A Critical Analysis on Dynamic Facades

[1]Ar.Mohsina . M, [2]Ar. M. Afzan Saleem, [3]Ar.Jaya Pravin, [4]Dr.G.Yogapriya

[1]Student of School of Environment Architecture and Design, [2]Student of School of Environment Architecture and Design,
[3]Student of School of Environment Architecture and Design, [4]Professor of School of Environment Architecture and Design
[1]Department Of Architecture
[1]SRM Institute of Science and Technology, Ramapuram, Chennai, India

***Abstract*—Facades are the outer building envelopes that not only enhance the aesthetics of the building but they also influence the indoor environment and user comfort. They form a barrier between the inside and the external environment. Different technologies are used to make facades environmentally responsive and reduce energy consumption and helps to improve lighting & ventilation. The paper will discuss the concept and the relevance of dynamic facades according to their design approach and types, implementations, current challenges and climate impacts. It will highlight parameters which make the building sustainable through its facades. These envelopes act as sieves between the indoor & outdoor environment, providing the users with shade, light, ventilation & aesthetics keeping energy consumption. Dynamic Facades could be an energy efficient solution. Different countries around the world have started recognizing this and using them as a part of the solution..** *(Abstract)*

Index Terms—**Dynamic Facades, Active technology, Passive Technology, User Comfort, Energy efficiency**. *(key words)*

I. Introduction

In recent years there has been an urgent need for reducing energy consumption and building sector constitutes one of the highest positions in consumption. However, there is also potential to minimize our consumption through active and passive solutions in the building design. Here we specifically focus on the building envelope and how it can adapt to the varying weather & climatic conditions still achieving energy efficiency. The enclosed structure contains approximately 80% of an environmental reaction, creating a secure structure that connects with its surroundings. Dynamic facades are far more multifunctional science; they reduce the heating & cooling loads, control lighting and ventilation. The adapted facades optimize the utilization of natural ventilation and maximize day-lighting. Moreover, the building’s energy can optimize the systems energy consumption and providing favourable indoor conditions for the users. This paper examines applications in various climate zones that deal with technological and environmental aspects in sustainable building skins, as well as their role in meeting environmental needs. Finally, the paper concludes with a comparison of the applications studied in order to arrive at various solutions to be applied on building facades that could control the surrounding environment and be sustainable. These case studies examined factors such as response to environment, context, adaptation, impulse, technology, method, material, and process.Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts. True Type 1 or Open Type fonts are required. Please embed all fonts, in particular symbol fonts, as well, for math, etc.

II. INTELLIGENT BUILDING FACADES

The term "intelligent facade" has been broadly defined by (Kroner, 1997) as a portion of an intelligent building that is designed interactively to meet the humanitarian, civilized, and contextual requirements of the occupants (domestically and globally) in accordance with nature; and by integration with other aspects of the building (Kroner, 1997). Meanwhile, (Wingginton & Harris, 2002) define: - The member that wraps the building in a different way than the traditional envelop in terms of the capacity of its materials, components, and ability to change the thermal and physical properties, as well as its visual properties (transparency) and color; where performance is achieved by involving the physics properties that achieve smart behavior. A dynamic surface that changes colors and transparency to balance the external and internal climates, providing a wonderful opportunity to regulate the indoor environment in terms of lighting, cooling, heating, ventilation, air quality, and noise. The following are the various forms of intelligent building facades.

2.1 Intelligent Building Envelope

The term "intelligent facade" has been broadly defined by (Kroner, 1997) as a portion of an intelligent building that is designed interactively to meet the humanitarian, civilized, and contextual requirements of the occupants (domestically and globally) in accordance with nature; and by integration with other aspects of the building (Kroner, 1997). Meanwhile, (Wingginton & Harris, 2002) define: - The member that wraps the building in a different way than the traditional envelop in terms of the capacity of its materials, components, and ability to change the thermal and physical properties, as well as its visual properties (transparency) and color; where performance is achieved by involving the physics properties that achieve smart behavior. A dynamic surface that changes colors and transparency to balance the external and internal climates, providing a wonderful opportunity to regulate the indoor environment in terms of lighting, cooling, heating, ventilation, air quality, and noise. The following are the various forms of intelligent building facades.

2.1.1 Double Skin Facade

The double skin facade is made up of two transparent “skins” that are set apart by a space. It employs equipment’s like solar/thermal sensors, fans it is categorized into an active facade. Natural ventilation, day-lighting, capture and utilization solar energy are some of the passive strategies used. Thus, lowering energy consumption. During the colder months, the space between these two layers acts as an insulation occurring in two ways. First sunlight generates heat that is trapped between the two layers. Secondly that the additional layer allows less heat to escape the building's interior. This minimizes the dependence on HVAC systems as it reduces the need to heat the building interiors and the costs associated. It is useful for acoustics insulation and keeps the comfort for occupants. The air in the cavity self-monitors in warmer climates. Due to the Stack Effect excess heat is removed as differences in air density create air buoyancy. Thus, when the temperature of air rises in the air cavity, the hot air is pushed out.

2.1.2 Ventilated Facade

A ventilated facade is constructed with air gap in-between the insulation and facade cladding open at the top and bottom. This allows for the natural ventilation of the facade. This facade has the advantage of protecting the interior enclosure from inclement weather. The building's energy efficiency is due to the continuous exterior insulation and ventilated chamber. It reduces humidity by allowing water vapor to escape from the interior.

2.1.3 Dynamic Facade

The building that is most visible, the facade is a crucial strategic component. This results in a building's environmental and aesthetic performances being improved. Energy exchange with the external environment through the facade significantly improves energy efficiency. The interior and exterior structures are protected by the façade, extending the building's lifespan. Not only does the facade protect both the interior and exterior environments of the building, but it also the bridges these environments together. As it may be trusted with a number of crucial tasks that control the building's energy use and indoor environmental quality.

III. DYNAMIC FACADES

The flexible part of the façade could be integrated, located outside, or even inside the core. Macro changes are those made to the building envelope by moving parts. Micro changes are those that may occur directly within the component or material. A mechanical, pneumatic, hydraulic, or material-based adaptable component is possible. Macro level scale modification can be done using mechanical, pneumatic, and hydraulic types of actuations. Micro level adaptation is shown by the material-based kind of actuation. Depending on the alteration that the material undergoes, they can be sub-classified as energy-exchanging or property-altering. Depending on how quickly the adaptable component responds, it may be classified as changing within seconds, minutes, hours, during the day, or during the seasons. Facade could demonstrate adaptation under varying settings either through a supervisory control unit, which is categorized as extrinsic. An aspect of the component that is considered to be intrinsic. What is altering in the facade system on impulse in order to adjust to the new circumstances The conditions that develop, and which alter over time, are connected to facade performances. The response may depend on factors such as thermal resistance, ventilation, solar radiation, and light permeability, among others. Table 1 gives the idea of adaptive facade network through case studies.

IV. USE OF SMART MATERIALS IN DYNAMIC FACADES

The primary element necessary for the design and construction of Intelligent Facades are Smart materials which have adjustable properties that can adapt its form in response to some stimuli. They can be combined as a hybrid with other materials impacting performance. Using Computational Technologies helps to make better choices of materials that are apt for that building and context. The choice of materials impacts the adaptability, occupant comfort, cost, aesthetics, and efficiency. Smart Materials can be classified as Property Changing Materials & Energy Exchanging Materials. Location of smart materials are segregated accordingly into Façade Structure Exterior / Interior Layer Treatment systems. The most utilized smart materials by designers and the construction industry is Glass (Active and Passive Systems & Concrete). Smart materials can be can be used for exterior walls, panel, cladding ect, that increases Facade efficiency. Researches recommend the use of active glass, as it is more efficient with improved featured performance, capable of adapting to a variety of different circumstances. Passive glass can be used in areas where active glass is not necessary.

Table :1 Case studies of adaptive facade network

Project Details		.	**Techniques Adapted**
Project Name	Al Bahar Towers		Parametric triangular umbrellas using PTFE are organized into hexagonal units attached to a glass facade, changes their form origami-like folding controls. • Visibility • User comfort • Decreasing - energy usage • Use of artificial
Location & Date	Abu Dhabi, 2012		
Architect	Adeas		
Climate	Hot Desert		

Typology & Height	Office - 145 m

Concept: The context of the site and its heritage, surrounding environs & technology were taken into consideration. The facade was designed to protect the users from external heat through Mash Rabiya units that resulted in a geometric origami using computational technology.

	
Building Facade	Facade Component
https://www.researchgate.net/figure/The-Al-Bahr-Towers-is-a-high-performance-design-inspired-by-its-context_fig1_283683836	https://inhabitat.com/abu-dhabis-stunning-al-behar-towers-are-shaded-by-a-transforming-geometric-facade/

- Lighting & air-cooling -
- Loads, energy consumption have been achieved through this facade

Facade Response Parameters	
Heat & Light Responsive	
Position of Component	Outside
Control Operation Type	Extrinsic
Scale of Component	Macro level
Adapting Time	Hours
Actuation of the system	Mechanical Active system
Adaptive Component	Mash-Rabiya units
Component Movement	Open – Close - Scaling

Project Details

Project Name	GSW Head-quarters
Location & Date	Berlin, Germany, 1999
Architect	Matthias Sauerbruch
Climate	Temperate
Typology & Height	Office - 81.5 m

Concept: This Low-energy building has been designed with Passive control of Energy consumption keeping in mind the well-being of users.

	
Building Facade	Facade Component
http://www.glasslimited.com/portfolio-item/gsw/	https://www.filt3rs.net/case/colorful-folding-perforated-panels-sh-berlin-058

Techniques Adapted

The transparency of the facade brings in for maximal daylight. Solar shutters & Blinds help transmit heat and light in a controlled manner The East and West sides have buffer zones with double layered glass facades to achieve higher insulation values.
Energy savings have been achieved up to 40% .

Facade Response Parameters	
Light & Ventilation	
Position of Component	Outside
Control Operation Type	Extrinsic
Scale of Component	Macro level
Adapting Time	Minutes
Actuation of the system	Mechanical passive system
Adaptive Component	Shutters and Blinds -
Component Movement	Open /close - Rotation

Project Details	
Project Name	KFW Westarkade
Location & Date	Frankfurt, Germany, 1999
Architect	Sauerbruch Hutton
Climate	Temperate Oceanic
Typology & Height	Office - 48 m

Concept: The facade designed is based on the pressure ring concept. This type of facade incorporates a hybrid ventilation.

	
Building Facade	Facade Component
https://www.fkn-gruppe.de/en/projects/kfw-westarkade-frankfurt-am-main.html	https://archello.com/story/2563/attachments/photos-videos/2

Techniques Adapted

Radiant floor slabs activated through slabs using Geothermal energy reduce energy consumption. Double-layered wind-pressurized glass facade provides natural ventilation,and solar protection with the blinds placed inside two layers of facade- open or close. Winter- Flaps close. Still air inside the cavity acts as a thermal barrier. Summer-Flaps open- Air flows in thus cooling the building.

Facade Response Parameters	
Wind, Light, Thermal Response	
Position of Component	Outside
Control Operation Type	Extrinsic
Scale of Component	Macro level
Adapting Time	Diurnal / Seasons
Actuation of the system	Mechanical passive system
Adaptive Component	Saw-tooth shaped double-skin facade
Component Movement	Open /close - Rotation

Project Details	
Project Name	Arab World Institute
Location & Date	Paris / 1981 to 1987
Architect	Jean Nouvel
Climate	Temperate Oceanic
Typology & Height	Office - 32 M

Concept: The facade was conceptualized connect heritage of the Middle East via traditional Jaali patterns also known as the mash-rabiyas.

	
Building Facade	Facade Component
https://structurae.net/en/structures/institute-of-the-arab-world	https://illustrarch.com/articles/3374-case-studies-about-dynamic-

Techniques Adapted

Sensor based responsive architecture with 240 photosensitive quadrangular panels that control light. 30.000 photoelectric cells, light sensitive diaphragms of stainless - steel function between two glass sheets of the South-West facade. This acts like a lens connected to a central system
These elements open or close on the basis of the environment conditions accordingly.

Facade Response Parameters	
Heat & Light Responsive	
Position of Component	Integrated
Control Operation Type	Extrinsic
Scale of Component	Macro level
Adapting Time	Minutes
Actuation of the system	Mechanical Active system
Adaptive Component	Light sensitive Diaphragms
Component Movement	Scaling

	facades.html			

Project Details	
Project Name	Pearl River Tower
Location & Date	Guangzhou, China 1999
Architect	Gordon Gill, Robert Forest
Climate	Temperate Oceanic
Typology & Height	Office - 309.6 M
Concept: The facade envelope is designed to increase the performance of the building. The facade is oriented to optimize the use of daylight while controlling solar loads.Thermal performance and high visual transmittance is increased daylight to the interior spaces by the integrated assembly.	
	
Building Facade	Facade Component

Techniques Adapted	
Wind is drawn through the body and into a series of turbines that generate electricity and ventilation. Double glazed wall with mechanized blinds used on the northern and southern facade. Triply glazed facades are on the eastern and western sides along with PV panels mounted on the louvers. This “Net zero-energy” building sells its excess power to the local electrical grid.	
Facade Response Parameters	
Light & Wind Responsive - Electricity generating	
Position of Component	Outside
Control Operation Type	Extrinsic
Scale of Component	Macro level
Adapting Time	Diurnal-Hours
Actuation of the system	Mechanical Active system
Adaptive Component	Double skinned glazed facade & Cavities Blinds
Component Movement	Rotation

https://global.ctbuh.org/resources/papers/download/1629-case-study-pearl-river-tower-guangzhou.pdf
https://www.building.am/pagegal.php?id=490
Source: Aelenei, D. et.al, 2018

IV.CONCLUSION

In this paper, a systematic review has been conducted for different types of dynamic façade systems using the proposed comparison matrix. Both active and passive systems have been discussed here based on their characteristics, movement capabilities and other features. Most of the case studies have utilized Active Systems in which actuators, motors, sensors along with BMS systems. Only three of them are based on hand-operation whereas the rest of them are controlled centrally. Building envelopes have to face constantly changing climatic conditions, and still maintain user comfort conditions of the indoor environment. There emerges the need for designing adaptable building facades. There are several different adaptive facade examples around the world and more are in the development process.
The integration of different approaches, systems and design of an adaptive facade is a process not only in the scale of element, but also in relation with the material as the smallest scale and the building as the largest. This study tries to look at dynamic facades with a holistic approach that considers the properties, climatic factors and facades performances of the building system towards which forms the basis of understanding.

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