The Advantages and Challenges of Smart Facades. Toward Contemporary Sustainable Architecture.

Adel abbas¹

¹ assistant professor, Cairo Higher Institute for Engineering, Computer Science and Management, Egypt, a_f_abbas@hotmail.com

ABSTRACT:
Smart facades, also known as intelligent facades, are building envelope designed to provide a range of functional benefits to building occupants. These facades incorporate advanced technologies and materials to optimize energy efficiency, regulate light and temperature, and improve indoor air quality. They also have the ability to adapt to changing environmental conditions, making them a key component of sustainable building design. While smart facades offer many benefits, there are also several challenges associated with their design, installation, and maintenance. This research paper will discuss the various types of smart facades, their benefits, and challenges.

KEYWORDS: Smart Facades, Building Envelope, Sustainability, Contemporary Architecture.

1. INTRODUCTION

Smart facades are a rapidly growing field of research that seeks to optimize the energy efficiency, building's occupant comfort, and overall performance of building exteriors. These facades incorporate a variety of innovative technologies and design strategies that allow them to adapt to changing environmental conditions and user needs, often in real-time. The potential benefits of smart facades are numerous and significant. By controlling the amount of sunlight, heat, and ventilation that enters a building, they can help to reduce energy consumption and lower carbon emissions. They can also improve the indoor environment by enhancing natural daylighting, reducing glare, and maintaining consistent temperatures and humidity levels.

However, the design and implementation of smart facades requires a multidisciplinary approach, involving expertise in architecture, engineering, materials science, and computer programming, among others. Additionally, there are practical challenges related to cost, maintenance, and user acceptance that must be addressed. This research aims to explore the current state of the smart facades, including their design, implementation, and performance, as well as the challenges and opportunities associated with their adoption.

By examining the latest research and case studies in this field, the study seeks to provide insights into the potential benefits of smart facades, as well as the strategies and best practices for their successful implementation in a range of building types.

Glass, despite its importance in providing transparency and natural lighting, can lead to increased energy consumption within buildings. This is primarily due to its poor insulation properties, which result in significant heat gain during hot weather and heat loss during cold weather. As a result, buildings with extensive glass facades often require more energy for heating and cooling, contributing to higher energy usage and environmental impact. Addressing these challenges through innovative architectural design and energy-efficient technologies is essential to mitigate the energy consumption associated with glass usage in buildings.

2. RESEARCH PROBLEM

How can smart facades improve building energy efficiency, occupant comfort, and indoor air quality while minimizing maintenance and operational costs?

3. RESEARCH GOALS

• Assess the economic feasibility of implementing smart facades.
• Studying smart facade technologies and the details of their installation in building facade
• Evaluate the aesthetic implications and potential of smart facades in contemporary architecture

4. METHODOLOGY

• The theoretical part is a review of smart facades from its inception until now, the amazing development of it and the benefit of the building with smart facades.
• The applied part deals with an analytical study of a group of contemporary buildings with smart facades, with a study of the impact of movable architectural elements on the shape and function of the facades.
5. SMART ARCHITECTURE

Smart architecture is an innovative approach to building design that integrates technology and smart systems to create sustainable, energy-efficient, and environmentally friendly buildings. Smart architecture goes beyond traditional building design and incorporates smart sensors, data analytics, and automation to optimize building performance and enhance the quality of life for its occupants. The goal of smart architecture is to create buildings that are both smart and sustainable. By integrating smart technology into the building design, architects can reduce energy consumption, enhance security, and improve the overall functionality of the building. For example, smart sensors can be used to monitor indoor air quality, adjust temperature and humidity levels, and detect any potential problems before they become serious issues. Smart architecture is also focused on creating spaces that are comfortable and healthy for their occupants, which achieved with natural lighting, optimal temperature control, and the incorporation of green spaces. By creating a healthy and comfortable environment, smart architecture can enhance the productivity and well-being of the building’s occupants. One of the most significant benefits of smart architecture is its impact on energy consumption. By optimizing building performance through automation and data analysis, smart architecture can significantly reduce energy consumption and costs. For example, smart lighting systems can adjust to natural lighting levels and occupancy patterns, reducing energy usage. Smart HVAC systems can adjust temperature and ventilation based on real-time data, further reducing energy consumption. [1] Another key benefit of smart architecture is its impact on sustainability. By optimizing energy usage, reducing waste, and incorporating green spaces, smart architecture can help minimize the building's carbon footprint. In addition, smart architecture can incorporate renewable energy sources such as solar and wind power to further reduce the building's reliance on traditional energy sources. “Fig. 1” Shows the Stages of Smart Architecture Development.

Smart architecture also has significant implications for building safety and security. Smart sensors can detect potential hazards such as fire or gas leaks, while automated systems can alert occupants and emergency services if necessary. Additionally, smart surveillance systems can monitor the building's perimeter and interior, enhancing security and reducing the risk of theft or vandalism. In conclusion, smart architecture is an innovative approach to building design that integrates technology, sustainability, and functionality. By optimizing building performance, enhancing occupant comfort and well-being, and reducing energy consumption, smart architecture can significantly improve the quality of life for building occupants while minimizing the building's impact on the environment. As the demand for sustainable and smart buildings continues to grow, smart architecture will play an increasingly important role in the future of building design. [2] Fig. 2 shows the benefit of intelligent buildings.

![Figure 1. Stages of Smart Architecture Development](http://ibse.hk/gee5303/)

![Figure 2. Intelligent building benefit](http://ibse.hk/gee5303/)
6. ECO-TEC FACADES SOLUTIONS

The building's outer envelope stands as a protective barrier, demarcating the realms of human construction from the wilds of nature. Its sentinel, the facade, is a shield of exterior cladding that melds with this envelope, exerting a pivotal influence on the edifice's performance and long-term ecological balance. This architectural juncture, where envelope and facade converge, wields immense significance in determining energy efficiency, thermal equilibrium, and structural integrity. The facade, more than a mere embellishment, orchestrates a delicate interplay between aesthetics and functionality, orchestrating a dance of light, air, and temperature that choreographs the building's sustenance. Its judicious design can mold the interior atmosphere, taming solar ingress, enabling natural ventilation, and cocooning inhabitants from the capricious moods of weather. Thus, the alliance of the building's outer skin and its facade is an indispensable pact, creating a sanctuary that resonates harmoniously with both nature and human habitation. The importance of the building outer envelope as follow:

i. THERMAL PERFORMANCE:
A well-designed envelope can significantly reduce the amount of heat lost or gained through the building's exterior, which can improve energy efficiency and reduce heating and cooling costs.

ii. MOISTURE CONTROL:
The building envelope also helps to manage moisture infiltration, which can lead to problems such as mold growth, rot, and structural damage. Proper design and installation of the envelope can prevent moisture from entering the building and allow moisture to escape from the interior space.

iii. INDOOR AIR QUALITY:
The building envelope also affects the quality of indoor air by controlling the entry of pollutants and outdoor air. A well-designed envelope can prevent the infiltration of pollutants and maintain a healthy indoor environment.

iv. DURABILITY:
The building envelope provides protection against external elements such as wind, rain, and snow. A durable envelope can prevent damage to the building's structure and maintain its integrity over time.

v. AESTHETICS:
The building envelope is also important for the appearance of the building. A well-designed and attractive envelope can improve the building's form and value.

ECO Technology Architecture is a design approach that emphasizes sustainable and environmentally friendly building practices, utilizing innovative technologies to minimize energy consumption and environmental impact. It integrates renewable energy sources, energy-efficient materials, and smart building systems to create eco-conscious and resilient structures.

Fig. 3 shows types of eco-tec facade

![Types of Eco-Tek Facades](https://erjeng.journals.ekb.eg/)

Figure 3. Types of Eco-Tek Facades, by author

7. PASSIVE FACADES

Passive facades use passive design strategies to regulate indoor temperature and lighting. They rely on materials and design elements that maximize energy efficiency and minimize heat loss. Examples of passive facades include high-performance glazing, thermal insulation, and natural ventilation systems. Passive facades designed to reduce the energy consumption of a building by improving its thermal performance by maximize the use of natural resources such as sunlight and air, and minimize the use of artificial heating and cooling systems.[3] Passive facades have several benefits, as reduced energy consumption, improved indoor comfort, and reduced greenhouse gas emissions. They are also cost-effective over the long term, as they reduce the needs for mechanical heating and cooling systems, which can significantly reduce energy bills.

Passive facades incorporate several design features, such as:

i. INSULATION: This involves adding insulation materials to the facade to reduce the amount of heat that escapes from the building during the winter and the amount of heat that enters the building during the summer.

ii. GLAZING: High-performance windows and glazing systems that provide better insulation and light transmission be used to reduce the amount of energy needed for lighting and heating.

iii. VENTILATION: Passive facades allow for natural ventilation by incorporating features such as openable windows and louvers to let fresh air into the building and allow stale air to exit.

iv. SOLAR SHADING: This refers to the use of shading devices such as overhangs, fins, and screens to block direct sunlight from entering the building during hot months.
8. DOUBLE SKIN FACADES (DSFs)

Double skin facades are an innovative building envelope design that consist of two layers of glass or other transparent materials separated by an air cavity. They can provide several benefits, including improved energy efficiency, acoustic insulation, and natural ventilation. However, their design and construction can be complex, requiring careful consideration of factors such as thermal bridging, condensation, and maintenance. Proper design and integration of the system into the building's HVAC system is essential for achieving optimal performance. The prevalence of double skin facades in sustainable building design is steadily increasing, especially in high-rise constructions, owing to their ability to offer additional advantages like solar shading and decreased wind loads. Double skin facades can be made of various materials, but the most common materials used for the external layer are glass and metal. The internal layer can also be made of glass, but other materials such as wood, gypsum board, or other insulation materials can also be used. The air cavity between the two layers can be ventilated or unventilated, and filled with insulation material to improve thermal performance. Additionally, shading devices such as louvers or blinds integrated into the cavity to control solar gain and glare. The choice of materials for a double skin facade system depends on various factors such as the building's location, climate, function, and aesthetic preferences. The selection of materials must also consider the environmental impact, durability, and maintenance requirements of the system. The air cavity between the two layers of double skin facades can be filled with insulation materials such as mineral wool, polyurethane foam, or aerogel. Insulation can improve thermal performance and reduce energy consumption, but it also increase the weight and complexity of the system. [4]

One of the most important and oldest elements in the double skin facades is the wooden louvered windows. They have long been cherished for their ability to bring a perfect balance of natural light and ventilation, these classic windows are regaining popularity for their harmonious combination of functional and aesthetic benefits. By allowing natural light to flood living spaces and facilitating effective ventilation, these windows create a more inviting and healthier home environment. Whether energy efficiency, classic appeal, and sustainability.

Fig. 4 Shows Traditional wooden louvered window and Table 1. Shows the materials used in double skin facades.

Table 1. Material used in double skin facades, by author. Images Source: www.google.com

<table>
<thead>
<tr>
<th>CLASS</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLASS</td>
<td>Glass is a popular material for the external layer of double skin facades because of its transparency, durability, and ability to control solar heat gain. It can be tinted, coated, or laminated to improve energy performance and reduce glare. However, glass can be expensive and heavy, and it requires careful detailing and installation to avoid thermal bridging and air leakage.</td>
</tr>
<tr>
<td>METAL</td>
<td>Metal panels or screens used as the external layer of double skin facades. They can provide shading and ventilation while allowing natural light to enter the building. Metal panels can be made of aluminum, steel, or other materials, and they can be finished with various coatings or perforations to achieve the desired aesthetic and functional requirements.</td>
</tr>
<tr>
<td>WOOD</td>
<td>Wood is a sustainable and renewable material that used for the internal layer of double skin facades. It can provide thermal insulation, acoustic performance, and a natural appearance. However, wood requires regular maintenance and protection against moisture and pests.</td>
</tr>
<tr>
<td>SHADING DEVICES</td>
<td>Various shading devices such as louvers, blinds, or perforated panels integrated into the cavity of double skin facades to control solar gain and glare. These devices can be made of various materials such as metal, glass, or fabric and can be operated manually or automatically.</td>
</tr>
</tbody>
</table>

Figure 4. Traditional wooden louvered window Source: www.google.com
There are several types of double skin facades, each with its own unique features and benefits. The type of double skin facade chosen depends on the building's location, climate, and design objectives. Architects and engineers must carefully evaluate the advantages and disadvantages of each type of DSF and select the most appropriate system for their project. [5]

i. CLOSED DSF:
A closed DSF is a system in which the inner and outer skins are sealed and separated by an air gap. The air gap provides thermal insulation, and the closed system prevents dust, moisture, and pollutants from entering the gap. The closed DSF is commonly used in high-rise buildings and in locations with extreme weather conditions.

ii. OPEN DSF:
An open DSF is a system that allows for natural ventilation between the two skins. The outer skin is typically fixed, while the inner skin can be operable to allow fresh air to circulate throughout the building. The open DSF is ideal for buildings in moderate climates, where natural ventilation can provide sufficient cooling and ventilation.

iii. PASSIVE DSF:
A passive DSF is a system that utilizes the stack effect to create natural ventilation. Warm air rises and escapes through the top of the double skin, while cooler air enters through the bottom, creating a natural airflow. The passive DSF is energy-efficient and is ideal for buildings in mild climates.

iv. ACTIVE DSF:
An active DSF is a system that utilizes mechanical ventilation to control the airflow between the two skins. The system includes fans, ducts, and sensors to regulate the airflow and maintain the desired temperature and humidity levels. The active DSF is suitable for buildings in extreme weather conditions and locations with poor air quality.

v. HYBRID DSF:
This type of DSF combines the benefits of both passive and active systems. It uses the ventilation cavity to provide insulation and natural ventilation, while also incorporating mechanical systems to enhance control over the internal environment, Fig. 5 Shows type of double skin facades.

Figure 5. Double Skin Facades, by author, Source: www.google.com

9. SMART FACADES TECHNOLOGIES
Smart facades represent a revolutionary approach to building envelopes, integrating advanced technologies to enhance energy efficiency, occupant comfort, and architectural aesthetics. By using advanced technologies such as sensors, actuators, and control systems to enhance the performance of building envelopes. They offer a range of benefits, including improved energy efficiency, occupant comfort, and indoor air quality. However, there are several challenges associated with the design, installation, and operation of smart facades that need to be addressed in order to fully realize their potential.
There are several types of smart facades, each with their own unique features and benefits. Smart facades incorporate mechanical systems that actively respond to changing environmental conditions such as temperature and light. They typically use sensors to monitor external weather conditions, and adjust internal conditions accordingly. Examples of active facades include sun shading devices, automated louvres, and adaptive glazing [2]. Smart facade is a type of building facade that can change in response to external or internal factors, such as weather, sunlight, or user needs. These facades are not just aesthetically pleasing; they also provide numerous benefits, including energy savings, improved indoor comfort, and increased user satisfaction. Smart facades are known as responsive interfaces; where it shows the ability to understand and learning from its surroundings, and adjusting its behavior accordingly. The building envelope is not passive, but dynamically transformed to regulate the internal environment, thereby reducing energy requirements. Smart facades incorporate materials that can change their properties in response to external stimuli such as temperature, light, or humidity. Examples of smart facades include thermochromics glazing, electrochromic glass, and photochromic materials. Smart facades offer numerous benefits for building owners, occupants, and the environment. By optimizing energy use and indoor comfort, they can help reduce energy costs and carbon emissions. They can also enhance the user experience by providing better views, more natural lighting, and increased control over indoor conditions. Additionally, smart facades can enhance the aesthetic appeal and value of a building, while promoting innovation and sustainability in the built environment. Despite their many benefits, smart facades are not without challenges. They can be more complex and expensive to design, construct, and maintain than traditional facades. They also require careful consideration of factors such as climate, orientation, and user needs to ensure optimal performance. Nevertheless, as the demand for more sustainable, energy-efficient buildings grows, smart facades are likely to become increasingly popular and widespread. Smart facades can also be designed to respond to weather conditions. For example, some facades are equipped with sensors that detect rain, wind, or other weather events. The facade can then adjust itself accordingly, closing off openings or adjusting the position of louvres to protect the interior from the elements. In addition to their energy-saving and aesthetic benefits, smart facades can also enhance a building's functionality. For example, some facades are designed to serve as a noise barrier, reducing the amount of noise that enters the building from the surrounding environment. This is particularly useful for buildings located in busy urban areas or near highways or other noisy areas. In conclusion, smart facades are an exciting new technology that is changing the way we think about building design. They offer a wide range of benefits, from energy efficiency and sustainability to visual appeal and functionality. As architects continue to explore the possibilities of smart facades, we can expect to see more and more buildings equipped with this innovative technology. [6]

These dynamic building skins come in various forms, each tailored to address specific requirements and challenges faced by modern buildings. From photochromic and thermochroic facades that adapt to changing light and temperature conditions to kinetic facades that respond to environmental elements, the diversity of smart facades promises to redefine the way buildings interact with their surroundings. In this exploration, there are several types of smart facades, each designed to address specific energy efficiency, comfort, and architectural requirements. Fig. 6 shows some common types of smart facades:

9.1 CLIMATE RESPONSIVE FACADES (ENERGY-CONSERVATION ADAPTIVE FACADES)

Climate responsive facades are building envelopes designed to adapt to varying weather conditions and maximize energy efficiency. These facades utilize materials and technologies that respond to changes in temperature, sunlight, and humidity, optimizing indoor comfort. Through dynamic shading elements, such as louvres or smart glass, they regulate solar heat gain and minimize cooling loads during hot periods. During colder seasons, climate responsive facades can enhance natural light penetration and passive solar heating, reducing reliance on artificial lighting and heating systems. Overall, these facades...
play a crucial role in sustainable architecture, promoting energy conservation and reducing a building's carbon footprint. 

_Through the above, the importance of climate responsive facades can summarized as follows:_

- Balance of maximizing natural light
- Sheering from the adverse radiation
- Control ventilation and thermal heat

9.1.1 **INTERACTIVE KINETIC FAÇADES**

It is a Self-animated buildings envelope that respond and adaptive to user needs and preferences. For example, an interactive facade might incorporate sensors that detect the presence of people or their movements, and adjust lighting or shading accordingly. It uses movable panels or louvers to regulate light and heat by blocking direct sunlight and reduce heat gain during the summer, while allowing sunlight to penetrate and warm the building during the winter. The panels can be adjusted throughout the day to optimize natural lighting and shade. This can significantly reduce the need for artificial lighting and air conditioning, resulting in lower energy bills and a more comfortable indoor environment. This type adjusting its shape or orientation to optimize energy use and indoor comfort and also can be integrated with sensors and automated controls to adjust the facade in real time, based on changes in weather or occupancy patterns. The facade's outer skin responds to thermal conditions by opening and closing, effectively regulating the building's temperature during winter and summer months. Simultaneously, the interior skin incorporates secondary ventilation, allowing individual control over each space's temperature. Building occupants can manually operate the secondary ventilation and shading systems on the interior skin to suit their preferences and needs. [7]

Fig. 7 Shows types of interactive facades.

![Interactive Kinetic Façades](source: govind d, aysha s (2023))

Kinetic facades controlled by several ways according to the following:

i. **NON-ELECTRICAL THERMO-HYDRAULIC SYSTEM**
   
   This system utilizes two fiber reinforced polymer absorber tubes filled with different thermos hydraulic fluids. These tubes track the sun's movement and heat up independently, causing a hydraulic cylinder's movement, which rotates external shading louvers into optimal positions.

ii. **ELECTRICAL CONTROLLING SYSTEM**

   Operating through either manual switches or automatic sensors, this system adjusts motor units to control the internal climate of a building. The louvres respond to the sun's movement to effectively shade the building's envelope.

iii. **BUILT ROBOTIC CONTROLLING SYSTEM**

   Employing a fleet of small robots called "Edge Monkeys," this system regulates energy usage, indoor conditions, and protects building facades. The robots handle tasks such as controlling opening movements, checking blinds, and managing thermostat settings as shown in fig. 8.

![Edge Monkeys Robots](source: https://continuingeducation.bnpmedia.com/)

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Here is a review of a collection of modern buildings that incorporate Kinetic Facades technology into their outer envelope.

**i. THE KIEFER TECHNIC SHOWROOM (2010)**

The building constructed in Steiermark, Austria, designed by Ernst Gieselbrecht and Partner, features a "user-control dynamic facade" that allows individual control of its 54 motors via electronic controls within the building. Unlike other Dynamic facades, this technology does not incorporate any responsive system and only responds to the user's input. The facade functions as a shading device, but users have the ability to adjust the angle of the panel and regulate the amount of light entering the interior space.[15] As evidenced by , the advantages of using Kinetic Façades technology are not limited to the climatic and environmental aspects, but rather it added to the building a unique architectural feature, which changes the shape of the facade in an unlimited way according to the change in the shape of the outer envelope elements as shown in fig. 9.

![Image of Kiefer Technic Showroom](https://www.arch2o.com/)

**ii. SDU-KOLDING UNIVERSITY OF SOUTHERN DENMARK (2014)**

In 2014, SDU inaugurated a state-of-the-art campus building in Kolding, which has rapidly become a prominent landmark within the city. The campus received numerous prestigious international design awards, including the esteemed International Architecture Award 2015, reserved for the world's finest and most influential new architectural structures. Nestled by the harbor, SDU's Kolding campus shares proximity with other renowned educational institutions like Design School Kolding, creating a unique opportunity to establish Kolding as a prominent hub for design and fashion research in Denmark. However, the educational offerings at SDU-Kolding extend beyond design to encompass diverse fields such as business administration and IT & communications programs. Currently accommodating approximately 2000 students and 150 staff, the distinctive triangular building boasts excellent facilities, catering to the needs of students. These facilities include a well-equipped canteen, a comprehensive library, and a bookshop, enhancing the overall learning experience. Fig. 10 shows facades of SDU- Kolding University.
The smart facades that epitomize sustainable architecture and advanced technology adapt to changing weather conditions, optimizing natural light, and temperature to reduce energy consumption. Integrated with state-of-the-art sensors, the facades automatically adjust ventilation and shading, ensuring a comfortable indoor environment for occupants, promoting green energy usage.

Innovative materials used in the facades contribute to energy efficiency and thermal insulation, promoting a low-carbon footprint.

SDU-Kolding's smart facades foster a dynamic aesthetic, transforming the building's appearance throughout the day. These intelligent facades contribute to the university's sustainability goals, aligning with their commitment to environmental stewardship.

Occupants can interact with the facades through smart controls, fostering an engaging and interactive environment. The incorporation of smart facades enhances the overall learning and research experience for students and faculty at SDU-Kolding.

SDU-Kolding's smart facades exemplify the fusion of modern technology and sustainable design, setting a benchmark for eco-conscious campuses globally.

The Kolding Campus features an innovative facade with solar shading and sustainable elements, utilizing nearby river water for cooling and integrating solar cells. Inside, a five-floor atrium displays a dynamic pattern as staircases and balconies repeat the triangular shape in various positions. The design exemplifies both aesthetic appeal and environmental consciousness. [18] Fig. 11 shows the used technology in the facades.

iii. AL BAHAR TOWERS (2012)

Al Bahr Towers in Abu Dhabi are a pioneering architectural marvel, boasting the world's largest computerized dynamic facade. This revolutionary design is a harmonious fusion of bio-inspiration, regional architectural influences, and cutting-edge technology. Representing an exemplary model of thoughtful contemporary architecture, these towers proudly lead the way in this new direction. The success lies in their ability to pay homage to the region's historical, cultural, and environmental heritage while simultaneously displaying a distinctive state-of-the-art design that embodies Abu Dhabi's aspirations and vision.

The building is characterized by facades that combine architectural formation with modern high-tech technologies. The outer envelope of the building is divided into two parts, the inner part is glass curtains walls, and the outer part is decorative formations elements, so that the two parts express the concept of double facades. The screen operates as an independent curtain wall, positioned two meters away from the building's exterior on its frame. Each triangle is coated with fiberglass and programmed to react to the sun's movement, effectively minimizing solar gain and glare. During the evening, all the screens will close, revealing more of the facade. At night, the screens will fold,

Figure 10. SDU-Kolding University source: https://www.sdu.dk/

Figure 11. SDU-Kolding Facade Technology source: https://www.sdu.dk/
completely closing to expose the facade. In the morning, as the sunrises in the east, the mashrabiyas on the eastern side of the building will begin to close, following the sun's movement throughout the day. This dynamic response ensures optimal solar control and enhances the building's functionality and aesthetics. [16]

Abu Dhabi encounters a hot and humid climate, with intensely sunny days where temperatures can soar up to 49°C and humidity levels reach 100% during the summer months. The task of constructing two distinctive towers emerged, driven by a design brief that envisioned a pair of 25-story structures. These towers were intended to stand as remarkable landmarks, capturing both the local architectural legacy of the region and the esteemed corporate identity of the clients' institution as shown in fig 12.

It is estimated that the screen reduces solar gain in more than 50% and reduces the need for air conditioning.[19] Screens ability to filter light has allowed to be more selective in the choice of glass. This allows us to use more naturally tinted glass, which allows more light inside and less need for artificial light. The intelligent facade, together with solar thermal panels for hot water heating and photovoltaic panels on the roof, minimize the need for internal lighting and cooling, altogether reducing total carbon dioxide emissions by over 1750 tons per year. For the project's sustainable engineering and sensitive cultural and urban approach, the towers were awarded the 2012 tall building innovation award. Fig. 13 shows the idea of moving parts in the outer envelope of the facades, Table 2 shows the technical data about the facades and table 3 shows Comparative analysis between the Examples of Kinetic Façades buildings.

<table>
<thead>
<tr>
<th>Dynamic units used across 2 towers</th>
<th>2098</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total floor areas</td>
<td>70000 m²</td>
</tr>
<tr>
<td>Reduction in solar gain</td>
<td>50%</td>
</tr>
<tr>
<td>Saving in carbon emissions</td>
<td>40%</td>
</tr>
<tr>
<td>Moving unit height</td>
<td>4 m</td>
</tr>
<tr>
<td>Reduction in co2 per year</td>
<td>1750 tons</td>
</tr>
</tbody>
</table>

Figure 12. Al Bahar Towers
source: https://www.archdaily.com/

Figure 13. The Idea Of Moving Parts In The Outer Envelope of The Al Bahar Towers Facades.
source: https://www.archdaily.com/

Table 2. Technical Data about Moving Parts in the Outer Envelope of Al Bahar Towers Facades by author.
source: https://www.archdaily.com/
The Kiefer Technic Showroom
SDU- Kolding University
Al Bahar Towers

<table>
<thead>
<tr>
<th>Kinetic Façades Examples</th>
<th>Austria - 2010</th>
<th>Denmark - 2014</th>
<th>Abu Dhabi - 2012</th>
</tr>
</thead>
</table>

Concept of Facades
"user-controlled dynamic facade" enables personalized manipulation of 54 motors through in-building electronic controls. Unlike typical responsive systems, this technology exclusively responds to user input. Operating as a shading mechanism, the facade permits users to modify panel angles for regulating interior light levels.

The facades automatically adjust ventilation and shading, ensuring a comfortable indoor environment for occupants. The facades are equipped with photovoltaic panels, harnessing solar energy to power various building functions, promoting green energy usage.

The outer envelope features glass curtain walls and decorative elements, highlighting a double facade concept. A distant screen with triangular fiberglass-coated panels adjusts with the sun to reduce solar impact, while the screens fold at night, revealing the building. Eastern units closing in the Morning for solar control.

<table>
<thead>
<tr>
<th>Type</th>
<th>User-Controlled Dynamic Facade</th>
<th>Automated Dynamic Smart Facade</th>
<th>Automated Dynamic Folded Smart Facade</th>
</tr>
</thead>
</table>

Kinetic units
- Perforated aluminum folding panels and automated shutters.
- 1,600 triangular shutters of perforated steel
- Stainless steel supporting frames, aluminum dynamic frames coated with fiberglass programmed to respond to the movement of the sun.

Kinetic Façades Examples

<table>
<thead>
<tr>
<th>Natural lighting</th>
<th>Natural Ventilation</th>
<th>Heat Exchange</th>
<th>Energy Generate</th>
<th>Cost Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used curtain walls with traditional glass to give maximum daylight and sunlight exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Enhancing Sustainability Through Facades
Kinetic facades reduce the amount of heat entering the building.

| - | - | Photovoltaic Cells in the roof of the towers. |
| saving up to 40% of cooling energy | saving 50% of cooling energy | saving 50% of cooling energy Photovoltaic Cells produce 5% of consumed energy |

| user-controlled dynamic facade | a climate-responsive kinetic facade |

Table 3. Comparative analysis between Kinetic Façades Examples, by author
9.1.2 SMART GLAZED FACADES

Smart glazed facades stand as sophisticated architectural constructs that merge advanced materials with responsive technologies. These facades typically feature dynamic glazing systems comprising electrochromic, thermochromic, or photochromic glass. The integration of these materials empowers the facade to adapt its optical properties based on external stimuli.

Electrochromic glass, for instance, utilizes an electrochemical process to modulate light transmission. An applied voltage triggers ions to migrate within the glass, leading to controlled changes in tint and transparency. Thermochromic glass employs temperature-induced molecular rearrangements to alter its opacity, responding to thermal fluctuations in its environment. Photochromic glass, on the other hand, reacts to ultraviolet (UV) radiation, darkening its tint in response to sunlight exposure. Smart glazed facades yield multifaceted benefits. They optimize energy consumption by dynamically regulating daylight and solar heat gain, thus reducing the reliance on mechanical heating, ventilation, and cooling systems. This inherent adaptability fosters a comfortable indoor environment while mitigating energy expenditures. [20]

Smart glazed facades integrate with building systems for real-time adjustments, factoring in sensors, weather, and user preferences to optimize responses. From skyscrapers to homes, they symbolize the fusion of aesthetics, innovation, and environmental mindfulness. There is many types of smart glass according to function as shown in Fig. 14.

i. THERMOCHROMIC GLASS

Thermochromic smart glass is an advanced material characterized by its ability to undergo reversible alterations in optical properties in response to changes in temperature. This phenomenon is rooted in the molecular composition and structure of the glass. At specific temperature thresholds, the molecular arrangement undergoes modifications, leading to changes in the absorption and scattering of light, which consequently affect the glass's transparency and opacity. The material's behavior relies on thermochromic compounds integrated within its matrix. These compounds, often organic in nature, possess distinct absorption spectra at different temperature ranges. When exposed to heat, the molecular configuration of these compounds adjusts, causing them to absorb light differently. This variation in light absorption results in the transition of the glass from a clear state to a tinted or frosted appearance. Fig. 15 shows the idea of thermochromic glass.

In architectural applications, thermochromic smart glass is harnessed to enhance both energy efficiency and occupant comfort. By responding dynamically to external temperature changes, the glass aids in regulating the internal environment of a building. During hot conditions, the glass darkens, attenuating solar radiation and reducing the need for air conditioning. Conversely, in colder environments, the glass maintains transparency, permitting solar heat gain and potentially minimizing heating requirements. The integration of technology further amplifies the glass's functionality. Smart sensors and control systems can be employed to precisely manage the transition process, allowing for real-time adjustments and customization based on external conditions and user preferences. This amalgamation of material science and technological innovation is driving the evolution of architectural design, fostering adaptive structures that engage with their surroundings in an energy-efficient and visually captivating manner [20]. Fig. 16 shows changing of thermochromic glass color due to temperature.
**PHOTOCHROMIC GLASS**

Photochromic smart glass technology involves applying a self-adhesive photochromic film onto existing glass surfaces. It doesn't require electrical power and is considered a form of passive smart glass. Depending on the model, it lets through 15% to 30% of light in sunlight and 60% to 75% when there's no sunlight. It takes a few minutes to transition.

In contrast, thermochromic smart glass changes tint with heat. Photochromic smart glass darkens in response to UV light, cutting glare and boosting energy efficiency, which fits the European Climate Law, which is aimed at achieving climate neutrality for Europe by 2050. Photochromism was discovered in 1867 by Fritsche but named in 1950 by Yehuda Hirschberg. It comes from the Greek "phos" (light) and "chroma" (color). The International Union of Pure and Applied Chemistry (IUPAC) defines photochromic as a reversible transformation of a chemical species due to absorbing electromagnetic radiation, where the two forms have different absorption spectra.

Photochromic windows or film on building facades help tackle glare issues from solar radiation. This affects productivity and causes color fading in furnishings and art, increasing air conditioning costs. Photochromic glass can be single panels or part of double- or triple-glazed units. Using photochromic glass aligns with green building standards like LEED and BREEAM, fostering sustainable architecture. It helps meet the 300-lux daylighting requirement across 50% of interiors without spiking cooling expenses. Manufacturing photochromic film often involves a high-vacuum magnetron sputtering process, like in semiconductor production. The resulting clear, scratch-resistant, self-adhesive plastic film is affordable for retrofitting existing building facades [20], as shown in fig. 17

**ELECTROCHROMIC GLASS**

Electrochromic materials change color when electrical current is applied. For this type of smart glass, an electrochromic layer is sandwiched between glass and conducting layers. Applying a charge activates ions in an electrolyte layer, which causes the electrochromic layer to change from dark (or opaque) to transparent. The glass stays clear on its own; additional electric power is needed only to switch back. Previously the transition from clear to opaque had been slow, but recent advancements have reduced the switching time to just 2 seconds. Electrochromic glass also has noise blocking properties [21], as shown in fig. 18.

**POLYMER DISPERSED LIQUID CRYSTAL (PDLC)**

PDLC technology uses a layer of LCD crystals sandwiched between conductive layers. Like electrochromic and SPD glass, its default off state is opaque. When an electric current is applied, the crystals align in parallel, becoming transparent and allowing light through [20], as shown in fig. 19.

**SUSPENDED PARTICLE DEVICE (SPD)**

SPD glass contains a stratum of particles positioned between dual conductive layers. Upon applying an electric charge to the conductive layers, the particles align, creating a pathway for light to traverse. In its dormant (dim) condition, SPD glass obstructs nearly 99% of incoming light [20] as shown in fig. 20.
Table 4 shows a comparison between the different types of smart glass in terms of the extent to which each type responds to weather conditions, achieving the comfort of building users and saving in energy consumption.

Table 4. Comparison between smart glass types, by author.

<table>
<thead>
<tr>
<th>SMART GLASS TYPE</th>
<th>REQUIRE ELECTRICAL POWER</th>
<th>OUTER EFFECT</th>
<th>INNER EFFECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermochromic Glass</td>
<td>–</td>
<td>Response To Changes In Temperature</td>
<td>Natural lighting</td>
</tr>
<tr>
<td>Photochromic Glass</td>
<td>–</td>
<td>Response To UV Light</td>
<td>•</td>
</tr>
<tr>
<td>Electrochromic Glass</td>
<td>•</td>
<td>Transition From Clear To Opaque</td>
<td>•</td>
</tr>
<tr>
<td>Polymer Liquid Crystal</td>
<td>•</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended Particle Device</td>
<td>•</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9.2 ENERGY-GENERATING FACADES

These facades incorporate solar panels, wind turbines, or other technologies to generate electricity or heat from natural elements. By capturing and converting energy from the environment, they contribute to sustainable and eco-friendly building practices. Energy-generating facades not only reduce a building's reliance on traditional power sources but also promote a greener and more energy-efficient future. Their integration in modern architecture displays a commitment to environmentally conscious design and renewable energy adoption.

9.2.1 PHOTOVOLTAIC (PV) FACADES

The photovoltaic smart facade, combines architectural aesthetics with renewable energy generation. It integrates solar photovoltaic panels into the building's exterior to efficiently harness solar energy. The system utilizes advanced technology to optimize energy production by tracking the sun's movement throughout the day. This innovative design not only generates clean electricity but also acts as a thermal buffer, reducing heating and cooling demands, and enhancing energy efficiency. With its sustainable features and intelligent design, the PV Smart Façade represents a significant step towards creating energy-efficient and environmentally responsible buildings. Additionally, some PV facades incorporate transparent solar cells, allowing natural light passage while generating electricity, providing both energy and aesthetic benefits that seamlessly blend with the building's overall design. In areas with ample sunlight, these PV facades can generate surplus energy to power the building's needs. [20] Moreover, the PV Smart Façade plays a pivotal role in promoting green building practices and reducing the carbon footprint of structures. By tapping into renewable energy sources, it contributes to a more sustainable and eco-friendly urban landscape. The seamless integration of solar panels into the facade demonstrates how technology and architecture can collaborate to address the challenges of climate change. As the demand for clean energy solutions continues to rise, Fig. 21 shows PV smart facades.

9.2.2 TRANSPARENT PV GLASS

Combines photovoltaic technology with glass, allowing it to generate electricity from sunlight while maintaining transparency. It's integrated into building facades, windows, and other surfaces, blending renewable energy generation with architecture. This technology enhances energy efficiency, natural lighting, and space optimization in structures, contributing to sustainability and reduced reliance on conventional energy sources. Ongoing research aims to improve efficiency, cost-effectiveness, and applications [22], Fig. 22 shows transparent PV glass.

Figure 21. PV Smart Façades
source: https://www.dreamstime.com/

Figure 22. Transparent PV glass
source: https://www.smartglassworld.net/
9.2.3 SMALL WIND TURBINES
Small wind turbines integrated into smart facades offer dual benefits: sustainable energy generation and aesthetic appeal. These turbines can retract into the facade to safeguard them from harsh weather and maintain the facade's appearance. Their flexibility enables storage within curtain panels, easily deployable for functionality. These turbines harness wind power in cities, fostering local renewable energy. Seamlessly blending into building designs, they boost efficiency while displaying a commitment to green tech. With smart features, real-time monitoring optimizes energy output, adapting to changing wind patterns. This fusion of architecture and renewables represents the future of eco-friendly urban design. [14].

Table 5. Comparison between smart facades based on mechanical movement and based on changing the properties of materials, by author.

<table>
<thead>
<tr>
<th></th>
<th>Kinetic elements</th>
<th>Material properties changing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional Adaptation</td>
<td>• Require complex electro mechanical systems.</td>
<td>• The integration of intelligent materials in facades allows for adaptive responses to external conditions, such as changing weather.</td>
</tr>
<tr>
<td></td>
<td>• Kinetic elements can adjust their position based on environmental conditions. For instance, they can open to maximize natural ventilation on a breezy day or close to provide insulation during colder weather.</td>
<td></td>
</tr>
<tr>
<td>Energy Reduction</td>
<td>• Kinetic facades play a pivotal role in energy reduction by adapting to external conditions, regulating sunlight and heat penetration.</td>
<td>• Smart adaptive glass can automatically adjust its tint based on sunlight intensity, reducing the amount of heat entering the building. This can lead to energy savings by decreasing the demand for HVAC systems.</td>
</tr>
<tr>
<td></td>
<td>• Minimizing HVAC systems demand, resulting in substantial energy savings and a more sustainable building operation.</td>
<td>• Also it can optimize natural daylight by reducing glare and providing consistent lighting levels, potentially decreasing the need for artificial lighting during the day.</td>
</tr>
<tr>
<td></td>
<td>• Offer enhanced energy efficiency and insulation, contributing to reduce energy consumption in buildings.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Provide Excellent Thermal Regulation And Daylight Utilization, In a More Comfortable Indoor Environment.</td>
<td></td>
</tr>
<tr>
<td>Energy Generation</td>
<td>• Kinetic elements, such as moving panels or louvers, can be designed to harness wind or solar energy.</td>
<td>• Integrating photovoltaic innovation with glass preserves transparency while enabling electricity generation from sunlight.</td>
</tr>
<tr>
<td></td>
<td>• These elements can generate power while also providing shade or ventilation, thus contributing to the building's energy efficiency.</td>
<td></td>
</tr>
<tr>
<td>Privacy and Shading</td>
<td>• Kinetic parts can provide on-demand privacy and shading without the need for additional window curtains enhancing user comfort and energy efficiency.</td>
<td>• Adaptive glass can provide on-demand privacy and shading without the need for additional window curtains or coverings, enhancing user comfort and energy efficiency.</td>
</tr>
<tr>
<td>Architectural Flexibility</td>
<td>• Kinetic elements add an architectural flexibility, allowing the facade to transform and adapt to different requirements and user preferences.</td>
<td>• Smart adaptive glass maintains a consistent appearance, which might be preferred in buildings with a more static architectural style.</td>
</tr>
<tr>
<td></td>
<td>• The movement of these elements can contribute to a unique and ever-changing appearance, enhancing the building's aesthetic appeal.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Enable architects to achieve innovative and visually appealing designs, promoting a harmonious blend of aesthetics and sustainability in contemporary architecture.</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>• Mechanical Parts Require Periodic Maintenance and Have Operational Running Costs.</td>
<td>• Require Less Maintenance and Have Lower Operational Costs.</td>
</tr>
<tr>
<td></td>
<td>• Kinetic elements may require more maintenance due to their moving parts. Regular upkeep and potential repairs can increase costs over time.</td>
<td>• Compared to kinetic elements. The glass panels do not have moving parts that could wear out or break.</td>
</tr>
<tr>
<td>Cost</td>
<td>• Offers sustainable building design with extra cost.</td>
<td>• Cost-effective choice for sustainable building design.</td>
</tr>
</tbody>
</table>
10. BENEFITS AND CHALLENGES FACING USING SMART FACADES TECHNOLOGY IN EGYPT

Climate change has a significant impact on energy consumption in Egypt. Rising temperatures, particularly in the hot summer months, lead to increased use of air conditioning and cooling systems, resulting in higher energy demand. Additionally, changes in precipitation patterns can affect hydropower generation, which is a source of electricity in the country. The increased frequency and severity of heatwaves also strain the electrical grid, leading to potential power outages and disruptions. To mitigate these challenges, Egypt is exploring renewable energy sources, such as solar and wind, to diversify its energy mix and reduce greenhouse gas emissions. Energy efficiency measures and the promotion of sustainable building practices are also being adopted to decrease energy consumption and minimize the environmental impact of climate change on the energy sector. Additionally, efforts to raise public awareness about energy conservation and climate change adaptation are crucial for a sustainable energy future in Egypt. Using Smart facades technology in Egypt contribute to sustainable building practices by reducing the carbon footprint of buildings. By incorporating features like photovoltaic panels, energy-efficient glazing, and automated shading systems, the adoption of smart facades in new construction buildings in Egypt offers a wide array of benefits, ranging from energy efficiency and cost savings to improved indoor comfort and environmental sustainability. These facades are a crucial component of modern urban development, helping address the challenges of climate change and resource conservation while enhancing the quality of life for building occupants. Fig. 24 shows amount of energy consumption in Egypt at year (2020-2021) and table 6 shows the benefits and challenging of using smart facades in Egypt.

![Figure 24. Quantities of Sold Energy in Egypt According to Purposes (2020-2021)](https://erjeng.journals.ekb.eg/)


Table 6. Comparison between smart facades based on mechanical movement and based on changing the properties of materials, by author.

<table>
<thead>
<tr>
<th>USING SMART FACADES IN EGYPT</th>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Improved Energy Efficiency:</td>
<td>In Egypt's hot and arid weather, smart facades can mitigate heat gain in summers and retain heat in winter, resulting in lower HVAC usage, reduced energy consumption, and cost savings.</td>
<td>• High initial Cost for Implementation: Smart facades are often more expensive to design and install than traditional facades, which can make them prohibitive for some building owners in Egypt.</td>
</tr>
<tr>
<td>• Enhanced Indoor Comfort:</td>
<td>By regulating indoor temperature, air quality and light levels, smart facades can create a more comfortable and productive indoor environment for building occupants in Egypt.</td>
<td>• Complexity: The advanced technology and materials used in smart facades can make them more complex to design and install than traditional facades. This can lead to longer installation times.</td>
</tr>
<tr>
<td>• Solar Power Integration</td>
<td>Photovoltaic (PV) panels can integrate directly into the building's envelope. These panels capture solar energy and convert it into electricity, reducing reliance on conventional energy sources and lowering electricity bills in Egypt.</td>
<td>• Integration: A different technologies and systems into a cohesive and effective solution requires careful coordination and collaboration between architects, other engineers, and building operators.</td>
</tr>
<tr>
<td>• Savings Cost</td>
<td>While the initial investment in smart facades may be higher than conventional building envelopes, the long-term cost savings in terms of reduced energy consumption that can contribute to the overall sustainability goals of the Egypt.</td>
<td>• Technical Expertise: The design, installation, and maintenance of smart facades require specialized knowledge and expertise. Finding qualified professionals who can effectively work with these technologies can be a challenge for building owners and operators.</td>
</tr>
<tr>
<td>• Increased Building Value:</td>
<td>Buildings with smart facades are often perceived as more advanced and desirable, which can increase the overall value of properties.</td>
<td>• Maintenance Requirements: Smart facades require regular maintenance to ensure that their sensors and mechanical systems are functioning properly. This can add to the overall cost and complexity of the facade.</td>
</tr>
</tbody>
</table>

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10.1 THE IMPACT OF USING SMART FACADES IN ACHIEVING UN SUSTAINABLE DEVELOPMENT GOALS IN EGYPT

Implementing smart facades in Egypt can have a significant impact on achieving several UN Sustainable Development Goals (SDGs) such as:

i. Health and Well-being:
   Improved indoor environmental quality due to smart facades positively impacts occupant health, aligning with SDG. 3 (Good Health and Well-being).

ii. Energy Efficiency:
   Smart facades can reduce energy consumption in buildings through optimized insulation and natural light utilization, contributing to SDG. 7 (Affordable and Clean Energy).

iii. Economic Growth:
   The adoption of smart facades can stimulate local innovation and green technology industries, aligning with SDG. 8 (Decent Work and Economic Growth).

iv. Responsible Consumption
   Reduced energy consumption leads to responsible resource use, contributing to SDG. 12 (Responsible Consumption and Production).

v. Climate Action
   By decreasing energy usage and emissions, smart facades support SDG. 13 (Climate Action) by mitigating the effects of climate change.

Fig. 25 shows UN Sustainable Development Goals (SDGs)

10.3 EXAMPLES OF EGYPTIAN BUILDINGS IMPLEMENTED SMART FACADE SYSTEMS

The use of smart facades in buildings in Egypt is very limited due to the challenges mentioned before, in addition to architects’ fear of the impact of these systems on the appearance of the facades.

Below a review two examples of administrative buildings that applied the smart facades in their outer envelope.

I. CIB BANK HEADQUARTER, GIZA (2010)

The building located in smart village at Giza, was constructed in 2010, and was classified at that time as green buildings, with double energy-saving facades, solar heaters and green walls. In
2017, the building was modernized by adding PV units to the facades. This opened the door to a new era of Egyptian architecture integrating solar energy into building facades.

The design concept depends on integrating a solar energy plant BIPV (Building Integrated PV) in the outer envelope of the building, which generates a unique project. The CIB building presented a distinctive PV integration project that provided numerous chances for visual improvement. This involved blending aesthetics with added functionalities. Besides converting solar energy into electricity, Building-Integrated Photovoltaics (BIPV) serve multiple roles, ensuring protection from weather, heat, sunlight, and noise for the building. These aesthetically pleasing facades and roof designs contribute to energy efficiency within a low-carbon architectural framework.

The (BIPV) system of CIB building consists of photovoltaic components that are integrated in the building envelope (Custom made Glass-Glass Solar modules 295Wp, 13 mm thickness, 64 kg) and constitute a part of the building structure (such as the roof or façade), thus replacing conventional building material. BIPV systems provide structural functionality (e.g., waterproofing, safety, sun protection) with the added value of electricity generation [23]. Fig. 26 shows CIB building.

**II. EPIC COMPLEX, CAIRO (2021)**

The building located in the new administrative capital in the east of Cairo. The land area is about 6431 m², and according to the information received from the project’s architectural design consultant - Prof. Dr. Muhammad Reda Abdullah – the design took into account the concept of sustainability by using the best international standards for the (FITWEL) certificate, which is a pioneering certification system that aims to design sustainable and healthy buildings that save energy and offer a healthy built environment for its occupants. The building is equipped with smart systems that save electricity and water consumption according to the following:

- Saving approximately 40% of electricity consumption, as the mall’s facades contain double-glazed panels in addition to moving elements, which helps prevent sunlight from entering the interior, thus reducing the consumption of air conditioning devices.
- The roof is equipped with solar panels to generate electricity. Saving 48% of the water used in operation through recycling wastewater and rainwater.
- The mall contains a number of sensors and devices that measure the rate of oxygen and carbon dioxide, and thus can adjust the ratio to constantly provide healthy air.

The designer was inspired by the idea of the moving units in the facades from the movement of migratory birds and their constant endeavor to move to the most stable and safe areas to be in harmony with the transfer of all vital activities and state departments to the New Administrative Capital. Fig. 27 shows Epic complex building.

**CONCLUSIONS**

Smart facades offer a wide range of advantages for building occupants, such as improved energy efficiency, enhanced indoor comfort, better natural lighting, and superior air quality. Despite their benefits, smart facades pose challenges related to their design, installation, and maintenance. These challenges include cost considerations, technical complexity, and the need for skilled professionals to manage and maintain the systems. Smart facades are
It is necessary to highlight the importance of using smart facades. Integrating photovoltaic technology into glass is considered the best application of smart facades, as it allows sunlight to pass through, connects the built environment with the natural environment, and generates sustainable electrical energy.

With advancements in technology and the growing emphasis on sustainable practices, the initial investment in smart facade systems can yield substantial returns over time.

12. RECOMMENDATIONS

- Further research and studies are needed to optimize the implementation of smart facade technology in Egypt, ensuring it aligns with the country’s specific climatic and economic conditions.
- This requires more cooperation between the architecture and mechatronics departments in order to reach the best solutions.
- Providing laboratories that help students and researchers conduct advanced scientific research related to smart facades technology, and also help students and researchers simulate their design models with laboratory measurement tools to verify the results accurately.
- It is necessary to highlight the importance of using smart facades, and encourage investors to contribute to the realization of this technology and the possibility of applying it to the administrative buildings that will be constructed, especially in the New Administrative Capital.
- Using available locally materials and technologies when designing and installing smart facades to overcome the difficulty of importing with hard currency.

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