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Opportunities and Challenges of Implementing Kinetic Façade Typology in Indonesia

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Abstract

The application of kinetic facade technology is gaining popularity worldwide as an innovative solution to enhance the environmental quality of buildings. However, in Indonesia, the implementation of kinetic facades remains limited and requires further in-depth study. Thus, our research aims to fill this gap by exploring the opportunities and challenges of implementing kinetic facade typologies in Indonesia. The research method involves a literature review and descriptive analysis. We collect data on the use of kinetic facades globally, analyze the factors influencing their implementation, and identify the opportunities and challenges encountered. The analysis results are expected to provide a better understanding of the implementation of kinetic facades in Indonesia. The identified opportunities include the potential to improve energy efficiency, reduce carbon emissions, and enhance the interior and exterior environmental quality of buildings. The challenges identified may encompass technical aspects, regulations, financial issues, as well as market awareness and acceptance of this new technology. Our study contributes a foundation for further development of kinetic facades in Indonesia. With a better understanding of the opportunities and challenges, architecture practitioners, engineers, and policymakers can take appropriate steps to address the challenges and capitalize on the opportunities to integrate kinetic facades into building designs in Indonesia, promoting sustainable and innovative development in the architecture sector.

Keywords:
kinetic facade, wind energy, green buildings, energy conservation, stakeholder survey

1. Introduction

Building facade design has been at the center of creating aesthetic and visual impressions in recent decades. A key task of building facade design is to protect the building from external factors while meeting user needs and reducing energy consumption (Schittich et al., 2006). The facade also plays a role in establishing the building's identity and can influence the interior environment. Building facades also have an important role in sustainability and energy saving (Concina et al., 2011). A new facade design trend gaining popularity in various countries is the application of kinetic facades (Dharmatanna et al., 2024). Traditional building facade design has been static despite changing climatic conditions, leading to the development of kinetic facades as an alternative (Kraisat et al., 2023). The purpose of kinetic facades is to reduce environmental impact by lowering heating, ventilation, and air conditioning (HVAC) loads and building lighting needs. The use of kinetic facades can significantly reduce energy requirements in buildings (Kensek & Hansanuwat, 2021). Additionally, these systems are believed to increase comfort for building occupants and have the potential to generate electricity.

Buildings are influenced by natural factors such as weather, climate conditions, wind speed, time, and human needs. All these elements and functions are not static but dynamic, requiring adaptation to the environment, which has led to the creation of kinetic facades (Ibrahim & Alibaba, 2019). A kinetic facade refers to a system that uses moving elements, such as panels, fins, or flippers, which react to wind and change the appearance or structure of the building. This system not only provides an attractive visual effect but can also improve the building's energy efficiency and thermal comfort. Unlike static or fixed facades, a kinetic facade moves dynamically, allowing movement on the surface of the building. An adaptive kinetic structure has the advantage of being able to adapt to changing conditions such as weather, time, and location. Moloney (2011) explored that the term "kinetic" in this context refers to a system's ability to respond to changes in geometry, either wholly or partially, without compromising its integrity. As for the changes in the movement of kinetic facades, they generally involve translation, rotation, scaling, and material deformation, as in Figure 1.

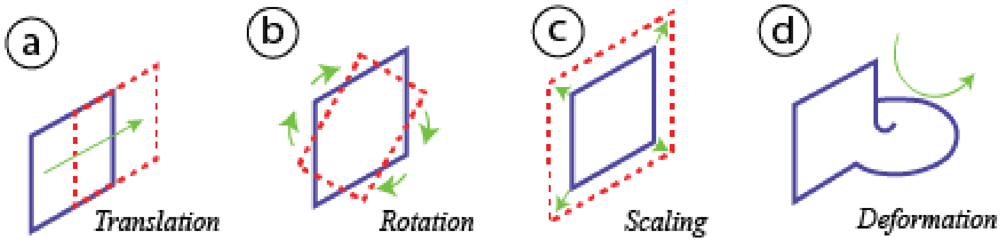


Figure 1. Types of movement: a) translation, b) rotation, c) scaling and, d) deformation.

The concept of kinetic facades has been identified by nature, technology, and architecture to create multifunctional elements that solve design problems with multidisciplinary strategies (Zul & Clark, 1970). It involves the application of geometric changes to create movement or positional changes in space. These changes alter the physical appearance and material characteristics of the facade without affecting the structural integrity of the building. The implementation of kinetics affects the efficiency of kinetic movement. The easier the kinetic motor system, the more optimal and efficient the kinetic system will be (Majed, 2013). The main concept of kinetic facades can be categorized kinetic control systems into six categories based on their level of complexity (Fox, 2000):

a. Direct Control: Controlled directly from outside the system by an energy source.
b. Indirect Control: Device movement depends on sensor feedback.
c. Internal Control: The device does not have direct control or mechanical mechanisms like mechanical hinges.
d. Responsive Indirect Control: Device movement depends on feedback from sensors.
e. Responsive Indirect Control Everywhere: The device has strong predictive capabilities using a predictive algorithm-based control system.
f. Heuristic Responsive Indirect Control: Device movement depends on a network of algorithms written with learning capabilities.

Many countries around the world have implemented wind-powered kinetic facades in their buildings. These facades have been adopted as integral parts of building designs, particularly in developed nations where they have become architectural icons. These buildings combine aesthetic beauty with energy sustainability. The successful implementation of kinetic facades not only enhances the aesthetics and sustainability of the buildings but also improves energy efficiency and bolsters the building's image and the city's identity. However, in Indonesia, the use of wind-powered kinetic facades is still limited and has not been extensively explored. Indonesia's rich geographical characteristics, featuring various types of winds both on the coast and inland, present a significant opportunity. With the fourth longest coastline in the world, measuring 99,093 km (BIG, 2015), Indonesia has a high wind energy potential, as shown in Table 1. This abundance of wind potential represents a substantial opportunity to utilize it in sustainable architecture projects.

Table 1. Wind speed and power density at various locations (Hesty et al., 2021a; Hesty et al., 2021b; Kementerian Energi dan Sumber Daya Mineral [KESDM], 2016).

Potential Group	Wind Speed at 50m (m/s)	Province
Lower	< 3m/s	North Sumatra,Papua, Mentawai,Jambi, East Nusa Tenggara, West Nusa Tenggara, Bengkulu, Southeast Sulawesi, North Sulawesi, and Maluku,
Low	3m/s - 4m/s	East Nusa Tenggara, Central Java, Yogyakarta Special Region, Lampung, South Sulawesi, North Sulawesi, Central Sulawesi, South Kalimantan, and North Sumatra
Medium	4.1m/s - 5.0m/s	East Java, Central Java, Bali, Yogyakarta Special Region, Bengkulu, West Nusa Tenggara, East Nusa Tenggara, South Sulawesi, and Central Sulawesi
Good	> 5m/s	Banten, Special Capital Region of Jakarta, Central Java, Yogyakarta, East Nusa Tenggara, West Nusa Tenggara, Southeast Sulawesi, North Sulawesi, and South Sulawesi

Thus, our research seeks to address this gap by investigating the opportunities and challenges associated with implementing kinetic facades in Indonesia. Our study provides a basis for the further development and adoption of kinetic facade technologies in the country. The remainder of our article is organized as follows: Section 2 discusses our analytical method, while Section 3 presents the results and discusses the policy implications. Finally, Section 4 concludes the analysis.

2. Methods

The research methods employed in this paper include a literature review, descriptive analysis, and the collection of information through questionnaires regarding the application of kinetic facades, the factors influencing their implementation, and the opportunities and challenges involved. The goal of the literature review is to understand the concepts, theories, and knowledge related to kinetic facades, their application in various buildings, and the influencing factors. To achieve this, we searched and analyzed literature sources relevant to the research topic, such as scientific journals, books, previous research reports, and other sources of information.

The information gathered from the literature review was then analyzed descriptively. This analysis produced a collection of information in the form of tables, diagrams, or graphs that clearly illustrate the buildings that use different kinetic facades based on location and wind speed. These descriptive analyses involve simple statistical calculations such as frequencies, percentages, or means to provide additional insights into the observed characteristics of kinetic facades.

Information was also collected using a questionnaire method, where respondents were asked to fill out an online survey. The questionnaire included structured questions about their awareness of kinetic facades, their application, the factors influencing their implementation, and the opportunities and challenges associated with them. The questionnaire was designed to align with the research objectives and could be distributed online or directly to respondents working in the construction or technology industries.

Following the collection of survey information, the research will proceed with analyzing the data. This can be done using descriptive statistical methods such as frequencies, percentages, or other ways of describing the characteristics of the information obtained from the questionnaires. The analysis may also include qualitative methods, such as categorizing the research findings to identify emerging patterns or trends.

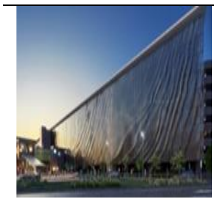
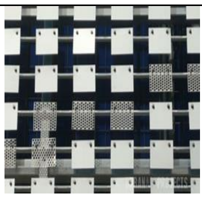
Conclusions will be drawn based on the evidence collected. From the results of the literature review, descriptive analysis, and questionnaire data analysis, we will draw conclusions about the application of kinetic facades in different buildings, the factors influencing their use, and the opportunities and challenges of implementing this technology.

3. Results and Discussions

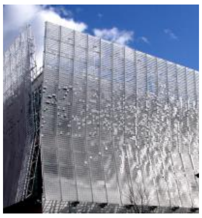
3.1 Precedent Study

Precedent studies are considered essential as they provide an overview of the implementation of kinetic facades in various countries. By examining these precedent studies, we can explore the possibilities of implementing kinetic facades in Indonesia. This section will highlight several examples of built architecture that have utilized kinetic design concepts, particularly those responsive to wind movement. Table 2 presents precedent applications of kinetic facades in various locations. The kinetic facades at these 20 locations feature different designs, materials, and movement systems, each with its own set of advantages and disadvantages. For instance, the kinetic facades at Brisbane Airport in Queensland, Australia, provide several benefits: they offer shade, control the light entering the building, serve as natural ventilation, and create a visual impression of a river. However, the aluminum panels used in these facades require anodizing and must be assembled at a separate location.

Table 2. Precedent studies in various locations.

Building Image	Kinetic Element	Building Information	Design Reason & Movement	Advantages & Disadvantages
		***Location/year:*** Brisbane Airport, Queensland, Australia ***Wind speed:*** 8 m/s ***Material:*** Aluminium Panels	Controls the sunlight coming in. Gives a visual impression of river waves.	**Advantages:** The façade is able to provide shadows and control the light entering, as natural ventilation and can provide a visual impression of a river. **Disadvantages:** Aluminum panels need to be anodized first and must be assembled in a separate place.
		***Location/year:*** Logan Airport Central Parking, Massachusetts, USA ***Wind speed:*** 8.2 m/s ***Material:*** Aluminium Panels	Controlled the sunlight coming in, giving a visual impression.	**Advantages:** The aluminum flapper panels on the façade can give a dynamic impression and give the impression of dancing in the wind. **Disadvantages:** The aluminum panels need to be anodized first and must be assembled in a separate place.

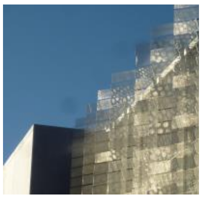
		***Location/year:*** Chandler City Hall, Arizona, USA ***Wind speed:*** 3.3 m/s ***Material:*** Aluminium Panels	Controlling sunlight ingress and shading.	**Advantages:** The façade is able to shade and control the light coming in. **Disadvantages:** The aluminum panels need to be anodized first and must be assembled in a separate place.
		***Location/year:*** RMIT University, Melbourne, Australia ***Wind speed:*** 6.9 m/s ***Material:*** Glass Discs Sandblast	Controlling the sunlight coming in includes photovoltaic cells and evaporative cooling.	**Advantages:** The use of a galvanized steel cylinder and horizontal or vertical aluminum axes on the façade is very easy to apply, the façade disc material includes photovoltaic cells in addition to functioning for evaporative cooling, and fresh air intake. **Disadvantages:** Facade disc material includes photovoltaic cells that had to be special ordered.
		***Location/year:*** Bernalte Vivero Empresas Toledo, Toledo, Spain ***Wind speed:*** 6.9 m/s ***Material:*** Ceramics	Controlling sunlight ingress, setting cooling and heating loads.	**Advantages:** The use of galvanized frames on the facade is very easy to apply. The kinetic façade provides a variety of facade shapes in this building and also functions as a controller of sunlight entering the building. **Disadvantages:** Kinetic façade in the form of ceramics that must be customized.
		***Location/year:*** Clay Roof House, Petaling Jaya, Malaysia/2015 ***Wind speed:*** 6.9 m/s ***Material:*** Clay Roof with Steel Frame	– Clay tiles can offer a good solution to screen facades vertically from the morning and afternoon sun. – Vertical steel bars are designed to hold	**Advantages:** – Environmentally friendly material properties – Can reduce the heat well – Health Safe – Materials are readily available, non-

		the clay tiles while allowing free movement of turning and rotating. – This minimizes solar gain through the windows and glass doors of the house's fenestration and provides a soft, vibrating lighting effect when viewed with internal lights switched on at night from outside. – Under sunlight, the tiles emit a warm orange color.	perishable, and not easily damaged by insects. – Recyclable. **Disadvantages:** – Vulnerable to cracking – Vulnerable to Leak
 	***Location/year:*** Children Museum of Pittsburgh, Pennsylvania, USA/2004 ***Wind speed:*** 4.5 m/s ***Material:*** Plastic with Aluminium Space Frame	– Strategically located to maximize the confluence of wind directions. – As an architectural facade that can control sunlight and shadows entering the room.	**Advantages:** – It has material characteristics that tend to be light, easy to install and dynamic. – Can maximize the inclusion of sunlight and wind. – Materials are available easily, there are many variants, durable and long-lasting. – A semi-transparent material that can control sunlight and shadows entering the room while still providing privacy. – Recyclable. **Disadvantages:** – Vulnerable to temperature and molds.

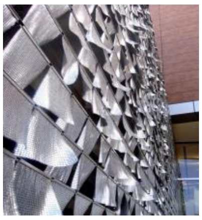
 	***Location/year:*** Ohio Center Parking Garage, Columbus, USA/2022 ***Wind speed:*** 3.3 m/s ***Material:*** Polycarbonate with Steel Space Frame	– Located in a strategic town center location that can maximize the confluence of wind direction from the bridge traffic speed and the bustling area of the town center. – As an architectural facade cladding that controls the daylight coming in but still maximizes the breeze into the building.	**Advantages:** – The materials tend to be lightweight, easy to install, and dynamic. – Maximises capture of sunlight and wind. – Provides an aesthetic impression with a facade that forms waves naturally. – Materials are easily available, have many variants, and are durable. – Semi-transparent that can control sunlight and shadows entering the room while still providing privacy. – Recyclable. **Disadvantages:** – Extra care on materials.
 	***Location/year:*** International Trade Center, North Carolina, USA/2006 ***Wind speed:*** 8 m/s ***Material:*** Stainless Steel with Steel Space Frame	– Located in a strategic/urban center location that can maximize the wind gathering. – As an architectural facade cover that can control sunlight and shadows entering the room.	**Advantages:** – Material properties tend to be lightweight, easy to install, and dynamic. – Materials are easily available, have many variants, and are durable. – Semi-transparent in nature that can control sunlight and shadows entering the room while still providing privacy. – Materials are easily available. – Easy maintenance and long-lasting. – Recyclable. **Disadvantages:** – Extra material maintenance. – Temperature susceptible.

 	***Location/year:*** The Dancing Pavilion, Rio De Janeiro, Brazil/2016 ***Wind speed:*** 3.6 m/s ***Material:*** Mirror with Steel Space Frame	– Located in tropical countries. – As well as the wind, the circular movement of the mirrors or facades is a result of the sensors from the activity or dance floor in the room. – As an architectural façade covering that can control sunlight, wind and shadows entering the room.	**Advantages:** – Simple and dynamic model and design with circular movement. – Materials are easily available. **Disadvantages:** – Extra material maintenance. – Testing is required first. – Tend not to be durable. – The material mass tends to be heavy.
 	***Location/year:*** Windswept Installation, San Fransisco, USA ***Wind speed:*** 4.7 m/s ***Material:*** Aluminium Anodized	– Strategically located with an offshore climate and onshore winds meeting from the central valley. – As an energy-generating architectural facade cladding.	**Advantages:** – The movement is more dynamic and can rotate 360 degrees. – Easy maintenance and durable. – Material properties tend to be lightweight, easy to install, and dynamic. – Materials are easily available and there are many variants. **Disadvantages:** – Materials must be specialized. – Testing is required first.
 	***Location/year:*** Wind Arbor, Singapore/ 2010 ***Wind speed:*** 4 m/s ***Material:*** Glass with Cable Net Structure	– Located in a tropical country. – As an architectural facade covering that can control sunlight and shadows entering the room.	**Advantages:** – It has transparent and dynamic material properties. – Materials are easily available and there are many variants. – The opacity can be adjusted to control sunlight and shadows entering the room

			while still providing private – Recyclable. **Disadvantages:** – Extra material maintenance. – has a long-lasting tendency. – Materials must be specialized.
 	***Location/year:*** Laser Interferometer Gravitational-Wave Observatory (LIGO), Los Angeles, USA/2006 ***Wind speed:*** 3.3 m/s ***Material:*** Pendulum Aluminium with Steel Structure	– Located in a strategic location with an oceanfront climate. – As an architectural facade covering that can control sunlight and shadows entering the room.	**Advantages:** – Easy maintenance and durable. – Material properties tend to be lightweight, easy to install, and dynamic. – Materials are easily available and there are many variants. **Disadvantages:** – Materials must be specialized.
 	***Location/year:*** Pages of Salt, Salt Lake City, Utah, USA/2020 ***Wind speed:*** 2.7 m/s ***Material:*** White Teflon Fabric with Steel Space Frame	– Located in a strategic location with an offshore climate. – As an architectural facade covering that can control sunlight and shadows entering the room.	**Advantages:** – Easy maintenance and durable. – Material properties tend to be lightweight, easy to install, and dynamic. – Materials are easily available and there are many variants. – The opacity can be adjusted to control sunlight and shadows entering the room while still providing privacy. – Recyclable. **Disadvantages:** – Resistant to temperature and moulds.

 	***Location/year:*** Moire Bridge, Union Station, Los Angeles, California, USA /2021 ***Wind speed:*** 3.3 m/s ***Material:*** Aluminium with Steel Panels	– Located in a strategic and densely populated location. – The enclosure also creates a cocooning feel that provides safe pedestrian respite from the vehicular traffic that flanks each side. – These patterns can also shift as the light fluctuates throughout the day, and at night appear as silhouettes on the illuminated surface inside the bridge.	**Advantages:** – Fast installation – Easy installation – Can still have value even if it is no longer used as a structural element **Disadvantages:** – Susceptible to buckling
 	***Location/year:*** Wind Fins of Neiman Marcus Store, Walnut Creek, California, USA/2012 ***Wind speed:*** 2.2 m/s ***Material:*** Glass Curtain Wall with Aluminium Steel	– Strategically located in the city center, it can maximize the meeting of wind directions with the dominant Mediterranean climate. – As an architectural facade covering that can control sunlight and shadows entering the room. – The smooth movement of the aluminum panels and the way they reflect light and colors from the sky and surrounding cityscape make it a work of art	**Advantages:** – Easy maintenance and durable. – Materials that tend to be lightweight, easy to install, and dynamic. – Fast in installation. **Disadvantages:** – Materials that tend to be lightweight Materials must be specialized. – Vulnerable to temperature and molds.

		with a porous and gossamer feel.	
 	***Location/year:*** Moving Goalspots National Football League, Inglewood, California, USA/2021 ***Wind speed:*** 2.2 m/s ***Material:*** Aluminium Block	– Strategically located in the city centre that can maximise the meeting of wind directions with the dominant Mediterranean climate. – As an architectural facade covering that can control sunlight and shadows entering the room.	**Advantages:** – Easy maintenance and durable. – Material properties tend to be lightweight, easy to install, and dynamic. – Materials are easily available and there are many variants. – Semi-transparent that can control sunlight and shadows entering the room while still providing privacy. – Recyclable. – Fast in installation. **Disadvantages:** – Materials must be specialized.
 	***Location/year:*** Sunset Curtain, Centene Parking Structure, Clayton, Missouri, USA/2013 ***Wind speed:*** 4.5 m/s ***Material:*** Steel Panels	– Architectural facade cladding that controls incoming sunlight while still maximizing breeze into the building. – Strategically located in the city center, that can maximize the meeting of wind directions that have generally cloudy weather throughout the year.	**Advantages:** – Material properties that tend to be lightweight, easy to install and dynamic. – Captures maximum daylight and wind. – Provides an aesthetic impression with a facade that forms waves naturally. – Materials are easily available, have many variants, and are durable. – Semi-transparent that can control sunlight and shadows entering the room while still providing privacy. – Recyclable. – Fast in installation. **Disadvantages:** – Extra care on materials.

 	***Location/year:*** Chain of Ether, ResMed Corporation, San Diego, California, USA/2009 ***Wind speed:*** 2.7 m/s ***Material:*** Metallic Fabric with Aluminium Chainmail	– Strategically located in a city center that can maximize the confluence of wind directions. – A kinetic façade extends into the building and covers the lobby walls from floor to ceiling, animated by the building's ventilation system.	**Advantages:** – Easy maintenance and material properties tend to be lightweight, easy to install, and dynamic. – Materials are easily available and there are many variants. – A semi-transparent material that can control sunlight and shadows entering the room while still providing privacy. – Recyclable. – Fast in installation. **Disadvantages:** – Materials must be specialized. – Vulnerable to temperature and molds.
 	***Location/year:*** Circadian Wind, Los Angeles, California, USA ***Wind speed:*** 3.3 m/s ***Material:*** Polycarbonate with Steel Structure	– Located in a strategic and densely populated location. – Architectural facade cladding that controls sunlight gain while maximizing breeze.	**Advantages:** – Material properties tend to be lightweight, easy to install, and dynamic. – Captures maximum sunlight and wind. – Provides an aesthetics impression with a facade that forms waves naturally. – Materials are easily available, have many variants, and are durable. – Semi-transparent that can control sunlight and shadows entering the room while still providing privacy. – Recyclable. **Disadvantages:** – Extra care on materials. – Vulnerable to temperature and molds.

3.2 Comparison of Responsive Facade System

Table 3 presents a comparative typology of kinetic facades based on the precedent studies in Table 2. The typology includes several aspects, which are system type (active or passive), control system type (manual or centralized), control element type (individual or full movement), facade function (daylight control, heat, or airflow control), response time (seconds, minutes, or hours), and the visibility of the facade system (low, medium, or high).

There are five types of movement in responsive facade systems: rotational, deformational, folding, sliding, and hybrid. Rotation involves an element rotating around an axis, either completely or oscillating back and forth along an arc. Deformation refers to a change in the shape of an element due to applied force. Folding involves the motion of a rigid panel within the system. Sliding involves an element moving back and forth along a specific axis. Hybrid systems combine multiple types of motion. The type of control system determines the factors that cause the system's movement. Kinetic facades can be categorized into manual or centralized control systems. Element control emphasizes whether the system elements can move individually. When elements have interdependent relative motion, the total motion results from all elements moving together. Response time refers to how long it takes for a component of the responsive facade system to react. This time scale can vary from seconds to hours. While many responsive facade systems typically stop moving within minutes, some can move within seconds due to wind.

A facade and its elements impact not only the building's exterior appearance but also its interior space. For instance, some facade systems do not obstruct the view from inside as long as the moving elements are transparent or do not obscure the view. However, some facade systems significantly obstruct visibility. Responsive facades are classified as low, medium, or highly visible based on this category. Visibility is considered moderate when the structural parts supporting the facade panel partially obscure the view when the system is folded or opened.

Table 3. Kinetic facade typology comparison based on precedent study.

Project	**Type of Movement***	**Type of Control System***	**Control of Type Element***	**Response Time***	**Visibility***
Brisbane Airport	Rotation (oscillatory motion), deforming	Central	Individually	Second	High
Logan Airport Central Parking	Rotation (oscillatory motion), deforming	Central	Individually	Second	Medium
Chandler City Hall	Rotation (oscillatory motion), deforming	Central	Individually	Second	Medium
RMIT University	Rotation (full rotation), deforming	Central	Individually	Second	Medium

Bernalte Vivero Empresas Toledo	Rotation (oscillatory motion), deforming	Central	Individually	Second	Medium
Clay Roof House	Rotation (oscillatory motion), deforming	Central	Individually	Second	Medium
Children Museum of Pittsburgh	Rotation (oscillatory motion), hybrid	Central	Individually	Second	Medium
Ohio Center Parking Garage	Rotation (oscillatory motion), deforming	Central	Total movement	Second	High
International Trade Center	Rotation (oscillatory motion), deforming	Central	Individually	Second	Low
The Dancing Pavilion	Rotation (full rotation), deforming	Central	Individually	Second	n.a.
Windswept Installation	Rotation (full rotation), hybrid	Central	Individually	Second	Low
Wind Arbor	Rotation (oscillatory motion), deforming	Central	Individually	Second	Medium
Laser Interferometer Gravitational-Wave Observatory (LIGO)	Rotation (oscillatory motion), deforming	Central	Total movement	Second	Medium
Pages of Salt	Rotation (oscillatory motion), folding	Central	Individually	Second	Medium
Moire Bridge	Hybrid	Central	n.a.	n.a.	n.a.

Wind Fins of Neiman Marcus Store	Rotation (oscillatory motion), deforming	Central	n.a.	Second	Medium
Moving Goalspots National Football League	Rotation (oscillatory motion), hybrid	Central	Individually	Second	Medium
Sunset Curtain, Centene Parking Structure	Rotation (oscillatory motion), deforming	Central	Total movement	Second	Medium, high
Chain of Ether, ResMed Corporation	Rotation (oscillatory motion), folding	Central	Individually	Second	Medium
Circadian Wind	Rotation (oscillatory motion), deforming	Central	Individually	Second	Medium

*notes:

Type of movement	:	Rotation (full rotation/oscillatory motion)/deforming/folding/ sliding/hybrid.
Type of control system	:	Hand operate/central
Control of type element	:	Individually/total movement
Response time	:	Second/minutes/hours
Visibility	:	Low/medium/high

From the 20 case studies in Table 3, 18 buildings implement oscillatory movement in the rotational system of facade elements, serving various purposes such as providing natural ventilation by allowing controlled airflow into the building, acting as sunshades, and regulating the amount of sunlight entering the interior spaces. This movement is predominantly influenced by wind and gravity factors, although it can also be powered by external energy sources, such as motors or specialized mechanisms. There are several types of oscillatory movements in these case studies.

One of the types is the motion panel. Facades can have panels installed on mechanisms that allow them to move back and forth. For example, the panels can swing horizontally or vertically, creating interesting motion patterns on the facade. This type is found in the Children's Museum of Pittsburgh and the International Trade Center buildings.

The second type is related to moving louver. Louver windows on the facade can be designed to move oscillatory. With the appropriate mechanism, the louvers can swing open or closed, providing control over light penetration and ventilation. This type is found in the buildings of the Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Wind Fins of the Neiman Marcus Store.

The third type is the Moving Curtain. Facades can have curtains or fabric placed in front of them, which move oscillatory. The gentle movement of the curtains blown by the wind can create beautiful visual effects while providing privacy and ventilation. This type is found in the Ohio Center Parking Garage, Wind Arbor, Chain of Ether, Pages of Salt, and ResMed Corporation buildings.

The next type is Dynamic Elements. Facade designs can include other elements designed to move oscillatory, such as swinging geometric-shaped panels, vibrating metal elements, or flexible plastic components. The movement of these elements can bring life and visual changes to the facade. This type is found in the Sunset Curtain, Centene Parking Structure, and Circadian Wind buildings.

Meanwhile, two buildings implement a full rotation system, as seen in the Dancing Pavilion and Wind-Swept Installation, where the kinetic facade model can move 360 degrees, predominantly influenced by wind, gravity, and other supporting motion sensors. This system also aims to provide natural ventilation by allowing controlled airflow into the building and serving as a sunshade to regulate the amount of sunlight entering the interior spaces.

All buildings feature kinetic responses with movement occurring within seconds, utilizing a central kinetic control system to regulate the motions and behaviors of the kinetic elements in the facade. This system is based on architectural designs that incorporate moving elements such as rotating, opening, closing, or linearly moving panels. The purpose of the central control system for kinetic facades is to provide flexibility and dynamism to the building, allowing the facade's appearance to be altered according to needs and preferences while also creating visually appealing effects.

Additionally, most buildings employ an individualized control system for their kinetic elements, meaning each element of the facade can move or change its position independently without relying on others. This approach requires a more complex control system but offers greater flexibility and creativity in designing visual effects. The type of material used also influences the type of movement in the kinetic facade. Buildings that utilize a total movement control system tend to use long, flexible, and lightweight materials such as curtains made of fabric or polycarbonate.

Most buildings have a low to medium level of visibility, which impacts several factors including visual appeal, interaction with the environment, building identity, lighting and transparency effects, as well as changing effects and dynamics. When designing a kinetic facade, it is crucial to consider the visibility factor, especially if the goal is to create a strong visual impact or establish a significant connection between the building and its environment. The optimal level of visibility should be determined by evaluating the location, direction of view, and interaction with the surrounding environment.

3.3 Recommendations

Based on the review of kinetic facade implementations in Table 3, selecting the appropriate types and materials for kinetic facades in Indonesia should take into account the wind speed at the installation site. For locations with low wind speeds (less than 3 m/s at 50 m height), a movement system featuring deforming and folding types is most suitable. The recommended control system is a central type that allows for individual control of the facade elements. The materials best suited for these facades include fabric, glass curtains, and aluminum blocks.

The movement system with deforming and folding types, along with the central control system, is also suitable for locations with wind speeds ranging from 3 to 4 m/s. In these cases, the control of the elements can be both individual and total movement. The recommended materials for such kinetic facades include polycarbonate, mirror, glass, and aluminum, which can be used for blocks, panels, pendulums, and composite panels.

For locations with wind speeds between 4.1 and 5 m/s, kinetic facade types can utilize movement systems such as deforming, folding, and hybrid with oscillatory motion and full rotation. The control system type should be centralized, and the element control can be either individual or total movement. The recommended materials include plastic, steel panels, and aluminum, which can be used in various forms, such as blocks, panels, pendulums, and composite panels.

For wind speeds higher than 5 m/s, suitable movement types for kinetic facades include deforming, folding, sliding, and hybrid systems with oscillatory motion and full rotation. Appropriate materials for kinetic facades in these conditions include ceramic, clay roof, plastic, stainless steel, sandblast disk glass, and aluminum. Kinetic facades for all wind speed categories should have a response time within seconds, and visibility can range from low to high.

3.4 Building Regulations

Other aspects that should be considered when implementing kinetic facades in Indonesia is regulations. There are four specific regulations governing green buildings, namely Regulation of the Minister of Public Works Number 2 of 2015 which applies to all regions, while the other three regulations are specific to certain areas. The regulation refers to the Building Law No. 28 of 2002 which emphasizes the importance of buildings that are in harmony with the environment.

Under the Building Law, there are government regulations that are more technical in nature, such as Government Regulation (PP) No. 36 of 2005 which emphasizes the harmony and balance of the environment and the importance of paying attention to the principles of saving and conserving energy and choosing building materials that are safe for the health of users and the environment.

The fourth layer of regulations consists of ministerial regulations. The Ministry of Energy and Mineral Resources contributes to environmental quality through Ministerial Regulation No. 26 of 2018, which encourages environmentally friendly mining activities. The ministry also promotes energy saving with Ministerial Regulations No. 13 and No. 14 of 2012, which advocate for energy management and mandate energy audits for certain types of buildings. In 2010, the Ministry of Environment introduced Ministerial Regulation No. 8 of 2010, which regulates environmentally friendly buildings and their certification process, defining an eco-friendly building as a green building. Additionally, the Ministry of Environment and Forestry issued Ministerial Regulation No. 5/MenLHK/Setjen/Kum.1/2/2019, emphasizing the application of environmentally friendly labeling for goods and services to fulfill eco-labeling policy requirements. The Minister of Public Works and Housing launched Ministerial Regulation No. 2 of 2015, related to green building regulations, which include principles of reuse, reduction, and recycling, considering the entire building life cycle from programming and planning to construction, use, and demolition. Furthermore, the Financial Services Authority issued Regulation No. 51/POJK.03/2017 to implement sustainable financial services.

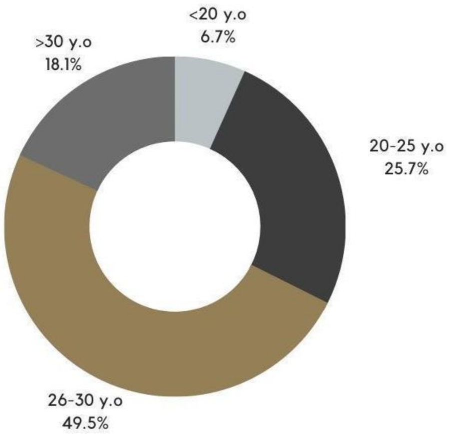
The final layer consists of regulations issued by Governors, Mayors, or Regents. Examples of such regulations include the Governor of DKI Jakarta Regulation No. 38 of 2012, the Mayor of Bandung Regulation No. 1026 of 2016, and the Mayor of Semarang Regulation No. 24 of 2021. These regulations are related to green buildings.

3.5 Survey Results

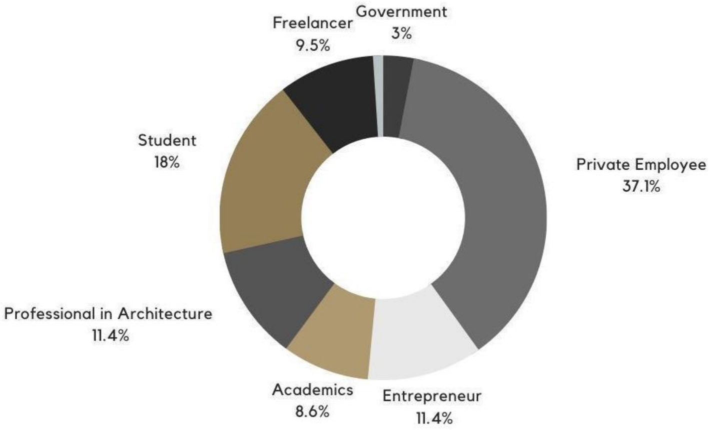
We conducted an online survey through Google Forms with 105 respondents in Indonesia. Figure 2a shows that the dominant age group of respondents is 26-30 years, comprising 49.5% of the total. The largest percentage of respondents is male, accounting for 61.9%, and the most common occupation among respondents is private employees, making up 37.1% (Figure 2b).

Approximately 96% of the respondents expressed a desire to implement energy-efficient buildings. Around 55.2% of the respondents are not familiar with kinetic facades. However, 79% of respondents showed an interest in implementing kinetic facade innovations in buildings. Figure 3 indicates that the most preferred materials for implementing kinetic facade innovations among respondents are aluminum, wood, bamboo, brick, plastic, concrete, steel, Hebel, glass, cloth, terracotta, and porcelain. Additionally, 89.5% of respondents favored using recycled materials.

Figure 4 shows that the factors most influencing respondents to implement kinetic facade innovation, in order of importance, are cost, design, location, material availability, and maintenance. More than 60% of respondents are aware of and prefer to learn about innovative applications of kinetic facades through social media platforms, as shown in Figure 5. Additionally, more than 50% of respondents favor a workshop-type education to support the innovation education system for kinetic facade application in Indonesia, as depicted in Figure 6.



(a) Age percentage of respondents.



(**b)** Percentage of respondents' job types.

Figure 2. Respondents' profile.

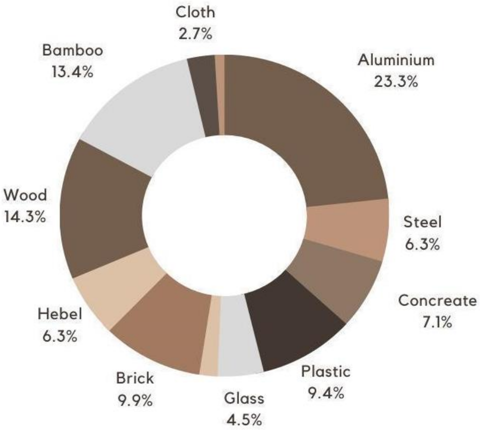


Figure 3. Type of material selected by respondents.

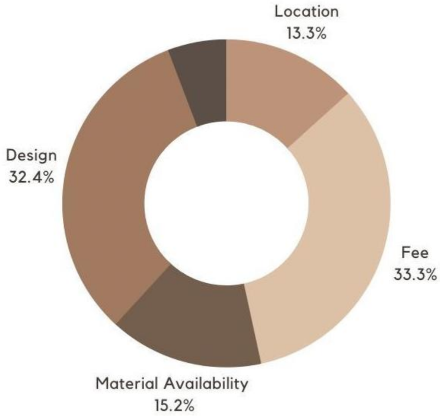


Figure 4. Most important factors to respondents in applying the kinetic facade innovation.

Based on the questionnaire data, 97.1% of respondents support the implementation of kinetic facade innovations in Indonesia, and 96.2% consider it effective. There is hope that Indonesia will further develop and improve the quality of its architecture through the application of kinetic facades. These innovations can be implemented in residential areas, housing complexes, offices, and public commercial facilities such as stadiums. Implementing sustainable development with kinetic facades will help respond to climate and environmental conditions while minimizing or recycling waste, being modern and functional, and supporting energy efficiency by reducing the load on active building systems.

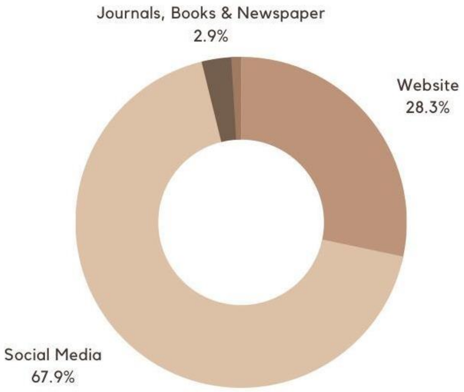


Figure 5. Media selected by respondents.

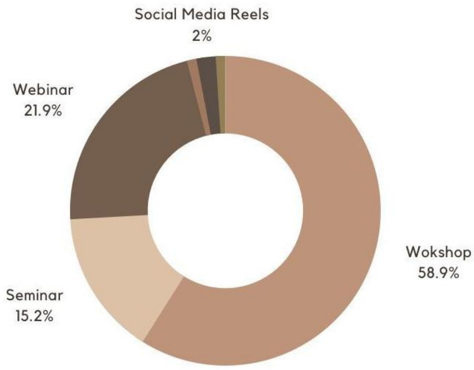


Figure 6. Percentage of informal learning methods chosen by respondents.

4. Conclusions

This research examines the influence of wind speed in various regions of Indonesia on the implementation of kinetic facade typologies, taking into account parameters such as building function, type of movement, control system, response time, and material usage. The novelty of our research lies in being the first to investigate the opportunities and challenges associated with implementing kinetic facades in Indonesia. Our study contributes by providing a comprehensive review of kinetic facades worldwide and establishing a foundation for the further development and adoption of this technology in Indonesia. Thus, our study extends the previous studies reviewing the kinetic facade technologies (Khraisat et al., 2023; Khraisat et al., 2024; Vazquez et al., 2023) by analyzing the opportunities and challenges of implementing the technology in Indonesia.

The findings are intended to guide planners and architects in optimizing kinetic facade designs that are well-suited to the climatic conditions of each region. Wind resources are crucial in determining the appropriate types and materials for kinetic facades. For wind speeds less than 3 m/s, fabric with deforming and folding movements is recommended. For speeds between 3 and 4 m/s, materials such as polycarbonate, mirror, and aluminum panels are suitable. For wind speeds above 5 m/s, materials like ceramic, clay, and stainless steel are preferred, with a broader range of movements including sliding and full rotation.

One crucial factor in the successful implementation of kinetic facades is community support. Questionnaire data reveals strong support (97.1%) and perceived effectiveness (96.2%) for kinetic facades, with the hope that such innovations will enhance architectural quality and support sustainable development across various building types in Indonesia. Therefore, it is important for the government to foster further support by implementing more comprehensive green building regulations at various levels, including regional (regional laws, governors, and mayors) and national levels (laws, government regulations, and ministerial regulations). With clear and consistent regulations, stakeholders will be more motivated to apply green building principles, including the use of kinetic facades. Furthermore, coordination among all stakeholders in green building is crucial to achieving optimal results. This involves collaboration among the government, architects, engineers, developers, and the community as a whole. By supporting and sharing knowledge with each other, we can maximize the potential performance of green buildings in Indonesia.

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