Facade Morphology with Kinetic System in Tall Buildings

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Abstract. *The urban population's dependence on natural resources to fulfill their daily energy needs is increasingly leading the earth to experience an energy crisis. One of the efforts that can be made to save the earth is to provide replacement energy. The solution to the energy crisis can be realized through architectural designs that care for nature by focusing on renewable natural resources. One form of implementation is by processing wind power into energy. The facade as the outermost surface of a tall building, has the potential to process wind power into energy because it receives the wind directly. Kinetic systems can be applied to the facade so that it can process the wind power available in the environment more effectively. This research aims to examine kinetic facade models from several architectural works that use kinetic design concepts and approach the average wind speed of Surabaya City. This research uses the methods of precedent study and comparative study. The result of this research is the discovery of hanging and rotational kinetic facade forms.*

Keywords: Morphology, Tall Building, Kinetic Facade, Wind Energy.

Abstrak. *Ketergantungan penduduk di perkotaan terhadap sumber daya alam untuk memenuhi kebutuhan energi sehari-hari semakin membawa bumi mengalami krisis energi. Salah satu upaya yang dapat dilakukan untuk menyelamatkan bumi adalah menyediakan energi pengganti. Penyelesaian krisis energi dapat diwujudkan melalui rancangan arsitektur yang peduli terhadap alam dengan menitikberatkan pada sumber daya alam yang dapat diperbarui. Salah satu bentuk implementasinya adalah dengan mengolah tenaga angin menjadi energi. Fasad sebagai permukaan paling luar dari bangunan tinggi memiliki potensi sebagai pengolah tenaga angin menjadi energi karena menerima angin secara langsung. Sistem kinetik dapat diterapkan pada fasad sehingga dapat mengolah tenaga angin yang tersedia di lingkungan dengan lebih efektif. Penelitian ini bertujuan untuk mengkaji model fasad kinetik dari beberapa karya arsitektur yang menggunakan konsep desain kinetik dan mendekati kecepatan rata-rata angin Kota Surabaya. Penelitian ini menggunakan metode studi preseden dan studi komparasi. Hasil dari penelitian ini adalah ditemukannya bentuk fasad kinetik yang menggantung dan rotasi.*

Keywords: *Morfologi, Bangunan Tinggi, Fasad Kinetik, Energi Angin.*

1. Introduction

Urban dwellers' dependence on natural resources to fulfill their daily energy needs is increasingly leading the earth to experience an energy crisis. Sustainability issues continue to be heard to build public awareness of the safety and sustainability of the earth. With the energy crisis, efforts are needed to develop technologies that can replace conventional energy and deal with related environmental problems. One possible solution to address the energy crisis is to use a more balanced architectural approach that emphasizes the use of renewable natural resources, for example, converting wind energy into an alternative source. The facade as the outermost surface of a tall building has the potential as a wind power processor because it receives the wind directly. Wind received by the outer surface of the building can be processed into wind power generation resources.

In this decade, the world of architecture has experienced progress in the field of facade design, especially facades that can move, better known as kinetic facades. Kinetic facades have moving elements such as panels, fins, or louvers that can respond to the wind. One of the benefits of an adaptable kinetic structure is its ability to adjust to shifting environmental factors including temperature, time of day, and location (Dharmatanna, Wulandari, dkk., 2024). The implementation of kinetic facade systems aims to reduce environmental impact by reducing dependence on mechanical systems such as HVAC and artificial lighting because the building sector absorbs a very large amount of energy use, which is 45% of the total global energy demand; about 50% of energy use in buildings is spent on the construction of indoor thermal comfort (Wulandari dkk., 2021). It can therefore improve comfort for building occupants and potentially be a source of electrical energy. Even though it is not intended as a replacement for mechanical systems, the use of kinetic facade systems can significantly reduce a building's energy demand (Kensek & Hansanuwat, 2011).

1.1. Morphology and Typology Theory

Morphology, as we know, is closely related to biology. In biology, morphology leads to the shape and structure of animals. Morphological studies are the study of form and the study of changes in form in the history of metamorphosis. In the world of architecture itself, morphology can be interpreted as a typological study in the metamorphosis of form (Iswati, T. Y., 2003). Some opinions say, typology is the study of types (Nurtantyo, 2018) and type is a group of objects that have similar structural and model characteristics. can be concluded typology is the study of type (Johnson, 1994). Type is derived from the Greek word "typos," which means impression, picture, or the form of an object. Generally speaking, "type" is used to characterize the general shape, constitution, or traits of Looking at a specific form or object from the perspective of a building object typology, the building's site, form, and arrangement of its components are the three key components (Keling, 2017). Morphology is the study of the grouping of objects into patterns through structural similarities, and typology is the study of types by classification and classification operations to produce types where from the classification and category can be seen diversity and homogeneity. Therefore, it can be concluded that morphology is the study of form in which typology is studied.

1.2. Kinetic Responsive Facade

A facade is one of the most important architectural elements that can express the function and meaning of a building. Facade comes from the word facies, which has synonyms of face and appearance. A façade can be defined as a layout that pays attention to the function of windows, doors, sun protection, and roof areas to create a harmonious and balanced unity of both horizontal and vertical structures, building materials, colors, and decorative elements (Garden, 1988). The essential elements of a facade are doors, windows, siding, trellis, and sun shading. An architectural technological advancement in facade design that is developing in various countries is the use of kinetic facades (Dharmatanna, Wijaya, dkk., 2024) . Kinetic Facades can be classified into two main factors: i.e., Facade Configuration and Facade Function. In the definition of kinetic, it is necessary to distinguish between kinetic and other approaches in designing designs that can move, and in the science of architectural theory and practice, kinetic or movement can be interpreted as (Moloney, 2011):

a. Occupant activity changes.
b. Occupants' physical movements.
c. Motion resulting from the optical effects of changes in light and air humidity.
d. Motion that occurs due to the movement of certain materials.
e. Movement representation through dynamically appearing shapes and surfaces.
f. A design method that uses the transformation of geometric shapes or other animation techniques.

In kinetic systems, there are four explanations of the form of kinetic transformation of the façade, which can generally be seen in Figure 1, namely: first movement in translation or movement in a plane; second movement in rotation or can rotate on its axis; third movement in scaling, which can enlarge or reduce the field; and the last is the movement of material deformation (Moloney, 2011). These four types of movement are commonly used in building facades that apply the kinetic concept.

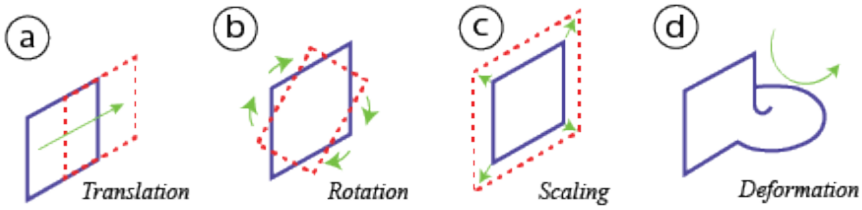


Figure 1 . Types of movement in kinetic facades.
Source: Adapted from (Moloney, 2011)

Overall, the kinetic concept can be an important strategy to optimize the structuring function of the facade, which must respond to different stimuli in response to occupant comfort. This objective will be investigated by identifying and modifying key facade factors. This is because basic knowledge from different disciplines is required to produce a kinetic design. (Susam, 2013).

1.3. Wind Movement Principle and Phenomenon

Tabel 1. Wind Speed Levels based on Natural Conditions

Class	Speed (m/s)	Condition
1	0.00 – 0.02	Stagnant
2	0.03 – 1.5	Calm wind movement; smoke will move upward.
3	1.6–3.3	Smoke will follow the wind movement.
4	3.4–5.4	Wind can be felt within the skin, causing the movement of objects such as leaves and wind catchers.
5	5.5 – 7.9	Blowing away objects like dust and paper while moving tree branches
6	8.0 – 10.7	Tree branch is moving, flag is waving
7	10.8–13.8	Big tree branch is moving; causing a small wave in the water surface of pond
8	13.0 – 17.1	Bending in the tree's perimeter; wind noise could be heard.
9	17.2 – 20.7	Breaking tree branches; Causing resistant forces when walking in the opposite direction from the wind
10	20.8–24.4	Breaking tree branch; building failure
11	24.4–28.4	Tearing down trees and causing heavy damage
12	28.5–32.6	Causing disastrous damage

Source: (Bachtiar & Hayattul, 2018)

Wind is one of the factors that affect weather and climate conditions, the difference in air pressure that results in the flow or blowing of air over land or a place. (Bachtiar & Hayattul, 2018). Wind energy is considered a promising alternative energy source due to its continuous availability in nature as well as being clean and renewable. The process of utilizing wind energy goes through two stages of conversion. First, the wind flow is used to drive the rotor (propeller) so that the rotor rotates. along with the wind. The level of wind speed that occurs based on natural conditions is described in Table 1. Second, the rotation of the rotor is connected to a generator to produce electricity. The use of wind power kinetic facades as a fundamental component of building design has been embraced by numerous nations worldwide. For instance, wind-powered kinetic facade buildings in industrialized nations have become symbols of architecture, combining energy sustainability with visual appeal. In addition to improving the building's appearance and municipal identity, the effective application of these kinetic facades has a positive impact on sustainability, energy efficiency, and aesthetics. Nonetheless, there is still a limited and underexplored use of wind power kinetic facades in Indonesia.

2. Methodology

The research method uses precedent studies and comparative studies. Since they can give a general picture of how kinetic facades have been implemented in various nations, precedent studies are thought to be essential. This precedent study can also be used to look for suitability to be applied in Indonesia. The precedent study in this section will explore several architectural works that have been realized and apply kinetic design concepts, especially those that move due to the influence of wind. This will help in finding the suitability to apply similar concepts in Indonesia. The limitations in this research are:

- The variables studied were windward facade design and building location.
- The key variable is Surabaya wind strength of 7 knots (bmkg data).

Precedent and comparative studies were conducted to derive recommendations for kinetic facades using the following parameters:

- Kinitekism in buildings includes kinetic elements and reasons for motion.

The key elements of kinetic design are the structural system, materials used, embedded computing/control mechanisms, and adaptive architecture.

3. Result and Discussion

3.1. Brisbane Airport

Figure 2. Brisbane Airport

Figure 2 shows the facade of the Brisbane Airport building. This building is located in the state of Queensland in Australia. This building with a height of 8 floors has a function as a parking building at the airport in the city of Brisbane. Brisbane has a subtropical climate with hot and humid summers and cool, dry winters. In summer, Brisbane is often hit by rockfalls, cyclonic winds, and droughts. The city's average wind speed is 8.01 m/sec, and the wind direction is from the east.

Figure 3. Kinetic Facade Panels at Brisbane Airport

The building has 250,000 cube-shaped kinetic facade panels, as can be seen in figure 3. The panels move as the air currents change, giving the facade a different appearance depending on the day's weather. They create a visual impression that is influenced by the wind movements in the area. The function of the kinetic facade is to control the incoming sunlight, provide shading, provide natural ventilation for the interior spaces, and give a visual impression of river waves.

(a.) (b)

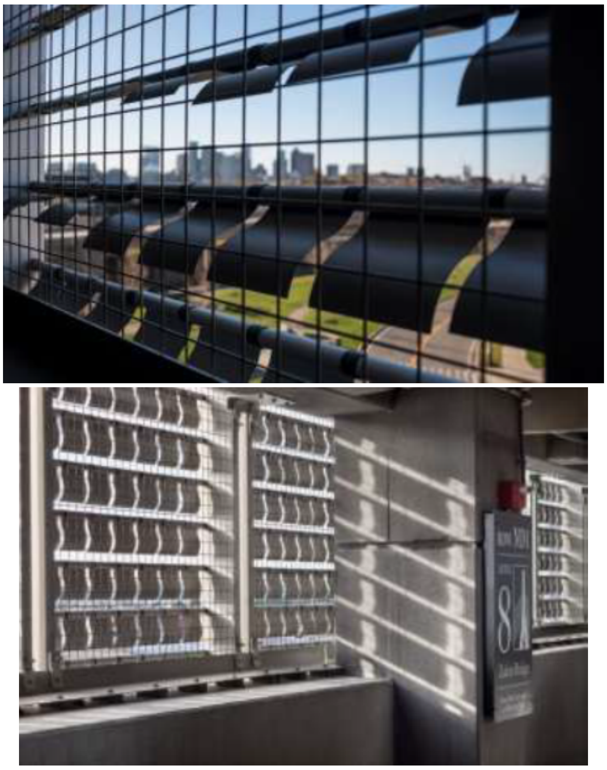
Figure 4. (a) Aluminium Panel Construction and (b) Assembling Process

The kinetic façade is made of aluminum panels fabricated onto a steel frame in figure 4. The panels are perforated and anodized with the aim of allowing the aluminum panels to move when blown by the wind and also increasing corrosion resistance. The paneling is done in the installation workshop, which is a collaboration with Hassell Architecture Studio as an Urban Art Project (UAP). The process of installing the facade installation on the building began with the completion of the facade installation first at the workshop, then gradually brought to the building site. The facade installation was installed on the facade wall of the building as a secondary skin. The facade installation was installed on the 2nd through 8th floors of the building. Therefore, this type of facade is a type of facade that is suspended from the building structure by installation. Benefits of the Brisbane Airport Parking Building's kinetic facade include natural ventilation, shadows and light control, and a river-like visual effect thanks to the aluminum panel material used on the facade. Two drawbacks to the Brisbane Airport Parking Building's kinetic facade are the requirement for the aluminum panels to be assembled separately and to undergo anodization beforehand.

3.2. Logan Airport Central Parking

Gambar 5. Logan Airport Central Parking

The building is located in the city of Baston, which is the capital of the state of Massachusetts in the United States. In Figure 5, the building, which has a height of 10 floors, has a function as a parking building at Logan Airport. The city of Baston has an average wind speed of 8.23 m/s with wind direction from the east. The building has a dynamic facade system consisting of more than 48,000 aluminum flapper panels that move in response to wind currents.



(a) (b)

Figure 6. (a) Kinetic Facade and (b) Atmosphere of Logan Airport Central Parking

In Figure 6(a), the curved, 6-inch (15.24 cm) square-shaped flapper panels were installed within 353 extruded aluminum frame support assemblies, spanning eight stories high and 290 feet (88 m) wide. With wind speeds of 130 miles per hour to test the durability of the system, the anodizing finish of the system also contributed to the durability of the facade installation. Clear anodizing was chosen to create a unique facade for the building, while clear anodizing not only contributes to long-lasting performance but also to accentuate the desired movement as light reflects off the aluminum steam flapper panels, controlling incoming sunlight and giving the impression of dancing in the wind. Another function of the dynamic facade of this parking structure is to optimize the passenger experience and enhance the view for the traveling public and visitors of the 9/11 Memorial and Hilton Hotel in this building, as can be seen in Figure 6(b). This type of facade is thus a type of facade that is suspended from the building structure by installation. The advantage of the kinetic facade on the Logan Airport parking building is the use of aluminum flapper panel material on the facade, which gives a dynamic impression like dancing in the wind. The disadvantage of the kinetic facade at the Logan Airport parking building is that the aluminum panels need to be anodized first and must be assembled in a separate place.

3.3. Clay Roof House

Figure 7. Clay Roof House

The house is located in Petaling Jaya, Malaysia, at the small part of the old town area. The normal wind speed is 2.9 m/s, and blown in east to west direction. The house's facade is covered with Indian clay tiles with premium quality that were previously removed and reused from the original roof. These clay tiles could protect the house from the sun, as the house is facing west, especially in the afternoon. The vertical steel bars are the main support of the clay tiles, and the joints enable the rotating movement of the tiles. This rotating motion helps to reduce the solar gain through the penetration of the windows and glass doors of the house, thus providing a soft lighting effect when viewed with the internal lights switched on at night from outside. In sunlight, the terracotta emits a warm orange color.

The house becomes an insulated, well-ventilated cube when this facade is used. The house's distinctive exterior is made up of screen grilles made of brick and tile that shield the interior from the outside. The exterior, green system, and floor design of the house all demonstrate true functionality. Figure 9 shows how the original terracotta roof tiles from the old, demolished house were reused to create clay lattice screens that rotated in time with the wind.

(a) (b)

Figure 8. (a) Clay Roof House kinetic facade; (b) Clay Roof House kinetic facade motion

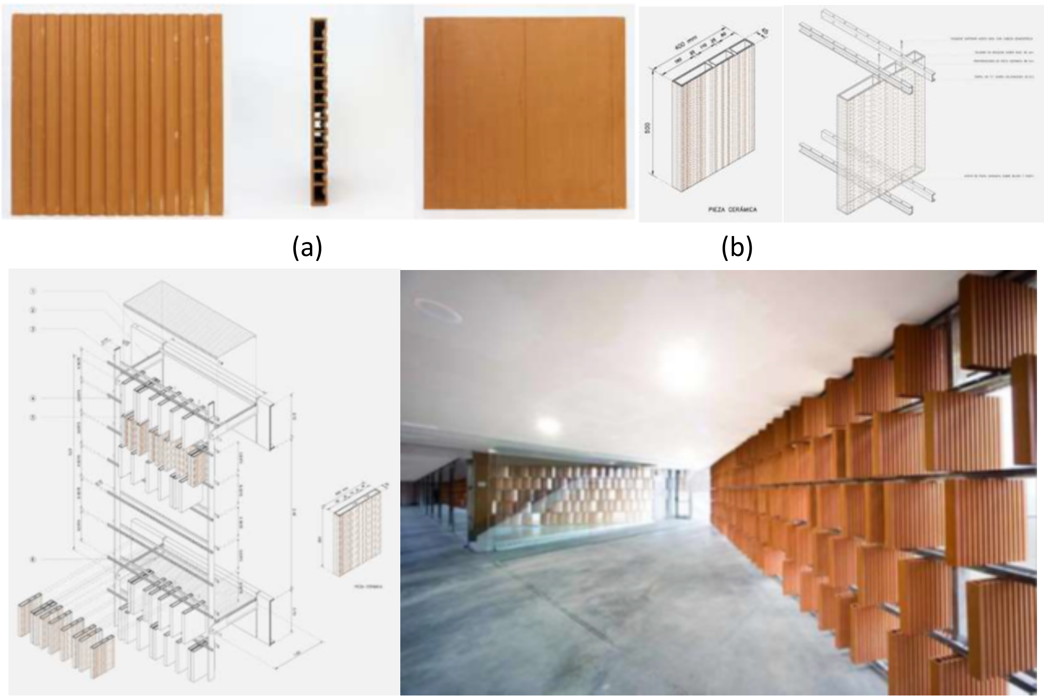
Figure 9. Clay Roof Movement Concept

This kind of veneer revolves around itself. The use of aluminum frames on the facade, which is incredibly simple to install, is one of the benefits of this house's kinetic facade. In addition to controlling the amount of sunlight entering the building, the kinetic façade offers this structure a range of facade shapes. The clay tile material used in this house's kinetic facade is a drawback because it is currently hard to find.

3.4. Bernalte Vivero Empresas Toledo

Figure 10. Bernalte Vivero Empresas Toledo

Bernalte Vivero Empresas Toledo is a business incubator building and chamber of commerce located in Toledo, Spain. The Toledo area has an average wind speed of 6.91 m/s with wind direction from the west. The building utilizes a kinetic facade of ceramic as an important material that reflects harmony with the surrounding context of Toledo. The contemporary ceramic lattice with dimensions of 50 cm long, 40 cm wide, and 45 cm thick is suspended from galvanized iron on the building structure so that it can rotate when blown by the wind.



(a) (b) (c) . (d)

Figure 11. (a). Ceramics for Kinetic Facade ; (b) Dimension ; (c) Installation Details ; (d) Bernalte Vivero Empresas Toledo Indoor Area

The use of ceramics in the facade creates a contemporary lattice that filters light and protects the incubator from the sun. The structure of the lattice, when blown by the wind creates a beautiful facade when viewed from afar. Thus, this type of facade is a rotational type of facade. The use of galvanized frames, which are incredibly simple to apply and offer a range of facade shapes on the structure, is a benefit of the kinetic facade on this particular building. Furthermore, this building's kinetic facade controls the amount of sunlight that enters the structure. The ceramic material for this dynamic facade material needs to be custom ordered, which is a drawback.

3.5. RMIT University

Figure 12. RMIT University

An Australian building situated in the state of Victoria. Situated in the City of Melbourne, it serves as an instructional facility owned by RMIT University. Melbourne experiences moderate winters and warm to scorching summers due to its temperate oceanic environment. Due to its location on the boundary between hot land and cool southern oceans, the city is well-known for its unpredictable weather. The average wind speed in the city is 6.94 m/sec, with a northerly wind direction. The building's façade makes use of automatic sunshades with fresh air intake, evaporative cooling, and photovoltaic cells to lower operating costs and enhance indoor air quality. The cells are easily replaced when new technology in solar energy research advances thanks to their architecture. A portion of the north facade will be used for industry and RMIT to perform joint research on solar cells. As solar technology advances, the entire building facade has the potential to be modified and may eventually provide enough electricity to power the entire structure. The façade is made up of a secondary skin that may be operated automatically and a double-layered inner skin with unique details on each building façade. From the first floor to the top story, the building is completely encircled by the secondary skin facade.

(a) (b) (c).

Figure 13. (a) and(b). The Facade of RMIT University; (c). Facade's Ring

Glass discs with a 600 mm diameter that have been sandblasted and fixed to either vertical or horizontal aluminum axis make up this secondary skin facade. Each axis is fixed to the exterior of a 130 mm-deep, somewhat larger-diameter galvanized steel cylinder. A single façade module is made up of 21 steel cylinders and glass discs arranged in a row on a 1.8 x 4.2 meter panel. The panel is then fixed to a secondary frame made of galvanized steel. The facade module is installed around 700 mm from the curtain wall surface of the building, so external service lines on every story of the structure may reach it. A typical panel consists of 12 operable glazing discs and 9 immovable discs. On the ground and building floors, all glazing disks are immovable. There are 86 panel modules on each level, and therefore a total of 774 panel modules for the nine levels of the building. Thus, this type of facade is a rotating type of facade.The combination of easily applied horizontal or vertical aluminum axes and galvanized steel cylinders on the facade gives this building's kinetic facade an advantage. The façade disk material serves as both a fresh air intake and evaporative cooling system in addition to having solar cells. This building's kinetic façade has the drawback of requiring specific orders for solar cells included in the facade disk material.

3.6. Chandler City Hall

Figure 14. Chandler City Hall

Located in Chandler City in the state of Arizona, USA. It is a multi-purpose building owned by the Arizona government. The city of Chandler is known for its desert climate with very hot summers and mild winters. The city's average wind speed is 3.33 m/s with wind direction from the east. The building has rectangular kinetic facade panels. The kinetic facade is made of aluminum panels bolted to a steel frame. The panels are perforated and anodized to allow the aluminum panels to move in the wind and to increase corrosion resistance. The paneling was done in the workshop, where the installation was made by Ned Kahn.

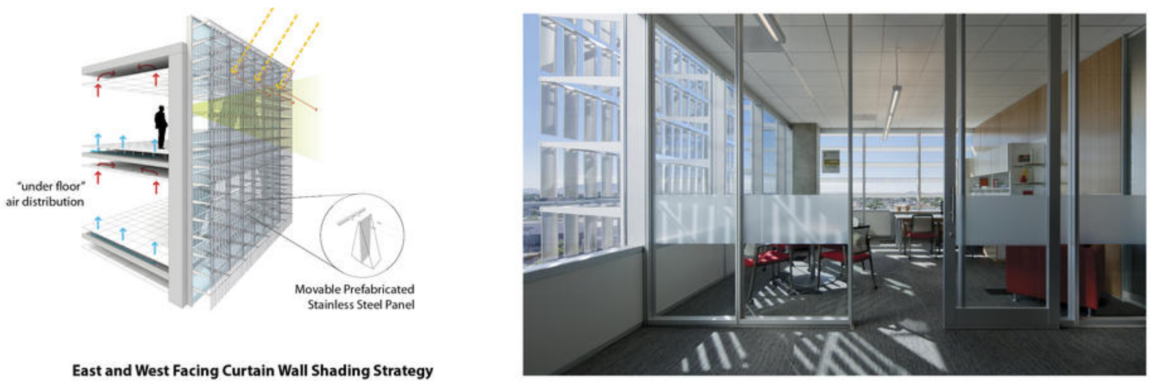


Figure 15. Chandler City Hall Facade Detail

The panels move with changing air currents; the kinetic facade creates a visual impression influenced by the wind movement in the area. The function of the kinetic facade controls the incoming sunlight and shading. The EUI of this building is 43 kBtu/sf/yr, with a 53% reduction from the regional average, meeting the 2030 challenge target. In this way, this type of facade is a type of facade that is suspended from the building structure by installation. The usage of aluminum panel material on the façade, which can create shadows and regulate incoming light, is a benefit of the adaptable facade on this structure. The aluminum panels for this kinetic facade have to be constructed separately and anodized beforehand, which is a drawback.

4. Conclusion

The six buildings selected are buildings with kinetic facades that utilize wind power, where the wind speed of the building is close to the average wind speed of Surabaya City in 2020 of 2.17 m/sec and the maximum average wind speed in 2020 of 7.9 m/sec. Based on the precedent study that has been conducted, of the six buildings, there are two types of kinetic facades found, namely hanging and rotational types. The material of the building is dominated by aluminum and clay with rectangular geometry.

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