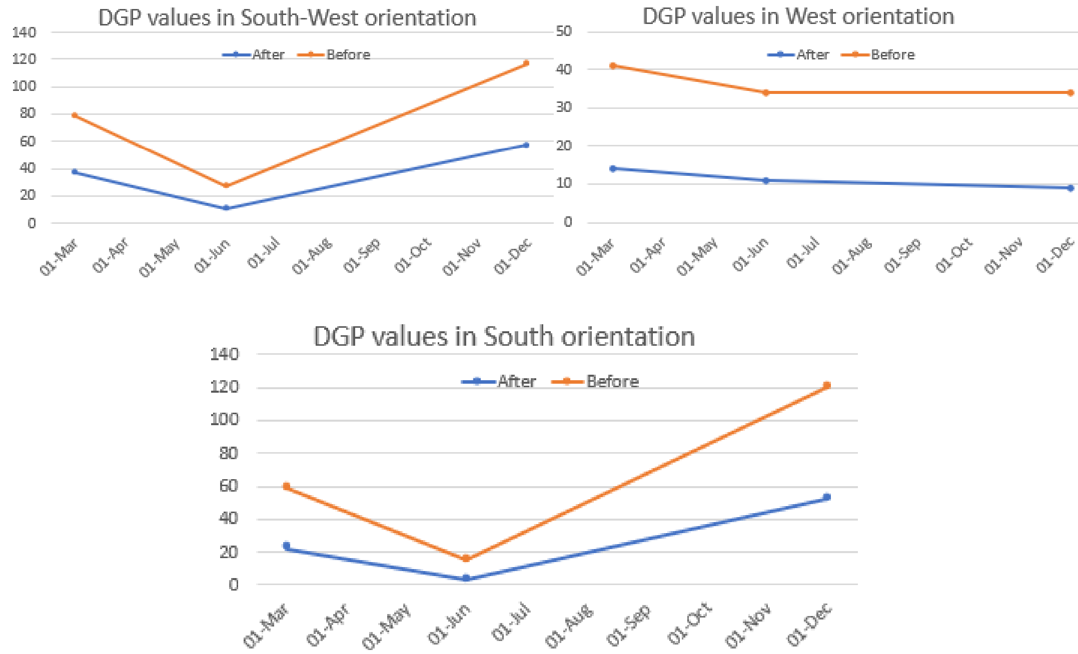


Fig. 13. Comparison of DGP results before and after using the interactive façade. Source: the researchers

7. Conclusion

The use of modular units in the design of facades, as well as modern and advanced shading systems, can improve the internal environment of the architectural space. As the 3D kinetic and interactive units have the possibility of self-shading and the flexibility to change according to daylight and occupants' positions, they are the ideal solution for facades in achieving the sustainability of the already existing building, improving its performance, and reducing its energy consumption. This paper suggested designing a classroom facade in Cairo, Egypt using the principles of origami, with a folding movement, and a method of changing its configurations according to certain parameters, the most important of which are the students' places and their influence on direct light from the sun, and an improvement was made using the program Climate studio and measurement ASE and sDA metrics. In the end, the paper produced the best façade configuration for 5 orientations, and an evaluation was made for it in terms of testing it according to DGP and SPT metrics according to two periods of the day. The results showed a strong improvement in the results for indoor quality and aesthetic perspective before and after using the kinetic interactive facade.

References

[1] B, Butterworth-Heinemann, "ASHRAE press. 4 - Architectural design impacts," *The ASHRAE Green Guide*, 2006, pp. 55–72.

[2] S. Harb, S. el- Haggar, and H. Sewilam, “Sustainable design guidelines for new and existing schools in Egypt,” M.S. thesis, the American University in Cairo, AUC Knowledge Fountain, 2018.

[3] R. Romano, “Kinetic adaptive façades. A systematic review of technological and adaptive features,” *PoliTO Springer Series*, pp. 499–519, 2021.

[4] A. Tabadkani, M. Valinejad Shoubi, F. Soflaei, and S. Banihashemi, “Integrated parametric design of adaptive facades for user's visual comfort,” *Automation in Construction*, vol. 106, p. 102857, 2019.

[5] S. M. Hosseini, M. Mohammadi, T. Schröder, and O. Guerra-Santin, “Bio-inspired interactive kinetic façade: Using dynamic transitory-sensitive area to improve multiple occupants’ visual comfort,” *Frontiers of Architectural Research*, vol. 10, no. 4, pp. 821–837, 2021.

[6] R. F. & C. Linn, “Kinetic architecture: Designs for active envelopes,” *ArchDaily*, 14-Aug-2014. [Online]. Available: https://www.archdaily.com/537359/kinetic-architecture-designs-for-active-envelopes. [Accessed: 20-Dec-2022].

[7] J. Moloney, “Designing kinetics for architectural facades: state change”, *Taylor & Francis*, 2011.

[8] A. Tabadkani, A. Roetzel, H. X. Li, and A. Tsangrassoulis, “Design approaches and typologies of adaptive facades: A Review,” *Automation in Construction*, vol. 121, p. 103450, 2021.

[9] J.-H. Kim, Y.-J. Park, M.-S. Yeo, and K.-W. Kim, “An experimental study on the environmental performance of the automated blind in Summer,” *Building and Environment*, vol. 44, no. 7, pp. 1517–1527, 2009.

[10] L. G. Bakker, E. C. M. Hoes-van Oeffelen, R. C. G. M. Loonen, and J. L. M. Hensen, “User satisfaction and interaction with automated dynamic facades: A pilot study,” *Building and Environment*, vol. 78, pp. 44–52, 2014.

[11] A. Ricci, C. Ponzio, K. Fabbri, J. Gaspari, and E. Naboni, “Development of a self-sufficient dynamic façade within the context of climate change,” *Architectural Science Review*, vol. 64, no. 1-2, pp. 87–97, 2020.

[12] N., Moulton, J. D., Rocco, J. T., Kider Jr., & S. M., Fiore, “An affective kinetic building facade system - Mood Swing”, *Proceedings of the 13th Conference on Advanced Building Skins*, 2018.

[13] S. Reichert, A. Menges, and D. Correa, “Meteorosensitive architecture: Biomimetic building skins based on materially embedded and hygroscopically enabled responsiveness,” *Computer-Aided Design*, vol. 60, pp. 50–69, 2015.

[14] J, Barnoin, “Towards an Origami Architecture”, *Towards an Origami Architecture*, 2020.

[15] M. Pesenti, G. Masera, and F. Fiorito, “Exploration of adaptive origami shading concepts through integrated dynamic simulations,” *Journal of Architectural Engineering*, vol. 24, no. 4, 2018.

[16] H. Yi, “Simulation of shape memory alloy (sma)-bias spring actuation for self-shaping architecture: Investigation of parametric sensitivity,” *Materials*, vol. 13, no. 11, p. 2485, 2020.

[17] Kynthia, Chamilothori, et al., “Climate-Responsive Shading Systems with Integrated Shape Memory Alloys (SMA)”, *Proceedings of the 8th Energy Forum on Solar Building Skins Conference on Advanced Building Skins*, 2013.

[18] R. M., Pavón, R. M., Bazán, J. J., x Cepa, A. A., Arcos Álvarez, J. M., Trigueros, M. G., Alberti, & J. R. Tellaeche, “New Use of BIM Origami- Based Techniques for Energy Optimization of Buildings”, *Applied Sciences*, 12(3), 1496, 2022.

[19] L., Heschong, V.D., Wymelenberg, M., Keven, Andersen, N., Digert, L., Fernandes, A.C., Keller, J., Loveland, H., McKay, R.G., Mistrick, B., Mosher, C.F., Reinhart, Z., Rogers, & M., Tanteri, “Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)”, The Illuminating Engineering Society of North America, 2012.