Kinetic Buildings in Climate-Responsive Architecture

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Abstract - *Climate-responsive architecture integrates the use of the climate data of an area, to construct efficient buildings that responds to, and works with the local climate, the scope of which includes, but is not limited to temperature, historical weather patterns, sun path and solar position, environmental conditions, seasonality, topography, etc. The design aims to minimize extreme energy use, have reduced impact on the natural environment, and above all, promote sustainability.*

Kinetic architecture responds to this need of intelligent, interactive, and adaptive architecture by including moving parts which are allowed to operate independently without compromising the structural integrity. Although this concept has been in use since the Middle Ages, an example being the drawbridge, increasing need for smarter use of energy has, in the late 20th century facilitated the use of moving parts in significant portions of the superstructure. Advancements in mechanics, electronics and robotics, fuelled by concepts such as Fuller's Tensegrity has brought into effect functional buildings that allow for these types of movements.

This paper explores the use of kinetic buildings in climate-responsive architecture, of which there are few examples, including buildings that use kinetic facades to regulate the entry of sunlight, to prefabricated skyscrapers with rotating floors. Although the concept is in use, it is not as commonly used as it should be to respond and adapt to the drastically changing climatic conditions.

Key Words: Climate-responsive architecture, kinetic architecture, kinetic buildings, kinetic façade, sustainability

1. INTRODUCTION

Kinetic architecture relies on the design of buildings in which transformative and mechanized structures aim to change the shape of buildings so as to match the needs of people to adapt to the elements on the outside. Although a considerable amount of time and effort has been spent on building 'intelligent homes' in recent years, the emphasis has now shifted on developing computerized systems and electronics to adapt to the interiors of a building to the needs of its residents, while responding and adapting to its external surroundings. In this way, movement has been produced mechanically by motors or by exploiting the movements of people, air, water, and other kinetic forces in space.

2. KINETIC BUILDINGS

Kinetic buildings can reposition parts of their structure to change their appearance, to create different usable space or to respond to external environmental conditions. Kinetic architecture concept is the design of buildings with transformative and automatic elements. The building's shape is changed to match the people's requirements and adapt to environmental conditions.

Kinetic architecture creates an ambiance to engage occupants that invites an emotional appeal and connects them to the outdoors. According to numerous studies, people are often drawn to natural day lighting, open ventilations, and scenic views. The open feel, while still enjoying the indoor comforts can positively enhance the overall guest experience significantly, thus kinetic architecture is an engagement touch point. Depending on means of revenue, by incorporating kinetic architecture to a building allows the space to be utilized year-round regardless of environmental conditions, and can provide a shorter cycle of ROI for the initial investment. Kinetic architecture also offers efficiency in space design to allow optimum space usage resulting in maximum revenue.

The Mercedes-Benz Stadium in Atlanta and the Bund Finance Center in Shanghai are among the famous examples of structures that incorporate kinetic architecture.

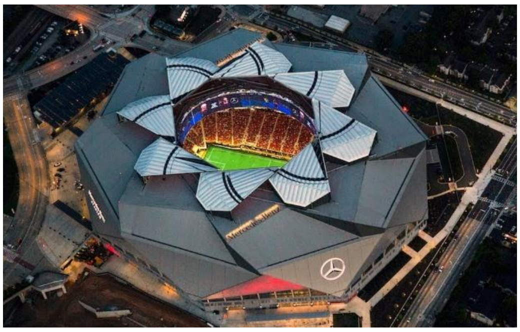

Fig -1: Mercedes-Benz Stadium, Atlanta, USA

The Mercedes-Benz Stadium has a retractable roof made of eight translucent triangular panels which, once opened, gives the impression of being spread bird wings. The roof also features a glass wall that can be opened at the same time as that of the roof, to aerate the stadium. The whole setup makes it possible to regulate the flow of light and is inspired by the motorized iris diaphragm of a photographic lens.

Fig -2: Bund Finance Center, Shanghai, China

The Bund Finance Center, home to the Fosun Foundation in Shanghai, China, features a façade consisting of three layers of curtains, made of copper tubes that are constantly moving, reminiscent of theatre curtains.

3. DESIGN AND WORKING OF KINETIC BUILDINGS

The design of kinetic buildings seeks to incorporate large-scale moving parts throughout a structure to enhance its adaptive capability. The moving elements of kinetic buildings are responsive systems that are produced mechanically or by the interaction of people, air, water, and other kinetic forces.

These kinetic elements are incorporated in different ways based on the requirements of the inhabitants and in response to the outside environment.

3.1 Kinetic Structure Systems

Kinetic structure systems can be outlined as buildings and/or building components with variable mobility, location, and/or geometry. The ways of a kinetic structural solution include folding, sliding, expanding, and transforming in both size and shape. On the other hand, performance means of a kinetic structural solution may be pneumatic, chemical, magnetic, natural, or mechanical. Kinetic structures can be categories into three groups.

3.1.1 Embedded Kinetic Structures

A part of a large architectural system is fixed in a location. The main aim is to control the main architectural system or building, in response to varying factors.

3.1.2 Deployable Kinetic Structures

These structures can be transported easily. They have a temporary location.

3.1.3 Dynamic Kinetic Structures

They are also part of a larger architectural system but act independently concerning control of the larger system. Such can be further subcategorized.

Mobile systems can be moved from one place to other. In transformable systems, the structure can change its shape. So, they are usually used for space-saving or user requirements. In incremental kinetic systems, kinetic devices may be organized in patterns in two or three ways to create different kinetic structures. Moreover, there are many possible pattern designs, the most common patterns are:

- Centric configuration: This type depends on a center point as a focal point of the space.
- Linear configuration: This type depends on an axis; it consists of a series of modules that are linked by their edges or their vertices to transmit the movement from one to the next.

3.2 Kinetic Interior

The application of the kinetic design concept ranges in scale from shop fronts to kinetic walls.

3.2.1 Transformable Spaces

Architects and interior designers through history tried to make our living and workspaces more dynamic and transformable to provide the changed needs of its habitants. The idea is applied in many levels such as multi-use furniture, and spatial flexible spaces.

3.2.2 Kinetic Walls

They are used to leave the impression that they respond to our actions. It is created by an array of connected elements. The response is created by three different strategies:

1. The movement is captured by centralized means using a camera. Then applying a subsequent inductive computer analysis of the taken images to do a centralized calculation of a corresponding reaction.
2. The movement is captured by methods that depend upon the sensors then applying a subsequent deductive analysis and the centralized calculation of a corresponding reaction.
3. The movement is captured by entirely decentralized methods. Then the direct and local reaction is taken up by many small elements.

3.2.3 Kinetic Facades

The concept of kinetic facades is using geometric transformation to create a motion in space. The movement affects the physical structure of the building facades without damaging the building structure. There are a lot of classifications of kinetic facades, the most common one is based on the façade transformation.

In translation object moves in vector direction. In rotation object moves around its axis. In scaling there occurs a change in size. In motion through material deformation the motion depends on changeable material properties.

4. CASE STUDY

4.1 Sharifi-ha House, Tehran, Iran

The Sharifi-Ha House is a residential building in Tehran, Iran. The house is in Darrous, which is nestled in the foothills of the mountains that divide northern Tehran from the Caspian Sea.

Fig -3: Sharifi-ha House in Tehran, Iran

The house occupies 14,000 square metres arranged over five levels and two underground floors and was completed in 2013. It features swiveling rooms, allowing for a shape-shifting façade, in order to adapt to Iran's fluctuating temperatures, and to suit the floor plan's functional requirements.

The seven-story high structure has every other floor with a turning box, which allows for a larger configuration of space. The three boxes, which can rotate individually, resemble drawers that slot into a simple concrete frame, when the rooms are turned horizontally inward, revealing their windowless wooden flanks. The home was designed by Iranian architect Alireza Taghaboni of NextOffice, with the collaboration of a large team of associates and consultants for the structural and mechanical aspects.

Fig -4: Sectional view of Sharifi-ha House

4.1.1 Architectural Concept

The design of this house is rooted in the Iranian tradition of flexibility of spaces, in which, to better adapt to the torrid summers and harsh winters in Tehran, the homes are provided with a summer living area, Taabestan-Neshin, and a winter living area, Zemestan-Neshin. Also traditional was the migration of families between separate summer and winter houses, but in this case, a single house – porous and transparent, fortified and sheltered – represents the seasonal migration while standing in the same place.

The house is organized into two blocks that hang from either side of a central void, one at the front of the house, and another at the rear. The void appears to draw light into both blocks the way a vacuum draws in air, even when the rooms on the front façade are swung inward.

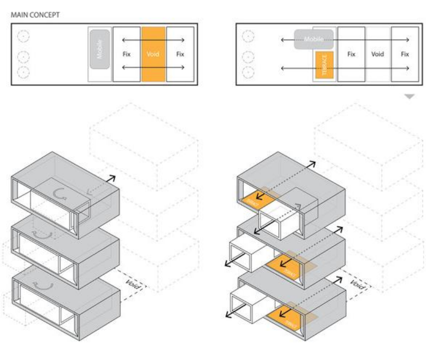

Fig -5: Conceptual drawing of Sharifi-ha House

In the Sharifi-ha House, the rooms are transformed at the touch of a button. In the 'open' mode, the three blocks pivot outwards on the rotating base, pointing the windowed ends to the sun, which creates a terrace on each floor. The 'closed' mode hides the windows to keep the house warm during Tehran's snowy winters.

Fig -6: Sharifi-ha House in various stages of 'open' and 'closed' modes

The rotation system, manufactured in Germany, derives from the mechanisms for the movements of theatre sets and the rotation of car show floors, and they consist of three motorized discs.

4.1.2 Design

The applied manufacturing technique for the turning mechanism is the same as that which is employed in turning theatrical scenes, turning the floor of car exhibitions, steel companies and the shipping industry.

The structural system was a customized one, due to the peculiarities of the design. After digitally modelling the structure, a series of SAP2000 analyses were undertaken to examine the static and dynamic performances of the proposed system. Being partially moveable is the dominant feature of this structural assembly, which was contemplated throughout the fabrication process by the German manufacture company. The main loads rest on the beams of the living rooms.

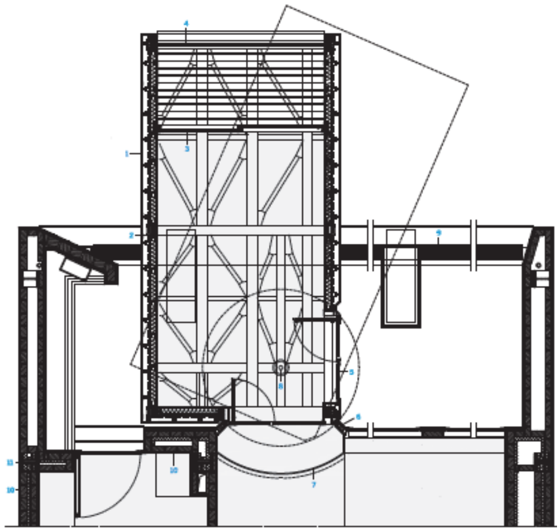

Fig -7: Open horizontal section across the rotating box

Due to various configurations the turning boxes take, the loading calculation can been estimated based on the largest possible loading value applied to the system. To prevent structural deformation controlling the probable vibrations in the turning boxes was considered during the design calculations of the structure.

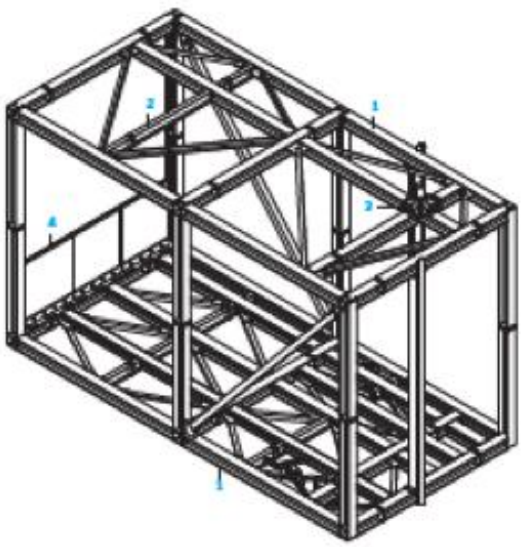

Fig -8: Axonometric view of the structure of the rotating box

The three rooms can rotate up to 90° to open to the landscape depending on the season.

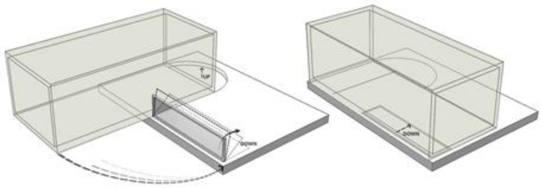

Fig -9: Rotation diagrams

4.1.3 Features

The main feature is the possibility of rotation of the three rooms up to 90°, which are located on the first, second and third level, towards the outside depending on the seasons and the desires of the occupants.

The boxes can support dead and live loads calculated at 25 tons each that is resting on the beams of both living rooms. The issues of handrails and air-penetration controlling were resolved by designing foldable handrails and refining the edges of the boxes.

The house plan is divided into four sections marked by the structural grid made of steel beams and columns, which consist of two blocks separated by a triple height central void, one located on the elevation with windows and the other in the deepest part of the plot. The triple height void ensures the entry of light into the house when the rotating rooms are in their closed position. A suspended bridge crosses the central void at each level connecting the rooms located on the main front and at the rear of the house. Balconies and internal windows surrounding the void provides sufficient ventilation. The rotating rooms on the first, second, and third levels, respectively houses a breakfast room, a guest room, and an office, adapting the house to the inhabitants' functional requirements depending on the season.

4.2 Al Bahr Towers, Abu Dhabi, United Arab Emirates

Al Bahr Towers consists of two 29-storey, 145 m high, office towers, located at the Eastern Ring Road, at the intersection of Al Saada and Al Salam Street, in the heart of Abu Dhabi, the capital city of the United Arab Emirates.

Fig -10: Al Bahr Towers

Abu Dhabi, being a desert region, has a hot and arid climate, extremely sunny with temperatures reaching up to 49°C and humidity up to 100% during summer. Furthermore, sandstorms being a frequent event, can compromise the structural integrity of the building, the intense heat and glare can render a comfortable indoor environment relatively impossible if not properly addressed.

Fig -11: External Automated Shading System of Al Bahr Towers

Designed by Aedas Architects, the distinguishing feature of the towers is its' external automated shading system, which consists of numerous umbrella-like glass elements that automatically open and close depending on the intensity of sunlight. Inspired by 'mashrabia', the geometrically designed wooden lattice screens used to fill the windows of traditional Arabic architecture since the 14th century, the façade of the towers is dynamically controlled by a building management system, which has helped reduce interior heat gains caused by sunlight by around 50%. The towers were completed in 2012.

4.2.1 Architectural Concept

The design of the external façade of the tower was derived by taking into account the environment, tradition, and technology. Inspired by the 'mashrabia' and mangrove flower, the towers consist of a series of transparent umbrella-like modules that open and close in response to the sun's path. The 'mashrabia' is a type of window protecting system mage of carved wood frameworks and used in traditional Arabic architecture. It offers protection from the sun and privacy inside the building.

Fig -12: Mangrove flowers

Fig -13: Traditional Mashrabia

The façade is controlled by a computer for responding to ideal solar and light situations. Similar to origami umbrellas, these shading elements unfold to various angles in response to the movement of the sun to optimize the solar exposure of the façade.

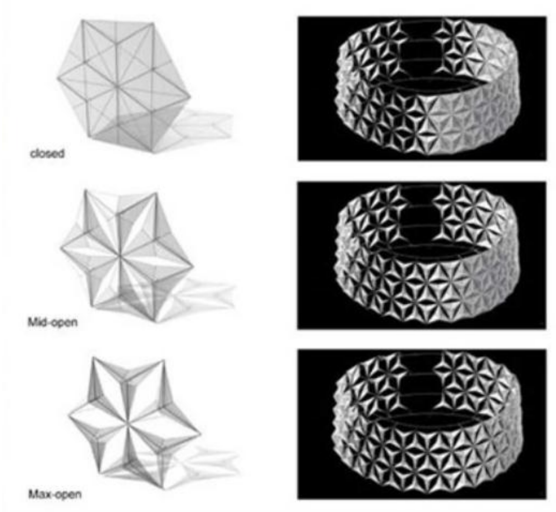

Fig -14: Shading elements at various angles of unfolding

The folding system transforms the shading screen from a seamless veil into a lattice-like pattern that, provides either shade or light. This reduces solar glare, by avoiding dark tinted glass and internal blinds that distort the appearance of the surrounding view. This system offers a better admission of natural diffused light. This reduces the use of artificial light and associated energy costs. Each triangular element is coated with fiberglass and programmed to respond to the movement of the sun as a way to reduce gain and glare. During evening, the elements remain closed.

4.2.2 Design

In the shading lattice, each unit comprises of a series of stretched PTFE (Polytetrafluoroethylene) panels and is driven by a linear actuator that progressively opens and closes once per day in response to a pre-programmed sequence that has been calculated to prevent direct sunlight from striking the façade and to limit solar gain to a maximum of 400 watts per linear meter. The installation is protected by a variety of sensors that open the units in the event of overcast conditions or high winds. This results in a reduction of CO2 emissions by 1,750 tonnes per year.

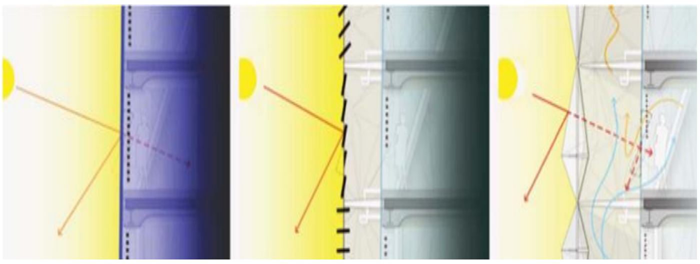

Fig -15: Comparison between common systems and Dynamic Mashrabia system

4.2.3 Features

The shading system comprises of 1,049 units fitted to each of the towers covering the east, south and west zones. When a façade zone is subjected to direct sunlight, the mashrabia units in that zone will unfold into a closed state providing shading to the inner glazing skin. As the sun moves around the building, each unit responds accordingly. The envelope blocks direct solar rays from landing inside occupied spaces during working hours, i.e., from 09:00 till 17:00.

The mashrabia is spaced 2000 mm from the surface of the glass wall. It has stainless steel supporting frames, aluminium dynamic frames, and fiberglass mesh infill. Each unit is 4200 mm in height and varying between 3600 mm and 5400 mm in width. Each unit is sub-divided into six triangular frames that unfold through a centrally positioned actuator and piston. The largest unit weighs around 625 kg.

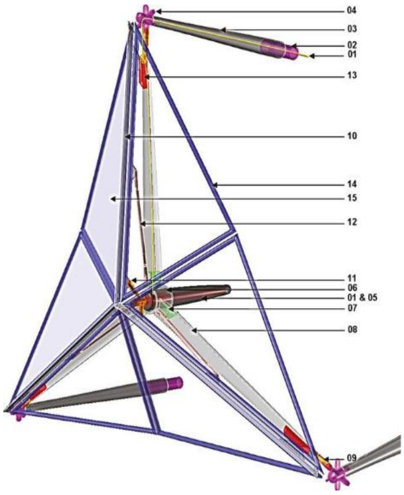

Fig -16: A single mashrabia unit

The control software and Human-Machine Interface (HMI) was developed using Siemens' platform. The HMI allows manual intervention of the operator in case of emergencies, maintenance requirements, etc.

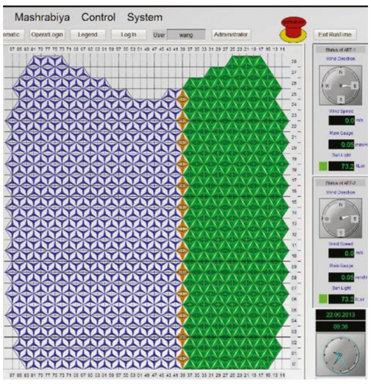

Fig -17: Mashrabia Control Sytem

Each unit has a unique ID, which is linked to positioning sensors located in the actuator of the corresponding unit. The software is linked to three sensors located at the top of each tower – light, wind, and rain sensors.

4.3 The Shed, New York, United States of America

The Shed is an art exhibition center located where the High Line meets Hudson Yards in New York, United States of America.

Fig -18: The Shed, New York, United States of America

Designed by architects Diller Scofidio + Renfro in collaboration with Rockwell Group, the structure was completed in 2019. The Shed being a non-profit cultural organization that commissions, develops, and presents original works of art across all disciplines, for all audiences, its Bloomberg building can physically transform to support the artist's most ambitious ideas.

The Shed is attached to 15 Hudson Yards, a skyscraper within the Hudson Yards real estate development. The structural engineering, kinetic façade, and design was done by Thornton Tomasetti.

Among the several architectural features, the most prominent one is its retractable shell that creates a space, named The McCourt, for large-scale performances, installations, and events.

Fig -19: Retractable shell of the Shed

4.3.1 Architectural Concept

The Shed is essentially a 200,000 square foot, eight level arts space with a telescoping outer shell. The Shed's design is inspired by Cedric Price's Fun Palace, a never-built design, the idea behind which was to create an unenclosed steel structure set on traveling gantry cranes resulting in a moveable form that would allow the public to control and rearrange their environment to host an array of activities.

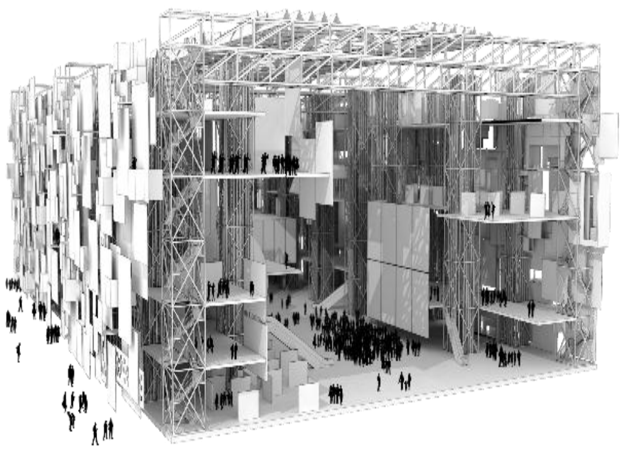

Fig -20: An interpretation of Cedric Price's Fun Palace

4.3.2 Design

The Shed comprises of two buildings – the base building, which holds two expansive column-free galleries totalling 25,000 square feet, a 500-seat black box theatre that can be further subdivided into more intimate spaces, event and rehearsal areas and a creative lab.

The outer shell creates a 17,000 square foot hall that is light, sound, and temperature controlled when fully deployed over an adjoining 20,000 square foot plaza. This flexible space can respond to variable needs in scale, media and technology, and can serve as a theatre with a seating capacity of 1,250 people or a standing audience of 2,700 people.

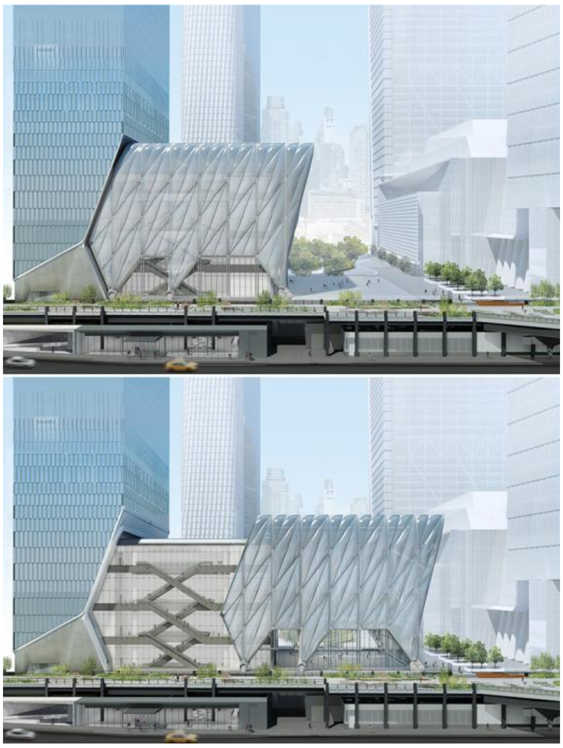

Fig -21: The shell – when closed and opened

When not needed, the 4,040-ton steel shell can nest over the base building after being pulled back on a double-wheel track that was built based on gantry crane technology, which is commonly found in shipping yards.

Fig -22: Wheels used to retract or extend the steel shell

4.3.3 Features

The Shed's moveable shell is 37 m tall and is made of an exposed steel diagrid frame, clad in translucent cushions of a strong and lightweight Teflon-based polymer, ETFE (ethylene tetrafluoroethylene), which has the thermal properties of insulating glass at a fraction of the weight. These ETFE panels measure almost 21 m in length.

The Shed uses a radiant heating system within the shell and a variable forced air heating and cooling system serving the occupied portions of the shell for maximum efficiency. The building was designed so as to achieve LEEDSilver certification and to exceed New York's energy codes by 25%.

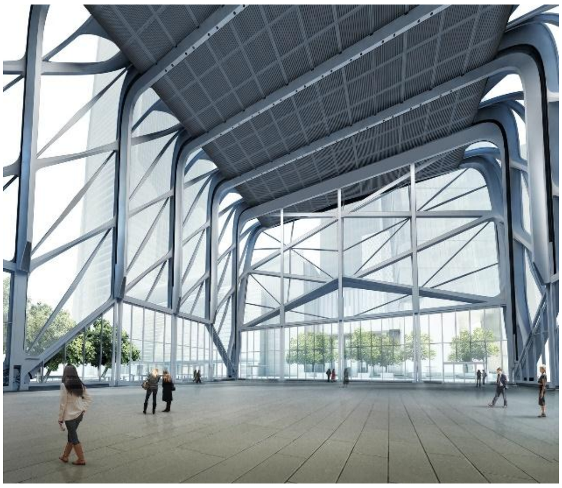

Fig -23: The McCourt – flexible space formed when the shell is opened

5. KINETIC BUILDINGS AND SUSTAINABILITY

The verb "sustain" has been common in English since 1290 AD. Oxford lexicon mentioned "sustainable" in 1400 AD and therefore the New Face of this verb in 1611 it's mentioned. Also, it looks that the verb "sustain" has been existing before. However the past few decades the definition of "sustain" contains a new face that is "what are often continuing in future". Recently we have a tendency to use the word sustain for explaining one thing in the world which might use or continue in the future or next generation. The applying of property ideas in design is introducing new fields that square measure property design, ecologic design, or inexperienced design that every one of the square measures an equivalent which means. One in all the foremost vital things in temporary design is property design. Property in design is pervasive. We will say that property design is that the most use of natural abilities and surroundings for users additionally minimize the adverse conditions of the development. Property in design is usually a lot cantered on environmental property in respect to design. A property building could be a building that has the smallest amount of adverse results on the natural surroundings throughout the lifetime of the building. However, it's to be understood that design relies on human thinking and is for shopper comfort and property in design is attempting for the most of human comfort and least injury and make less pollution to the surroundings.

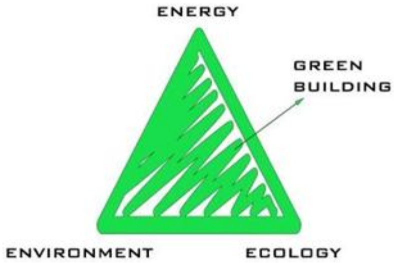

Fig -24: Three main pillars of sustainable architecture

Dynamic buildings square measure a result of decade-long expertise within the analysis of innovative building parts, capable of interacting with climate conditions and regulation energy flows through the building surface. The ''intelligent" building is so one whose external parts become components of thermal self-regulation, guaranteeing indoor comfort whereas reducing energy consumption.

Table -1: Principles of Sustainable Architecture

Principles of sustainable architecture	
saving energy	The maximum use of renewable energy sources and minimize the use of fossil fuels.
Reducing the use of new resources	Reuse of recycled materials and reduce the use of new materials
Harmony with the climate	Harmony with the climate and energy sources available at the construction site
According to human needs and meet them	Meet mental and physical human needs and improve quality of life
Harmony with the site	Lack of compatibility with surroundings
Holism	According to the urban environmental sustainability in the design of buildings and the construction of a healthy environment.

The construction technique and also the ability to supply energy on their own are two of the foremost outstanding options of Dynamic Design buildings. These buildings square measure made from ready-made units, custom-made in a very workshop, to suit terribly high-quality standards, leading to quick construction, value savings, and fewer folks on the website.

Although we tend to board a Dynamic Universe full of movement, the look methodology that has been given to design is static: buildings look similar all the time. As an associate approach to "Dynamic Architecture", the look of a building with ever-changing pure mathematics is examined to explore factors that influence the look of this building kind.

5.1 The Harmony of Sustainable Architecture and Dynamic Structure

The dynamic structure relies on property design. Not solely modification the road of the sky however conjointly with the dynamic structure is following sun direction and alters direction to the wind direction. This development will use nature as a natural providing energy. Within the buildings with dynamic structure enter time, dimension Buildings won't rigid boundary form. And cities modification abundant quicker than we expect. Dynamic design buildings perpetually dynamic and the form. Every floor is severally ready to slowly rotate 360 degrees around its centre at any moment. As a result, the buildings don't have a hard and fast facade. The dynamic structure relies on 3 main concepts:

- Dynamic design: It means every floor ready to rotate severally and through the time modification and shape of the building.
- Green architecture: with this methodology the building ready to manufacture energy (sun and wind) by itself.
- Industrial production: during this methodology, we tend to area unit exploitation parts and ready-made with top quality.

Table -2: The Features of Dynamic Structure

The features of dynamic structure
Using advanced manufacturing
The ability to produce its own energy
using components and prefabricated
Requires fewer workers than conventional methods
Increase speed of work and reduce the cost of construction

5.2 Scope of Kinetic Buildings

Kinetic buildings aim to control and manage buildings with a better communication between building systems and users. This means using all the advancements in technology to focus on client needs like comfort, productivity, energy savings, etc.

Kinetic buildings are adaptable to multiple users, transforming a building in ways that makes it much more useful and dynamic.

Successful kinetic structure design requires experience and creativity to capture design opportunities while ensuring compatibility of structural movements and long-term reliability.

Kinetic architecture allows parts of a building to operate independently without altering the structural integrity of the it.

The kinetic façade proves to be an effective approach to designing a building envelope, which reduce energy consumption, making the kinetic façade an optimal method to address harsh climates, especially in case of sun shading, and to provide convenient natural lighting and fresh air.

Kinetic architecture can change the way we live, work, and spend our free time, but it has challenges of its own. One of them is how to incorporate the new style into the subsequent addition of the building. Special considerations must be kept in mind while designing and executing these kinetic elements as they require a high level of collaboration among many aspects. Architects need to foresee the changes a building might go through in the future and how the kinetic elements fit into it.

In 2018, commercial and residential structures accounted for 40% of the world's total energy consumption. With climate change being a growing concern, kinetic architecture could be instrumental in reducing the carbon footprint and incorporating sustainability into everyday lives.

6. CONCLUSION

Developing stronger design science is important. Opening the lines of communication between design and science disciplines is censorious. Each can inform the other in exiting new ways – where science can find creative solutions and design can develop more innovative creations.

Kinetic buildings can follow the rhythms of nature and can change direction and shape from spring to summer, from sunrise to sunset, and adjust themselves to the weather, such that the buildings turn alive. Furthermore, kinetic architecture allows the architects to develop realistic considerations of human and environmental conditions.

Adaptive response to change must intelligently moderate human activity and the environment and build on the task of enhancing everyday activities by creating architecture that extends to our capabilities.

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