

Review Article

A Systematic Review of Kinetic Architecture as a Strategy for Improving Thermal Comfort in Office Buildings in Hot-Dry Climates

Faeza Bakr Muhammed Amin ^{1,*} , Zhiyar Raad Fayege ² , Husein Ali Husein ³ 

¹ Department of Interior Design, Faculty of Engineering, Tishk International University, Erbil, 44001, Iraq

² Architectural Engineering and Sustainability Program, School of Science and Engineering, University of Kurdistan-Hawler, Erbil, 44001, Iraq

³ Department of Architecture, College of Engineering, Salahaddin University-Erbil, Erbil, 44001, Iraq

*Corresponding Author: Faeza Bakr Muhammed Amin, E-mail: faeza.bakr@tiu.edu.iq

Article Info	Abstract
Article History	This study employs a systematic literature review (SLR) to assess the impact of kinetic architecture on thermal comfort in various buildings, with a focus on offices in hot-dry climates. Comprehensive searches were done using Google Scholar, Semantic Scholar, and Scopus, respectively, applying the PRISMA method. The search yielded a selection of 109 relevant articles spanning from 2008 to 2024. The study's findings examine how kinetic façades help mitigate the issues in hot, dry climates, where prolonged exposure to the sun and rapid temperature fluctuations are common. Simulation tools are the preferred method for evaluating the performance of kinetic systems. Such systems are especially important in hot and dry regions because they help control solar radiation, ventilation, and thermal comfort, thereby decreasing energy usage while ensuring comfort inside buildings. In dry areas with extreme temperature fluctuations and limited water or energy resources, these systems can enhance natural ventilation, encourage nighttime cooling, and automatically provide shade to buildings during intense sunlight. The reviewed literature gap is that relevant studies often rely solely on simulations, resulting in limited experimental validation in real-world contexts. This study suggests that large-scale experiments are necessary to assess the practicality and durability of kinetic façades.
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Keywords	
Kinetic Architecture	
Thermal comfort	
Office Buildings	
Hot-Dry Climate	
Energy efficiency	
Systematic Literature Review	



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1. Introduction

In hot, dry climates, office buildings are among the highest energy consumers due to the high energy demand required to maintain indoor thermal comfort, a fundamental factor in employee health, well-being, and productivity. Building façades play a vital role as a protective barrier against harsh external conditions and a regulator of the indoor environment, serving as a primary interface between interior spaces and the outside. As they are utilized in contemporary building design, the visual appeal of glass façades frequently

exacerbates preexisting conditions by permitting excessive solar radiation. The energy efficiency of buildings is compromised by the high transparency in their designs, which also introduces discomfort in workstations exposed to direct sunlight [1, 2]. This further increases energy consumption and CO₂ emissions, emphasizing the need for efficient solutions [3]. In kinetic architecture, as described by Elmokadem, et al. [4], buildings are designed with transformative and automated features. The shape of the structures may be modified to suit people's needs and adapt to the surroundings. Kinetic architecture is the dynamic and adaptable response to these challenges. Kinetic façades actively respond to environmental conditions, reducing energy demand while enhancing thermal comfort in extreme climates. Studies show that kinetic façades in office buildings can reduce cooling energy consumption by as much as 40%, while also providing a sustainable means to achieve thermo-visual comfort [3, 5]. Alternative strategies, such as using solar control glass, aim to reduce cooling loads and glare but often fall short in hot, dry climates due to persistent, intense solar radiation [3, 5]. Emerging technologies, such as semi-transparent photovoltaic (STPV) modules, offer a dual function, filtering sunlight while generating electricity, and have demonstrated promise when integrated into building envelopes, particularly in sun-drenched regions [6]. In parallel, climate-responsive fenestration design, including optimized window orientation, appropriate glazing, and external shading, significantly contributes to reducing thermal loads and improving visual comfort in hot-dry climates [7]. These strategies highlight the evolving toolkit of passive and active façade systems, reinforcing the potential of kinetic façades, especially when synergized with STPV and optimized fenestration, to enhance occupant comfort and energy efficiency in extreme environmental conditions.

Advances in technology and a greater interest in energy-efficient designs have driven a growing interest in kinetic façades. Approximately one-third of global energy consumption is attributed to buildings, making them significant contributors to greenhouse gas emissions [8]. In addressing this, recent façade designs are evolving into passive systems by integrating renewable energy sources and innovative features that can absorb the intensity of solar radiation and enhance energy efficiency [9, 10]. One such development is the kinetic façade, developed to achieve environmental adaptation through stable interior environments as external conditions change [11]. Based on the coupling of nature, technology, and architecture, kinetic façade concepts incorporate flexible components and interdisciplinary strategies to solve complex design issues [4, 12]. Studies have also examined the relationship between daylight and productivity in office environments [13, 14]. Daylight has recently been shown to impact workers' health, sleep quality, physical activity, and overall well-being, all of which are directly related to productivity. For instance, office workers with abundant daylight exposure sleep 46 minutes longer than those without access to natural light [15, 16].

Furthermore, employees of offices with limited window views experience lower vitality and physical activity [16]. These findings highlight the importance of integrating well-designed façade systems to allow maximum daylight use without compromising thermal comfort and energy efficiency. Through their ability

to adapt to environmental stimuli, kinetic façades play a critical role in enhancing thermal comfort, improving daylight quality, and promoting efficiency in office buildings [17].

Architects' continuous use of these systems is integral to creating sustainable and productive work environments in hot-dry climates. Over the past decade, kinetic façades have been a popular subject of architectural research. However, the function of different shading devices is not well researched, and their effect on thermal comfort in office buildings in hot-dry climates is scarcely being investigated. This study addresses the following three questions:

1. What are the main kinetic system types used to improve thermal comfort in office buildings?
2. How do kinetic façades perform in hot-dry climates?
3. How much do kinetic façades reduce energy usage and cooling loads in office buildings?

2. Methodology

This study employs a systematic literature review (SLR) as a qualitative method to investigate the influence of kinetic architecture on thermal comfort in various buildings, with a specific focus on offices in dry, hot climates. Using the PRISMA method, an extensive search was conducted on Google Scholar, Semantic Scholar, and Scopus. The focus on literature post-2008 is directed toward sustainability and energy efficiency in the built environment, which has received heightened attention since then. This change was prompted by global frameworks, such as the 2007 report by the Intergovernmental Panel on Climate Change (IPCC) and related international agreements, which emphasized the urgent need to address thermal comfort as a critical component of climate change adaptation strategies worldwide [17].

2.1. Data Sources

This study involves a systematic literature review (SLR) investigating the role of kinetic architecture in enhancing thermal comfort in office buildings in hot-dry climates. This research adheres to the PRISMA guidelines to ensure a transparent, rigorous, reproducible review. A systematic search for relevant literature was conducted using Google Scholar, ScienceDirect, and Semantic Scholar, as well as relevant publications between 2008 and 2021. In the Title, Abstract, and Keywords fields, the carefully selected keywords of "kinetic façade", "thermal comfort", "energy efficiency", "adaptive façade systems", "hot-dry climates", and "visual comfort" were used.

The articles focused on adaptive or interactive façade systems as part of their contribution to the link between kinetic architecture and thermal or visual comfort, particularly in hot and dry climatic conditions. These studies covered a range of topics, including parametric simulations, literature reviews, and climate-based daylight metrics (CBDM). Visual and thermal comfort, the mechanisms and regulation of kinetic façades, biomimetic façade systems, and other topics were also discussed. The papers were published in prestigious journals, such as *Building and Environment* (Elsevier) and the *Journal of Building Engineering*,

and were written by authors from research institutions in Egypt, the Netherlands, Italy, and Turkey. These investigations have yielded significant insight into how kinetic architecture can enhance employee comfort in hot and dry climates in office buildings. The research methodology data processing followed three phases, as shown in Figure 1.

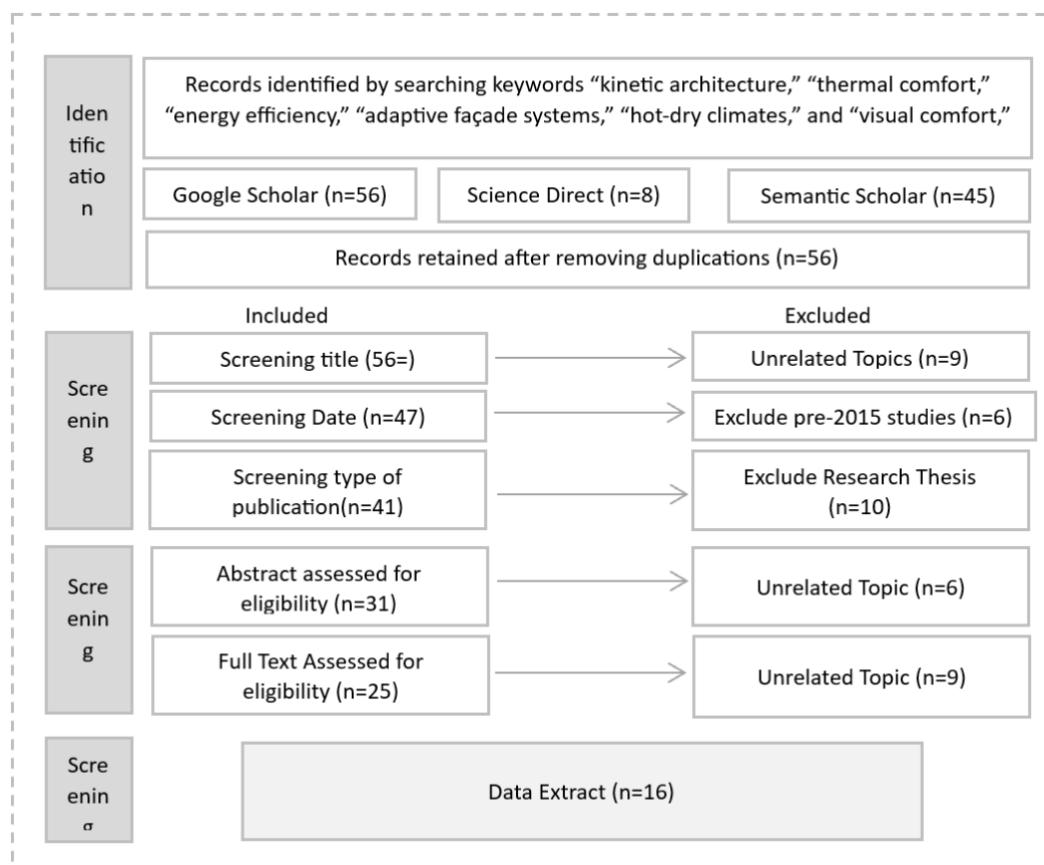


Figure 1. Study screening and selection according to the Preferred Reporting for Systematic Review Protocol (PRISMA) guidelines.

2.2. Inclusion and Exclusion Criteria

First, searches on Google Scholar, Semantic Scholar, and ScienceDirect for the selected keywords yielded 109 results. From the original 88 studies, 53 duplicates were removed. The remaining studies were reviewed according to the following inclusion and exclusion criteria to confirm their relevance and high quality.

- Criterion 1: The title and/or abstract needed to have at least two of the selected keywords: "kinetic architecture", "thermal comfort", "adaptive façade systems", "hot-dry climate", "energy efficiency", "reactive façade", or "daylight performance". This led to the removal of nine studies.
- Criterion 2: To focus on recent advances in the last decade, most updates and studies reported before 2015 were excluded. Six studies were excluded as they failed to meet this criterion.
- Criterion 3: The study had to be either a review or a research paper. Thus, 10 research theses were removed.

- Criterion 4: The thermal comfort and kinetic architectural interventions addressed by the study had to be at the building scale, especially in office buildings in hot-dry climates. Six studies were excluded due to interventions in climates other than urban or metropolitan scales.
- Criterion 5: The relationship between kinetic architecture and thermal comfort needs to be analyzed using an established methodological approach, literature reviews, parametric simulations, or performance-based metrics. Studies that had no methodological rigor were excluded.

Applying these criteria resulted in 16 studies being included in the systematic review. This provided a concentrated dataset to explore further the importance of kinetic architecture in sustaining thermal comfort in hot, dry climates (Figure 1).

2.3. Data Extraction and Data Synthesis

In the first data extraction phase, the research team systematically collected all necessary details from each study to ensure conformance with the research goals. The extracted items were (1) names of author(s), (2) year of publication in the last decade, (3) geographical context, (4) study design and methodology, (5) building type, (6) biological analogies, (7) type of kinetic façade, (8) mechanism for operation, (9) system and regulation, (10) analysis methods, and (11) impact of kinetic façade. The selected articles were reviewed in detail, and specific factors and design interventions associated with kinetic architectural systems, as well as their impact on thermal comfort in an office building, were identified. Particular emphasis was placed on the significance of these interventions in addressing problems specific to hot, dry climates, including wide temperature variations, high solar radiation, and energy conservation needs.

All the collected data were then summarized within an analytical framework. This research investigated kinetic building systems to enhance thermal comfort, reduce energy consumption, and improve indoor conditions, presenting the results within a relationship framework. The results were summarized and presented in an analysis diagram ranking factors and design interventions according to the corresponding authors and methods.

3. Results and Discussion

3.1. Bibliometric Analysis

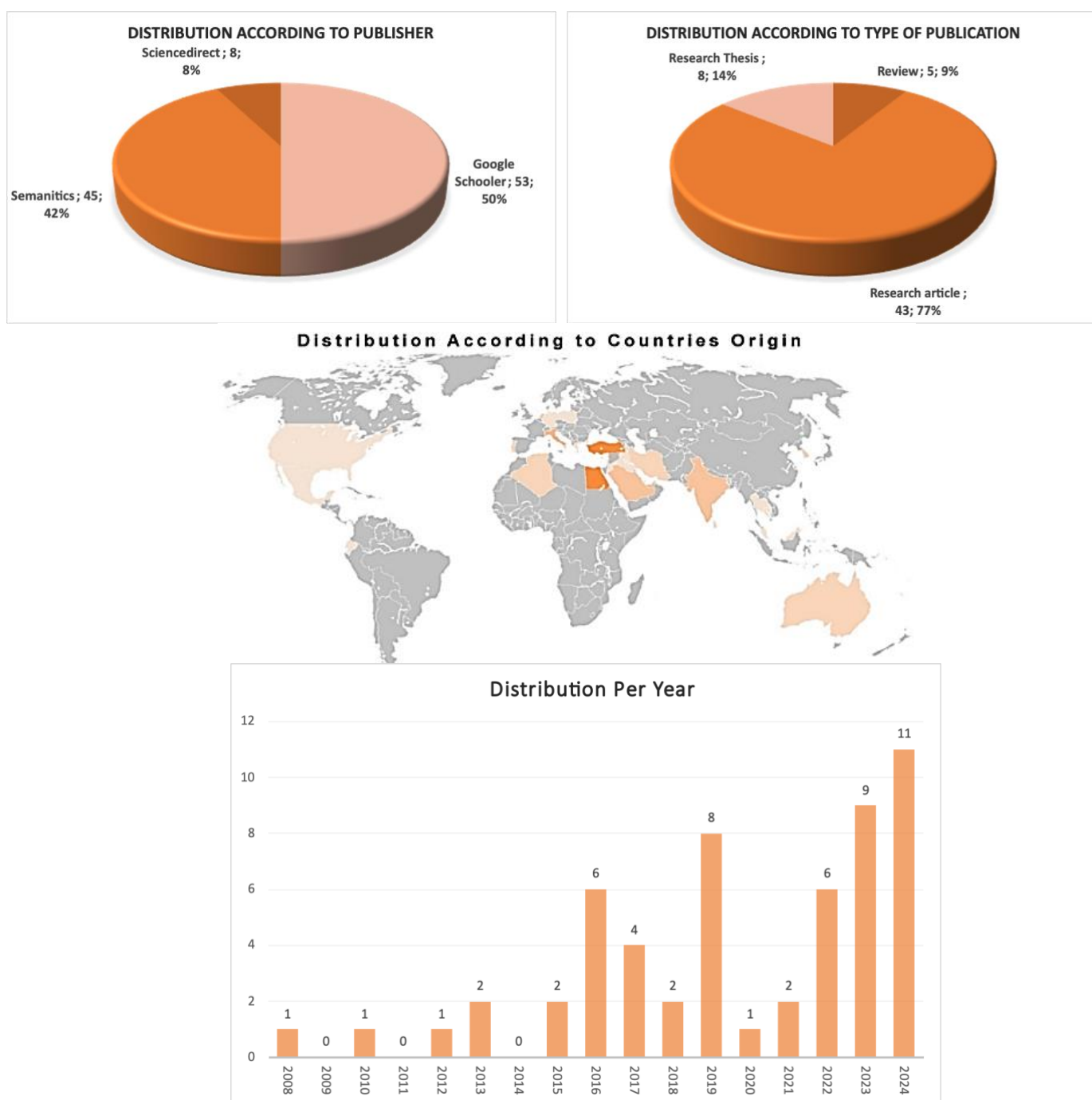
Results from the bibliometric analysis (Figure 2) indicate the distribution of reviewed articles by publisher, type of publication, publication year, country of origin, and journal. Over the analyzed period, Google Scholar was the main platform of publication (50% of the articles), followed by Semantic Scholar (42%) and ScienceDirect (8%).

Regarding the publication type, research articles were the most common, accounting for 81.2% of the total, followed by review papers at 18.8%. As noted earlier, research theses were excluded. Between 2022

and 2024, there was a noticeable increase in publications, peaking at 11 in 2024. The scientific community's growing interest in this field is a contributing factor to this increase.

The geographical distribution reveals that most authors were affiliated with Egypt, Iraq, Turkey, and the surrounding areas. This may be attributed to the focus of the research area being on hot-dry climates. Authors from other countries made minor contributions.

However, journals such as the International Journal of Sustainable Energy, Automation in Construction, and Journal of Green Building have made notable contributions. Taken as a whole, these journals exemplify the interdisciplinary approach of this research domain, which brings together engineering, sustainability, and architecture.



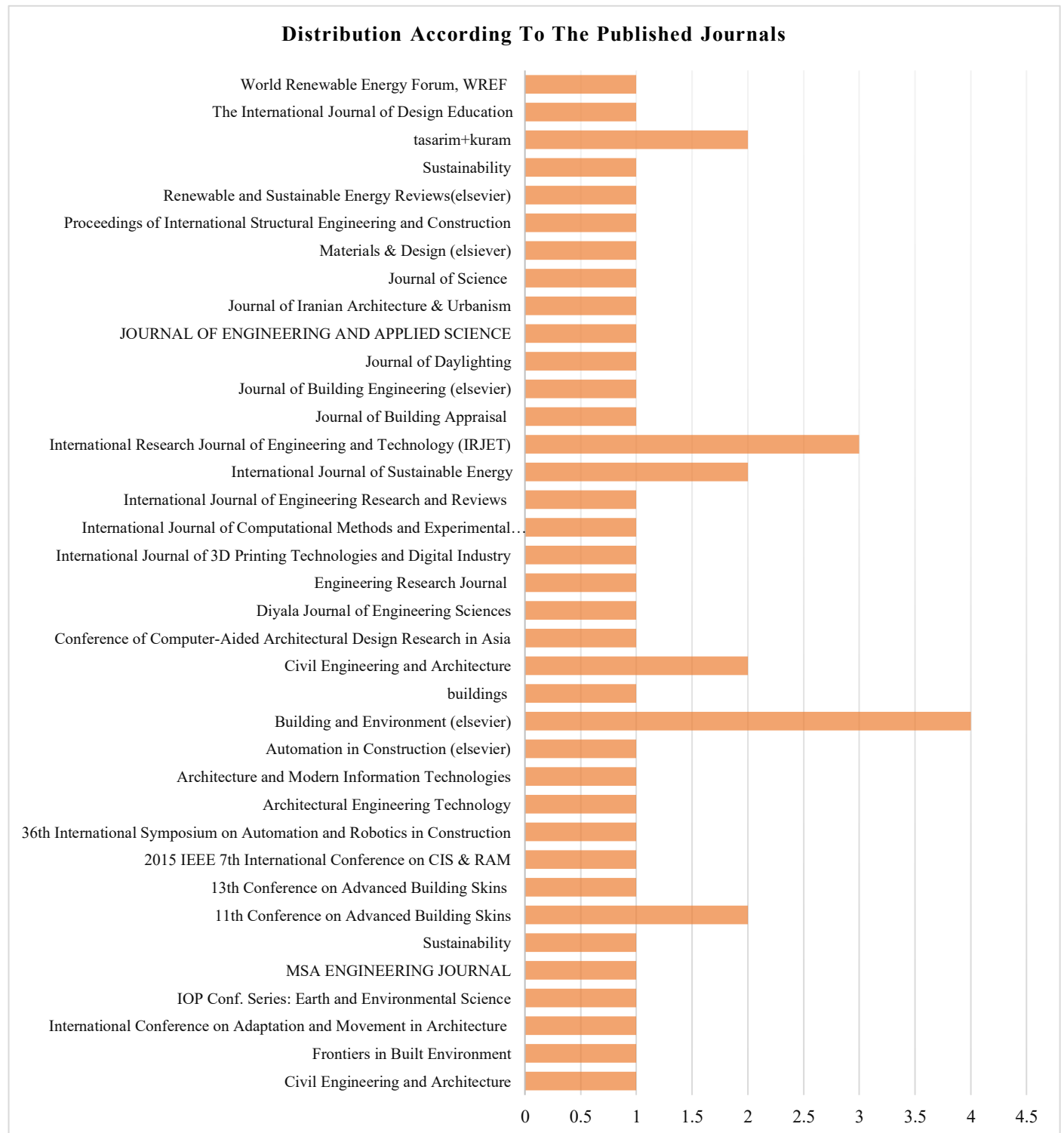


Figure 2. Study screening and selection according to the Preferred Reporting for Systematic Review Protocol (PRISMA) guidelines.

3.2. Overview of the results

This section presents a summary of the reviewed studies. It includes details about the author(s), their countries of origin, the types of buildings studied, research methods, simulation tools, biological

connections, and how kinetic architecture has impacted energy efficiency and thermal comfort. Table 1 summarizes the current research landscape and presents these findings.

Table 1. Application of kinetic façades and their impact on thermal performance: a systematic literature review.

Categorizing Articles Based on Building Typology	Author	Country	Impact of Kinetic Architecture	Research Method	Biological Analogies
Office	Hosseini, et al. [18]	Iran	Daylight performance Visual comfort Electric lighting Energy consumption.	Simulation (Rhinoseros-Ladybug and Honeybee) and parametric simulation (Brute Force algorithm)	Plant's leaves stomata Morpho butterfly wings
	Sankaewthong, et al. [2]	Thailand	Daylight factor (DF) LEED	Simulation Rhino Grasshopper Plugin Climate Studio and Wallace	Physical DNA, phototropism behaviour, and Eshelby twist movement
	Fikery, et al. [16]	Egypt	Visual Comfort Energy consumption	Simulation Diva Rhino Grasshopper Climate Studio	Not specified
	Ben Bacha and Bourbia [3]	Algeria	Energy performance Indoor thermal comfort	Simulation Rhino GECO-Grasshopper	Not specified
	Sangtarash, et al. [19]	Iran	Control of light entering Quality of daylight Visual quality	Simulation Rhino Grasshopper and Honeybee Plus with Ladybug	Capra Wall rotating mechanism
	Ahmady, et al. [20]	Egypt	Energy consumption Interior thermal comfort Temperature Moisture	Simulation Rhino and Design Builder	Monkey Puzzle Tree Leaf
	Wanas, et al. [21]	Egypt	Daylight performance	Simulation Rhino Grasshopper and Diva	Origami Kaleidocycle
	Hosseini, et al. [5]	Iran	Real-time daylight control Visual Comfort Daylight conditions are used to determine occupant positions in real-time.	Simulation Rhino Grasshopper and Diva	Not specified
	Hosseini, et al. [22]	Iran	Daylight performance based on occupants' position Daylight glare aesthetics and privacy	Simulation Rhino Grasshopper and Diva	Orosi
	Jahanara and Fioravanti [23]	Italy	Light to manage strategies Daylight performance	Simulation Rhino Grasshopper and Diva	Lotus plant's
	Brzezicki [24]	Poland Iran Thailand	Daylight comfort Minimizing solar heat gain Visual Comfort Illuminance levels	Simulation Rhino Grasshopper Ladybug and Honeybee, and experimental analysis (mock-up)	Not specified

Various types of buildings	Khraisat, et al. [25]	Not country-specific	Maintaining natural light levels Reducing heat gain Providing an attractive design Conserving energy Diminishing daylight illuminance Reducing sun glare and radiation Lowering internal temperature Improving brightness Filtering beneficial daylight Preventing visual discomfort Providing high daylight performance Maintaining the equilibrium between daylight View out Energy balancing User satisfaction Permitting natural ventilation	Systematic literature review	Not specified
	Hosseini, et al. [5]	Not country-specific	Visual Comfort Thermal comfort Energy efficiency comfort condition	Qualitative review (Morphological Analysis Biomimicry Parametric Design Microclimate Modifier	Plant movements and animal skin patterns
	Gonçalves, et al. [26]	Not specified	Thermal comfort, Energy efficiency Daylight performance	Systematic Literature Analysis	Not specified
Commercial buildings	Jayakumari, et al. [27]	Australia	Reducing energy consumption Ensuring thermal and visual comfort Reducing lifecycle costs Occupant productivity and comfort Reduces heat gain during summer and allows passive heating during winter.	Simulation Rhino Grasshopper	Not specified
Public building	Alawaysheh, et al. [28]	Dubai	Energy savings in terms of electricity, cooling loads and cost savings Daylight illuminance levels Aesthetic values. Energy performance-based design, daylight control-based design Thermal control-based design and	Simulation Rhino Grasshopper Integrated Environmental Solutions (IES)	Star configuration movement mechanism.

As shown in Table 1, the articles are categorized into four sections based on the type of building. Kinetic architecture is an innovative approach to enhancing thermal comfort, energy efficiency, and lighting in office buildings in hot, dry climates. These areas, characterized by extreme solar radiation, significant temperature fluctuations, and intense daylight, necessitate responsive and adaptive architectural solutions

that mitigate these environmental challenges. The harsh conditions are examined in the reviewed studies to demonstrate how kinetic systems, such as dynamic façades and shading devices, operate. Buildings in hot, dry climates are among the biggest beneficiaries of kinetic architecture, as they reduce solar heat gain, lower cooling energy demands, and enhance indoor thermal comfort. Ben Bacha and Bourbia [3] have shown a 43% reduction in cooling loads by applying 40 semi-transparent photovoltaic modules. To that end, Ahmady, et al. [20] have demonstrated how adaptive façades can regulate office building internal temperatures and reduce energy consumption [29]. These results support the reduction of environmental requirements in hot-dry regions, where cooling is the dominant load.

Another significant benefit of kinetic systems in hot-dry climates is daylighting optimization. This is due to office spaces frequently experiencing brightness and visual distress due to intense sunlight. Jayakumari, et al. [27] have demonstrated that the use of kinetic façades can enhance the productivity and comfort of occupants [25]. Further, Sangtarash, et al. [19] and Wanas, et al. [21] have said that adaptive shading devices, such as triangular geometric patterns and radiance materials, can control the amount of light that comes in and make it more comfortable to work [17, 18]. Additionally, Hosseini, et al. [18] have stressed the benefits of using see-through materials in kinetic louvers because they allow more natural light to enter and reduce the need for artificial lighting, which helps save energy and improves the health of a building's occupants [16].

3.2.1. Overview of Kinetic Façade Systems and Their Functional Components

Table 2 below provides an overview of the most critical studies on kinetic façade systems, focusing on their types, materials, operational mechanisms, and control systems. This summary lays the groundwork for understanding how kinetic architecture can enhance the energy efficiency and thermal comfort of office buildings.

Table 2 shows that systems operate through panels driven by advanced rotational, translational, and folding motions. These panels are powered by actuators and motorized mechanisms that actuate precise panel angles and openings. Biomimetic strategies are employed in various designs, including stomata-inspired movements that enhance adaptability to fluctuating climatic conditions. Some researchers have used biological examples to inform their design of kinetic systems. For instance, stomata-inspired mechanisms [16] and star configuration movements [5] can make the systems more resilient in harsh weather conditions. Employing biological analogies can generate strategies for designing façades that actively adapt to changing environmental conditions, resulting in enhanced thermal comfort and improved energy efficiency.

Management systems and sensors are also essential parts of kinetic façades. Light and thermal sensors with parametric control algorithms can dynamically configure the façade configurations based on real-time

environmental conditions. Tools such as Grasshopper, Honeybee, Diva, and Rhino further enhance the design of these façade configurations by simulating multiple scenarios and improving climatic responsiveness. These innovative systems enable kinetic façades to conform to environmental stimuli and occupant needs for thermal comfort and visual satisfaction.

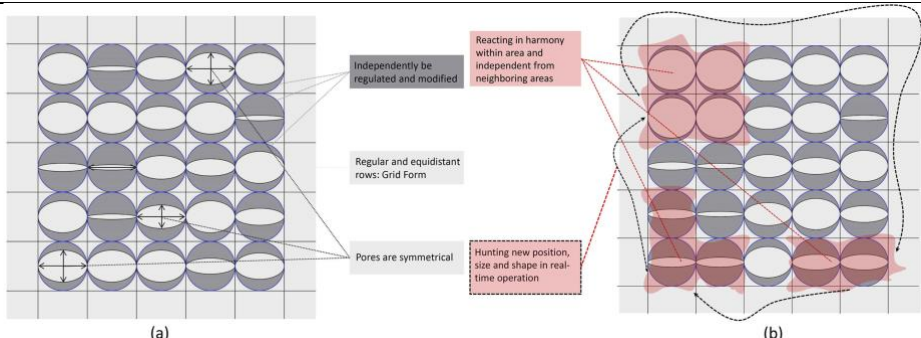
Table 2. Key features of kinetic façade systems in office buildings.

Citation	Material of the kinetic system	Type of kinetic façade	System and Regulation
Hosseini, et al. [18]	Translucent material	Interactive Kinetic Louvers: louvers that adjust dynamically	<i>Smart system:</i> -Parametric and generative design algorithms - Light sensors to detect daylight levels. - Occupancy sensors are used to detect user presence and preferences. -Temperature sensors to manage thermal comfort.
Sankaewthong, et al. [2]	Fabric	Twisting Kinetic Façade: Inspired by biomimicry principles, this kinetic façade integrates DNA structure, phototropism, and Eshelby twist behaviour	<i>Intelligent System: Environmental Sensors</i> -Light sensors to detect daylight levels. -Systems to measure sunlight intensity for responsive adjustments.
Fikery, et al. [16]	Reflective materials, light shelf	Adaptive Kinetic Shade with Light Shelf: Integrates horizontal, vertical, and combined panel movements	<i>Smart system:</i> -Light sensors to monitor daylight levels and adjust panel movements for optimal light control.
Ben Bacha and Bourbia [3]	Semi-transparent PV modules	Hexagonal-Patterned Kinetic Façade	<i>Smart system:</i> -Light sensors to monitor daylight levels and manage solar radiation. -Thermal sensors to adjust panel positions for optimal thermal comfort.
Sangtarash, et al. [19]	Triangular geometric patterns (not mentioning material)	Triangular Geometric Kinetic Façade	<i>Smart system:</i> -Light sensors to monitor and adjust daylight penetration. -Sensors to track solar angles for precise adjustment of façade positions.
Ahmady, et al. [20]		Parametric Kinetic Façade: spiral pattern of parametric units	<i>Smart system:</i> -Light and thermal sensors monitor sunlight and temperature levels to adapt the façade's position for optimal performance.
Wanas, et al. [21]	Radiance materials	Kinetic Louvers System	-Intelligent system: Light sensors monitor illuminance levels to adjust louver configurations in real-time.
Hosseini, et al. [17]	Not specified	Adaptive daylight façades and dynamic shading devices	<i>Smart system:</i> -Light sensors to manage daylight levels. -Temperature sensors for thermal comfort. -Wind sensors to optimize ventilation and structural stability.
Hosseini, et al. [5]	Transparent PV material	Interactive Kinetic Façade	<i>Intelligent system:</i> -Sun position tracking sensors. -Occupancy sensors to detect user locations and adjust configurations accordingly.

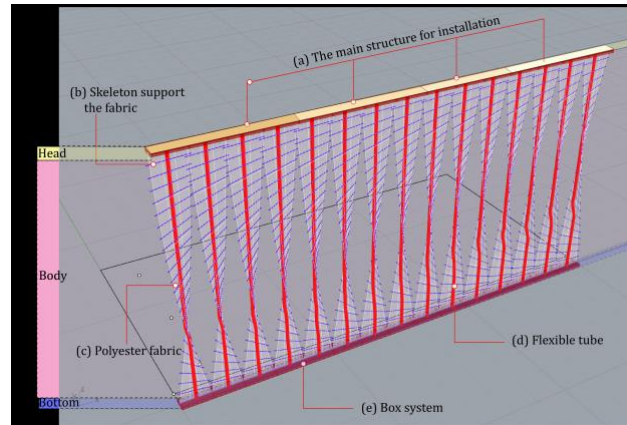
Hosseini, et al. [22]	Colored glass	Integrated Interactive Kinetic Façade with Colored Glass	<i>Smart system:</i> -Light sensors to monitor daylight intensity and glare. -Occupant position sensors to adjust the façade elements dynamically.
Khraisat, et al. [25]	Not specified	Dynamic Kinetic Façade: Rotational and translational kinetic systems	<i>Smart system:</i> -Light sensors to monitor daylight levels. -Thermal sensors to manage heat gain and ensure interior comfort.
Jahanara and Fioravanti [23]	Not specified	Hexagonal Biomimetic Kinetic Façade	<i>Smart system:</i> -Light sensors monitor daylight levels to trigger adjustments.
Brzezicki [24]	Not specified	Bi-sectional Kinetic Shading System (KSS)	<i>Smart system:</i> -Algorithm-Driven Control -Internal illuminance sensors measure light levels to trigger adjustments.
Jayakumari, et al. [27]	Photovoltaic	Dynamic Kinetic BIPV Façade	<i>Smart system:</i> -Solar irradiance sensors monitor sunlight levels. -Environmental sensors track seasonal variations in solar angles.
Alawaysheh, et al. [28]	Not specified	Geometric Kinetic Façade: rotating panels with geometric transformations	<i>Smart system:</i> -Sun-tracking sensors to monitor solar angles. -Light sensors to measure indoor and outdoor illuminance levels.
Gonçalves, et al. [26]	Not specified	Parametric Kinetic Façade with Adaptive Modules: This façade uses parametric modules inspired by biomimicry and morphological design principles	<i>Smart system:</i> -Light and thermal sensors monitor environmental conditions to trigger adjustments.

However, while not all studies mentioned material selection, this is one of the critical factors in the success of kinetic systems in such climates. Polished metals [13] and STPV modules [3] are examples of reflective materials with acknowledged outstanding performance in cutting down solar heat gain and improving daylight distribution. Moreover, culturally integrated materials, such as colored glass inspired by traditional Orosi windows [20], offer both aesthetic and functional benefits and are suitable for hot, dry climates where cultural aspects often play a crucial role in architectural design, as shown in Table 1.

Table 3. Summary of operational mechanisms of kinetic façade systems in office buildings.

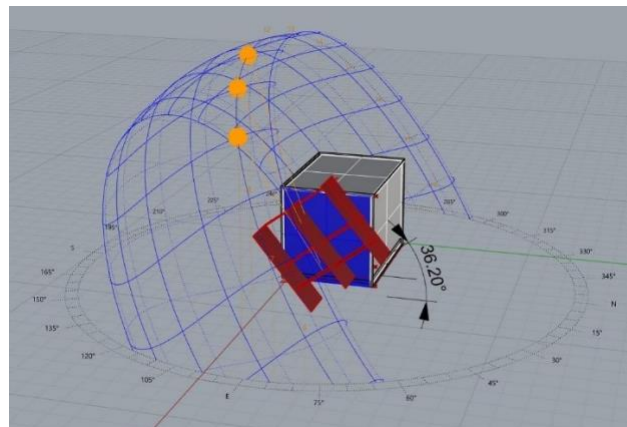
Citation	Sketch	Mechanism for Operation
Hosseini, et al. [18]	 (a) (b)	Translational, rotational, and resizing mechanisms

Sankaewthong,
et al. [2]



Twisting
Mechanism and
Controlled
Flexibility

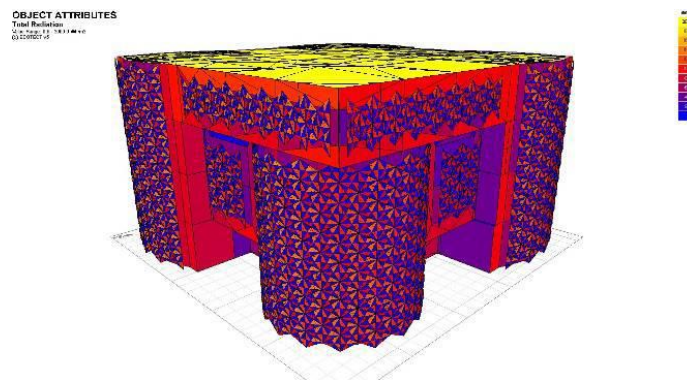
Fikery, et al.
[16]



Panel Rotation
and Tilt and
Light Shelf
Integration:

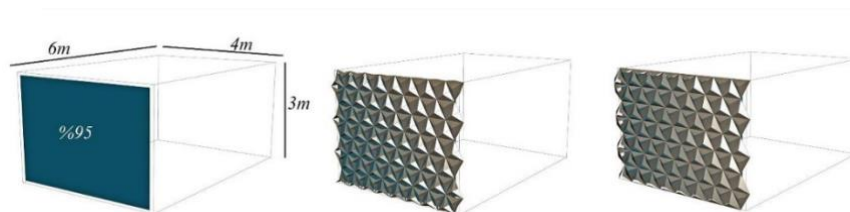
Panels operate
with rotation
angles ranging
from 0° to 35°

Ben Bacha and
Bourbia [3]

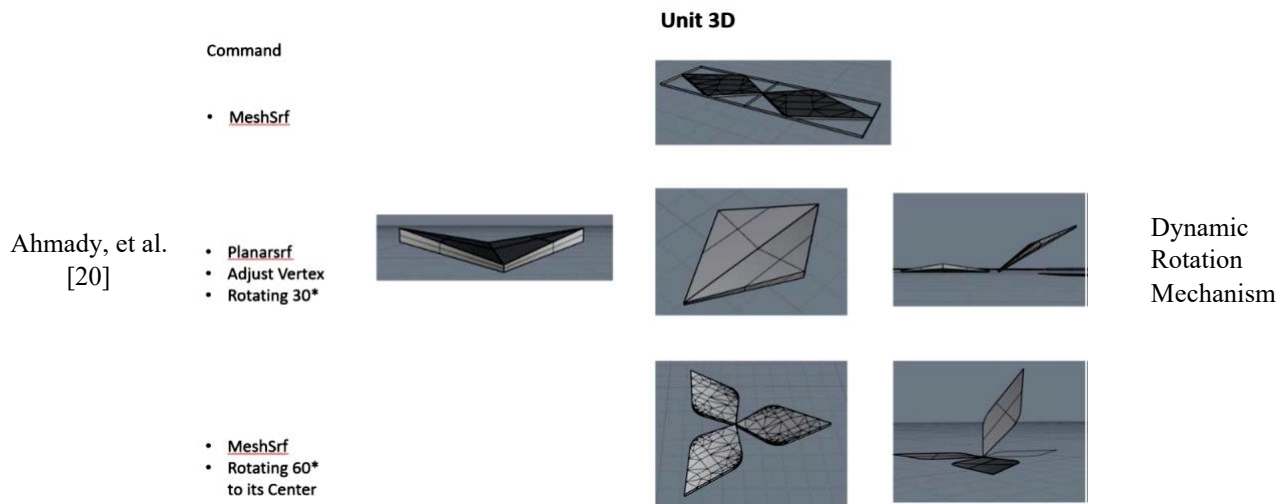


Dynamic
Opening
Variation

Sangtarash, et
al. [19]



Dynamic
Movement:
Folding and
rotational
mechanism



Wanas, et al.
[21]

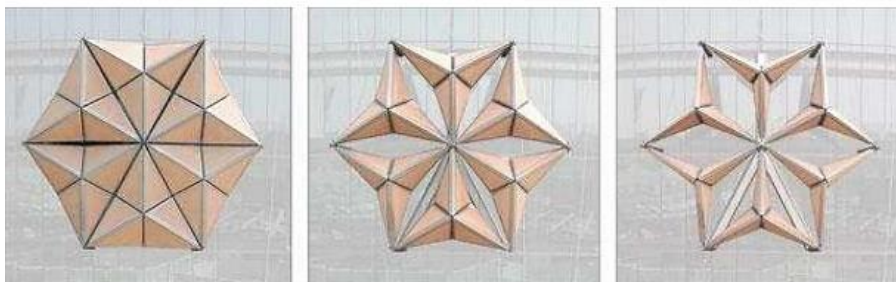
Time		8 : 00	12 : 00	16 : 00	DL % Per Day
Date					
Best Cases	21st June	DL= 52% UN= 4.89 UL= 48% OL= 0% L1= 2.33 m. L2= 1.33 m. L3= 1.25 m. A= - 45°	DL= 91 % UN= 3.20 UL= 1 % OL= 8 % L1= 2.67 m. L2= 2.30 m. L3= 2.25 m. A= - 45°	DL= 47 % UN= 5.14 UL= 53 % OL= 0 % L1= 2.33 m. L2= 1.67 m. L3= 1.17 m. A= - 45°	63 %
	21st December	DL= 58 % UN= 4.46 UL= 36 % OL= 5 % L1= 2.33 m. L2= 2.05 m. L3= 2.00 m. A= - 15°	DL= 88 % UN= 2.70 UL= 0 % OL= 12 % L1= 3.00 m. L2= 2.00 m. L3= 1.75 m. A= - 5°	DL= 45 % UN= 4.36 UL= 52 % OL= 3 % L1= 2.33 m. L2= 1.38 m. L3= 1.33 m. A= - 15°	63 %
	21st March	DL= 48 % UN= 4.95 UL= 49 % OL= 3 % L1= 2.33 m. L2= 1.38 m. L3= 1.33 m. A= - 25°	DL= 90 % UN= 3.30 UL= 1 % OL= 9 % L1= 2.67 m. L2= 2.30 m. L3= 2.25 m. A= - 35°	DL= 48 % UN= 5.19 UL= 49% OL= 3 % L1= 2.00 m. L2= 2.05 m. L3= 2.10 m. A= - 35°	62 %
DL % Per Hrs. through 3 days		52 %	90 %	47 %	63 %
Worst Cases	21st June	DL= 26 % UN= 3.17 UL= 74 % OL= 0 % L1= 2.33 m. L2= 2.00 m. L3= 1.25 m. A= - 5°	DL= 56 % UN= 3.90 UL= 36 % OL= 8 % L1= 2.33 m. L2= 2.00 m. L3= 1.25 m. A= - 5°	DL= 26 % UN= 3.17 UL= 74 % OL= 0 % L1= 2.00 m. L2= 1.50 m. L3= 1.13 m. A= 15°	36 %
	21st December	DL= 23 % UN= 3.95 UL= 74 % OL= 3 % L1= 3.00 m. L2= 2.50 m. L3= 2.13 m. A= 25°	DL= 52 % UN= 2.85 UL= 44 % OL= 4 % L1= 3.00 m. L2= 2.50 m. L3= 2.13 m. A= 35°	DL= 14 % UN= 4.09 UL= 83 % OL= 3 % L1= 3.00 m. L2= 2.50 m. L3= 2.13 m. A= 35°	30 %
	21st March	DL= 34 % UN= 4.67 UL= 64 % OL= 3 % L1= 2.67 m. L2= 1.83 m. L3= 1.21 m. A= 35°	DL= 53 % UN= 4.21 UL= 42 % OL= 5 % L1= 3.00 m. L2= 2.50 m. L3= 1.75 m. A= 35°	DL= 34 % UN= 4.63 UL= 64 % OL= 3 % L1= 3.00 m. L2= 2.00 m. L3= 1.25 m. A= 35°	40 %
DL % Per Hrs. through 3 days		28 %	54 %	25 %	35 %

The abbreviations in the table are:
DL = Day-Lit , UL= Under-Lit , OL= Over-lit , UN= Uniformity , A= Angle,
L1, L2, L3 = Louver 1, Louver 2 and Louver 3 distances from room's floor



Movement Mechanics:
Rotational Movement and Vertical Transition

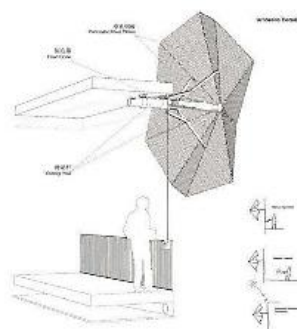
AL BAHAR FAÇADE DETAIL



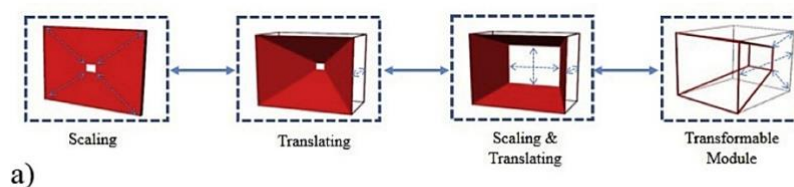
Hosseini, et al.
[17]



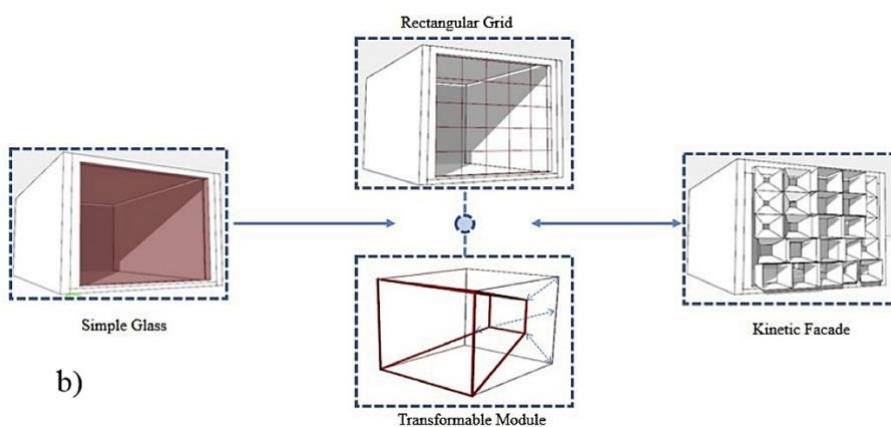
AL BAHAR, ABU DHABI



rotational,
sliding, and
folding
movements,



a)

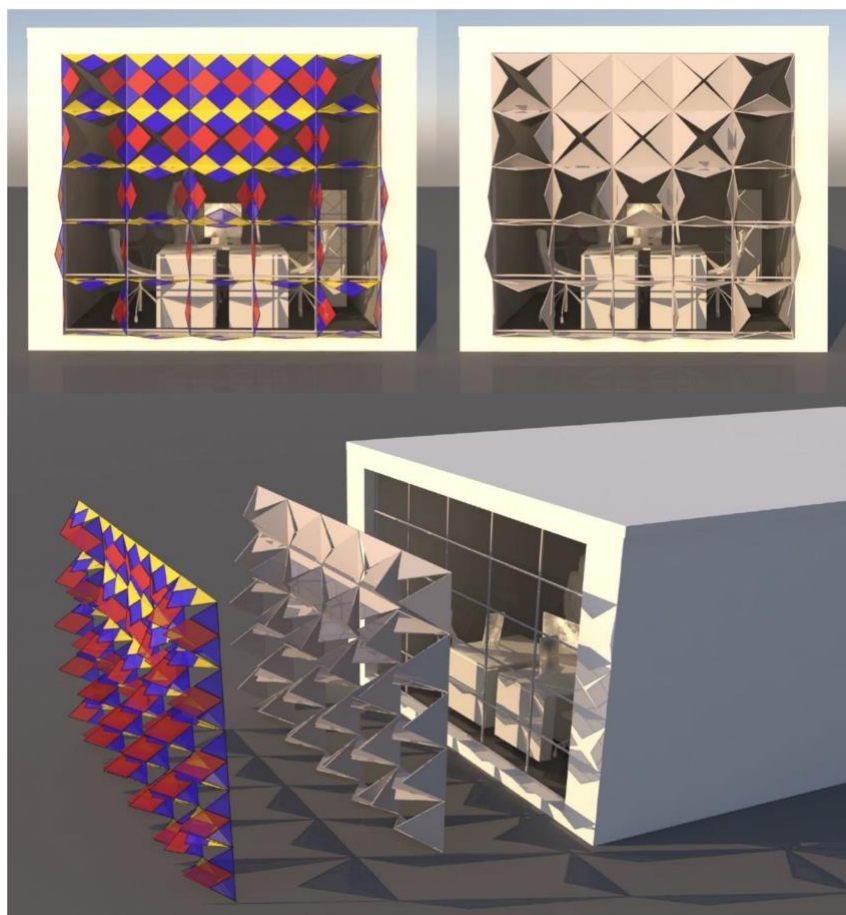


b)

Hosseini, et al.
[5]

Movement
Patterns: modular
rectangular
elements capable
of (2D) and (3D)
transformations.

Hosseini, et al.
[22]



Dynamic
Modular
Movements:

The façade
elements pivot
and rotate in two
configurations:

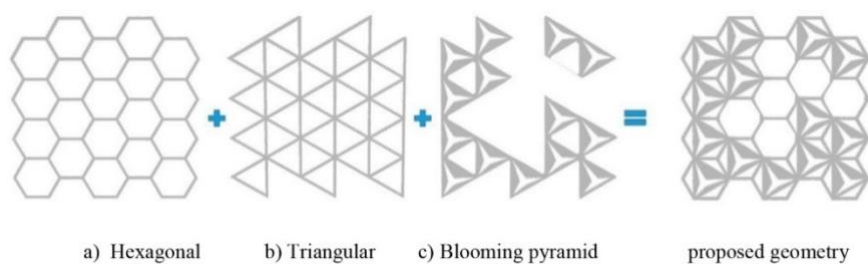
-Rotation angles
between $0-45^\circ$
for fine-tuned
daylight
adjustments.

-Broader
rotations up to
 90° for
maximizing
sunlight control.

Khraisat, et al. No sketch
[25]

Movement
Mechanisms:
Panels rotate and
slide based on real-
time solar angles
and occupant needs

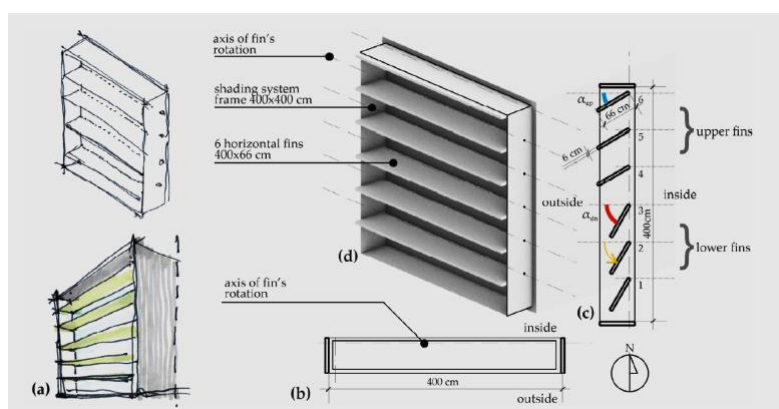
Jahanara and
Fioravanti [23]



Dynamic Folding
and Blooming:

The panels fold
and extend based
on solar angles
and daylight
requirements

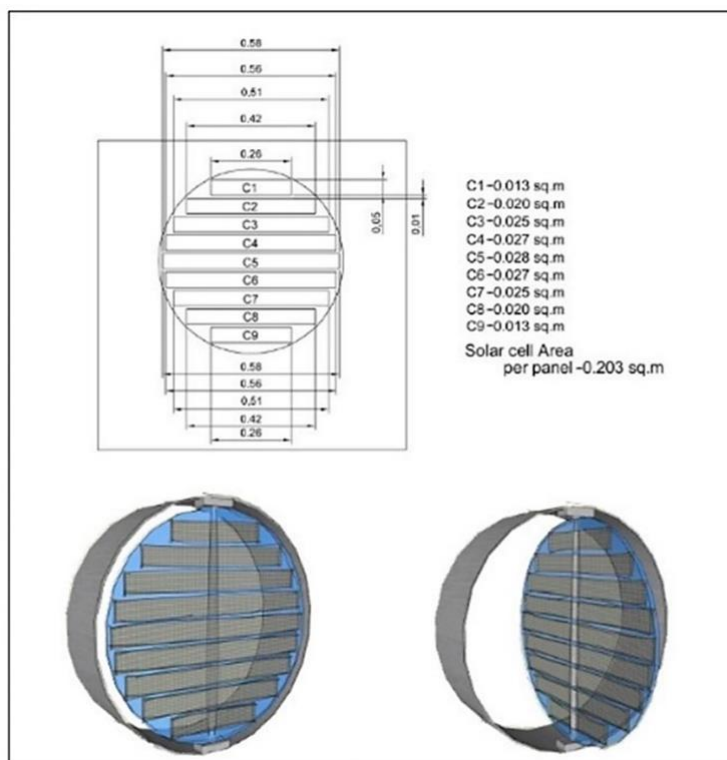
Brzezicki [24]



Dynamic
Rotational
Adjustment:

Fins rotate
around an
eccentric axis
located along
their edges

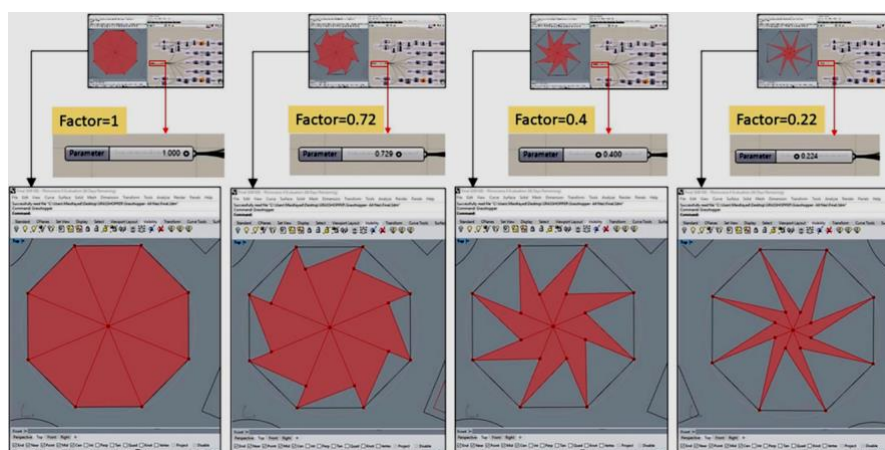
Jayakumari, et
al. [27]



Movement
Mechanism:

The kinetic façade employs vertical tilting and rotational movements to track solar altitude and adjust PV panel angles between 0% (fully open) and 100% (fully closed)

Alawaysheh,
et al. [28]



Rotational and
Scaling
Mechanism:

Panels rotate around a central axis and adjust their openings through scaling transformations

Gonçalves, et
al. [26] No sketch

Movement
Dynamics:

Individual modules perform singular movements such as rotation and folding

As shown in Table 3, the operational mechanisms of kinetic façade systems exhibit a diverse range of dynamic behaviours, including folding, sliding, rotating, and tilting, which enable them to adapt effectively to environmental stimuli. These mechanisms are designed not only for visual and thermal regulation but also to enhance energy efficiency and user comfort in real-time. Systems that incorporate translational, rotational, and resizing movements enhance flexibility, while parametric and bio-inspired

strategies, such as twisting, blooming, or modular transformations, improve climate responsiveness. Several studies have utilized actuators to achieve fine-tuned motion control, enabling precise adjustments of angle, shading, and opening based on solar angles or indoor light requirements. The integration of solar-tracking and user-responsive features also supports optimized daylight harvesting and reduced heat gain. Importantly, the modular and often biomimetic nature of these mechanisms makes them adaptable to diverse architectural forms and functional needs, especially in hot, dry climates where environmental extremes demand highly responsive envelope systems.

4. Discussion

4.1. Typologies and Functional Characteristics of Kinetic Facades

The review reveals a diverse range of kinetic façade types used in office buildings to enhance thermal performance and interior comfort. These include interactive kinetic louver systems that utilize rotation, translation, and resizing mechanisms to dynamically adjust according to solar conditions [16, 19]. Twisting kinetic façades, as demonstrated by Sankaewthong, et al. [2], reflect biomimetic principles and can adapt flexibly to changing solar angles throughout the day. Adaptive light shelves and hybrid systems, which incorporate both horizontal and vertical movement components, further enhance daylight control and reduce overheating [13, 14, 24].

More complex configurations, such as triangular folding panels [17] and parametric kinetic designs [24, 29], integrate computational design to optimize responsiveness and aesthetic integration. Many of these systems are inspired by natural organisms (e.g., butterfly wings or leaves), offering both functional and symbolic environmental adaptability.

Despite the variety of typologies, most studies focus on conceptual proposals or simulation-based validations. Comparative field data assessing long-term comfort performance across façade types is still lacking.

4.2. Performance in Hot-Dry Climates

Kinetic façades are particularly effective in hot-dry climates, where extreme solar radiation, sharp temperature fluctuations, and prolonged daylight exposure present significant environmental challenges. These systems mitigate overheating by dynamically regulating solar heat gain, allowing buildings to respond to solar angles throughout the day. For instance, twisting kinetic façades and triangular folding systems are designed to optimize daylight penetration while minimizing thermal discomfort [2, 19].

Studies show that kinetic façades also support thermal stability, helping maintain indoor temperatures without over-reliance on mechanical cooling systems [3, 28]. For example, semi-transparent photovoltaic-integrated kinetic modules have been shown to reduce cooling loads by up to 43% while maintaining visual

comfort and natural lighting [27]. Additionally, dynamic shading systems reduce glare and visual fatigue in office environments [21, 28].

Despite these promising outcomes, most studies remain simulation-based. Very few assess performance through post-occupancy or long-term field studies, particularly in regions such as Iraq, Egypt, or the Gulf States, where the hot, dry climate context is highly relevant [3, 21, 28].

4.3. Energy Efficiency and Reduction of Cooling Loads

A major benefit of kinetic façades lies in their ability to enhance energy efficiency through adaptive shading, daylight modulation, and responsive thermal control. By automatically adjusting to sunlight intensity and internal heat loads, these systems reduce the need for artificial lighting and air conditioning [5, 6, 20].

Smart control technologies, such as light and temperature sensors, actuators, and solar tracking algorithms, are widely integrated into kinetic façades to achieve real-time responsiveness [18, 26, 29]. Several studies highlight the integration of parametric tools and generative design software that enable predictive performance optimization, allowing the system to minimize cooling and lighting loads effectively [18, 20, 24].

For instance, Ahmady, et al. [20] and Gonçalves, et al. [26] demonstrated that parametric kinetic systems can significantly improve thermal comfort and reduce energy demand in office buildings located in hot-dry environments. Similarly, Biyik, et al. [6] emphasize the dual advantage of using building-integrated photovoltaics (BIPV) in kinetic façades for both shading and energy generation. Nevertheless, the current literature rarely includes comprehensive cost-benefit analyses or maintenance evaluations. Questions related to system affordability, reliability, and usability remain insufficiently explored, posing potential challenges for widespread adoption in real-world settings [3, 26, 27].

5. Conclusion

This study conducted a systematic literature review (SLR) to investigate the role and impact of kinetic façades in office buildings in hot-dry climates. Comprehensive searches were conducted in Google Scholar, Semantic Scholar, and Scopus, yielding a focused set of studies from 2015 to 2024.

The reviewed literature revealed several key trends. Most research was concentrated on office buildings in hot, dry regions, with a strong focus on improving indoor environmental quality through adaptive envelope systems. Simulation-based methodologies and performance-driven design were commonly used, with an emphasis on thermal comfort, energy efficiency, and daylight management. There was also an increased reliance on responsive technologies, including sensors and parametric design tools.

Based on these findings, the use of kinetic façades emerged as a critical strategy for enhancing indoor thermal conditions, daylight performance, visual comfort, and overall energy efficiency. These systems not

only contribute to a building's aesthetics and privacy but also dynamically manage solar radiation and ventilation based on climate conditions. For example, during hot summers, responsive systems can reduce cooling loads by blocking excessive solar gain. At the same time, in colder months, the same façades can be programmed to allow passive heating through solar radiation, thereby reducing mechanical energy demands throughout the year.

Furthermore, kinetic façades enhance occupant well-being, especially in work environments where glare reduction and visual comfort directly impact employee productivity and satisfaction. The reviewed systems encompass a range of dynamic components, including rotational louvers, folding panels, and parametric shading devices. These are typically controlled by actuators and smart sensors (e.g., thermal sensors, light detectors, and solar angle trackers) that allow real-time adaptation to environmental changes.

In conclusion, kinetic façades offer a highly adaptable and climate-responsive solution for office buildings in hot, dry environments. Their capacity to respond intelligently to varying thermal and daylight conditions makes them essential in shaping energy-conscious and occupant-friendly architectural futures.

6. Future Research

Although there has been extensive progress, the field of kinetic architecture requires further exploration to address many of its remaining gaps. Existing studies are primarily based on simulations and have received limited experimental verification in real-world scenarios; therefore, testing the practicality and durability of kinetic façades using large-scale experiments is essential. Furthermore, occupant behaviour and preferences in the performance and acceptance of these systems remain underexplored. Future research is encouraged to adopt a user-centered approach to gain a deeper understanding of how occupants perceive and interact with kinetic façades. Furthermore, developing economic, sustainable materials is necessary to support the scalability and accessibility of kinetic systems. These innovations must strike a balance between cost, performance, and environmental impact to promote broader adoption. In certain regions, such as hot, dry climates and Arabic nations, the application of kinetic façades is still in its infancy, and research should be expanded beyond office buildings to other building typologies, including hospitals, residential buildings, and public spaces.

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