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# Spatial adaptation through kinetic Facades

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**Abstract**

The term kinetic architecture is not new to architectural thought. The concept of movement and its practical reflection are increasingly evident in final products thanks to kinetic activities and developments in construction technology. The need for adaptable spaces has also emerged, which was the prerequisite for the emergence of the concept of kinetic in architecture. What characterizes the design approach to this concept is “kinetic," which will now play an increasingly important role, both theoretically and practically. The uses of kinetic in architecture today can be expanded beyond what was previously possible. The research examines the methods of kinetic analysis used, exploring their direct and indirect applications in the architectural field. The research also focuses on interactive spatial adaptation through kinetic facades, seeking to establish the foundations for the application of kinetic facades as a means of improving building performance. The motivation behind this is the creation of adaptable spaces. This is achieved by constructing kinetic structures capable of physical transformation through kinetic to adapt to ever-changing requirements and conditions. The research is based on three approaches: first, an inductive approach that defines the concept of kinetic architecture, its principles, and patterns; second, an analytical approach that studies a number of global projects; Third, the research concludes with findings and recommendations for the application of kinetic interfaces. The research also proposes the use of kinetic methods in the design of kinetic interfaces to create adaptable spatial arrangements, ultimately enabling their application in achieving spatial adaptation.

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Keywords: Kinetic architecture; Adaptation; Responsiveness;User requirements.

## 1. INTRODUCTION

Many kinetic concepts have recently emerged in architecture, including kinetic architecture, particularly at the level of building facades. Some of these concepts are characterized by their ability to adapt and interact with the surrounding environment and its variables [15]. The emergence of these interactive concepts and their application in architecture has led many architects to focus on applications that achieve environmental interaction between buildings and their external environment. Therefore, this research focuses on studying the role of kinetic applications at the architectural facade level in developing this architectural trend, making it more effective and efficient for future application. The focus has been on kinetic facades, as they are the vital separating element between the external environment and the interior spaces of buildings.

## 2. RESEARCH PROBLEM

The research problem lies in the lack of optimal use and study of the technological data that can be applied at the facade level to achieve spatial adaptation of spaces within buildings, which is the basic objective of construction.

## 3. RESEARCH HYPOTHESIS

By applying the idea of kinetic architecture to buildings, especially at the facade level, it is possible to achieve spatial adaptation within buildings.

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## 4. RESEARCH GOAL

The research aims to address the contradiction between Kinetic architecture applications and architectural stability, despite the possibility of adaptability within buildings through Kinetic responsive to environmental variables. This can be achieved through a set of sub- goals, **as follows:**

- Study the concept and principles of kinetic architecture.
- Study the relationship between kinetic architecture and environmental changes.
- Develop a set of design criteria for kinetic architecture that architects can provide.

## 5. RESEARCH METHODOLOGY

The research study relies on three approaches:

- The theoretical approach: This relies on the study of kinetic architecture, its principles, and movement patterns.
- The analytical approach: through the analysis of several contemporary models whose design is derived from the concept of kinetic architecture.
- The deductive approach: aims to extract the most important results for achieving spatial adaptation o in accordance with the principles of kinetic architecture

## 6. CONCEPT OF KINETIC ARCHITECTURE

Historically, a building's success has been judged on its ability to withstand time and the destruction of nature, rather than by meeting changing human needs and desires as well as changing surrounding environments. To begin by familiarizing yourself with the term “kinetic architecture,” the term “kinetic” refers to everything produced by movement. The term “architecture” is a noun that refers to the design or style of a building or buildings (7). When the term "kinetic architecture" is combined, it refers to the design of buildings produced by movement. As defined by Michael A. Fox - founder of the Kinetic Design Group at MIT - defines kinetic architecture as “buildings and/or building components with variable movement capacity, location and/or geometry”.(27). the previous statement emphasizes the importance of kinetics in architecture and how it can be used.

At the Smart Architecture Conference in Georgia, USA, Carmina Sanchez-del-Valle (2005) described the term "Kinetic" as "Having the capacity to be affected by reversible geometrical changes in whole or in part without losing the integrity of the system". It was also mentioned, that creating structures both kinetic and adaptive, make them gain the ability to respond to changing conditions like weather, sun location, etc. For that, she justifies the use of adaptive kinetic structures due to the following reasons: economy of means, responsibility towards the natural environment, and the satisfaction of human needs and desires.(28). Moreover, she justifies that these reasons are the same given for most architectural projects; yet what makes adaptive kinetic structures differ from others is their ability to produce work to better modulate efficiencies, broaden the contemporary aesthetic and give it more relevant meaning by turning the embodied energy fully visible. Kinetic architecture was also defined by Kostas Terzidis (2008) as "The integration of motion into the built environment, and the impact such results has upon the aesthetics, design, and performance of buildings may be of great importance to the field of architecture. While the aesthetic value of virtual motion may always be a source of inspiration, its physical implementation in buildings and structures may challenge the very nature of what architecture really is". In addition, Robert Kronenburg (2007) said that "A building becoming kinetic at the touch of a button can introduce a potent reinvention of something inanimate, giving it the quality of being alive"(15)

Adaptive kinetic architecture creates ecological system as its components have shifting interdependencies when responding to changing environment (Sanchez-del-Valle, 2005). That confirms that kinetic architecture is not only about transformable or moving buildings but also about creating a relation between the built environment and natural environments. "Buildings that continuously attune their configurations in accordance with changing environmental conditions use less energy, offer more occupant comfort, and feature better overall space efficiency than static buildings" (Hoberman, 2008).

To conclude all definitions listed above, "Kinetic Architecture" can refer to buildings or building components that act in respond to surrounding changes whether changes are indoor and/or outdoor and whether they are forced by environmental factors and/or human ever-changing demands

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## 7. PRINCIPLES OF KINETIC ARCHITECTURE

The principles of kinetic architecture describe many concepts related to movement and interaction with data to achieve good building design. Throughout the ages, design principles have generally focused on designing good human-made built spaces across all parameters and scales. However, most of these principles relate to the basic building elements, such as the structural framework or fixed building elements, and do not pay extensive attention to the individual elements or capabilities of certain data that enable building change over time. **The following is an examination of the design approach and principles of kinetic architecture:**

### *7.1. Serial Repetition Form*

Determining the form of kinetic elements is more complex than that of static elements. Determining kinetic form in architecture can be achieved through serial repetition, which is the repetition of a specific, sequential, and regular pattern or shape. The way kinetic elements are combined in a clear sequence has a significant impact on the form and output of the architectural product. The overall effect of the group can take the form of a swarm, while the typical kinetic of an individual moving element can be in response to and interaction with external changes or needs. [16]

### *7.2. Time*

Time is always linked to matter and kinetic. Time in architecture is also a fundamental dimension that influences the design of a building and its relationship with users, their needs, and the building's surrounding environment. While space simulates the spread and interaction of all elements, time simulates the sequence and repetition of events depending on the changing time. [19]

### *7.3. Physical Equilibrium*

Physical equilibrium helps analyze the kinetic and stability of objects, as physics is concerned with the study of the motion of objects and the causes of motion under the influence of forces. The motion of objects can be divided into translational kinetic, rotational kinetic and oscillatory kinetic. [9]

### *7.4. Mass and Weight*

Mass represents the amount of matter in an object. It is a constant quantity that does not change with location. It has become necessary to consider the effect of an element's mass in both the construction and design of kinetic architectural elements. Weight also refers to the force of Earth's attraction to an object, and it changes with location due to differences in gravitational force. Therefore, the weight of an element affects its visual appearance, especially kinetic elements. [16]

### *7.5. Speed and Acceleration*

Speed expresses the transition between two different states through the change in an object's position relative to time. Thus, speed is a component of kinetic. Kinetic results from the acceleration and deceleration of a kinetic object, as acceleration describes how the speed of an object changes over time. It is expressed through indirect sensory perception and is perceived through rhythm and repetition. [16]

### *7.6. Interaction*

Interaction is defined as the mutual influence of two or more elements on each other. Therefore, some kinetic gain significance due to the inability to understand their source or mechanism. The idea of two-way influence is central to the concept of interaction, as opposed to unidirectional causality. The combination of many simple interactions can lead to surprising kinetic phenomena. Changes can also involve interaction. Interactive architecture is a practical guide to creating dynamic spaces and objects capable of performing a range of practical and human functions. These complex physical interactions are achieved through the creative combination of embedded computing (intelligence) and its tangible physical counterpart (kinesics) [17].

### *7.7. Algorithmic Complexity*

An abstract way to represent running time by using temporal and spatial sequences to transform them into a kinetic design parameter integrated into architectural work. [19]

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## 8. INTERACTIVE KINETIC EFFECTS

### *8.1. Light*

A kinetic element interacts and responds to light to maximize its use in building interiors. A kinetic element interacts with and responds to light to maximize its use in building interiors. This type of interactive kinetic has been applied to numerous projects, particularly in hot or desert climates. In addition to its application to facades exposed to light, these kinetic elements are applied and interacted according to the given data to create an efficient and economical system. An example of this is the design of a canopy for the roof of an open courtyard in the Aldar Central Market in the United Arab Emirates, which utilized a kinetic design that operates through a network that can be opened and closed. See Fig. 1.

Fig. 1. A roof canopy for an open courtyard in the Aldar Central Market, Abu Dhabi, United Arab Emirates [https://www.mediaoffice.abudhabi/ar/economy/aldar, access 8-2025).

### *8.2. Sound*

It employs a system that kinetic in response to external variables based on sound. This interaction occurs through absorption, reflection, or transmission. This interaction depends on the building design; materials used, and sound frequencies. Since sound negatively impacts the comfort of building users, it is essential to consider acoustic aspects in building design to ensure a comfortable and quiet environment. The idea of the Silvankanin sound-responsive wall was inspired by cellular components that react to various stimuli by opening and closing cells that interact with sound by absorbing sound and emitting light. Other potential stimuli for the wall were varied, such as light, human factors, and touch. Thus, various sensors and actuators were used to achieve the required response. [20]

### *8.3. Wind*

Wind is one of the most important influences on the interactive kinetic patterns of buildings. Buildings interact with wind by being affected by the pressure and suction forces it generates. The effect of wind varies depending on wind speed, direction, and intensity. This is particularly important in coastal areas or facades exposed to significant winds. The Super Cilia Skin system was created, inspired by the beauty of grass that reacts to the movement of the wind. It consists of a set of actuators that represent information and, by changing their physical direction; function as a prototype of this system, capable of visual and tactile expression. These cilia move in response to computer-controlled magnetic fields, allowing them to represent information by dynamically changing their physical direction. [24] See Fig. 2.

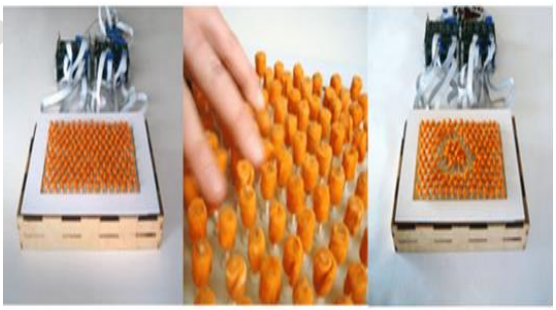

Fig. 2. Super Cilia Skin is a touch sensitive surface made of orange felt and actuators (Courtesy of Mitchell Joachim) [https://www.researchgate.net/figure/Super-Cilia-Skin, access 8-2025).

## 9. SPATIAL ADAPTATION IN ARCHITECTURE

Kinetic architecture relies on both embedded computing (intelligence) and physical (structural engineering and kinetics), addressing the adaptive requirements of human-environmental interaction. Combining these two disciplines enables any environment to reconfigure itself, automate physical change, and respond, interact, adapt, and interact. Adaptive is defined as the flexibility of space in the face of changing system requirements. Adaptability in built projects has been either integrated into the logic of system creation. Adaptable architecture ranges from internal organization and external environmental mediation to the ability to transform/change the entire structure. (27)

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## 10. SPATIAL ADAPTATION REQUIREMENTS IN ARCHITECTURE BASED ON THEIR IMPACT ON KINETIC ARCHITECTURE

### *10.1. Spatial adaptability in architecture*

It refers to the ability of buildings to adapt to their surrounding environment and changes in use over time. This includes several aspects such as adapting to climate, changing the functions of spaces, interacting with users, and using technology to achieve greater flexibility. [26]

### *10.2. Human needs to obtain spatial adaptation*

Human needs are many and varied. Emphasis will be placed on those that can be met through kinetic architecture. **These are classified as follows:**

- Physical needs of users: These are the basic needs of users within buildings, and include thermal comfort, variable humidity, shading, ventilation, wind and storm reduction, visual comfort, acoustic comfort, the ability to change functions, rationalization of energy consumption and generation, and efficient resource management.
- Non-material needs: These include the psychological, social, and emotional needs of the individual, including the provision of an outdoor view, aesthetics, privacy, containment and safety, consideration of psychosocial aspects, belonging, and identity. [25]

## 11. THE IMPACT OF HUMAN NEEDS ON KINETIC ARCHITECTURE

### *11.1. Physical needs*

#### *10.1.1 The Impact of Thermal Comfort on Kinetic Architecture:*

Thermal comfort significantly impacts kinetic architecture, enabling buildings to adapt to climate change and improve the internal conditions for users. This includes the possibility of utilizing renewable solar energy to control energy and avoid excessive heat within spaces. One of the following strategies can be used to control the internal temperature of spaces, **including**:

**A. Using materials that respond to the surrounding environment's temperature(Thermal Bimetals):**

These are materials that change their shape and properties when exposed to heat, such as thermal bimetals, which expand and contract with temperature fluctuations, acting as protection against the sun. See Fig. 3. [1]

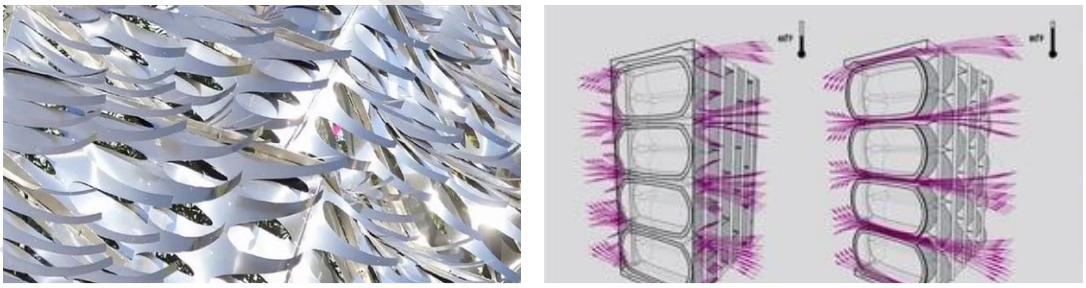

Fig. 3: Thermal Bimetals [Spendlove, T. (2016). Breathing BioMetal Regulates Building, erging-materials-thermo-bimetals Temperature - A Moonshot Project > ENGINEERING.com. [Online] Engineering.com. Available at: http://www.engineering.com/DesignerEdge,access 7-2025].

**B. Use of materials that respond to electrical:**

The response occurs through a change in their internal properties resulting from interaction with electrical energy. This change occurs in the shape, color, or optical properties of the material when an electric current is passed through it. The flow of current is controlled manually or automatically. See Fig. 4. [8]

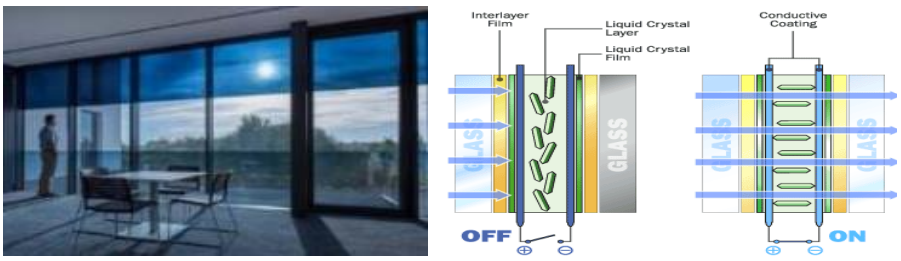


Fig. 4: switchable electric glass [Spendlove, T. (2016). Breathing Bio Metal Regulates Building, erging-materials-thermo-bimetals Temperature).

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**C. Using a system that responds to the internal temperature:**

A system that controls the internal temperature of an object or appliance through various response mechanisms, such as closing and opening according to the building's internal temperature. This system aims to maintain the temperature within a specific range and is affected by changes in the surrounding environment. An example of this is Home static facades, in which the facade responds to the internal temperature by deforming the facade windows when the temperature rises. When the temperature drops, the window returns to its original shape, allowing light to enter again. [1]

D. **Using a spatially responsive system:**

This system responds by relying on the spatial characteristics of the project site, with the aim of maximizing the site's potential. This is achieved by orienting part or all of the building or connecting the interior and exterior according to changing climate or external views. An example of this is the Al-Sharifiya House, where the building allows for a full 90-degree rotation, allowing for changes in direction and taking advantage of climatic conditions throughout the year. See Fig. 5. [3]

Fig. 5: Shows the reorientation of rooms in the Sharifi-Ha house according to the climatic seasons. (https://www.archdaily.com/522344/sharifi-ha-house-nextoffice, access 7-2025)

*10.1.2 Use of shading systems*

These are systems that respond to the needs of users to achieve adequate comfort from shading and its effect on the internal temperature and visual comfort. This is done through responsive kinetic systems by analyzing and interpreting changes in the surrounding environment to obtain the desired response and interaction result. This is done by allowing or preventing solar radiation according to the different seasons during the year. See Fig. 6. [5]

Fig. 6: The use of moving systems on facades is shown to be beneficial in shading within spaces. (Enrich Ruiz-Geli, Media-ICT, www.worldbuildingsdirectory.com/project.cfm?id=3752, (Accessed: 7, 2025).

*10.1.3 Use of kinetic systems for Ventilation:*

Ventilation within spaces is one of the most important design objectives required for any architectural project, as it helps reduce interior temperatures. It is therefore a design strategy for low-energy buildings, as it saves energy used in industrial ventilation systems during building operation. Kinetic architecture helps achieve this through the application of Kinetic facade systems. This can also be achieved by developing smart materials with varying permeability or modifying their internal properties based on carbon dioxide levels. See Fig. 7. [7]

Fig. 7: Modules of the south façade of the Arab World Institute show the kinetic façade to achieving ventilation, (https://charifbo.medium.com/exploring-kinetic-architecture, and access 8-2025).

*10.1.4 Use of kinetic systems for Humidity:*

Humidity is a natural climatic factor that affects human thermal comfort, in addition to its impact on building components. Reactive systems can be used to reduce the humidity level in the interior of buildings to mitigate these negative effects. These systems include materials that respond to humidity, which is influenced by their water content or internal humidity. See Fig. 8. [7]

Fig. 8: Use of hygroscopic materials (wood) in the humidity-sensitive pavilion through closing and opening. (https://www.archdaily.com//hygroskin-meteorosensitive-pavilion-achim, access 8-2025).

*10.1.5 Use of kinetic systems for achieving visual comfort:*

Visual comfort is achieved by controlling the quality of natural lighting within a building, as natural lighting plays a key role in visibility. See Fig. 9. [3]

Fig. 9: Automatic window opening control based on users' lighting needs.( https://alubuild.com/en/architecture-kinetic-facades/ access 8-2025)

*10.1.6 Use of kinetic systems for Acoustic Comfort*

Acoustic comfort means providing a quiet and comfortable environment within the building. It is also one of the most important factors affecting the mental and physical health of building users, as unwanted noise and sound interference are reduced, which enhances calm and focus and improves the quality of life and health. See Fig. 10. [22]

Fig. 10: Automatic window opening control based on users' lighting need The Flare-fagade system is a modular dynamic system that can be installed or building's facades or any wall surface.) https://www.academia.edu/, access 7-2025.)

*10.1.7 Systems for on Protection from Wind and Storms*

Many weather changes and fluctuations occur, including differences in atmospheric pressure between regions, which lead to wind movement, resulting in damage to facades. Therefore, it is important to ensure that the building is well-sealed during wind and storms. This means that windows are tightly closed to prevent wind damage. This is primarily achieved by utilizing kinetic architecture in buildings. When undesirable storms occur, buildings close their openings to prevent dust-laden storms from entering the building. See Fig. 11. [1]

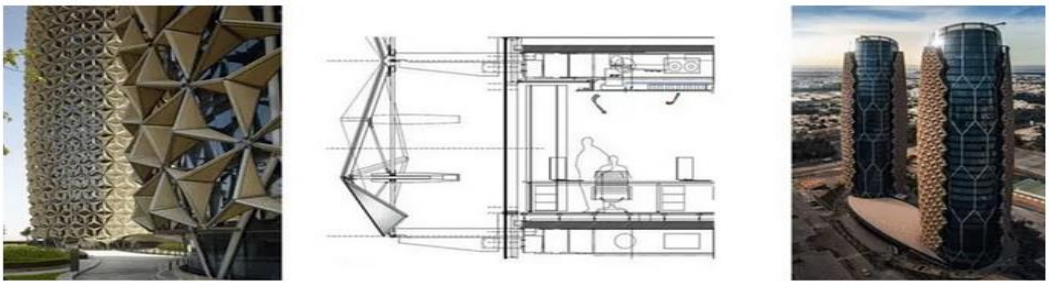

Fig. 11: Kinetic architectural structures with peripheral configuration to Protection from Wind and Storms.( https://charifbo.medium.com/exploring-kinetic-architecture, access 8-2025)

*10.1.8 Function change and development systems:*

This occurs through two strategies. The first is the ability to multitask, which arises from multiple performance requirements or the need to implement new changes over time. The second is the ability to evolve, a flexible characteristic that handles changes over long periods of time, while the ability to multitask primarily deals with the required changes. See Fig. 12. [12]

Fig. 12: It demonstrates that through movement and adaptation, a building can change as needed, allowing for multiple uses within the same space or by making the space closed or open.( https://byarchlens.com/-kinetic-architecture/, access 8-2025)

*10.1.9 Energy Generation Systems:*

Energy generation systems through movable and responsive facade systems are among the most important strategies for achieving building sustainability, along with the creative approach pursued by many contemporary architects to harness renewable energy sources. [6]

*11.2. Un Physical needs*

*10.2.1 Providing External Views*

Visual communication between the interior and exterior is an important element that must be considered in the architectural design of a project, as it often provides psychological comfort for users, in addition to providing natural lighting through the availability of sunlight in the building spaces. It also helps provide information about the climate during the day, as well as views of the sky and natural landscapes. [18]

*10.2.2 Aesthetic* form

The aesthetic composition of facades can be integrated through the use of kinetic elements, which allows for the facade to change shape sequentially. Aesthetic and technical approaches also contribute to kinetic architecture. The aesthetic element in kinetic architecture takes forms that include utilitarianism, technology, attracting attention, avoiding boredom, and interacting with the environment. [23]

*10.2.3 Privacy and Containment*

It is important to understand the difference between the two terms. Privacy refers to the independence and ability of an individual or group to isolate them. Therefore, the principle of privacy for certain private spaces must be considered when initiating projects. Containment, on the other hand, is defined as separating a specific area within a building from the surrounding environment and shaping it according to human needs for tranquility and protection, thus creating an environment conducive to human life and activity. Despite the different definitions, the relationship between them is direct, as the greater the privacy, the greater the containment. Therefore, both can be controlled in several ways, **including**: [10]

A. **Opening and closing**: The elements used in kinetic architecture are controlled by opening and closing the windows in the building, which facilitates controlling the degree of privacy and containment.

B. **Moving walls:** Kinetic architecture allows for the ability to control the location of walls, whether by kinetic them from their place, erecting them, or not erecting them, according to the needs of users. This leads to easy control of the degree of privacy and containment according to the users' needs for internal spaces.

C. **Block movement**: The movement of the building block can be controlled, whether at the level of a part or the entire building, and its position and direction can be changed according to the user's needs. This helps in easily controlling the privacy and degree of containment desired for users.

D. **Glass Partition Movement**: These partitions operate by rotating via a motor inside the double-glazed window. When closed, the partitions act as a completely enclosed facade, providing the desired privacy and containment. When opened, privacy is achieved while reducing the degree of enclosure of the interior space.

E. **Molecular change upon passing an electric current**: Materials whose molecular arrangement changes to achieve transparency or opacity upon passing an electric current, resulting in changes in optical, physical, thermal, or surface properties, thereby controlling privacy and containment. [2]

F. **Change in response to incident light**: This is a change that occurs in the nature of materials when the intensity of the light they are exposed to varies. This change is affected by a change in their color or transparency, thus enabling control of privacy and containment. [4]

*10.2.4 Achieving* safety

A. **Shared security systems**: Both fixed and mobile buildings share the need to ensure internal security through a variety of systems, such as video surveillance and video intercom systems. **Examples include**:

- Video surveillance systems: Video surveillance systems are primarily used in buildings, as they detect changes in the environment and enable remote control of all functions as desired by users.
- Video intercom systems: These transmit audio and video within buildings and are then controlled via super-distribution systems. [11]

B. **Security systems for kinetic architecture:** Kinetic architecture is characterized by a distinctive type of security system, namely, controlling the kinetic of the building's outer envelope. The building allows the outer envelope to be controlled by the kinetic of the outer envelope components.[14]

*10.2.5 Social and Psychological Aspects*

The psychological and social health of users depends on many factors. Social psychologists have conducted several studies to understand the psychological and social health effects of users, **and they found the following**:

- Natural Lighting: Direct sunlight can be refreshing due to the irregular diffusion of light and the changing radiation.
- Privacy: kinetic facades have clear social and utilitarian significance, as facades such as kinetic mashrabiyas provide a significant degree of privacy for users, a matter of utmost importance to Arab society.
- Changing Shape of Blocks: Kinetic architecture plays a significant role in users' satisfaction due to the frequent changes in the shape of facades based on their desires.

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• External View: The ability to communicate with the external environment and monitor events and changes, leading users to achieve a high degree of psychological calm and reducing anxiety about being distracted by the outside world. [14]

*10.2.6 Affirmation* of belonging and identity:

For the concept of belonging to be truly realized, belonging must be direct, complete, and comprehensive. It is also considered a factor in building society. A person's belonging to their community encourages them to preserve it and ensure its continued growth and prosperity. There are many types of belonging, all of which influence kinetic architecture, including national, religious, political, and intellectual belonging. [13]

## 12. ANALYTICAL STUDY:

Projects were selected that met the study's objectives, and were consistent with a set of criteria, including that kinetic architecture be the main focus of these projects, the novelty of the projects, the diversity of the projects in terms of their exposure to different climatic elements, the level of adaptation, and the diversity of projects between regional and international.

TABLE 1: A TABLE SHOWING THE ANALYTICAL STUDY OF THE MODELS UNDER STUDY [RESEARCHER]

| Case studies | | Case (1) Bund Finance Center | Case (2) Sharifi-ha House | Case (3) Mercedes Benz Stadium |
|---|---|---|---|---|
| Study areas | |  |  |  |
| site | | Shanghai, China | Tehran - Iran | Atlanta, Georgia, USA |
| Architect | | Foster + Partners, Heatherwick Studio | NextOffice -Alireza Taghaboni | tvsDesign in collaboration with HOK, Goode Van Slyke Architechture, and Stanley Beaman & Sears |
| year | | 2017 | 2014 | 2017 |
| Job | | Art and Cultural Center | residential building | football stadium |
| Area | | 420,000 m2 | 1400 m2 | 5793 m2 |
| concept | | The Bund Financial Centre is famous for its three-tiered kinetic façade. Inspired by traditional Chinese theater curtains, each rotating layer of this façade consists of vertical bronze-colored stainless steel tubes. Powered by electric motors, these curtains hang from the third floor and rotate around the building for several hours, accompanied by music.[31] | The house mimics ancient Iranian houses, opening up to provide light, ventilation, and spacious balconies in the summer. In the winter, the house closes in to Tehran's harsh, cold climate, creating small openings to conserve heat. [32] | The building is considered a cutting-edge architectural concept due to its technological advancements. The stadium features a system that allows for increasing or decreasing the number of seats. It also houses restaurants, cafes, shops, and hotels. The building also features a retractable roof that opens and closes at record speed. [33] |
| Adaptation level | | Totally | Totally | partial |
| movable structure | | Exterior cladding (curtain wall) | Rotation of blocks | ceiling |
| Motivation to use kinetics | | Controlling high solar radiation protection for the purpose of shading spaces inside the building. | Design flexibility to adapt the building to the external environment. | Visual comfort (glare protection) for users and protection from weather elements such as storms, rain, etc. |
| Movement pattern | | Rotation and sliding of the curtain facade | rotation | Sliding and rotating for covering system |
| Control method | | electronic | electronic | electronic |
| kinetic architecture and human needs | | | | |
| **Physical needs** | thermal comfort | The fluid movement of the layers, inspired by theatre curtains, provides thermal comfort within spaces as a result of the external shading of the facade. | The rotation of the building masses contributes to achieving thermal comfort inside the building throughout the seasons. | The eight petals move to close the roof when temperatures rise, and the facade is made of insulated metal panels and ETFE panels, which reduce interior temperatures. |
| | shading | Shading is achieved by the curtain around the outer facade of the center. | The shading of the building can be checked by rotating the box blocks. | Shading is increased by the closing of the petal units in the covering. |

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| | | | | |
|---|---|---|---|---|
| | Ventilation | Ventilation is achieved through the gaps between the units and their lengths, which range from 2 to 16 m, allowing the air entering the building to be filtered. | The handrail details are designed so that air penetration is controlled by the folding handrail design. | The material used in the roof construction is ETFE, which is resistant to pollutants, dust, and chemicals in the air. |
| | Humidity | Humidity can be controlled by controlling temperature. | The ability of the building to close itself off allows for a moderate humidity level. | Humidity can be controlled by controlling temperature. |
| | visual comfort | The brightness level can be controlled by moving the units used on the facade, which contributes to achieving visual comfort. | Achieving an appropriate lighting level through the movement of building blocks. | The roof opens to allow sunlight in and closes to protect from glare. |
| | Acoustic Comfort | This is achieved through the fluid movement of the curtain wall. | This is easily achieved when the building rotates and closes. | It does not represent a necessity for the nature of the project. |
| | Wind and Storms | The ability to change the level of the movable facade through wind sensors contributes to protection against unwanted winds. | The building can be closed automatically, which contributes to protection from winds. | The possibility of closing the roof petals contributes to protection from the wind. |
| | change function | Changing the shape of the moving facade does not contribute to the function of the building. | The rotation of the blocks creates variable interior spaces that facilitate different activities. | Building operators can easily reconfigure the building to accommodate activities. |
| | energy generation | A significant amount of energy used for lighting and ventilation is saved from being used in industrial processes required for lighting and ventilation. | A certain amount of energy is saved that would otherwise be consumed in processing lighting, heat, etc. | The building saves 40% of energy consumption compared to typical stadiums, and the site contains more than 4,000 photovoltaic panels capable of generating 1.6 million kilowatt-hours annually. |
| Un Physical needs | External Views | Communication between the indoor and outdoor environments is provided by the control systems used for the curtain wall facade, which allows for sliding units. This allows for a quality view of the exterior through the building's surroundings. | Communication between the indoor and outdoor environments is provided by control systems used to control the circulation of the building's masses. This allows for a quality exterior view through the building's perimeter. | Communication between the indoor and outdoor environments is provided by control systems used to close and open the roof covering, creating views of the sky and the landscape. |
| | Element of Beauty | The fluid movement of the glossy magnesium exterior gives an aesthetic sense of a moving facade. | Converting the 2D interface to a 3D interface achieves more mass excitement. | Converting the 2D interface to a 3D interface achieves more mass excitement. |
| | Privacy | Ease of privacy control due to the ease of controlling the movement of the external interface units. | Ease of privacy control due to the ease of rotation control of the block. | Depending on the nature of the activities being carried out, the building does not require privacy. |
| | safety | A matrix is designed that can be used by the automatic control system to control the movement of the curtain wall. | By using rotating discs and using moving handrails. | A matrix is designed that can be used by the automated control system to control the movement of the roof. |
| | Social and Psychological Aspects | The exterior view provides a positive aspect for psychological comfort and the intellectual and cultural cohesion of the community, reflected in the external formation of the facade, in addition to its contribution to achieving all the thermal comfort requirements of users within the spaces. | It provides psychological comfort due to the building's external view, ventilation, and natural lighting. | The availability of daylight and outdoor views creates user interest and drives away boredom. |
| | Belonging and Identity | The idea of the curtain facade is related to traditional Chinese stage curtains, and resembles an ancient Chinese crown. | The opening and closing of the building is a reference to traditional Iranian houses. | The appearance of the Mercedes logo when the roof is closed gives the feeling of belonging. |

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## 13. RESULTS OF THE ANALYTICAL STUDY

By presenting the analytical study of the projects under study and the extent to which human needs criteria are met through the application of kinetic architecture, the following is observed:

- Many human needs are met through controlling the movement of the building's outer envelope.
- Emphasis is placed on kinetic architecture models to optimize their use in saving energy used for lighting and ventilation.
- Achieving direct or partial external views.
- Emphasis is placed on achieving psychological and social comfort by addressing the diverse needs of users and linking buildings to the identity and ideology of the surrounding urban community by enriching the human mind's mental image of the place and the built environment.
- Achieving control and control over the kinetic of various building elements through mechanical or manual operating systems.
- Achieving direct or partial external views.

## 14. RESULTS

- Kinetic architecture offer architects and designers powerful tools for creating buildings that are not only visually captivating but also environmentally responsible and human-centric.
- Design criteria for evaluating kinetic buildings can be derived by studying the relationship between kinetic architecture and changing human needs. The derived criteria can be applied to evaluate kinetic buildings and the extent to which they meet these changing human needs. From this, the kinetic building's integration rate can be derived based on the fulfillment of a number of human needs.
- The design of interactive kinetic buildings can combine the character, function and idea of the building with achieving the maximum efficiency of the building during its operation in terms of (thermal comfort - interaction with changing humidity levels - achieving shading - achieving ventilation - protection from winds and storms - visual comfort - acoustic comfort - the possibility of changing the function - generating and saving energy - providing an external view - achieving the element of Beauty - achieving privacy and containment - achieving security - emphasizing the psychological and social aspect - emphasizing belonging and identity).
- Kinetic architecture embodies the dynamic potential of contemporary architecture, improving energy efficiency and user requirements by activating spaces and fostering vital connections.
- The importance of kinetic architecture lies in its ability to meet changing human needs in response to various environmental changes.
- The effectiveness of kinetic architecture is achieved through the amount of interaction and change with the surrounding environmental conditions and with the users, not by the amount of technological application in buildings without interaction and adaptation.
- The effectiveness of a kinetic building is determined by the extent of its change and interaction with environmental conditions and users, not just the amount of technology available.
- In designing buildings based on kinetic architecture, the design requirements of the building can be combined with the achievement of the highest standards that ensure maximum efficiency of the building during its operation, in terms of the various requirements of the users inside the building.

## 15. CONCLUSION

It can be concluded that the general development of interactive movement in kinetic architecture is moving toward interaction with environmental changes, such as daylight, wind, and sound, without neglecting interaction with humans. Therefore, architects must consider the radical changes in the field of interactive architecture, as the design of interactive kinetic buildings can combine the character, function, and concept of a building while achieving maximum building efficiency during operation in terms of (thermal comfort, interaction with changing humidity levels, shading, ventilation, protection from wind and storms, visual comfort, acoustic comfort, the possibility of changing functions, energy generation and saving, providing an external view, achieving aesthetics, achieving privacy and containment, achieving security, emphasizing psychological and social aspects, and emphasizing belonging and identity). Another conclusion of the study is that it is not necessary to move large parts of a building to be kinetic; rather, the concept of kinetic architecture can be achieved by moving small parts together. However, developments in materials and interactive applications in buildings facilitate and simplify this process. Kinetic architecture not only adds aesthetic beauty to architecture but also plays an environmental role by protecting the building from sunlight and improving its functionality.

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