# A REVIEW ON THE APPLICATION OF KINETIC ARCHITECTURE IN BUILDING FACADES

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**Abstract:-***Technology influences the fields of Communication, Manufacturing and Production, Automobiles and the Building Industry. Architectural technology widens its influence from the earlier design stage, execution and post occupancy maintenance .The technological development leads to the application of Kinetic technology in Architecture which results in Interactive architecture which plays an increasingly key role in today's scenario. The Interaction /Response can happen at any level either with the environmental/climatic factors such as light, temperature, wind, sound, touch or with occupant/user needs. According to the varied functions the mechanism also varies. Conventional Buildings with Static envelopes are responsible for maximum Energy consumption and Greenhouse Gas emissions. A building envelope must be adaptive to external stimuli & function without human interference and should become energy efficient and as energy Generators. This paper attempts to review the literature & descriptively analyze the interactive application of kinetic architecture (methods and systems) and its applications, by the comparative analysis of various buildings (case references & live study). The need for future development in kinetic façade technology had also been discussed.*

***Key Words***: Kinetic Architecture, Building Envelope, Energy Efficiency.

## 1. INTRODUCTION

Cities and towns around the world have static dwellings, which are the dominant model for the societies and based on the principle that dwellings should be stationary. But kinetic architecture refers to the idea of change over time. Throughout the architecture history, we have been concerning the facade treatment for a much pleasant visual impact to the public. But what pushes its own boundary now, is how we make the facade more than just a static vertical architectural element.

What if a facade functions more than just an envelope of a building? What if a facade responds to climate, technology, sunlight, or even natural element such as wind? What if a facade can constantly react to the surrounding and forms a pattern of movement by itself? What if, a "dynamic facade" proposal that could respond to the environment and minimize the energy consumption?

## 2. BACKGROUND STUDY

### 2.1 Why Kinetic?

KINETIC -Greek word κίνησις Kinesis meaning "Motion". FACADE –French word façade meaning "Exterior side of the building".There are just three main reasons for applying motion in buildings. The first one is of visual means. The second reason is to control or influence the climate inside buildings. The last reason is to improve the spatial functionality.

### 2.2 What is Kinetic Architecture?

Kinetic architecture is an integration of form and technology that has inspired from nature and geometric complexity in buildings should not neglect the need of better energy efficiency performance.

### 2.3 Benefits

Facade defines not only building appearance and its architectural expression, but also how well it functions. The success of a building is measured in terms of technical functionality with regard to comfort, pleasant ambience, and sustainability. Hereby façade play an important role in building as it sets a TONE for the rest of the buildings.

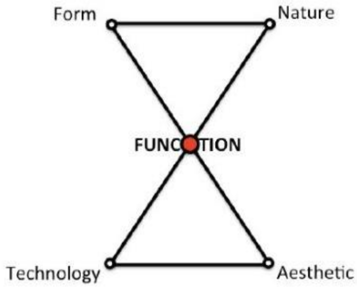



**Fig -1**: Benefits of Kinetic Facade

### 2.4 Evolution Of Kinesis

The invention of wheel was the motive of using kinesis in architecture. Adaption and mobility were first seen architecturally as movable stones, logs or skins covering cave or hut openings. Colloseum is the first kinetic retractable roof (pepe,2001). Movable bridges were first used for protective purposes. The draw bridge which was usually a Bascule type that pivoted upward on trunnions was commonly used in that era. Mechanisms of these bridges movement was by direct pull of chains near one end, assisted by winches and levers. Bascule bridges were developed in 16$^{th}$ century by Leonardo da Vinci. Moreover kinetic structures will differ from conventional structures from both shape and materials. As technology develops methodology of constructing buildings also changes from movement of floors to entire structure as shown in figure.

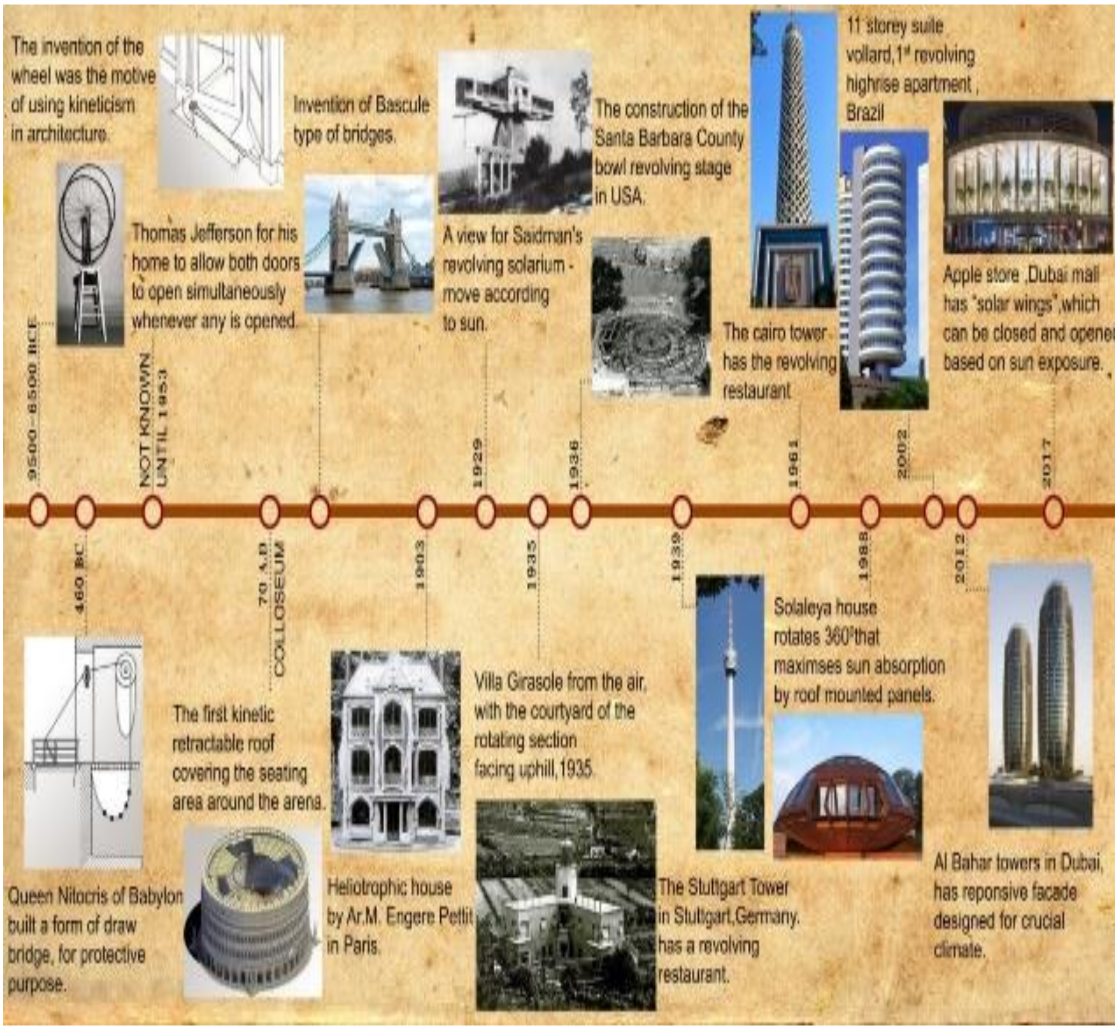



**Fig -2**: Evolution of Kinetic facade

### 2.5 From 'Invariable, Static, Generic' to 'Dynamic, Adaptive, Responsive, Customized '

The facade forms the zone of the building that protects the inside of the building from outside as a shelter and at the same time mediates the interaction between the two.

| Static | Kinetic |
|---|---|
| Constructive elements do not change their structure. | Does not show higher<br>• Air tightness<br>• Thermal insulation |
| Features, Properties, Functions are immutable. | Maximizes solar hear gain. |
| Uses large amount of energy. | Uses less amount of energy. |

## 3. LITERATURE REVIEW

The Review was carried over the Buildings that have been designed with the integration of Kinetic elements/facades, across the world.

### 3.1 Al Bahar Towers

An inspiration from the 'Mashrabiya' is The Abu Dhabi Investment Council Headquarters, **Al-Bahr Towers**,

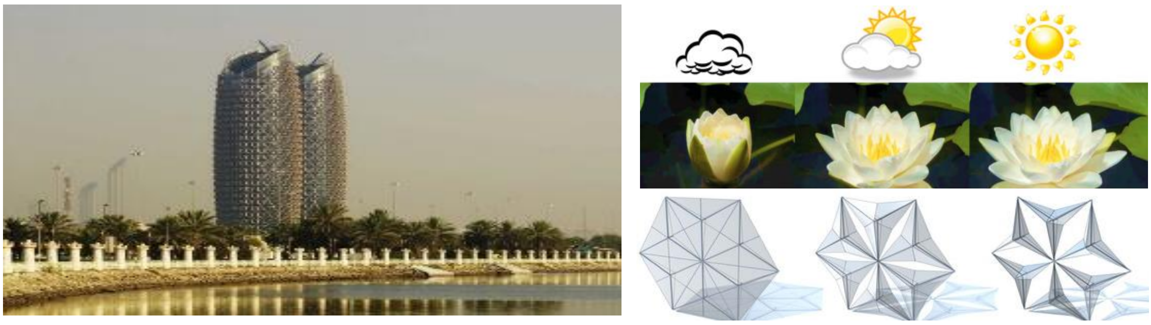
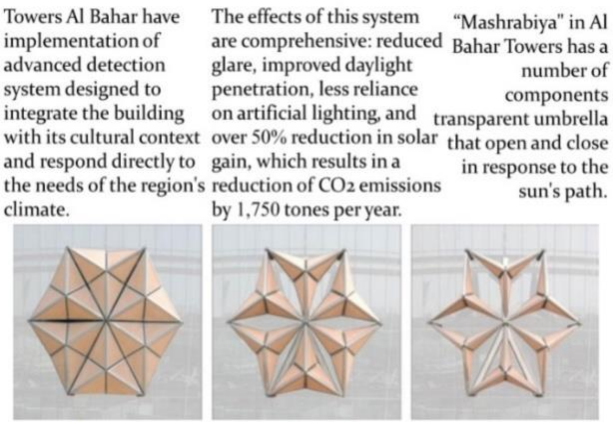


**Fig -3**: Evolution of Kinetic facade

designed by Aedas architects and Arup engineers. It consists of a shading system of PTFE clad Mashrabiyas.This is Modular, dynamic, solar shading which has 1049 modules per tower. Origami Umbrellas, Open and close in response to movement of the sun-to optimize the solar exposure of the façade. It is stated that, 'the system is predicted to reduce the solar energy entering the building by 20% and is one of a number of innovative measures to improve environmental performance and limit energy use. They also claim that the design has resulted in 40% saving in carbon emissions. Abu Dhabi has hot desert climate. June - September are extremely hot and humid –max. Temp >45 °C. Battle against sun's heat, mostly with air conditioning.



### 3.1.1 Visibility and Lighting

It is stated that in an office building needs 250 to 2000 lux for working conditions. It is designed in such a way that light sensors located at the perimeter of the ceiling near the curtain-wall read lower than 250 Lux, dimmers linked between the sensors and artificial lighting are activated to maintain the required comfort threshold.


**Fig -4**: Solar analysis

This figure illustrates the facade opening and resulting improvement in energy performance during mid-season at 9:00 am. The north face experiences direct solar rays only for a short time in the morning and later in the afternoon, i.e. before and after working hours. Shading units in the North zone was therefore unnecessary.

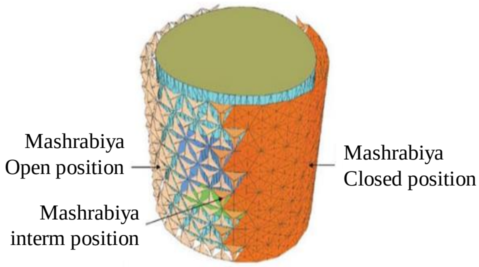
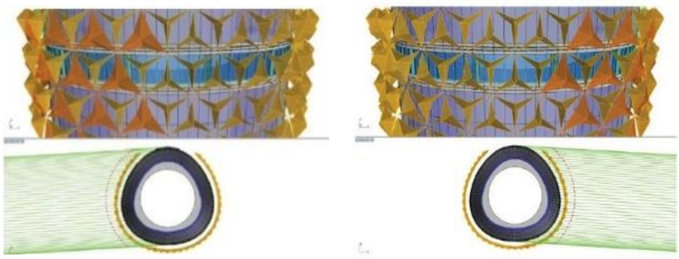



**Fig -5**: Various positions in shading analysis

### 3.1.2 Shading Performance

Based on optimized categorization of solar rays.

1. If solar rays land on the curtain-wall between **00** and **79** degrees. **Un-folded configuration**–Require full front cover.
2. If solar rays land on the curtain-wall between **80** and **83** degrees. **Mix-folded configuration**-Require partial front cover. (Partial views).
3. If solar rays land on the curtain-wall greater than **83** degrees. **Fully-folded configuration**-No front cover, Maximum unobstructed views.



Time: 13:30, 79 < Sun-Angle < 83◦ Time: 09:07, 79 < Sun-Angle < 83◦.

**Fig -6**: Shading performance of the facade

### 3.1.3 Control Mechanism

LINEAR screw-jack actuator & electric motor-triangular facets, fold into center-preprogrammed sequence. Limits direct solar gain to maximum of 400 watts/m.Embedded pre-set programme simulate the movement of the sun and deploys the Mashrabiya units in corresponding folding configurations.The forces exerted by the actuator are self-equilibrated & are not transmitted to the support structure.

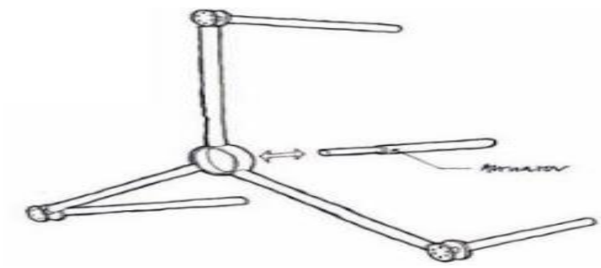


**Fig -7:** Controller (Actuator) unit in mashrabiya

1. Automatically by (BMS) that computes the state of each module in response data which is sent (light & anemometer sensor for measuring wind speed.)

2. HMI allows manual intervention of the operator in case of emergency.

3. Each unit has a unique location & ID on the screen-linked to positioning sensors located in the actuator of each unit.

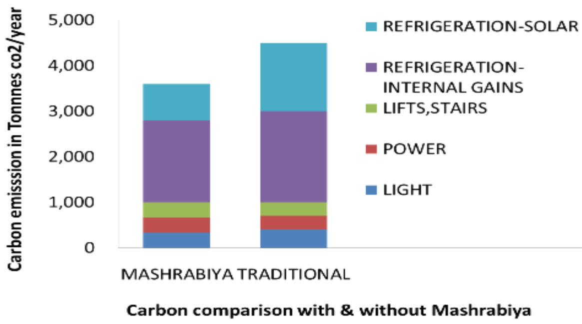



**Fig -7:** Comparison with and without Mashrabiya

Each module-façade varies smoothly between the open and closed states, allows to obtain optimal balance-outside conditions and interior requirements throughout the building's floor plan.The software is linked to three main sensors located at the top of each tower for sensing Light, Wind, and Rain. The system offers live feedback to the operator including wind speed, light intensity, rain levels, faulty units and their folding positions. This feedback is used to override the pre-set programme and to move the units into mid-fold position in the event of unusual conditions, like a storm.

### 3.1.4 Benefits

1. 50% energy savings-office spaces alone, & up to 20% for the building overall.

2. 20% reduction in carbon emission with up to 50% for office spaces use alone(reduction in AC & lighting usage).

3. 15% reduction in overall plant size and capital cost.

4. 20% reduction in materials and overall weight due to the highly fluid, rational and optimized Design.

5. Better naturally lit spaces through better admission of natural diffused light.

6. Better visibility of external natural views, less use of obstructive and psychologically trapping Blinds.(decreased glare)

### 3.2 Keifer Technic Showroom

First type is the "user-control dynamic facade", the Kiefer Technic Showroom by Ernst Gieselbrecht + Partner, a built project located in Steiermark, Austria (2007). "The way the dynamic facade works is through electronic controls within the building that can individually control each of the 54 motors within the facade. It is a simple technology which does not include any type of responsive system and responds only to the use input from the building occupants." The facade itself is functioning as a shading device but given the users to control the angle of the panel, and amount of light transmitted into the interior space.

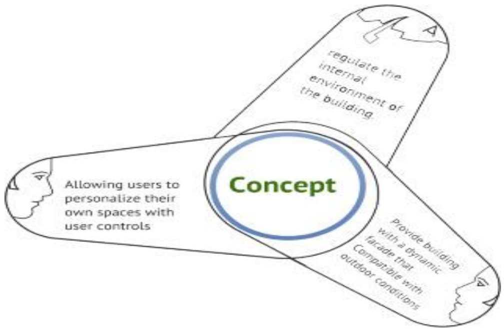



**Fig -8:** Concept of Keifer showroom

#### 3.2.1 Façade –Design Element

On the south side, a double skin façade is located. Façade consists of 2 layers, static one made of polygonal glass and a dynamic one located in front of it. This building creates a work environment. Kineticism in façade element allowing the building to respond to different conditions-includes environmental changes, individual desires and different activities that may take place within the building.

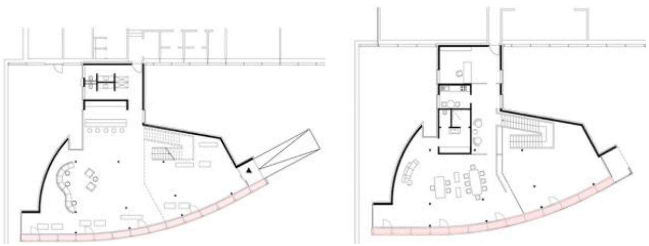


**Fig -9:** Planning (façade highlighted)

The façade is made up of 122 Aluminium Panels which is the main cause for the movement. The facade mechanisms were advanced due to the availability of electrical components and controls in the 1960s.In 2007, the responsive facade of the Kiefer Technic Showroom by Ernst Giselbrecht (Khoo, 2013) was designed to optimize internal climate situations based on outdoor environmental conditions, users' preferences and facades' appearance appeals.

**Fig -10:** Movement pattern of Facade

### 3.2.2 Reason for Motion

Installed to control-indoor climate & light.56 Different engines-level of light and temperature can be adjusted in any room to achieve optimal conditions for different activities. The façade responds to both environmental conditions and individual needs.

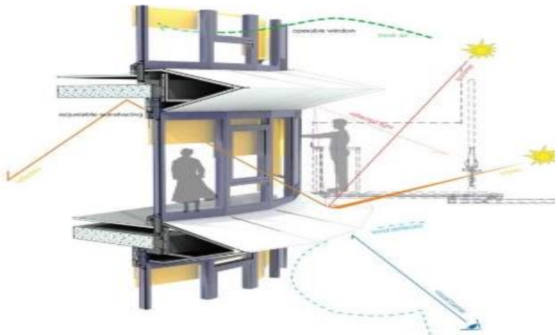


**Fig -11:** Application of Motion

### 3.2.3 Rotating panels Facade

They Used 122 rotating panels-expose and seal the building. Panels are attached to motors fixed at each bay, allowing to rotate in various patterns. It runs in vertically direction along the east & west, and runs horizontally along the south. Architect afforded privacy and transparency by installing a moveable cladding on the entire southern façade of the showroom. This cladding made it easy to realize the transparent façade while maintaining the cozy atmosphere in the rooms.

Insulated space

Activated space

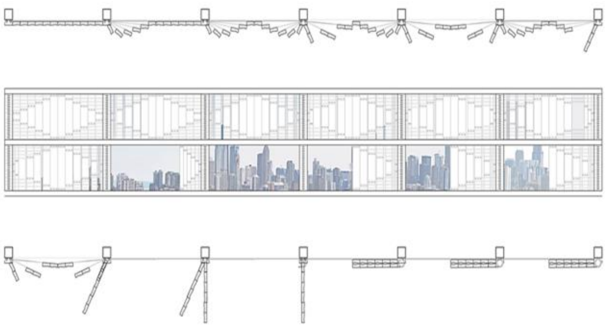


**Fig -12:** Rotation of Panels and its application

### 3.2.4 Building Visual Quality

Adding movement to building façade turned into a kinetic sculpture that continuously present new faces-infinitely changeable and programmable position patterns.The architect used a Kifertechin technology in the dynamic façade adding an extra privilege to the showroom by turning it to an eye catcher advertisement for the services as well as the quality the company is capable of presenting.

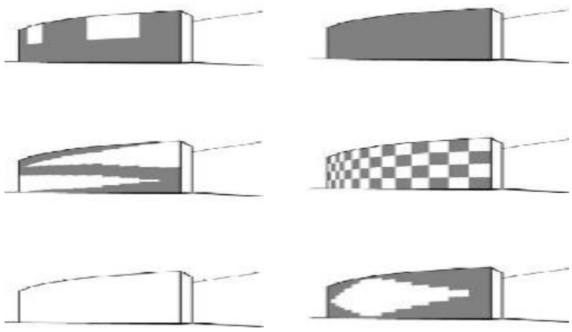


**Fig -13:** Solid void relationship

### 3.2.5 Indoor Environment Quality

Creates comfortable indoor environment as it works as a sun protection as well as light and temperature regulator.


### 3.2.5 Control Mechanism

Aluminum panels of the dynamic façade are moved though a complex system of hinges, guide rails and electrical motors.It is programmed to move automatically or controlled manually.

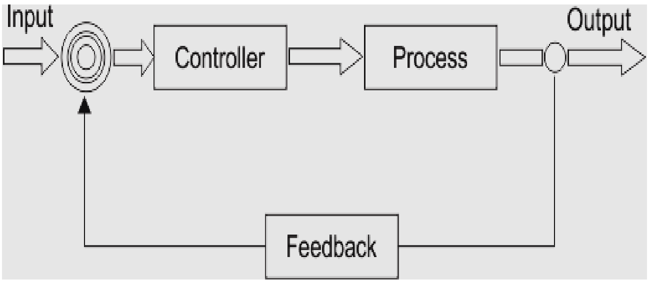



**Fig -14:** Control Mechanism

### 3.3 Q1 Building ThyssenKrupp Quarter

Thyssenkrupp is a company with a history stretching back over 200 years and many good traditions.Rising 165 feet, and standing at the head of a long reflecting pool that leads some 980 feet to an access road, the headquarters building (otherwise known as Q1) is the clear center of operations on campus.

**Fig -15:** Thyssen krupp Q1

A complex sun shading system makes the lack of air conditioning possible in the glazed structures. Stainless steel louvers and fins open and close based on the sun's path to maximize views out, while reducing glare and cutting down on heat gain. But the sun shading system—with its triangular, square, and trapezoidal fins—also serves to give the campus buildings their signature appearance.

### 3.3.1 Façade Design Element

Nano particles treatments applied to intelligent façade systems-capacity to neutralise airbourne pollutants, capture CO2 and clean the air around each structure.Façade-react to environmental factors- Temperature, wind patterns, atmospheric moisture levels, & sunlight-optimal thermal comfort for the inhabitants, Make maximum use of renewable energy production opportunities.

### 3.3.2 Geometric Composition

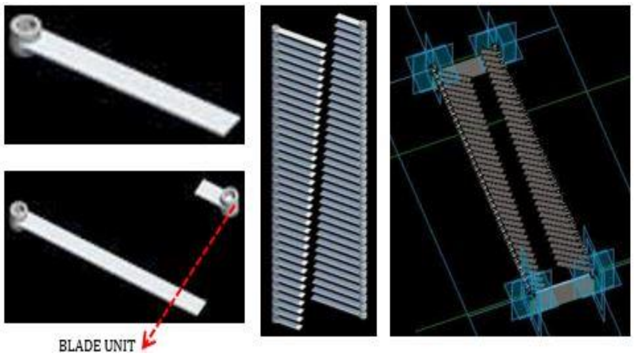
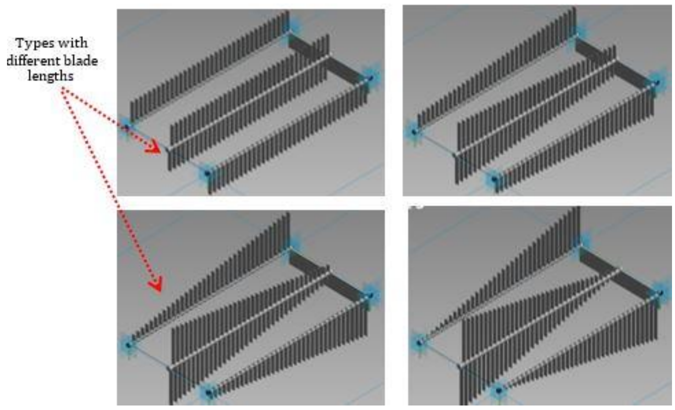



**Fig -16:** Geometric Composition

A pair of the blade unit are put together to form pattern. Pattern on the façade is of size 3' x 12'-series of blade length which can be changed(arithmetic progression).A pair of the blade unit will Rotate symmetrically.Angle, slopes, dimensions are changed for required movement of lamellas or slats.For proper movement Sun angles are calculated and specified rotating angle is specified. Angles are repeated 12 times, since there are 12 units on each side-building.




### 3.3.3 Façade-Lamella unit

The façade is made of 3 layers: The thermal layer special enclosure made of glass. The inner is given a textile for glare protection.The outer layer is made up of a sun screen.

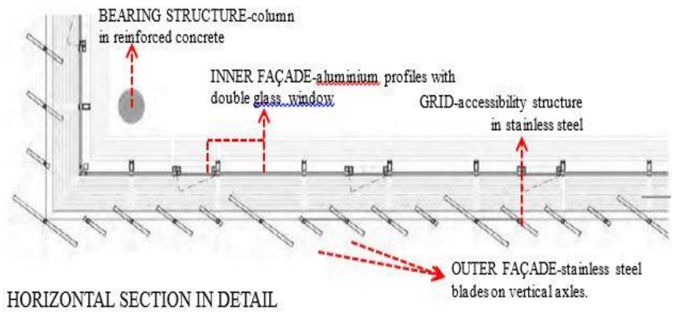



**Fig -17:** Horizontal Section in Detail

This lamellas are Used in Traditional method since shading elements act on the principle of Physical shading by obstruction, introducing adaptiveness of the system. GRID system acts as fixed shading for periods when sun is high in sky, & as catwalk with width of 50cm allows windows to open and maintenance of façade.

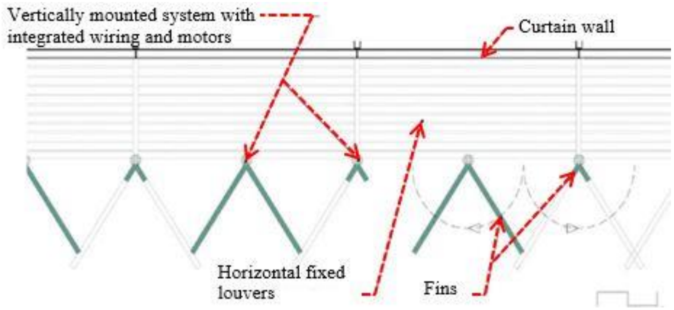



**Fig -18:** Sun shading system in section

Both shading system and curtain wall is fixed to concrete slab on each floor through steel profiles. Movement is versatile in single blind panel but folding not possible. Maximum sunlight is achieved by single panel also.

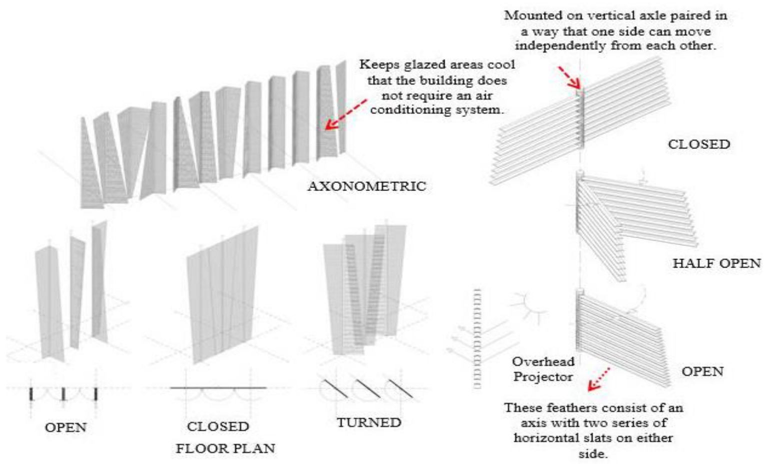



**Fig -19:** Shading units

### 3.3.4 Shading Performance

Individual elements perform various operations:

1. If solar rays land on the curtain-parallel to the thermal glazed envelope.FOLDED CONFIGURATION–Require full front cover.
2. The rays hitting the curtain wall at various location of the sun. VARIABLE CONFIGURATION-Variable perpendicular to the angle of sun.
3. Solar rays land on the curtain perpendicular to thermal glazed envelope the horizontal louvres intertwine over a double-axis, OPEN CONFIGURATION-Max.unobstructed views.

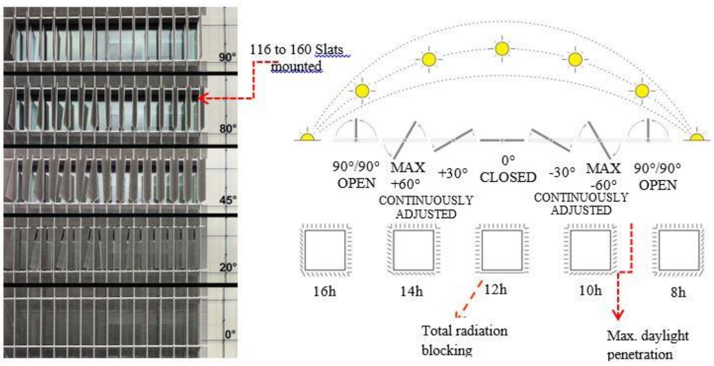



**Fig -20:** Moving pattern of Facade

Cantilevered fins at each side of the stud can twist independently, as arms that rotate from widely open (0º) to parallel and intertwined (90º).While talking about the movement of the shading system, it is directly connected to the presence of sun. This means the system is idle in night time and is continuously being adjusted during the day.

### 3.3.5 Control Mechanism

The double axle to which the slats are attached is driven by a linear motor. Slats rotate around-vertical axis and follow the sun's position.400,000 metal “Feathers” anchored to 3,150 routered stainless steel movable stalks controlled by totally 1,280 motorized elements. It automatically controlled by Building Management System (BMS)-according to the response to data sent.

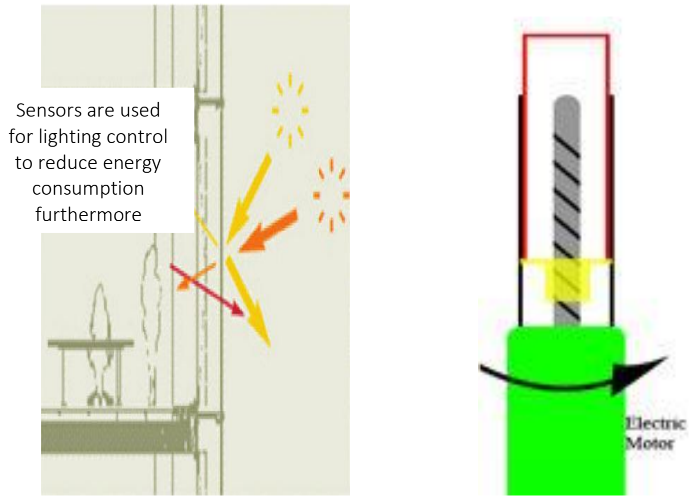



**Fig -21:** Controllers and Motor

Two factors influence movement:

1. Seasonal movement - Sun
2. Real time measurement –Roof which sends data to Meterological station (detecting Weather condition, Position, Radience).

Combined and preprogrammed which directs linear motors located on Grid, one per every two axles causing the movement of both pair of blinds on each vertical axle.

### 3.3.6 Visibility and Lighting

Both measurements have been done with shading completely closed to verify values during the maximum protection from the glare and sunlight. Comparing to the office standards which demand 500 lux for the work area. But the illuminance recorded is 0-400lux. This means additional lighting might be needed during the closure of the façade. However it is worth noticing that shading blades are designed to refract the sunrays towards the ceiling which would add to overall illuminance and might not be truthfully represented in 3D analysis.

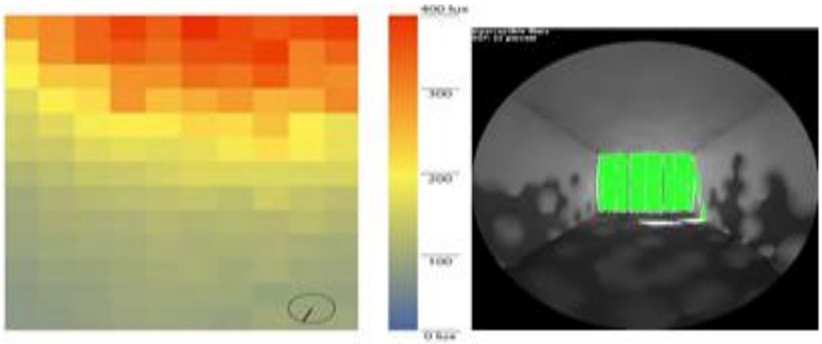


**Fig -22:** Lighting analysis

### 3.4 Moving Landscape Bidaser House

**Fig -23:** Bidaser House

From the concept of merging an age old tradition of joint family living has disintegrated into small nuclear families. Despite this change of cultural attitude in the present Indian context, a large number of families, bound by family business and obliged by traditional ingrained values, still choose to live together they continued, where it arises Moving Landscape Bidaser house by Gurjit Singh Matharoo.

### 3.4.1 Planning- Conceptual

Plan of the house-a linear pavilion,-every space-lined with glass on the facing sides - it's the first enclosure.The rest of the structure is in 200mm thin walls in concrete, eliminating the need for any beams and columns and making for cleanest interior volumes.

Additionally, this saves constructed dead space by about 3% and for the 18,000 total covered area, this equals to 540 Sq.ft or the size of an average sized room. The second enclosure is a layer of massive 15' high, 9'wide & 1'foot, 6"thick Bidasar stone walls along the entire perimeter-an impregnable shell.

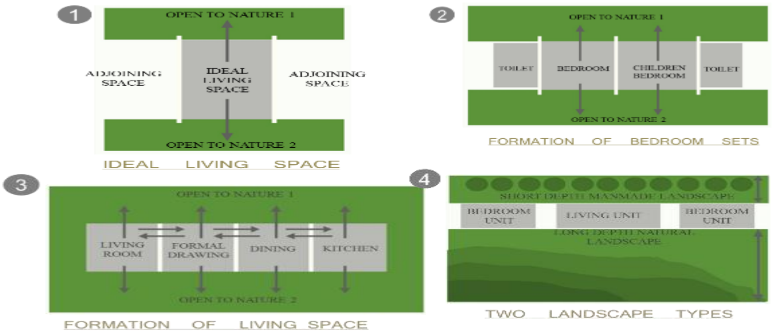



**Fig -24:** Planning

### 3.4.2 Façade –Design Element

On some walls, two tiers of panels pivot in alternate directions, while other walls feature panels that slide back and forth.Totally 63 moving walls surrounding the house serve dual purpose in summers when they create local pockets of shade that bring the overall ambient temperature down.East West facing-Pivoting & Sliding wall (4.5m height).South East & North west - facing Sliding wall on 2 floors (3m height).Other interior faced- Pivoting wall on 2 floors (3m height).

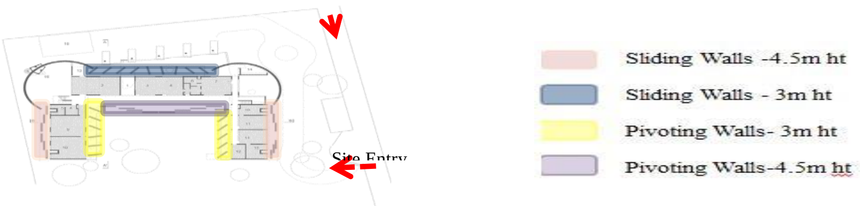



**Fig -25:** Façade Location and height

### 3.4.3 Façade –Detail

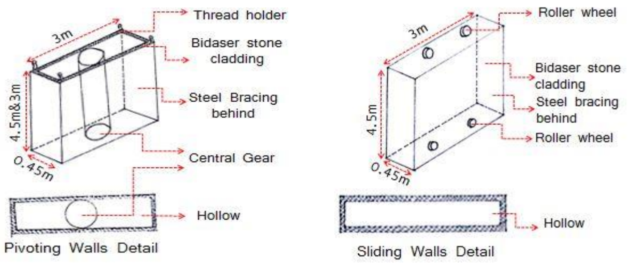



**Fig -26:** Details of the facade

The above fig shows the detail of the façade unit in which the stone is pivoted and slided through GEARS and MOTORS respectively. These two are hollow inside in which stone is cladded on steel braces on all 4 sides with gear placed inside and rollers on pivoting and sliding respectively.These are the Stone Screens that run along exterior of the house.

### 3.4.4 Reason for Motion

“Impregnable shell” installed to vary the amount of light, ventilation and privacy in home. Facade panels-creates-buffer between the inside & outside, protecting the inner layer shell of concrete and glass from intense sunlight and 45°C heat, thereby reducing first the area to be air conditioned allow cool evening breezes to waft through.

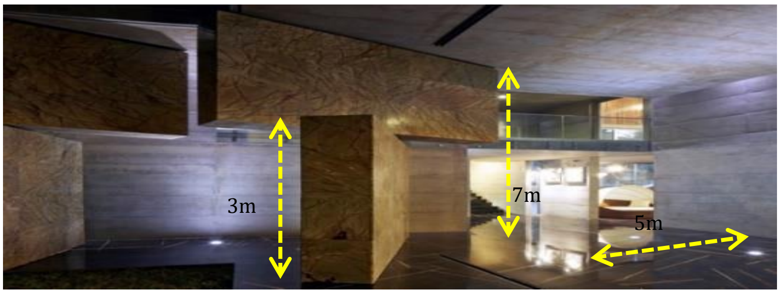



**Fig -27:** Movement of Facade

### 3.4.5 Control Mechanism

Stone walls of the house are Pivoted or Slided by using remote control according to the need. The Engine room system and the building blocks of the building are all hidden, making them more attractive (BMS-Building Management System).Transmitter-(LED) is built into the pointing end of the remote control handset. Infrared light pulses form a pattern unique to that button. The receiver in the device recognizes the pattern and causes the device to respond accordingly.


**Fig -28:** Controller and movement

### 3.4.6 Sustainable Feature

Besides heat reduction, the house is a simple optimal construction in fair finish concrete. While performing a reasonable function, the embodied energy of concrete is actually only 1/15 of that of stone while being almost as inert and long lasting. In order to provide the same structural strength, earthen materials must occupy as much as nine times the space of concrete. So, concrete and steel fare hugely better than earth, brick and stone.

### 3.4.7 Benefits: Quantitative & Qualitative

The space doubles up as passages, verandahs entrance vestibule and circulation space-protection from rain, eliminating the need for air-conditioning. This saving is substituted with enhanced living and direct contact with nature in what we term as Value architecture**.**

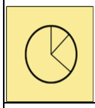
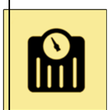
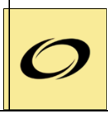

**Fig -29:** Thermal value

It improves user comfort, physical and psychological well-being of occupants. It gives virtual identity to the residence and it naturally lit spaces through better admission of natural diffused light. It gives very good visibility to external natural views of landscape. Improved comfort by reducing heavy air conditioning loads.

**Fig -30:** Plan drawn by Ar.Gurjit singh matharoo

### 4. COMPARITIVE ANALYSIS

| | | | | | |
|---|---|---|---|---|---|
| GENERAL INFORMATION | Name | Al-bahar towers | Kiefer technic Showroom | Thyssen Krupp Q1 | Moving landscape Bidaser House |
| | Image |  |  |  |  |
| | Completion year | 2012 | 2007 | 2010 | 2012 |
| | Architect, Location | Aedas architects, Abu-Dhabi | JSWD Architekten + Chaix& Morel ET Associates, Bad Gleichenberg, Austria | Ernst Giselbrecht + Partner ZT, Germany | Gurjit Singh Matharoo, India |

| | | | | | |
|---|---|---|---|---|---|
| | Type | Office | Office & showroom | Office | Residence |
| KINEISM IN BUILDING | Kinetic elements | Aluminium & Duplex steel Sheet | Aluminum Panels | Steel Louvers | Bidaser Forest Stone |
| | | Whole exterior | Elevation elements | Whole Exterior | Whole Exterior |
| | Reason For Motion | Environmental – light control | Environmental – light control | Environmental – light control | Environmental – light control |
| PRINCIPLES OF MOVEMENT |  | Mashrabiya screen can trace the path of the sun over the course of a day and a year. | Facade changes EACH DAY, EACH HOUR showing new faces | Facade changes according to the movement of sun position | Spinning & pivoting wall take 30 sec. of time for one rotation /sliding. |
| |  | It has two degree of movement and visually creates a balance. | It has single degree of movement and visually creates a balance. | It has Two degree of movement and visually creates a balance. | **SLIDING** 2 DEGREE of Movement **PIVOTING** 3 DEGREE of Movement |
| |  | The screen surface moves with a predetermined-speed and harmonious acceleration. | The screen surface moves with a predetermined-speed and harmonious acceleration. | The screen surface moves with a predetermined-speed and harmonious acceleration. | **PIVOTING** The speed is fixed while setting Gear and it have constant speed. **SLIDING** Acceleration is also predetermined during construction itself. |
| |  | These are rigid materials made of (PTFE), creates a serial repetition. | These are rigid materials made of aluminium panels, | These are rigid materials made of Steel Slats | These rigid materials have serial Repetition along faces of the building. |
| |  | ---- | ---- | ---- | Wall cladding is light weight visually as it is hollow inside. |
| |  | It is complex visually and during construction | ---- | ---- | ---- |

| | | | | | |
|---|---|---|---|---|---|
| | | ---- | It shows mysterious effects for passers by. | It creates a various movements which gives interactive movement | ---- |
| TYPOLOGY OF MOVEMENT | | Rigid elements, which expand and contract according to sun rays. | Rigid elements, which expand and contract according to sun rays. | Rigid elements, which Open and Close contract according to sun rays. | Rigid elements, which move according to the user need. |
| PRINCIPLES OF MOVEMENT | Actuator | LINEAR screw-jack actuator & electric motor-triangular facets, | By GUARD RAILS AND CARRIAGES, | By VERTICAL Actuator | By GEARS and MOTORS |
| | | Pre-programmed sequence | Pre-programmed sequence And By user also | Pre-programmed sequence | Remote Control |
| | Materials | Frame –combo of aluminum and duplex stainlessteel, Unit is made up of PTFE and mash is with fiber glass coated with Teflon. | Combo of aluminium panels, stainless steel and glass | combo of Stainless steel and combo of chromium- nickel-molybdenum | WALLS-combo of Bidaser stone and steel frame(bracing) & Glass inner façade. |
| | Control Systems | Indirect Control | Indirect Control | Indirect Control | External Control |

## 5. TO CONSIDER

Architectural and sustainable strategy must go hand in hand in the design of the façades of buildings, and both passive and active design thinking should inform this process.

In addition to facilitating views and the appearance of the building, each façade (and each part of that façade) can contribute to

1. Daylight,
2. Solar control,
3. Energy generation,

Insulation and/or thermal buffering according to its exposure to sunlight and daylight (daily & seasonal cycles) on a three-dimensional grid.

In addition to the façade systems which automatically open and close vents and blinds according to the weather, each part of the façade plays its part in several aspects of building physics according to where it is.

## 6. RECOMMENDATIONS

Factors to be considered for the **Design of dynamic facades**,

1. Integrating different aspects of façade performance
2. Integration between the building and its occupants
3. Integrating the façade and the available technology.

To improve the quality of the architectural environment, KINETIC ARCHITECTURE can be the solution to create environmental friendly, safe, organized, enjoyable and adaptable environments.

Simple Kinetic systems -developed involving researchers-variety fields. These systems-designed using local materials & systems that suites that particular place.

Material deformation will be effective, if the properties and the life span of the materials are improved. Experiments-to produce a best solution.

Comparing Kinetic elements with whole dynamism,It is achieved through elements which is affordable as well as sufficient and sustainable.

India is a tropical monsoon climate. Climate- varies places all over india.In the case of delhi, the summer and winter are extreme. Hence dynamic/kinetic elements that responds to heat as well as cold will be effective. In case of places where there is uniform solar radiation, dynamic elements that responds to heat is sufficient.

## 7. CONCLUSION

It is not required to move large parts of the building to be dynamic, but the movement of small parts can achieve the concept of kinetic architecture. Lack-actual movement in kinetic architecture which refers to complexity in design & high cost and difficulty in implementation-evolution of smart materials makes it simpler and easier. Kinetic architecture is not only the architectural aesthetics but also play an environmental role in sun shading and improving the functionality of the building. Way-control dynamic systems can affect the cost as well. Manually controlled systems-decrease cost while using pre-programmed automated systems involving sensors & detectors can push cost even higher. Used for conceptual reasons and to attract audience and represent cultural as well as social dimensions.

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