Evaluation of the effect of kinematic axes and the geometric model of the kinetic facade on providing natural lighting in an office building in Tehran

Fataneh Sangtarash
Ph.D. in Architecture, Department of Architecture, ST.C, Islamic Azad University, Tehran, Iran (fataneh.sangtarash@iau.ir)

Niloufar Nikghadam*
Associate Professor of Architecture, Department of Architecture, ST.C, Islamic Azad University, Tehran, Iran (n_nikghadam@iau.ir)

Rima Fayaz
Professor of Architecture, Department of Architecture and Urban Planning, Tehran University of Art, Tehran, Iran (fayaz@art.ac.ir)

Mohammad Reza Matini
Assistant Professor of Architecture, Department of Architecture and Urban Planning, Tehran University of Art, Tehran, Iran (m.matini@art.ac.ir)

ORIGINAL RESEARCH ARTICLE

Sangtarash, Fataneh, Niloufar Nikghadam, Rima Fayaz, and Mohammad Reza Matini. "Evaluation of the effect of kinematic axes and the geometric model of the kinetic facade on providing natural lighting in an office building in Tehran". *Soffeh* 36, no. 2 (2026):127–148. DOI: http://doi.org/10.48308/soffeh.2024.236665.1349

Received: September 23, 2024
Revised: October 09, 2024
Accepted: December 04, 2024
(Pages: 127–148)

Abstract

Background and Objectives: Kinetic façades represent a dynamic design approach that integrates movement to adapt to environmental conditions the concept of motion as a design input. One of the strategies of this facade is to control the light entering the interior. Fixed or dynamic horizontal shades are the best choice for south orientation, while vertical shades are usually used in east and west directions. Studies have shown that horizontal shading is more efficient than vertical shading. Indoor lighting conditions can affect the occupants' visual comfort, satisfaction, thermal comfort, health, mood, motivation, performance,

Keywords:
Motion axes, geometric model, kinetic facade, natural lighting, office building in Tehran, façade lighting direction.

*. Corresponding Author Email Address: n_nikghadam@iau.ir

http://doi.org/10.48308/soffeh.2024.236665.1349

Research Questions:

1. Which rotational motion axes of the kinetic façade (horizontal, vertical, and diagonal) provide optimal daylight performance for the north, south, east, and west façades of an office building in Tehran?

2. How do the two geometric models of the kinetic façade (rectangular and circular) affect daylight performance indicators (ASE, UDI, and DGP) across the four façade orientations?

3. Which combination of geometric model and rotational motion axis provides the most effective daylight performance for each façade direction in the climate of Tehran?

and productivity. Literature indicates that geometric and movement models play a role in controlling daylight and glare, although less attention has been given to movement axes in four directions. Also, it is unclear what kind of movement axis is appropriate for each façade direction. This research aims to utilize natural lighting using geometric models and rotational motion axes of the kinetic facade in the north, south, west, and east facades of an office building in Tehran. The novelty of this article is in examining the motion axes of the kinetic facade in response to Tehran's climate. For this purpose, the rotational motion axes in three horizontal, vertical, and diagonal modes in four directions have been measured to create optimal light in the interior space. The selection of samples is based on constructed examples that have not been used in previous studies, and the focus of this research is more on rotation motion axes and two geometric models, circle and rectangle.

Methods:This study utilises an applied, quantitative research methodology and is quantitative in nature. Using the simulation tool, the rotational motion axes of the kinetic facade are analyzed and evaluated in four directions, considering both circular and rectangular geometric models, and in relation to daylight in an office building in Tehran. Rhino software version 6.32, Grasshopper plugin and Honeybee Plus plugin version 0.0.06, and Ladybug version 1.5.0 were used for simulation. The Python programming language has also been used to calculate averages. The first step is to simulate the movement of the sun with the Ladybug plugin according to the weather file of Tehran. In the next step, a sample office room with an open plan, measuring 4 m in width, 6 m in length, and 3 m in height, accommodating six employees, was evaluated according to the dynamic daylight indicators. The room had a window-to-wall ratio of 90% of the facade without shades. In the next step, the existing two geometric modes of the kinetic facade, circle and rectangle, have been measured and compared according to the rotational movement axes (horizontal, vertical, and diagonal) in four facade directions. Then, according to the responsiveness of the facade to natural lighting, the most optimal geometric model and movement axes based on angle and dimensions (length, width, and radius) are suggested for all four directions of an office building in Tehran.

Results and conclusion :Recent research on kinetic facades in Iran and around the world indicates that kinetic facades are more responsive than fixed types in reducing glare and controlling daylight. Among them, geometric models, kinematic modes, movement axes, geometric model dimensions, room dimensions, the opening and closing angle of the geometric model of the facade in relation to the location of the sun, and the climate of the region play a significant role in optimising natural lighting in the interior space. According to the glare index (ASE) findings, the north facade does not require a shade, as the interior space receives sufficient daylight without one. Therefore, natural lighting simulation analysis with a kinetic facade has been done only for three directions of the south, east, and west facades. According to the simulation results, the two indicators, ASE and UDI, are of special importance. This is because when the shade opening or angle is half-closed, less light enters the space. As the percentage of useful light index decreases below 500 lux, the interior space may receive less than 500 lux of useful daylight at its far end.

Additionally, when the aperture or angle of view is open, more light enters the interior space and the amount of glare (ASE) shows values above 10%, which means that indoor glare and visual discomfort may occur. Therefore, optimising these two indicators is necessary to receive useful daylight in the interior. In the next step, the values of the two indices ASE, UDI less and DGP were averaged using the Python programming language. The simulation results show that the geometrical models of rectangle and circle with a rotating movement model with the horizontal axis at the top in the south, west, and east walls and with the diagonal axis at the top, both geometrical models in the east and west facade of an office building in Tehran are appropriate for providing optimal dynamic daylight indices. After comparing the geometric models based on the ASE and UDI indices in three directions, it is evident that the rectangular geometric model with a rotating movement model on horizontal and diagonal axes outperforms the circle geometric model with a rotating movement model on horizontal and diagonal axes. Also, the most suitable rotational motion axes of the kinetic facade for the two western and eastern facades are the horizontal and diagonal axis at the top and for the southern facade the horizontal axis at the top. Among the limitations of this research is the lack of an office building built with a kinetic facade in the field, so that a comparison can be made between the simulated results and field measurements.

On the other hand, natural lighting measurement devices in the indoor environment have limitations and cannot simultaneously measure the amount of daylight and glare in the indoor environment. In future research, it is possible to evaluate the kinetic facade with a rectangular geometric model and rotational movement model with horizontal and diagonal axes in four directions of the facade based on the amount of energy consumption, visual comfort, and thermal comfort using simulation or field observations. Furthermore, this facade can be studied in different climates and cities to determine its use with a geometric model and a proportional movement model in each city, according to the internal daylight. The results of this research can be applied to similar climates outside of Iran.

Introduction

Kinetic facade is a research field that considers movement as an input to designa primary objective of employing such facades is to control the amount of light entering the interior space. A kinetic facade can provide protection from solar radiation, enhance natural lighting efficiency, and create visual and thermal comfort conditions[1]. Optimal passive solar control dictates that horizontal shading devices are the most effective solution for minimsing solar heat gain on southern exposures, while vertical shading is typically employed for controlling low-angle sunlight on the east and west[2]. The most suitable fixed shading device for the south, southeast, and southwest facades is the frame-shaped shade. Studies have also shown that horizontal shading is more efficient than vertical shading[3]. Research indicates that lighting conditions in an environment can affect visual comfort, satisfaction, thermal comfort, health, mood, motivation, performance, and productivity of occupants. Poor lighting conditions that do not meet essential regulations fail to satisfy the lighting requirements of various activities, and insufficient lighting fixtures lead to inadequate illumination in workspaces[4]. Satisfaction with lighting conditions relates to desk illuminance, the amount of reflected light on computer screens, illuminance levels for computer work, access to exterior views, and overall light quality in the workspace. The European standard emphasises the minimum lighting requirements for an actual work area rather than the entire room[5]. According to this standard[6], a typical office workplace requires an illuminance level of 500 lux. Similarly, in accordance with Part 13 of Iran's National Building Regulations[7], the illuminance level for a typical office is considered to be 500 lux. Another study suggests that the optimal illuminance intensity in office spaces ranges from 600 to 650 lux, and illuminance levels between 550 and 600 lux provide comfortable conditions. Illuminance below 550 lux is not desirable for users[8]. This study aims to optimise daylight harvestingthrough geometric models and rotational movement axes of the kinetic facade on the north, south, west, and east facades of an office building in Tehran. The innovation of this research lies in investigating the kinetic facade's movement axes in response to Tehran's climate. For this purpose, rotational movement axes in three types horizontal, vertical, and diagonal have been evaluated on the four facade orientations to achieve optimal interior lighting. The selection of samples is based on those that have not been used in previous studies, with a focus on rotational movement axes and two geometric models: circle and rectangle.Additionally, in previous research, two influential natural lighting indicators, ASE and UDI less, have received less attention. The results of this study can be applied in similar climates. Considering the objective, the following questions are posed: Which of the rotational movement axes ,diagonal, horizontal, or vertical, in the kinetic façade of each orientation of an office building responds better to natural lighting? Which geometric model, either a circle or a rectangle, combined with the kinetic rotational movement model in the façade, optimally provides natural lighting in an office space in Tehran?

Research Background

Research on kinetic façades, focusing on movement mechanisms and geometric models, has primarily addressed daylight performance, glare control, visual comfort, and façade optimisation. Most of these studies have been conducted through simulation-based methods and in hot-arid climates. The present paper, however, specifically concentrates on visual comfort and

1. Kontovourkis, O., Michael, A., Alexandrou, K., & Vassiliades, C. (2015). 'Lighting performance simulation and adaptive control of an advanced building skin based on human behaviour inputs'. *10th International Conference On Advanced Building Skins, Bern Switzerland,(2015)*: 1340-1349.

2. Qayabkloo, Zahra. Fundamentals of Building Physics 4 (Passive Cooling). Tehran: Jihad Daneshgahi, Amirkabir Industrial Branch, (2013).

3. Kasmai, Morteza. Climate and Architecture. Isfahan: Khak Publications, (2013).

4. Katabaro , Justine, and Yan Yonghong. 'Effects of Lighting Quality on Working Efficiency of Workers in Office Building in Tanzania'. *Journal of Environmental and Public Health*,(2019): 1-12.

5. Veitch, Jennifer, Kelley Farley , and Guy Newsham. Environmental Satisfaction in Open-plan Environments: 1. Scale Validation and Method. *NRC/IRC Research Report IR-844, National Research Council Canada, Institute for Research in Construction, Ottawa, Ontario, Canada (2002).*

indoor daylighting performance. Rasouli et al.[9] investigated the annual performance of double-skin façades for an office space in Tehran, incorporating horizontal and vertical louvers in both fixed and movable states. The building was modeled in Rhinoceros, and the parametric design of the louvers was developed using Grasshopper. The findings indicated that movable shading systems outperformed their fixed counterparts, with movable horizontal louvers delivering the most effective results. Tabadkani et al.[10] examined an adaptive façade designed to improve daylight use and visual comfort in an office building in Tehran. The façade employed a hexagonal geometry combined with a folding (origami-inspired) mechanism. The computational model utilised an open-plan office space (the case study zone) defined by the dimensions 7.0 m (length) × 5.5 m (width) × 3.0 m (height). This space featured a Window-to-Wall Ratio (WWR) of 81% on its southern façad. Results showed that the origami-based geometry enhanced daylight penetration, while its impact on glare reduction was limited to certain interior areas.

A prior study examined a modular, responsive façade system specifically designed to optimise indoor daylight harvesting and enhance visual comfort. Hosseini et al.[11] explored an interactive façade system for daylight and glare control through simulation. The case study was situated in a hot-arid climate, and the façade incorporated a square pattern with three-dimensional movable shading modules, which operated in response to the sun's movement and occupants' positions. The study revealed that the system was effective in mitigating both perceptible and imperceptible glare.

A study[12] has investigated a responsive facade with a modular model to utilise daylight and visual comfort. The geometric model consists of triangles, hexagons, and circles in both regular and irregular patterns. The geometric dimensions of the office room in Izmir, Türkiye are 12 m wide, 15 m long, and 6.5 m high. Results confirmed that the implementation of the kinetic façade led to a substantial mitigation of visual discomfort and glare when compared against the static baseline model.. The triangular folding geometric pattern offers greater flexibility in controlling daylight and airflow than the square pattern. In addition, they can adapt to different daylight needs. in a study by Li et al.[13], The influence of various adaptive façade parameters on indoor daylight performance within an office environment was assessed utilising the environmental analysis plugins, Ladybug and Honeybee, integrated within the Grasshopper computational framework. For multi-objective optimisation, the *Wallacei X* plugin and the *XGBoost* machine learning algorithm were applied to account for environmental variations in daylight. The façade was simulated with three geometric patterns—triangle, rectangle, and hexagon combined with horizontal and vertical kinetic movements at different sizes and angles under the climate conditions of Shanghai. The results showed that the length, width, and height of the room, in relation to its orientation and angle, had a greater impact on glare reduction and dynamic daylight availability. In a study by Samadi et al.[14], a computational approach was developed to achieve optimal daylight in interior spaces with a southern façade equipped with a shading system. Optimisation was carried out using the *Galapagos* plugin.

6. BS EN-12464-1. *Light and lighting. Lighting of work places Indoor work places.* BSI standards (2021).

7. National building regulations of Iran, *topic 13: design and implementation of electrical installations in buildings*. Tehran: Iran Development Publishing, (2016).

8. Maryam Fakhari, Rima Fayaz, and Maryam Mehravar. 'The acceptable illumination level for office occupants in Tehran.' *Architecture and Urban Planning of Iran*, Volume 12, No. 1 (1400): 79-92.

9. Rasuli, M., Y. Shahbazi, and M. Matini. 'Horizontal and Vertical Movable Drop-Down Shades Performance in Double Skin Façade of Office Buildings: Evaluation and Parametric Simulation'. Naqshejahan 9, no. 2 (2019): 135–44.

10. 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* 102857, (2019). doi:https://doi.org/10.1016/j.autcon.2019.102857.

The optimisation results indicated that the upper window height between 0.08 and 1.65 m, room geometry with a height of 3 m, length of 9.5 m, and width of 6 m, along with the distance from the window and the use of a hexagonal rather than a square pattern, had a more significant influence on glare mitigation and dynamic daylight performance.

In related work, Sangtarash et al.[15] conducted a comparative analysis of two kinetic movement patterns—rotational and folding—applied to a triangular geometric façade to achieve optimal daylighting on the southern exposure of an office building in Tehran.The simulations were conducted using the *Honeybee* and *Ladybug* plugins. The results demonstrated that the rotational movement model outperformed the folding movement model in responding to natural daylight requirements. In a study[16], a biomimicry approach was applied to enhance daylight performance in an office building in Egypt, where a geometric pattern inspired by the behavior and organisation of a snake was examined. Ultimately, a rhombus-shaped geometry with folding along both horizontal and vertical axes was considered for daylight analysis. The geometry of the simulated space was parameterised with the following internal dimensions: 6.0 m (depth) × 4.0 m (width) × 3.0 m (height).. In this analysis, the window was placed within a frame with depths of 0.5 m and 1 m for comparison. The results indicated that a frame depth of 1 m performed better than a 0.5 m depth in improving daylight availability. It was further highlighted that the most influential parameters in enhancing daylight performance were the rotation angle, the distance of the façade from the window frame, and the degree of horizontal and vertical folding.

The review of prior research indicates that the geometric and kinetic patterns of shading devices play a significant role in controlling daylight and glare. However, less attention has been paid to movement axes across the four façade orientations. Moreover, it remains unclear which movement axis is most suitable for each orientation. The present study therefore, focuses on two geometric patterns, circular and rectangular, combined with rotational kinetic movements along diagonal, horizontal, and vertical axes to investigate daylight performance across the four façade orientations.

Theoretical Framework

Geometric and Kinematic models of Kinetic Façades

Geometric and kinematic models represent two key axes in the design of kinetic façades. These models play a crucial role in defining how the façade opens and closes, its control mechanisms, choice of materials, and structural stability. Movement within the façade (or its modules) requires geometric adaptability of its components to maintain structural coherence while transforming[17]. Unlike static façades, the design of a kinetic façade demands an interactive design process beginning with the selection of geometry and movement analysis, followed by the development of both digital and physical models, and culminating in the selection and design of joints and materials in relation to the intended movement mechanism. The classification of kinetic structures generally follows three main domains: the typology of movement (kinematics), the material properties, and the inherent characteristics of the dynamic el-

11. Hosseini, Seyed Morteza, Masi Mohammadi, and Olivia Guerra-Santin.'Interactive kinetic façade: Improving visual comfort based on dynamic daylight and occupant's positions by 2D and 3D shape changes.' *Building and Environment 165* 106396.(2019). www.elsevier.com/locate/buildenv.

12. Kızılo¨renli, Ecenur, and Feray Maden.'Modular responsive facade proposals based on semi-regular and demi-regular tessellation: daylighting and visual comfort.' *Frontiers of Architectural Research*. (2023). doi:DOI:10.1016/j.foar.2023.02.005.

13. Li, Yuanyuan, Huang Chenyu, Zhang Gengjia, and Jiawei Yao. 'Machine Learning Modeling And Genetic Optimisation Of Adaptive Building Facade Towards The Light Environment.'*Proceedings of the 27th International Conference of the Association for ComputerAided Architectural Design Research in Asia (CAADRIA)*.(2022): 141-150.

ements.. In general, movement is categorised into sliding, rotation, folding and opening/closing. Depending on the design of the mechanism, multiple types of movement may coexist within the same structure[18]. Schumacher et al.[19] classified kinetic movement structures into partial and overall displacement. Herzog et al.[20] further categorised façade and window movements into vertical flat, angled, horizontal and vertical planar, horizontal curvature, vertical curvature, and combined horizontal–vertical types.

From the perspective of movement typologies, kinetic façades are generally divided into four categories: folding, sliding, scaling, and rotation[21]. In another study, kinetic façade movement was classified into translational, rotational, scaling, and material-based deformation[22]. Among these, scaling movements are less common due to material limitations and high costs. In contrast, rotational and folding mechanisms have become increasingly popular in recent years, although many designs still lack sufficient performance-based optimisation. Overall, dynamic façade design is a complex process that requires consideration and definition of multiple factors, including available resources, the type of dynamic systems employed, aesthetic qualities, and user preferences and acceptance, all in relation to the building's functional performance.

Daylighting

Several indices have been introduced to evaluate daylight performance in indoor spaces. These indices are generally classified into two groups: static and dynamic. **(a) Static index:** Evaluation using static indices is carried out for a fixed condition, usually under an overcast sky[23].

(b) Dynamic index: Due to the limitations of the static approach, dynamic indices were developed. These indices take into account design parameters, climate conditions, and sky variations. Based on meteorological data, they allow the evaluation of indoor lighting conditions and users' visual comfort throughout the year. The most important indices for assessing visual comfort are as follows:

Useful Daylight Illuminance (UDI): This index represents the percentage of occupied time during a year when horizontal illuminance at a specific point falls within a defined range. Considering the lower and upper thresholds of illuminance, the evaluated time is divided into three categories: (i) periods when daylight is too low (UDI less), (ii) periods when daylight is within the useful range (UDI useful), and (iii) periods when daylight is too high (UDI more), which can cause visual discomfort. Although the exact thresholds may vary in different sources, the range of 300–3000 lux is commonly recommended as sufficient daylight[24].

Daylight Autonomy (DA): This index indicates the adequacy of daylight in an indoor space. It is defined as the percentage of the annual occupied time when the required illuminance level at a given point is met solely by natural daylight. According to the Illuminating Engineering Society (IES) standard, a space is considered 'acceptable' if daylight provides at least 300 lux 50%<55% of the occupied hours, and 'preferred' if daylight provides 300 lux 50%< 75% of the time.

Spatial Daylight Autonomy (sDA): This index evaluates whether a work plane in a space receives sufficient daylight during annual working hours[25].

14. Samadi , Sahba , Esmatullah Noorzai , Liliana O Beltra, and Saman Abbasi. 'A computational approach for achieving optimum daylight inside buildings through automated kinetic shading systems.' *Frontiers of Architectural Research*.(2020): 335-349.

15. Sangtarash, F.; Nikghadam, N.; Fayaz, R.; Matini, M.R. A comparative study of the kinetic movement pattern of a triangular geometric facade regarding natural lighting in an office building in Tehran. *Journal of Iranian Architecture & Urbanism*. (2023), 14(2): 159-175.

16. H. F. Hassan, Fayrouz, Khaled A. Y. Ali, and Salwa A M. Ahmed. 'Biomimicry as an Approach to Improve Daylighting Performance in Office Buildings in Assiut City, Egypt.' *Journal of Daylighting*. (2023):1-16.

17. Sharaidin, Kamil. 'Kinetic Facades: Towards Design for Environmental Performance'. PhD diss., RMIT University, (2014).

18. Başar, C. 'Topolojik ve Deneyimsel Bağlamlar Üzerinden İncelenmesi'. Master's thesis, Istanbul Technical University, (2014).

Annual Sunlight Exposure (ASE): Since *Spatial Daylight Autonomy (sDA)* does not define an upper limit for daylight levels, the ASE index was introduced to identify the portion of a space exposed to excessive direct sunlight. ASE evaluates the potential source of visual discomfort or glare[26]. It is defined as the percentage of a target area that receives direct sunlight with an illuminance of 1000 lux or more for over 250 hours per year[27].

Daylight Glare Probability (DGP): DGP is one of the most common indices for assessing glare in indoor environments. It measures the illuminance entering the eye in relation to time. The values are interpreted as follows: > 0.35 = imperceptible glare, 0.35–0.40 = perceptible glare, 0.40–0.45 = disturbing glare and < 0.45 = intolerable glare[28].

Materials and Methods

This study is applied in purpose and quantitative in nature. Using simulation tools, it analyzes and evaluates rotational movement axes with circular and rectangular geometric patterns of kinetic façades on the four orientations of an office building in Tehran, based on daylight performance. the simulations were conducted using Rhinoceros version 6.32, the Grasshopper plugin, Honeybee Plus version 0.0.06, and Ladybug version 1.5.0. In addition, the Python programming language was employed for averaging the numerical data.

In the first step, as illustrated in Figure 1, the solar path for Tehran was simulated using the Ladybug plugin and the corresponding weather file. In the subsequent step, a reference open-plan office space with a window-to-wall ratio (WWR) of 90% was modeled. The base case model, without any shading devices, was evaluated using dynamic daylight performance metrics. The simulation results[29] in Figure 2 and Table 1, indicated that the north façade does not require kinetic shading; therefore, the south, east, and west façades were further investigated. In the next phase, two geometric configurations of kinetic façades (circular and rectangular) were examined with respect to three rotational movement axes (horizontal, vertical, and diagonal). The kinetic façade modules were programmed to respond adaptively to the solar path, opening and closing according to the incident solar angles, such that the degree of openness gradually decreased as the sun's altitude and azimuth shifted[30]. Finally, simulation data for the south, east, and west façades were compared and analyzed in terms of daylight availability. Based on façade responsiveness to natural illumination, the optimal geometric configuration, movement axis, rotation angle, and dimensions (length, width, and radius) were proposed for the three primary façades of a typical office building in Tehran.

Simulation

As depicted in Figure 3 the geometry of the simulated office space was defined with a width of 4 m, a length of 6 m, and a height of 3 m, resulting in a floor area of 24 m², designed for four occupants. The transparent façade was placed only on one side of the room along its width, and the model was rotated toward the cardinal orientations. The reference model was located in Tehran at a latitude of 35.69° and a longitude of 51.32°. No surrounding obstructions were considered to eliminate external shading effects. The façades were programmed

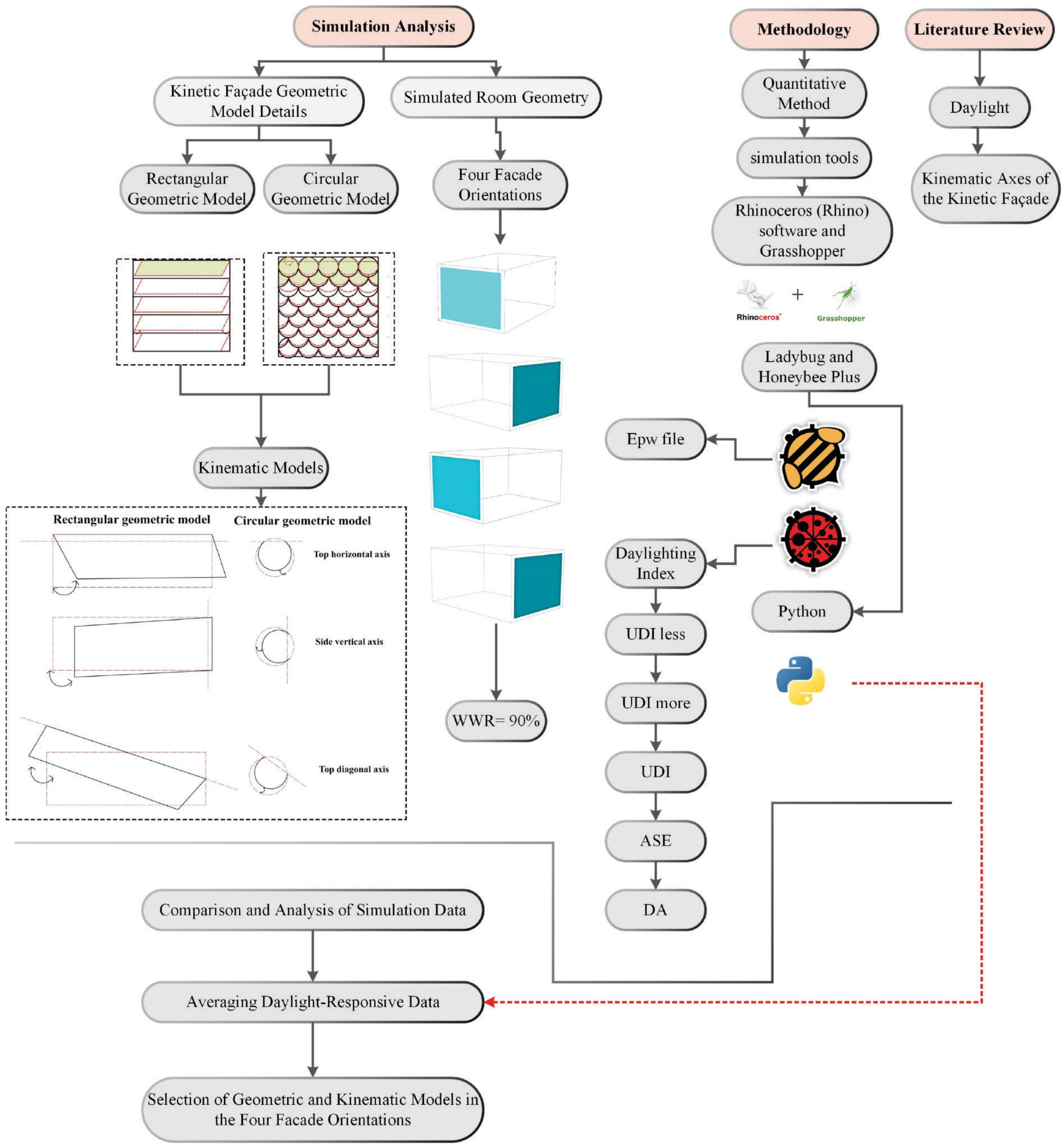
19. Schumacher, Michael, Michael Marcus, Vogt Luis A, and Cordón Krumme. *Architektur in Bewegung – Neue dynamische Komponenten und Bauteile*. German: Birkhäuser, (2019).

20. Herzog, T., Krippner, R., & Lang, W. Facade Construction MANUAL. Munich: DETAIL Business Information GmbH, (2017).

21. A.H.A. Mahmoud and Y. Elghazi, 'Parametric-based Designs for Kinetic Facades to Optimise 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.

22. Jaafar Ahmad Ibrahim and Halil Zafer Alibaba, 'Kinetic Façade as a Tool for Energy Efficiency', *International Journal of Engineering Research and Reviews* (2019): 1–7.

23. Housing in Hot and Dry Climate of Iran (Case Study: five-door rooms in Yazd Traditional Houses)', *Journal of Architectural Thought* 4, no. 8 (Autumn/Winter 2020–21), https://doi.org/10.30479/AT.2020.10857.1231.



24. Nabil, A., and J. Mardaljevic. 'Useful daylight illuminances: A replacement for daylight factors.' *Energy Build.no* 38 (2006): 905–913.

25. Hosseini, N, and M HeiraniPour. 'The Role of Orosi's Islamic Geometric Patterns in the Building Façade Design for Improving Occupants' Daylight Performance.' *Published by solarlits.com. This is an open access article under the CC BY license, (2020):201-221. (https://creativecommons.org/licenses/by/4.0/).*

26. Elghazi, Y, A Wagdy, S Mohamed, and A Hassan. 'DAYLIGHTING DRIVEN DESIGN: OPTIMISING KALEIDOCYCLE FACADE FOR HOT ARID CLIMATE.' *Fifth German-Austrian IBPSA Conference RWTH Aachen University,*(2014): 314-321.

Figure 1. Research process,
Source: Authors.

27. Erlendsson, Ö. *Daylight Optimisation-A Parametric Study of Atrium Design: Early Stage Design Guidelines of Atria for Optimisation of Daylight Autonomy*. Sweden: School of Architecture and the Built Environment.

28. Suk, J. Y., Schiler, M., & Kensek, K. 'Investigation of existing discomfort glare indices using human subject study data.' *Building and Environment,Sol Energy, no78* (2016): 15–28.

29. Sangtarash, Fataneh, et al. 'Utilising Kinematic Models of Kinetic Facades to Obtain Optimal Natural Lighting in an Office Building.' Journal of Architectural Engineering 31, no. 1 (2025): 04024050. https://doi.org/10.1061/JAEIED.AEENG-1705.

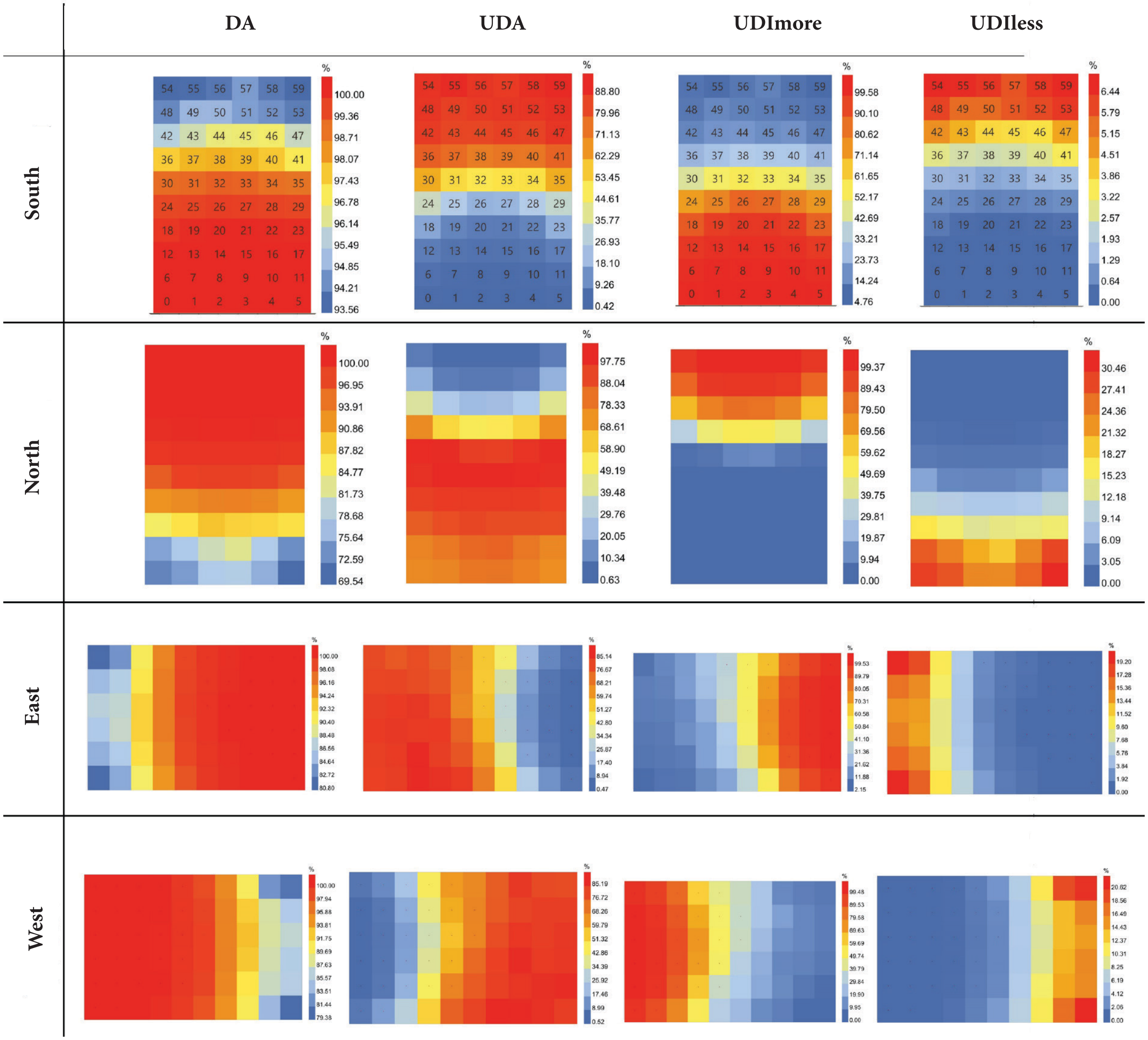


Figure 2. Simulation results of annual dynamic daylight in four directions.[31]

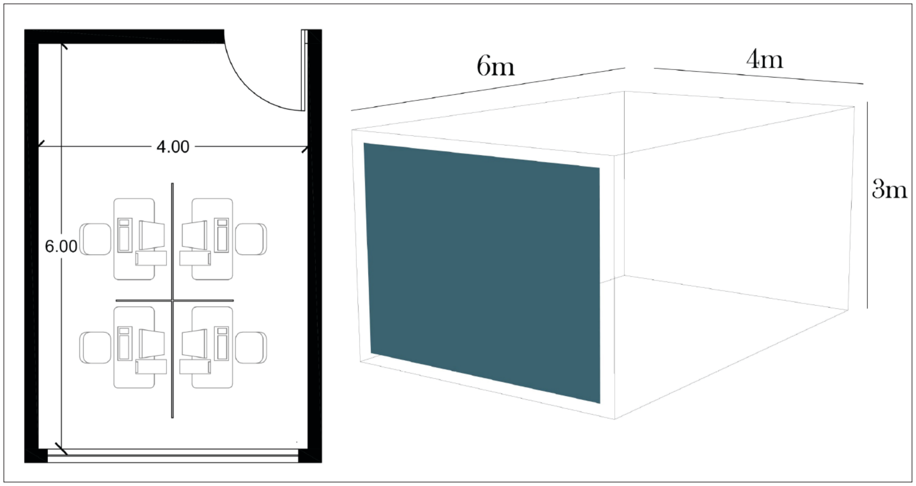
Table 1. Annual dynamic daylight analysis in four façade orientations.[31]
Note: ASE values exceeding 10% (highlighted in Gray color & Underline) indicate a potential risk of glare and visual discomfort.

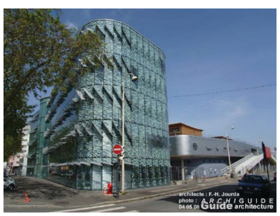
Façade orientation	Dynamic daylight index					
	DA	UDI	UDI more	UDI less	sDA	ASE
South	100%	88.80%	99.58%	6.44%	100%	50%
North	100%	97.58%	99.37%	30.46%	100%	0%
East	100%	85.14%	99.53%	19.20%	100%	48.33%
West	100%	85.19%	99.48%	20.62%	100%	40%

to open and close adaptively in response to the sun's position and the surface normal vector. The Tehran (Mehrabad) weather file (2004–2018) was downloaded[32] and imported into the simulation patch. Daylight simulations were conducted for three representative days of the year: March 21 (spring equinox), July 21 (summer solstice), and December 21 (winter solstice). The autumn equinox was excluded due to its similarity to the spring equinox. Simulations were performed for every working hour between 08:00 a.m. and 4:00 p.m.The daylight performance of the reference model was evaluated based on a sensor grid of 59 points, distributed at 0.6 × 0.6 m intervals. A reference workplane[33] at 0.76 m above the finished floor level was selected, representing the average desk height in office spaces. Public holidays on Thursdays and Fridays were considered in the occupancy schedule. Peak occupancy hours were calculated using the software, and three representative times (09:00 a.m., 12:00., and 4:00) were chosen for daylight analysis.

Artificial lighting was not included in the simulations, and dynamic daylight performance metrics, including DA, UDI, UDI more, UDI less, sDA, and ASE, were analyzed. The geometric and kinetic movement patterns of the façades are summarised in Table 2, while the characteristics of the simulated office room are presented in Table 3.

Figure 3. Plan (right) and mass (left) of the simulated model, Source: Authors.



Constructed Samples			
name	Hôpital Jean Mermoz (arch. F.-H. Jourda, 2008)	North Mediterranean Health Center / Ferrer Arquitectos, 2010	BBC Pavilion- 2019
Geometric model	rectangle		circle
Kinematic Model and Axis	Rotational Kinematic Model with Diagonal Axis	Rotational Kinematic Model with Horizontal Axis at the Top	Rotational Kinematic Model with Horizontal Axis at the Top
figure			

30. Fataneh Sangtarash, 'The Explanation of the Geometric and Movement Pattern of the Kinetic Façade for Optimal Response to Natural Light Case Study: Office Building in "hot and dry" Climate of Tehran', Dr.Arch. diss., Faculty of Art and Architecture, Azad University, South Tehran Branch, (1402).

Table 2. Geometric and Kinematic Patterns of Kinetic Façades.

Utilising the Honeybee plugin, the daylight performance and visual comfort indices were assessed via the Radiance and DAYSIM simulation engines.The main assumptions for the Radiance parameters are summarised in Table 4.

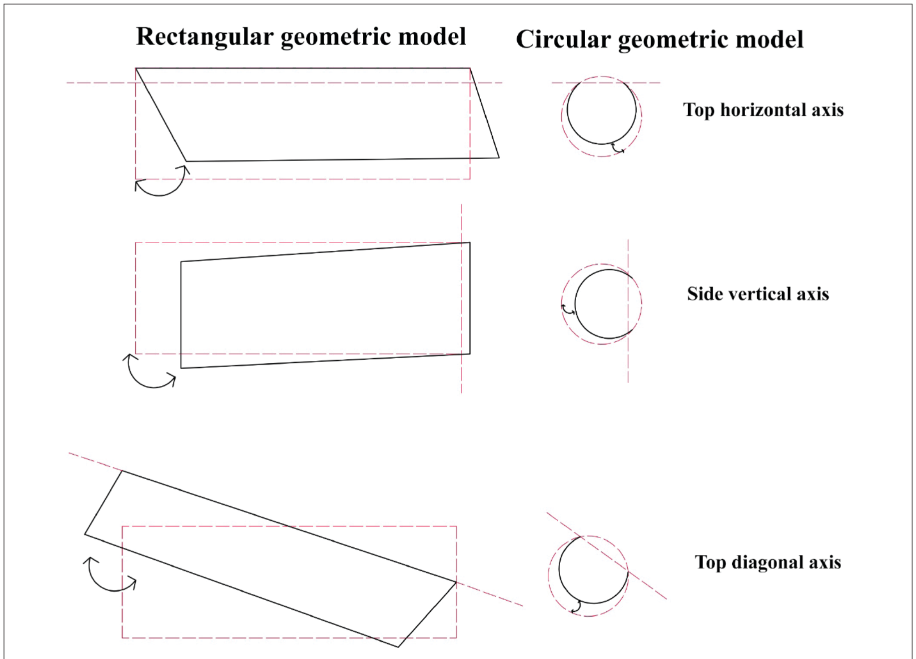
Table 3. Specifications of the Simulated Room.

Room Dimensions	Width: 4 m, Length: 6 m, Height: 3 m
Ceiling Reflectance	80%
Wall Reflectance	50%
Glass Visible Transmittance	90%
Floor Grid Dimensions	0.6 m
Floor Measurement Points	Point 59
Window-to-Wall Ratio (WWR)	90%

Table 4. Radiance Parameters for Daylight Availability Metrics.

Ambient Divisions	Ambient bounces
512	2

Figure 4. Circular and rectangular geometric models with three rotational axes of kinematics.



Results

Phase I involved the computation of annual dynamic daylight metrics for the south, east, and west façades, utilising a static baseline model (i.e., without kinetic shading). The resulting performance values are summarised in Table 4.

Subsequently, Phase II focused on the systematic application and performance simulation of two main geometric patterns—circular and rectangular—each integrated with three distinct rotational movement axes: horizontal (top pivot), vertical (side pivot), and diagonal (top pivot), as illustrated in Figure 4.

As shown in Table 5,circular and rectangular geometric patterns with three rotational movement axes were simulated and analyzed for the south, west, and east façades on three representative days of the year: July 21, March 21, and December 21. Based on dynamic daylight performance metrics, including UDI less and ASE, each pattern was compared and analyzed in terms of movement axis, geometric configuration, and, for each day, the optimal angle and dimensions (length, width, and radius) for the three façades were determined. It should be noted that the dimensions of the geometric patterns and their movement axes were kept constant across the three façades, Conversely, the rotation angle (or degree of openness) was treated as the primary independent variable, which was iteratively adjusted for each façade to achieve optimal dynamic daylight performance.

Intolerable glare (indicated in Gray color & Underline in Table 5) was observed in some cases. The vertical-axis rotation pattern at the side, combined with both circular and rectangular patterns, was unsuitable for all façades, producing intolerable glare at 4:00 p.m. on the selected days. For the south façade, the diagonal-axis rotation pattern at the top caused intolerable glare in both circular and rectangular patterns at the same time,whereas the east and west façades responded adequately to daylight. The top-pivoted horizontal-axis rotation mechanism, implemented for both circular and rectangular modules, proved highly effective in maintaining a favorable balance between Useful Daylight Illuminance (UDI) and Annual Sunlight Exposure (ASE) criteria across all three cardinal façades, given the specific design constraints (90% WWR) and the Tehran (Iran) climate reference file.The optimal range of façade openness for the circular pattern is 5° to 90° (south), 5° to 20° (west), and 5° to 10° (east). For the rectangular pattern, optimal openness ranges are 40° to 60° (south and west) and 80° to 90°(east).

Detailed performance data for the diagonal-axis rotation pattern with both circular and rectangular geometries are provided for reference.

Circular Geometric Model with Rotational Kinematic Axis at the Top (Diagonal Axis)

The circular geometric model, integrated with a top-pivoted diagonal rotation axis (as depicted in Figure 5, The radius of each circle is 0.18 m. In the first step, the opening angle of the western and eastern façades was simulated from fully open (0°) to fully closed (95°). The opening angle of the façade ranges from 95° (open) to 0° (closed), while the most suitable angles are as follows: 95° to 85° in 5° increments for the western façade and 90° to 95° for the eastern façade. The façade opens according to the sun's position (95°) and gradually closes (0°) during the simulation.

After simulating the façade on the 21st day of March, June, and December at 9:00 a.m., 12:00 p.m. and 4:00 p.m., it was determined, according to Table 6, that the circular geometric model with a rotational kinematic axis at the top (diagonal axis) provides adequate daylight response for both the western and eastern façades.

Rectangular Geometric Model with Rotational Kinematic Axis at the Top (Diagonal Axis)

The rectangular geometric module was configured with a top-pivoted diagonal rotation mechanism, the setup of which is detailed in Figure 5.Each rectangle measures 0.5 × 1 m. In the first step, the opening angle of the western and eastern façades was simulated from fully closed (0°) to fully open (95°). The opening angle ranges from 95° (open) to 0° (closed), while the most suitable angles are: 90° to 65° in 5° increments for the western façade and 90° to 75° for the eastern façade. The façade opens according to the sun's position (95°) and gradually closes (0°) during the simulation. (Figure 6.)

After simulating the façade on the first day of March, June, and December at 9:00 a.m., 12:00, and 4:00 p.m, it was determined, according to Table 7, that the rectangular geometric model with a rotational kinematic axis at the top (diagonal axis) provides adequate daylight response for both the western and eastern façades.

Discussion

Based on recent research on kinetic façades in Iran and worldwide, it is observed that kinetic façades perform better than their fixed counterparts in reducing glare and controlling day-

31. Sangtarash, Fataneh, et al. 'Utilising Kinematic Models of Kinetic Facades to Obtain Optimal Natural Lighting in an Office Building'. *Journal of Architectural Engineering* 31, no. 1 (2025): 04024050. https://doi.org/10.1061/JAEIED.AEENG-1705.

32. *climate.onebuilding.org*.

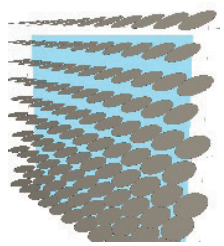
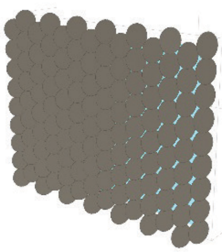
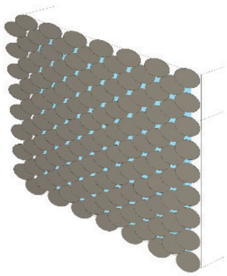
33. National Building Regulations Office, *Saving Energy Consumption/Topic 19* (Tehran: Iran Development Publishing House, 1401).

light. The performance of adaptive façades in achieving optimal interior daylight is critically determined by the synergistic relationship between several interdependent factors: module geometry, kinematic movement typology, room volume and configuration, and the dynamic control strategy relative to solar position and local climate Evaluating these factors comprehensively, while considering the overlap of daylight indices such as UDI, UDI less, UDI more, ASE, and DA, can further highlight their importance.

Comparison of Circular and Rectangular Geometric Models

As shown in Figure 7, the data for useful daylight below 500 lux (UDI less) indicate that the rectangular geometric model with a horizontal axis provides more optimal dynamic daylight

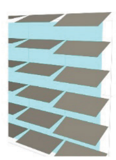
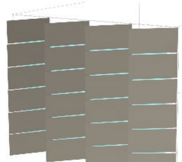
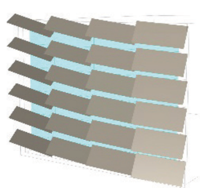
Table 5. Comparison of Circular and Rectangular Geometric Models with Three Rotational Kinematic Axes in the Southern, Western, and Eastern Façades.

Models	Geometric models	Motion axis	Daylight Index	South	East	West
	Circle	Top Horizontal axis	Dimensions	0.18m	0.18m	0.18m
			Open angle (°)	5° to 30°	5° to 10°	5° to 20°
			Avg UDI Less	47.84%	51.46%	59/86%
			Avg ASE	1%	1.66%	4%
			DGP	0	0	0
		Side Vertical axis	Open angle (°)	50° to 40°	20° to 25°	20° to 25°
			Avg UDI Less	86.20%	84.81%	45.84%
			Avg ASE	30.22%	12%	11.85%
			DGP	0.62 Intolerable at 12:00 p.m. on the 21^{st} day of each quarter	0.68 Intolerable at 09:00 a.m. on day 21^{st} of each quarter	1 Intolerable at 4:00 p.m. on 21^{st} July
		Top Diagonal axis	Open angle (°)	50° to 95°	90° to 95°	95° to 85°
			Avg UDI Less	70.81%	49.74%	52.88%
			Avg ASE	14%	6.66%	8.33%
			DGP	0.71 Intolerable at 4:00 p.m. in 21^{st} December, and a level of 0.56 was recorded at 12:00 p.m. on day 21^{st} of June and March.	0	0

performance for the interior of an office building in Tehran compared to the circular geometric model with a horizontal axis at the top, with differences of 16% in the southern façade, 9% in the western façade, and 7% in the eastern façade. This performance is significant, as it indicates comprehensive daylight coverage where the Useful Daylight Illuminance (UDI) threshold of 500 lux is met across the entire reference workplane, ensuring no under-lit zones within the space. However, the values for useful daylight below 500 lux (UDI less) are similar for both circular and rectangular models with a rotational diagonal axis at the top in the eastern and western façades. Conversely, the Annual Sunlight Exposure (ASE) values for the southern façade with the top-pivoted diagonal axis surpass the 10% tolerance level across both geometric models (circular and rectangular). This breach suggests a significant risk of direct sun penetration, resulting in visual discomfort and potential glare for the occupants. In contrast, for the eastern and western façades, the ASE values are below 10%. Moreover, for the southern, eastern, and western façades with a horizontal axis at the top, the ASE values are below 10%, indicating that these spaces are free from glare and the results are acceptable.

The results unequivocally confirm that a horizontal-axis kinetic shading device offers su-

Table 5. Comparison of Circular and Rectangular Geometric Models with Three Rotational Kinematic Axes in the Southern, Western, and Eastern Façades.

Models	Geometric models	Motion axis	Daylight Index	South	East	West
	Rectangular	Top Horizontal axis	Dimensions	1 × 0.5m	1 × 0.5m	1 × 0.5m
			Open angle (°)	60° to 90°	80° to 90°	60° to 90°
			Avg UDI Less	31.66%	44.70%	50.71%
			Avg ASE	2.29%	6%	0
			DGP	0	0	0
		Side Vertical axis	Open angle (°)	60° to 30°	65° to 40°	60° to 30°
			Avg UDI Less	68.22%	86.95%	90.47%
			Avg ASE	33%	10%	12%
			DGP	0.66 Intolerable at 12:00 and 4:00 p.m. on the 21st of each quarter	0	0
		Top Diagonal axis	Open angle (°)	80° to 40°	90° to 75°	90° to 65°
			Avg UDI Less	66.78%	49.86%	54.54%
			Avg ASE	24.44%	2.22%	7%
			DGP	0.56 Intolerable at 12:00 p.m. on the 21st of each quarter	0	0

perior performance for the southern façade of a Tehran office building when compared to its vertical-axis counterpart, particularly in mitigating high-angle solar heat gain. The rotational kinematic model performs better in responding to natural daylight than the folding kinematic model, and using a kinetic façade significantly reduces glare compared to a model without movable elements. Kinetic façade factors, including room length, width, and height relative to orientation, the distance of the façade from the glass, as well as the depth and angle of the shading device, have a significant impact on glare, dynamic daylight, and energy savings in an office building in a hot and arid climate[34]. Moreover, daylighting not only contributes to energy savings but also enhances occupant productivity and comfort[35]. These façades[36] Overall, kinetic façades demonstrated improved energy efficiency and enhanced visual comfort relative to static shading systems. This improvement is quantified by a significant increase in Spatial Daylight Autonomy (sDA), which directly translates to better daylight distribution and a substantial improvement in Useful Daylight Illuminance (UDI) availability.[37]. A recurrent methodological limitation in recent literature is the incomplete evaluation of dynamic daylighting

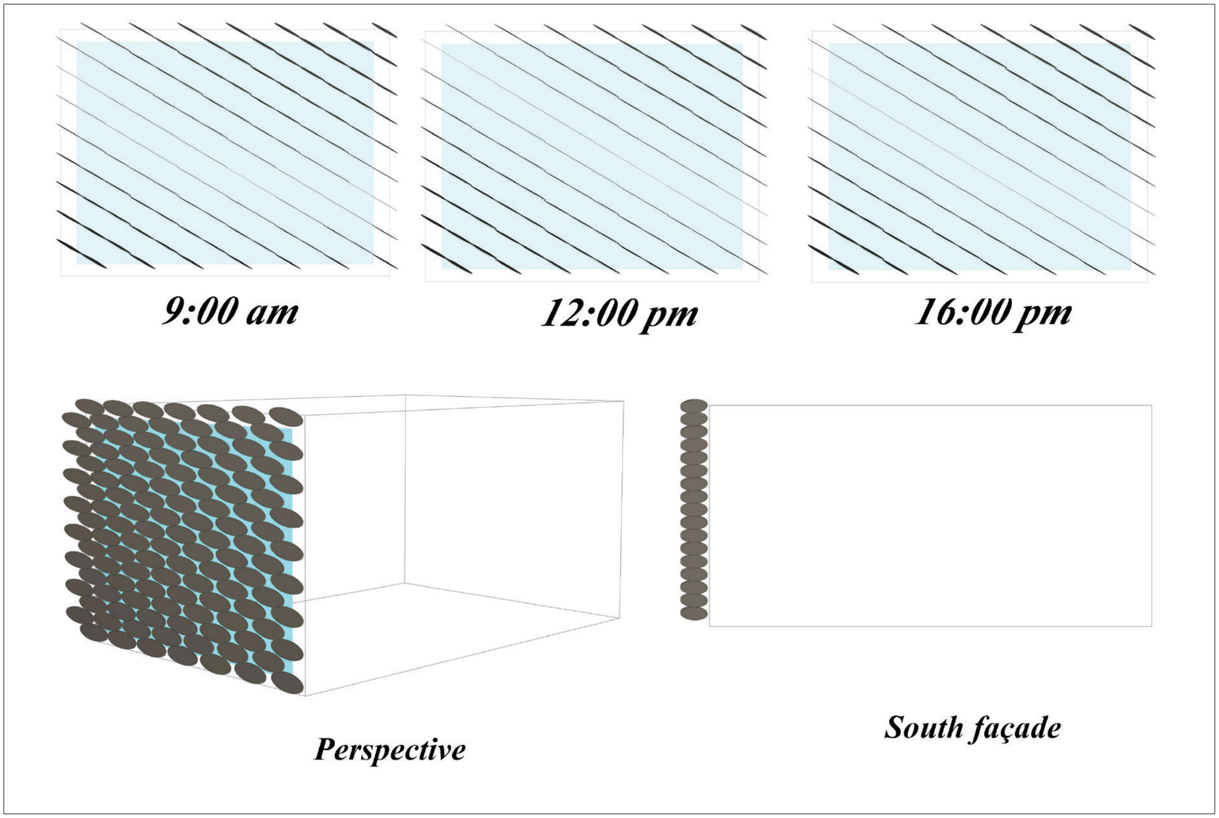


Figure 5. Façade Angle of the Circular Geometric Model with Diagonal Kinematic Axis According to the Sun's Position at 9:00 a.m., 12:00 and 4:00 p.m.. for the Western Façade.

34. Zekraoui, Djamel, and Noureddine Zemmouri. 'SMART AND DYNAMIC FACADES: A PATH TO ENERGY OPTIMISATION IN ARID ENVIRONMENTS.' *journal of Architectural and Engineering Research*, (2024): 84-102

35. Sureshkumar Jayakumari, S.D., S.T. Imalka, R.J. Yang, C. Liu, S. Yang, M. Marschall, P.S. Corradini, A.F. Benito, and N Williams. 'Energy and Daylighting Performance of Kinetic Building-Integrated Photovoltaics (BIPV) Façade.' *Sustainability* 16,(2024): 9739. doi:https://doi.org/10.3390/su16229739.

36. Zheng, Yiqian, Jinxuan Wu, Hao Zhang, Caifang Lin, Yu Li, Xue Cui, and Pengyuan Shen. 'A novel sun-shading design for indoor visual comfort and energy saving in office space in Shenzhen.' *Energy and Buildings*, (2024): 115083. doi: https: //doi.org/10.1016/j.enbuild.2024.115083.

performance, often relying exclusively on metrics such as Annual Sunlight Exposure (ASE) and Spatial Daylight Autonomy (sDA) without incorporating a comprehensive set of indices. While several geometric and kinematic models have been explored, none have proposed a specific, unified geometric and kinematic model tailored to the Tehran climate (hot and arid) that optimises daylighting and visual comfort for all four façades. The findings of this study are therefore consistent with previous research, confirming that kinetic façades effectively improve natural daylighting and visual comfortThe successful performance is attributable to the adaptive control strategy, wherein the façade modules modulate their openness in direct response to the sun's position. Furthermore, the rotational kinematic model utilising a horizontal axis consistently outperformed the vertical-axis rotation model in optimising internal daylight availability. Additionally, the size of the geometric pattern and room dimensions significantly affect daylight performance.

Among the limitations of this study is the absence of an actual office building with a kinetic façade for field measurement, which would allow comparison between simulation and real-world results. Furthermore, measuring devices for natural daylight in interior spaces have limitations, as it is not possible to simultaneously measure incoming daylight, useful daylight below 500 lux, and glare. Consequently, quantifying these disparate metrics simultaneously introduces a substantial computational challenge, even within multi-objective optimisation frameworks. This inherent conflict contributes to

Index	December 21			March 21			June 21		
	9	12	16	9	12	16	9	12	16
West Facade									
DA	99.95%	99.95%	99.95%	99.90%	99.95%	99.90%	99.90%	99.90%	99.90%
UDI	88.59%	88.33%	87.49%	88.70%	88.07%	88.02%	88.64%	87.18%	88.64%
UDI Less	50.76%	52.01%	51.57%	51.07%	55.94%	54.63%	53.06%	53.03%	53.69%
UDI more	65.15%	65.88%	64.94%	64.21%	65.04%	64.15%	65.36%	64.47%	64%
sDA	100%	100%	100%	100%	100%	100%	100%	100%	100%
ASE	8.33%	8.33%	8.33%	8.33%	8.33%	8.33%	6.66%	10%	8.33%
East Facade									
DA	100%	99.90%	99.90%	100%	100%	100%	99.90%	99.90%	100%
UDI	88.12%	87.81%	88.80%	87.76%	86.08%	87.13%	87.70%	87.39%	87.34%
UDI Less	49.35%	53.22%	51.96%	49.35%	46.05%	50.03%	50.18%	47.93%	49.56%
UDI more	70.02%	70.80%	70.38%	71.32%	70.80%	71.85%	69.18%	68.29%	70.17%
sDA	100%	100%	100%	100%	100%	100%	100%	100%	100%
ASE	6.66%	6.66%	6.66%	6.66%	6.66%	6.66%	6.66%	6.66%	6.66%

Table 6. Façade with Circular Geometric Model and Rotational Kinematic Axis at the Top (Diagonal Axis).

37. Bahdad, Ali Ahmed, Nooriati Taib, Fahad Saud Allahaim, and Ali Mohammed Ajlan. 'Parametric Optimisation Approach to Evaluate Dynamic Shading Within Double-Skin Insulated Glazed Units for Multi-Criteria Daylighting Performance in Tropics.' *Journal of Daylighting*, (2024): 349-371. doi:10.15627/jd.2024.24.

the complexity and dimensionality of the final parametric design space. Future research could evaluate rectangular kinetic façades with horisontal and diagonal rotational axes on all four façades, considering energy consumption, visual comfort, and thermal comfort, using either simulation or field measurement. Moreover, these façades could be assessed in different climates and cities to identify the most appropriate geometric and kinematic configurations for optimal interior daylighting in each location. The results of this study could also be applied to similar climates outside Iran.

Conclusion

This study aimed to optimise natural daylighting in an office building in Tehran using kinematic façades with horizontal, diagonal, and vertical rotational axes and two geometric models (circular and rectangular) on the north, south, west, and east façades. Initially, the geometry of a sample office room without a kinetic façade was simulated to assess natural daylight. Initially, the geometry of a sample office room without a kinetic façade was simulated to assess natural daylight. Based on the glare index (ASE), it was inferred that the northern façade

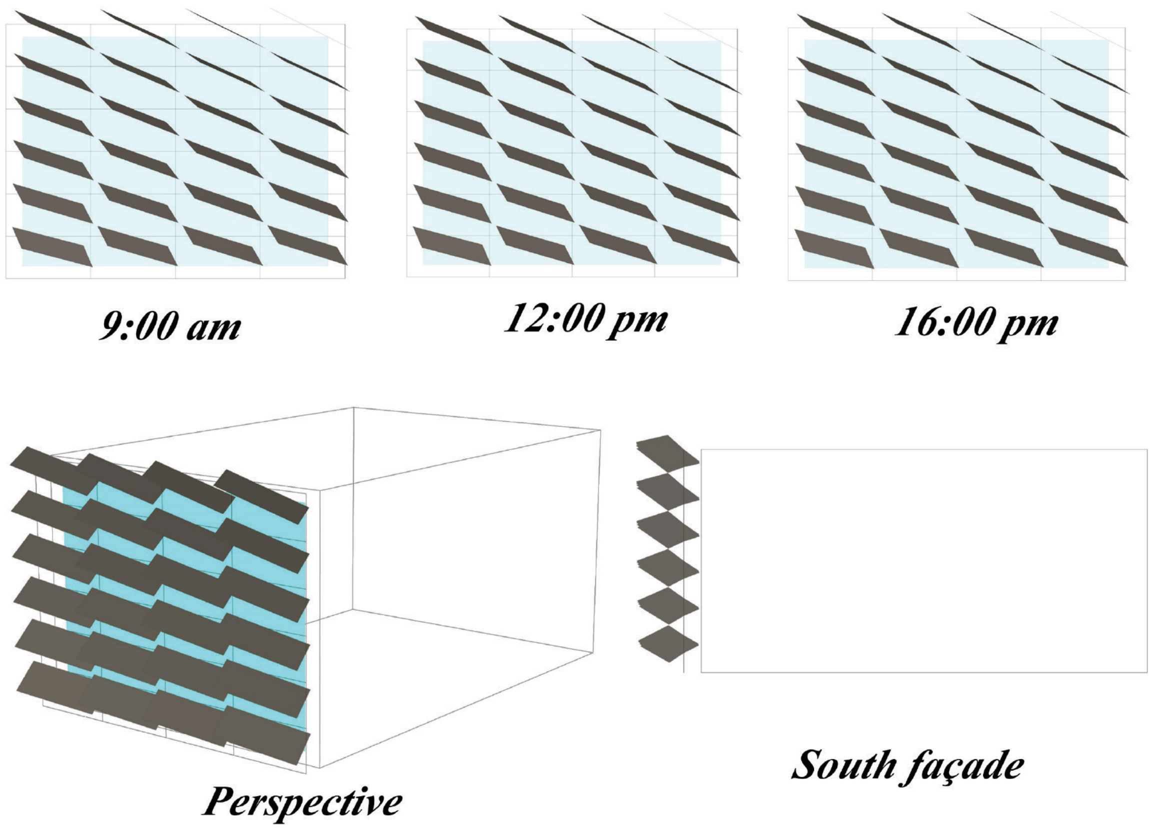


Figure 6. Façade Angle of the Rectangular Geometric Model According to the Sun's Position at 9:00 p.m., 12:00 and 16:00 p.m. for the Western Façade.

required no dedicated shading, as the space received adequate useful daylight even without a shading system. Therefore, the kinetic façade analysis was conducted only for the southern, eastern, and western façades. The circular and rectangular geometric models with a rotational kinematic structure and three axes (horizontal, vertical, and diagonal) were simulated and compared for the southern, western, and eastern façades. The simulation results highlighted the critical importance of the ASE and UDI less indices. When the shading device is partially closed, less light enters the interior, and a higher percentage of UDI less than 500 lux may result in areas of the interior receiving insufficient daylight. Conversely, when the façade is fully open, excessive daylight admission results in ASE values exceeding 10%, indicating a high risk of glare and visual discomfort. Therefore, optimising these two indices is essential for achieving adequate useful daylight in interior spaces. Next, the values of ASE, UDI less, and DGP for the rotational kinematic models with horizontal, vertical, and diagonal axes for both circular and rectangular geometries were averaged for the 21st day of March, June, and December using Python. Based on these analyses, the optimal kinematic axes and geometric models were selected.

The simulation results indicated that:

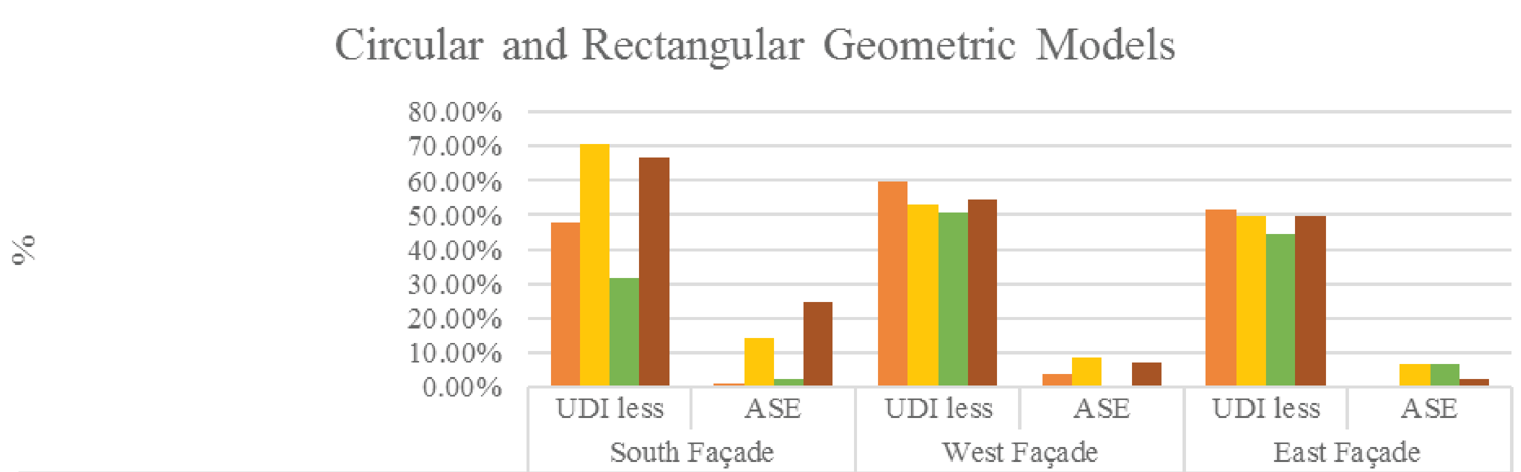
- Circular and rectangular geometric models with a horizontal rotational axis at the top respond adequately to dynamic daylight for the southern, western, and eastern façades.
- Circular and rectangular models with a diagonal rotational axis at the top provide sufficient

Index	December 21			Murch 21			June 21		
	9	12	16	9	12	16	9	12	16
West Facade									
DA	100%	100%	100%	100%	100%	100%	100%	100%	100%
UDI	89.95%	90.74%	90.32%	89.43%	89.80%	89.01	89.95%	89.74%	91.89%
UDI Less	53.22%	54.42%	53.79%	55.36%	56.04%	55.36%	53.64%	54.63%	54.42%
UDI more	87.60%	87.49%	88.07%	85.30%	85.03%	86.03%	83.31%	82.42%	983.99%
sDA	100%	100%	100%	100%	100%	100%	100%	100%	100%
ASE	6.66%	6.66%	6.66%	6.66%	6.66%	6.66%	10%	1.66%	10%
East Facade									
DA	100%	100%	100%	100%	100%	100%	100%	100%	100%
UDI	89.06%	89.38%	90.32%	88.96%	88.54%	88.75%	89.95%	89.80%	91.89%
UDI Less	47.10%	52.96%	51.13%	45.63%	48.98%	49.87%	57.56%	50.34%	45.26%
UDI more	88.59%	87.91%	88.12%	89.06%	86.66%	87.96%	83.62%	84.35%	85.24%
sDA	100%	100%	100%	100%	100%	100%	100%	100%	100%
ASE	3.33%	1.66%	5%	1.66%	1.66%	1.66%	1.66%	1.66%	1.66%

Table 7. Façade with Rectangular Geometric Model and Rotational Kinematic Axis at the Top (Diagonal Axis).

daylight for the western and eastern façades.

The simulation also demonstrated that parameters such as the façade opening angle, size (length, width, radius), clockwise or counter-clockwise rotation, and the reflectance of glass and wall surfaces are important factors affecting daylight performance in kinetic façades. Finally, by comparing geometric models based on ASE and UDI less indices, it was concluded that the rectangular geometric model with horizontal and diagonal rotational axes at the top provides more optimal daylighting than the circular geometric model with the same axes for the southern, western, and eastern façades of an office building in Tehran. The most suitable rotational axes for the kinetic façades are: horizontal and diagonal for the western and eastern façades and horizontal for the southern façade.



	South Façade		West Façade		East Façade	
	UDI less	ASE	UDI less	ASE	UDI less	ASE
Circular Geometric Model with Rotational Pattern and Top Horizontal Axis	47.84%	1%	59.86%	4%	51.46%	0%
Circular Geometric Model with Rotational Pattern and Top Diagonal Axis	70.81%	14%	52.88%	8.33%	49.74%	6.66%
Rectangular Geometric Model with Rotational Pattern and Top Horizontal Axis	31.66%	2.22%	50.71%	0%	44.70%	6.66%
Rectangular Geometric Model with Rotational Pattern and Top Diagonal Axis	66.78%	24.44%	54.54%	7%	49.86%	2.22%

Figure 7. Comparison of Circular and Rectangular Geometric Models.

References

BS EN-12464-1. *Light and lighting. Lighting of work places Indoor work places.* BSI standards, (2021).

Anselm, Akubue Jideofor. 'Passive annual heat storage principles in earth sheltered housing, a supplementary energy saving system in residential housing.' *Energy and Buildings* 40, no. 7 (2008): 1214-1219.

Bahdad, Ali Ahmed, Nooriati Taib, Fahad Saud Allahaim, and Ali Mohammed Ajlan. 'Parametric optimisation approach to evaluate dynamic shading within Double-Skin insulated glazed units for Multi-Criteria daylighting performance in tropics.' *Journal of Daylighting* 11, no. 2 (2024): 349-371.

Compilation and promotion of national building regulations. Iran's national building regulations, topic 13, design and implementation of electrical installations of buildings. Tehran: Iran Development Publishing House, (2015). (In Persian).

Elghazi, Y., Ayman Wagdy, Sahar Mohamed, and Asmaa Hassan. 'Daylighting driven design: optimising kaleidocycle facade for hot arid climate.' In *Aachen: Fifth German-Austrian IBPSA Conference, RWTH Aachen University*, pp. 314-321. 2014. Elghazi, Yomna, Ayman Wagdy, and Sahar Abdalwahab. 'SIMULATION DRIVEN DESIGN FOR KINETIC SYSTEM; OPTIMISE KALEIDOCYCLE FAÇADE CONFIGURATION FOR DAYLIGHTING ADEQUACY IN HOT ARID CLIMATES.' *14th Conference of International Building Performance Simulation Association, Hyderabad, India* ,(2015):7-9. 'https://doi.org/10.26868/25222708.2015 .2705'

Erlendsson, Örn. 'Daylight optimisation: A parametric study of atrium design.' *Master Science's Thesis, Royal Institute of Technology, Stockholm, Sweden* (2014).

Fakhari, Maryam, Rima Fayaz, and Maryam Mehravar. 'The acceptable illumination level for office occupants in Tehran.' *Journal of Iranian Architecture & Urbanism (JIAU)* 12, no. 1 (2021): 79-92.

Hassan, Fayrouz HF, Khaled AY Ali, and Salwa AM Ahmed. 'Biomimicry as an approach to improve daylighting performance in office buildings in Assiut City, Egypt.' *Journal of Daylighting* 10, no. 1 (2023): 1-16..

Hosseini, Seyedeh Nazli, SM Morteza Hosseini, and Milad HeiraniPour. 'The role of Orosi's Islamic geometric patterns in the building facade design for improving occupants' daylight performance.' *Journal of Daylighting* 7, no. 2 (2020): 201-221.Hosseini, Seyed Morteza, Masi Mohammadi, and Olivia Guerra-Santin. 'Interactive kinetic façade: Improving visual comfort based on dynamic daylight and occupant's positions by 2D and 3D shape changes.' *Building and Environment,no 165(2019):* 106396. www.elsevier.com/locate/buildenv.

Ibrahim, JAAFAR AHMAD, and HALIL ZAFER Alibaba. 'Kinetic facade as a tool for energy efficiency.' *Int. J. Eng. Res. Rev* 7 (2019): 1-7.

Katabaro, Justine, and Yan Yonghong .'Effects of Lighting Quality on Working Efficiency of Workers in Office Building in Tanzania.' *Journal of Environmental and Public Health,(2019):* 1-12.

Kızılo¨renli, Ecenur, and Feray Maden. 'Modular responsive facade proposals based on semi-regular and demi-regular tessellation: daylighting and visual comfort.' *Frontiers of Architectural Research.2023.* doi:DOI:10.1016/j.foar.2023.02.005.

Kontovourkis, O, A Michael, K Alexandrou, and C Vassiliades. 'Lighting performance simulation and adaptive control of an advanced building skin based on human behaviour inputs.' *10th International Conference On Advanced Building Skins, Bern Switzerland,(2015):* 1340-1349.

Kasmaei, Morteza. 'Climate and architecture.' *Tehran: Khak Publishing* (2003).

Li, Y. U. A. N. Y. U. A. N., C. H. E. N. Y. U. Huang, G. E. N. G. J. I. A. Zhang, and J. I. A. W. E. I. Yao. 'Machine learning modeling and genetic optimisation of adaptive building facade towards the light environment.' In *Proc., 27th Int. Conf. of the Association for ComputerAided Architectural Design Research in Asia*, (2022): 150-141.

LM-83-12, IES. *Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE).* North America: the Illuminating Engineering Society (2012).

Mahmoud, Ayman Hassaan Ahmed, and Yomna Elghazi. 'Parametric-based designs for kinetic facades to optimise daylight performance: Comparing rotation and translation kinetic motion for hexagonal facade patterns.' *Solar Energy* 126 (2016): 111-127.Nabil, A., and J. Mardaljevic. 'Useful daylight illuminances: A replacement for daylight factors.' *Energy Build. no* 38,(2006): 905–913.

Office of National Building Regulations. Energy saving / Topic 19. Tehran: Iran Development Publishing House, (1401).

Pourahmadi, Mahbubeh, Mohamadi Mohammad Ali Khan, and Farhang Mozaffar. 'An Analytical Study on the Effect of envelope's physical parameters on the Visual Comfort of Traditional housing in hot and Dry Climate of Iran (Case Study: five-door rooms in Yazd Traditional Houses).' (2021): 135-153.Qiyabaklo, Zahra. 'Fundamentals of construction physics 4 (passive cooling)'. Tehran: Jihad University, Amirkabir Industrial Unit, (2012). (In Persian).

Rasuli, M., Y. Shahbazi, and M. R. Matini. 'Horizontal and vertical movable drop-down shades performance in double skin façade of office buildings; Evaluation and parametric simulation.' *Naqshejahan-Basic Studies and New Technologies of Architecture and Planning* 9, no. 2 (2019): 135-144.

Resolution of the Supreme Administrative Council 'Organisation of the administrative spaces of the executive bodies of the country.' Deputy for compilation, revision and publication of laws and regulations, (1390).

Sangtarash, Fataneh, Rima Fayaz, Niloufar Nikghadam, and Mohammad Reza Matini. 'Optimal window area of a kinetic facade to provide daylight in an office building in Tehran.' *Space Ontol. Int. J* 11 (2022): 61-75.

Sangtarash, Fataneh, Niloufar Nikghadam, Rima Fayaz, and Mohammad Reza Matini. 'A comparative study of the kinetic movement pattern of a triangular geometric facade regarding natural lighting in an office building in Tehran.' *Journal of Iranian Architecture & Urbanism (JIAU)* 14, no. 2 (2023): 159-175.

Sangtarash, Fataneh, Niloufar Nikghadam, Rima Fayaz, and Mohammad Reza Matini. 'A comparative study of the kinetic movement pattern of a triangular geometric facade regarding natural lighting in an office building in Tehran.' *Journal of Iranian Architecture & Urbanism (JIAU)* 14, no. 2 (2023): 159-175. Sangtarash et.al. Utilising Kinematic Models of Kinetic Facades to Obtain Optimal Natural Lighting in an Office Building. J. Archit. Eng., 2025, 31(1): 04024050. DOI: 10.1061/JAEIED.AEENG-1705.

Samadi, Sahba, Esmatullah Noorzai, Liliana O. Beltrán, and Saman Abbasi. 'A computational approach for achieving optimum daylight inside buildings through automated kinetic shading systems.' *Frontiers of Architectural Research* 9, no. 2 (2020): 335-349.

Schumacher, Michael, Michael Marcus, Vogt Luis A, and Cordón Krumme. *Architektur in Bewegung – Neue dynamische Komponenten und Bauteile*. German: Birkhäuser.2019.

Sharaidin, Kamil. *Kinetic facades: towards design for environmental performance*. Environmental Science, Engineering RMIT University: Thesis Doctor of Philosophy (PhD). (2014).

Suk, J. Y., Schiler, M., & Kensek, K. 'Investigation of existing discomfort glare indices using human subject study data.' *Building and Environment,Sol Energy,no78,(2016):* 15–28.

Sureshkumar Jayakumari, Sujan Dev, Samarasinghalage Tharushi Imalka, Rebecca Jing Yang, Chengyang Liu, Siliang Yang, Max Marschall, Pablo Sepulveda Corradini, Adolfo Fernandez Benito, and Nick Williams. 'Energy and daylighting performance of kinetic building-integrated photovoltaics (bipv) façade.' *Sustainability* 16, no. 22 (2024): 9739..

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.

Veitch, Jennifer, Kelley Farley, and Guy Newsham. 'Environmental Satisfaction in Open-plan Environments: 1. Scale Validation and Method.' *NRC/IRC Research Report IR-844, National Research Council Canada, Institute for Research in Construction, Ottawa, Ontario, Canada. (*2002).

Zekraoui, Djamel, and Noureddine Zemmouri. 'SMART AND DYNAMIC FACADES: A PATH TO ENERGY OPTIMIsATION IN ARID ENVIRONMENTS.' *journal of Architectural and Engineering Research,* (2024): 84-102.

Zheng, Yiqian, Jinxuan Wu, Hao Zhang, Caifang Lin, Yu Li, Xue Cui, and Pengyuan Shen. 'A novel sun-shading design for indoor visual comfort and energy saving in office space in Shenzhen.' *Energy and Buildings* ,(2024):115083.

https://climate.onebuilding.org/WMO_Region_2_Asia/IRN_Iran/index.html.