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# THE IMPACT OF USING SMART MATERIAL TECHNOLOGIES IN MANAGING LIFE CYCLE COST OF ADMINISTRATIVE BUILDINGS' FACADES PROJECTS IN EGYPT

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## ABSTRACT

The world is moving towards a zero-carbon vision, which has encouraged architects in many countries to use smart materials technologies in the building facade to maintain the internal environment of the building by limiting energy waste and thus reducing carbon and harmful gas emissions. Furthermore, employing life cycle cost analysis methods early in the project significantly reduces resource waste and preserves the surrounding environment by imposing recommendations for the building's most appropriate facade materials that could be used in terms of the long run most economically feasible and functionality maintainable.

This paper is based on study of the glazing facades COOL-LITE SKN 154/154 of the main administrative building of Credit Agricole Egypt at fifth setlement, in terms of the systems used to improve the internal environment of the building and comparing them in terms of the life cycle cost of materials with two other smart materials, namely Electrochromic Glass and Photovoltaic smart facade materials system, where the net present value is analyzed for initial cost, operating costs and disposal costs for the 3 scenarios during a 60-year study period, with the aim of reaching out the most feasible economic materials and functionally suitable on the long term, The study concluded that, In conclusion, from a LCC aspect, Photovoltaic is the most economically feasible material on long term, while from an initial cost aspect, the existing facade is the most suitable.

**KEYWORDS:** Smart Materials Technologies, Smart Materials, Smart Materials Systems, Administrative Buildings Facades, Life Cycle Cost

# أثر استخدام تكنولوجيا المواد الذكية في إدارة تكلفة دورة حياة واجهات مشروعات المباني الإدارية في مصر

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## الملخص

يتجه العالم نحو رؤية خالية من الكربون، الأمر الذي شجع المهندسين المعماريين في العديد من البلدان على استخدام احدث تقنيات المواد الذكية فى واجهات المبانى للحفاظ على البيئة الداخلية للمبنى من خلال الحد من هدر الطاقة وبالتالي تقليل انبعاثات الكربون والغازات الضارة. علاوة على ذلك، فإن استخدام أساليب تحليل تكلفة دورة الحياة في وقت مبكر من المشروع يقلل بشكل كبير من هدر الموارد ويحافظ على البيئة المحيطة من خلال فرض توصيات بشأن مواد الواجهة الأكثر ملاءمة للمبنى والتي يمكن استخدامها على المدى الطويل والأكثر جدوى من الناحية الاقتصادية وقابلة للصيانة من الناحية الوظيفية.

تقوم هذه الورقة البحثية على دراسة الواجهات الزجاجية COOL-LITE SKN 154 / 154 للمبنى الادارى الرئيسى لبنك كريدي اجريكول مصر بالتجمع الخامس، من حيث الانظمة المستخدمة لتحسين البيئة الداخلية للمبنى ومقارنتها من حيث تكلفة

دورة حياه المواد مع ماديتين اخري ذكيتين وهما Electrochromic Glass وPhotovoltaic ، حيث يتم تحليل القيمة الحالية الصافية لفترة دراسة مدتها 60 عامًا للتكلفة الأولية للمواد الثلاث، وتكلفة التشغيل وتكاليف التخلص بهدف الوصول للمادة الاقل تكلفة من الناحية الاقتصادية و المناسبة وظيفيا على مدار 60 عاما مدة الدراسة. خلصت الدراسة إلى أن بالنظر لل LCC، تعتبر Photovoltaic هي المادة الأكثر جدوى من الناحية الاقتصادية على المدى الطويل، بينما من حيث التكلفة الأولية، فالافضليه للواجهه الحاليه.

**الكلمات المفتاحية :** تقنيات المواد الذكية، المواد الذكية، أنظمة المواد الذكية، واجهات المباني الإدارية، تكلفة دورة الحياة.

# 1. INTRODUCTION

Architecture is the art of building through organizing materials and forms in an accurate way to satisfy a specific purpose, every architecture project has its personal and individual character due to many variable factors; building materials are one of these facets. For centuries building technologies and construction methods were improved and the world has recently gone through two material ages, the plastics age and the composite age, with the middle of these two ages ushering in a new era of developed materials, the era of smart materials, which has a great influence on new architectural forms today. It was stated that the difference between the traditional materials and smart materials is the reaction with external influences, and responsive to external stimulus in order to control temperature changes or solar radiation [1]. Briefly, Traditional building materials static tend to resist the forces of building, while the smart materials are dynamic in this respect treat in order to respond to conditions in the energy context.

The building project should thus consider smart materials with their systems in the design especially for façade as an essential element, whereas the previous studies of the development of building façade technologies and how smart building facades of all types have developed throughout the world in response to the demands of climate and local conditions have proven that the role of a façade with respect to energy and the indoor climate is to bring indoor requirements into harmony with the dynamically changing conditions outdoors to the greatest extent possible.

Moreover, the ideal smart façade materials with their systems are the ones that reduce the energy required for the building's system & take into account the life cycle cost analysis of the building during the study period, which starts from the selection of a specific location of the investment till the end of the project's life, throughout the preliminary stages, operation stage that include the facades services and maintenance till the building disposal life in terms of the currency equivalent net present value (NPV).

Egypt Faces a problrm of a hot desert climate that experiences extreme heat during the summer months, resulting in high temperatures and ultraviolet rays that hit the building's façade, causing an uncomfortable environment for the building's users, which led to significant challenges in maintaining a comfortable internal space environment for consumers by unclean energy that’s mostly employed in indoor air conditioning systems, as well as constant lighting and other applications that are hazardous to the environment in the long term, and according to Architecture 2030 website & IEA data from IEA (2022), the fundamental issue nowadays is that the construction sector accounts for more than 35% of global final energy use, nearly 40% of energy-related $CO_2$ emissions, and almost 45% of global resources consumption, 27% of them are from building operations annually, while the rest 13% are from building and infrastructure materials and construction annually.

Accordinglt, this study considers the significance of adopting smart facade materials with their systems in the construction of new administrative buildings, which is also related with stronger demands to be economically and operationally beneficial for the building during its entire life cycle. This is accomplished through LCC analysis for a case study of three facade materials, one high-performance material and two smart materials for Credit Agricole headquarter in New Cairo, Egypt, to compare and choose the best cost-effective facade material. covering all life phases expenses, including initial, operation, and disposal.

In aiming to Shed light on the problem faces the building's façade in Egypt and hot arid region, and implementing UN Organization recommendations for the construction and real estate industries during (COP27), held in Sharm-el-Sheikh, Egypt, November 2022, for the construction and real estate industries, to maximize the use of renewable energies, smart materials & smart design techniques to minimizing the $CO_2$ emissions for zero carbon vision by 2050 and supporting the concerns to use smart façade materials with their systems by integrating Life cycle cost analysis methods not only the initial cost calculations but also thw whole life calculation started from the beginning of project stage following by the operation stage till the disposal life by imposing recommendations to maintain the internal environment of the building using appropriate materials, resulting in limitation of the resources from being wasted, and preserves the surrounding environment and thus reduces energies usage, carbon and harmful gases emission.

The article is structured as follows: First, description of the proposed methodology used to reach the aims of the research then a literature review of the current state of smart facade material with their case study and a life cycle cost analysis reviews, followed by case study applied smart façade materials technologies on it and calculating it's Life cycle cost impact on the building and obtaining the results. While the final clause summarizes the research findings and limitations and outline future research directions.

## 1.1. Research Methodology

To help architects and building designers in choosing the most economically efficient smart facade materials alternatives, two methods are used in this study:

1) Qualitative Analysis
   - Literature review study from published and unpublished sources that discuss smart materials, life cycle cost & case studies,
   - Interviews with the concerned parties of the selected case study to obtain the annual operational cost for the selected building.
   - Triangulation process to test the data validity.
2) Quantitative Analysis for the case study includes
   - Comparative analysis for the existing building façade life cycle cost and two other alternatives were done to compare and choose the most cost-effective system.

## 1.2. Smart Materials Technologies

### 1.2.1. Definations

Since the early 1990s, when the first'smart material' appeared commercially in the construction business, the language of the material world has changed drastically, and many other terms are now used to refer to smart materials or even smart systems. Examples of that are smart materials, adaptive systems, responsive materials, computational materials... etc.

According to Newman, 1997," Smart Materials are materials with the ability to perform sensing and actuating functions, similar to those in living systems, upon the application of an external stimulus. This stimulus can be in the form of light, sound, temperature, electric field, magnetic field and stress. These smart materials also carry the potential to become intelligent materials, i.e., besides their sensing and actuating properties, such materials will be able to learn and adapt with time and may ultimately simulate living systems". [1].

### 1.2.2. Smart materials technologies requirements

The requirements of materials to become a smart, have five fundamentals that differentiate them from the known traditional materials:

1. Immediacy – The materials responding to external stimuli in real-time.
2. Transiency – They react to multiple environmental states.
3. Self-actuation – Intelligence is internal to the material rather than external to it.

4. Selectivity – Their reaction is discrete and predictable.
5. Directness – The reaction is limited to the 'activating' event [2].

### 1.2.3. Smart materials technologies characteristic

Smart materials have a number of characteristics that differentiate them from traditional materials. Whether as a single material or on a system's level, those characteristics can be defined more through the following **Table 1**:

**Table 1:** Smart Materials technologies Characteristics & their Types

| Type of Smart Material | Input | Output |
|---|---|---|
| | **Property Change Materials** | |
| Photochromic Materials | Change in ultraviolet radiation | Change their colour |
| Thermochromic Materials | Change in temperature | Change their colour |
| Thermotropic Materials | Thermal energy | Changes its microstructure |
| Shape Memory Alloys | Thermally or/and stress-driven (SMA) | Change in the microstructure through a crystalline phase |
| | **Magnetically driven (MSM)** | |
| Electrochromic Materials | Voltage | Change their colour |
| Liquid Crystals | Electric potential difference | Colour change |
| Chemochromics | Chemical concentration | Colour change |
| | **Energy Exchange Materials** | |
| Photovoltaic smart material with their system Smart material system | Radiation energy | Electrical current |
| Thermoelectric | Electrical current | Temperature differential |
| Piezoelectric | Mechanically stressed | Electrical charge |
| | Reversibility | |
| Electro-strictive | Electric potential difference ⟺ | Deformation |
| Thermoelectric | Temperature difference ⟺ | Electric potential difference |

1. Property Change Materials, They are materials that are subject to change in any or all of their characteristics, such as electrical, magnetic, chemical, mechanical, or thermal, when subjected to external factors associated with the surrounding environment, such as when the material absorbs the input active (automation) / passive (solar radiation) energy and undergoes a change in the mentioned above properties, with most cases requiring no external control system to cause these changes to occur.
2. Energy Exchange Material, Its concept is based on the first law of materials in physical science, which states that energy can transform from one form to another to produce another form of energy, and that it can do so directly and reversibly. Thus, in energy exchanges, the materials remain the same while the energy changes.
3. Reversibility, It possesses bidirectionality and reversibility. As a result, the reversibility is the same as that of the materials that exchange energy, but in the other direction. Phase-changing materials have the ability to absorb energy and release it into the environment, depending on which way the phase change happens.

### 1.2.4. Smart materials technologies characteristics benefits in architecture

4. Enhanced the durability of the building facade.
5. Decreasing the maintenance ratio through the building's life cycle, as many have the ability for self-diagnosis, self-healing, and structural control.
6. Gives the facades superior strength, toughness, and ductility.

7. The flexibility of shaping facades.
8. Maximized the abrasion, corrosion, chemicals, and fatigue resistance.
9. Life-cycle cost efficiencies.
10. Quick response to the outer environment changes, In proportion to the consumer's comfort:
    - Control of Air Flow and Natural ventilation,
    - Thermal insulation & Moisture control,
    - Control of Sunlight and other Form of Radiant Energy,
11. A good choice as a sustainable material especially the bio-materials and nanomaterials.
12. by changing some of its properties it can be used as a perfect sensor for the outside environmental change, structural diffusion & and many more.

### 1.2.5. Smart materials technologies applications

The application of advanced technologies, based on smart materials & their systems, have many applications in many disciplines including the architectural & civil field, in which smart materials can defined as an individual materials with inherent adaptive properties, while smart materials systems involve the integration of smart materials into a larger system or structure that incorporates sensors, actuators, and control mechanisms to achieve a specific functionality or response.

### 1.2.6. Smart materials technologies classifications

One of two processes detects smartness in a material or system **(Fig. 1).**

1. Internal mechanisms, They are the inner characteristics of materials, which are determined by their internal structure and composition. Many of a material's chemical, mechanical, electrical, magnetic, and thermal properties are generally essential to it at the point at which the material receives the input energy and changes.
2. External mechanisms, They are external characteristics that are influenced by other circumstances. The colour of a material, for example, is determined by the nature of the external incident light as well as the microstructure of the material that is exposed to the light. If the mechanism affects the material's energy state but does not change the material itself, the input results in an exchange of energy from one form to another.

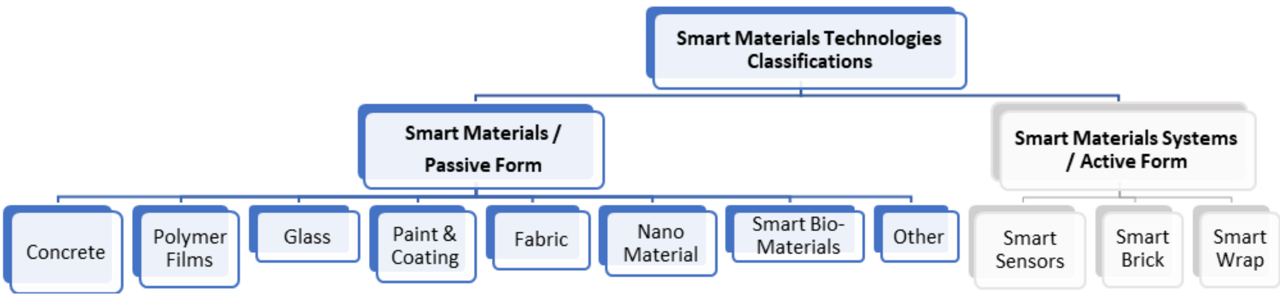



**Fig. 1:** Smart Materials Technologies Classifications

### Smart façade material

In the architecture field the smart materials mainly depend on the ability of these materials to change their shapes and characteristics to significantly improve the sustainability of buildings by which the energy used reduced, by using discretely acting only where necessary and operate discretely and locally, so improving the building's life cycle cost, that mainly depend on the ability of these materials to change their shapes and characteristics based on passive form, under the influence of external stimuli such as humidity, temperature, solar radiation, light, air movement and pollution, or active form under the influence of the building occupant by just a click on a switch when a voltage is applied in a specific area of the building, As a result, many of the benefits provided by these technologies can be taken advantage of by a wider range of designs for new and retrofitting buildings. The following are examples of smart façade materials employed recently in the architectural industry (Table 2).

**Table 2:** smart façade materials

| Type of smart material | Types | Applications | Applications |
|---|---|---|---|
| **Polymer films** | Radiant color film, | Reflecting 98% of visible light in average and is transparent. The colour of the reflection is determined by the angle at which the light hits it, and their performance increases as the angle of the sun increases. Their technologies rely on the nanotechnology concept to limit heat gain. | It's applied to the glazing window or doors |
| | Photochromic films, | Change its color when subjected to light and it blocks 99% of the uv harmful light and 80% of the ir. | |
| | Thermochromic films, | Change color with the external temperature. This enables the effective use of solar heat in winter, to heat up the buildings while locking the penetration of solar heat in summer to keep the room temperature low. | |
| | Photovoltaic smart material with their system smart material system films, | Thin and flexible solar cells with varying transparency and colours are put to huge surfaces. | |
| **Smart glass** | Passive smart glass | Does not involve an electrical stimulus. Rather, it reacts to the presence of natural stimuli such as light (photochromic glass) (pc) or heat (thermochromic glass) (tc). | Photochromic glass, it's transmission adapts to the light level of the environment, as the transmittance values can range from 15%-30% when exposed to sun's rays and 60%-75% when there is no fallen solar radiation. |
| | | | Thermochromic glass, it's changes tint automatically due to the increase in temperature from solar infrared, |
| | Active smart glass | Its switchable glass reacts to applied stimuli, therefore, changes light transmission properties when a voltage is applied | Electrochromic glass, when energized by an electrical current, the electrochromic smart glass changes its transparency |
| | | | Suspended particle devices (spd), by using voltage-driven, small light-absorbing microscopic particles interact with the electric current applied making it go from clear to dark blocking up to 99.4% of light |

## 1.3. Smart Materials Technologies Case Study

### 1.3.1. Al Bahar towers, Abu Dhabi, UAE,

Building Type: Administrative Building,
Climate Condition: Hot Desert Climate / Arid Desert Climate,

Smart Material Used: Responsive facade system & Photovoltaic smart material with their system Smart material system (PV) (Fig. 2).

**Criteria of selection:**

This case study is used to illustrate the execution of Responsive facade system “Property Exchange Materials” in a smart building envelopes, to control solar heat gain through the facade and enhance the indoor environmental quality and the use of Photovoltaic smart material with their system Smart material system Panels in a building envelopes, to convert solar energy into electric energy (Energy – Exchange), in a concept of energy efficiency as part of a smart architectural approach.

**Building requirements based on climatic data:**

In this area buildings should be designed to let in as much direct sunlight as possible, while yet being energy efficient by reducing heat and delaying its transfer from the harsh external conditions in both summer & winter, and reducing the energy consumption results from the buildings.

**Smart façade material manifestations in the building:**

The facade concept is inspired by the traditional Islamic object "Mashrabiya" and honeycomb-inspired structure as automated dynamic solar screen, and the use of a highly unitized panels glazed envelope, providing the best possible levels of internal visual and thermal comfort.

PTFE-coated glassfibre mesh was identified as the most durable and best- performing solution as a fabric for the shading system screen which is computer-controlled to respond to optimal solar and light conditions and operated through sun tracking software that controls the opening and closing sequence according to the sun’s angle. In overcast or high wind conditions, a series of sensors integrated into the building envelope will send logged signals to the control unit, causing all units to open, The South-facing roofs of each tower incorporate Photovoltaic smart material with their system Smart material system cells, which generate approximately 5% of the total energy required from renewable energy sources.

**LCC analysis:**

According to Aedas’ Peter Oborn” the envelope will reduce the solar gain by more than 50% which translates to a reduction of air conditioning usage and accordingly reduction in $CO_2$ emissions of 1750 tonnes per year, that will reflect in minimizing the building life cycle cost.

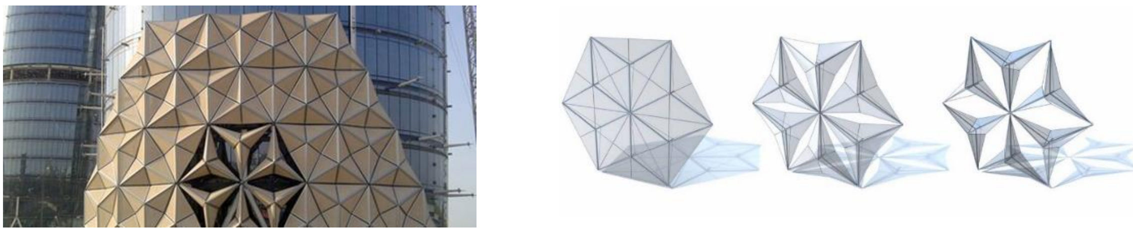


**Fig. 2: Al Bahar Tower - Smart Facade System.**

**1.3.2. Kolding campus, south denmark university,**

Building Type: Mixed Use
Climate Condition: Temperate Climate with precipitation evenly distributed over the year.
Smart Material Used: Sensor Perforated Aluminum Panels (Fig. 3).

**Criteria of selection:**

This case study is used to demonstrate the implementation of an Active climate-responsive kinetic façade system "Energy Exchange" in a smart building envelopes, to allow maximum sunlight into the building during the winter months while preventing sunlight from entering the building during the summer months.

**Building requirements based on climatic data:**

1. Artificial heating devices may need to be put in the building during the winter. These artificial mechanisms can also be eliminated by using passive solar building design.
2. Because of the low position of sun in the sky for much of the year, a vertical shading feature would be more effective than a horizontal shade element.

**Smart façade material manifestations in the building:**

Kolding Campus has a kinetic vertical solar shading system of perforated steel shades equipped with sensors that continuously measure heat & light levels and mechanically regulate shutters via a small motor allowing the facade panels to transition from open to half-open to fully open. These shutters can also be operated manually, providing optimal daylight and comfortable indoor climate spaces along the façade.

**LCC analysis:**

Through the use of passive design principles and the dynamic façade, over 70-75% of the building's energy consumption was locked in during the early design phases. The 13,700 m$^2$ facility uses a total of 38 KWh/m2/year and meets the requirements of Energy Class 1 Buildings, making the Kolding Campus one of the world's first low energy universities 'Mixed Use facility'. According to the minimization of the energy consumption of the building, which is used as an indicator of Life cycle cost minimization of the building.

**Fig. 3.** Kolding Campus Smart Façade System.

## 1.4. Life Cycle Cost

### 1.4.1. Definations

Flanagan et al., 1989, stated that the life cycle costing is an economic estimation method that evaluates the entire cost of a building over its operating life, including initial capital costs, maintenance costs, operating costs and the ultimate disposal of the asset at the end of its life [3], While according to Dell'Isola & Kirk, 2003: Life cycle cost analysis is an economic assessment of an item, system or facility over its lifespan, expressed in terms of equivalent cost, using baselines identical to those used for initial cost and it’s used to compare various options by identifying and assessing economic impacts over the life of each option.

### 1.4.2. Difference between life cycle cost & value engineering

**Table 3:** Difference between Life Cycle Cost & Value Engineering

| Type of Smart Material | Input | Output |
|---|---|---|
| Focus on: | Function | Total cost of a facility, |
| Challenge: | Reducing cost and maximizing function | Reducing total cost, margining the functional requirement, |
| Tool: | Analyzing the function eliminating and modifying non-essential functions that represent unnecessary costs. | Identifying high-cost spots and study alternatives that have lowest life cycle cost, |
| Main Savings Area: | Initial cost | Total Cost of ownership, |

### 1.4.3. LCC objectives

Life cycle cost is very important to be determined in the early design stage of the buildings, making it easier to choose from the alternative design options for the main actors and final decision-makers, as that the objectives of using it can be summarized as follows:

1. Consider the relationship between the important variables, the organization's objectives and its environment.
2. Focuses on cost optimization throughout the entire life cycle
3. Consider the impact of all costs rather than only initial capital costs
4. Optimization the financial advantages of buildings energy efficiency measures
5. Mapping the risks of a building according to life cycle costs analysis
6. Facilitate Comparing & choice between different alternatives during the early design stage.

In summarize the main objective of a LCCA is to determine costs and benefits of design alternatives to facilitate informed decision-making.

### 1.4.4. LCC applications

LCC is a very adaptable management tool because it allows for both short-term monitoring and long-term cost planning, To maximize the benefits of LCC, the techniques should be applied at the earliest stages of the design, during planning, budgeting, preliminary design, and design development phases for all disciplines (Noshy, 2004), LCC applications in construction sector can be defined as follows in **Table 4**.

**Table 4:** LCC Applications In Construction Sector

| | |
|---|---|
| **LCC identifies whole costs** | LCC methods enable researchers to recognize the whole costs emanating from the building throughout its operational life without looking at only the initial capital costs. |
| **LCC acts as a decision-making tool** | LCC helps in decision making and leads to functioning and monetary investment strategies |
| **LCC acts as a management tool** | LCC allows researchers to select the best resolution and also allows for good control of the asset during its operation |
| **LCC acts as a maintenance guide** | LCC provides diverse maintenance systems to be adopted, as well as maintenance cycles and their occurrences and to make repairs/replacement decisions, improvements, refurbishment decisions and also to agree on the maintenance budget. |

### 1.4.5. LCC limitations

Many stakeholders and developers override LCC information as it is believed that it presents unfactual information but more approximated results as the capital cost is the most real data enters in the LCC Calculations Furthermore all the other data is predicted and not real data. in addition, it is ignored because most developers after constructing are not managing the buildings themselves as they disposed of the building on completion. so, they are considering the maximum short term financial profit regardless of the long-term costs of the buildings, moreove, The absence of suitable, applicable and consistent historical figures and statistics of data, led to the difficulty of getting the correct level of information to calculate LCC.

### 1.4.6. LCC considerations

LCCA is a process of evaluating a building's economic performance over its entire life cycle, in **Fig. 4**, a theoretical model integrates six following steps representing the project phases and its relation with time and cost, the horizontal axis represents a project phase and the time required to update life cycle costing analysis, while the vertical axis represents the acquisition cost of moving from one stage to another over the construction project's life span.

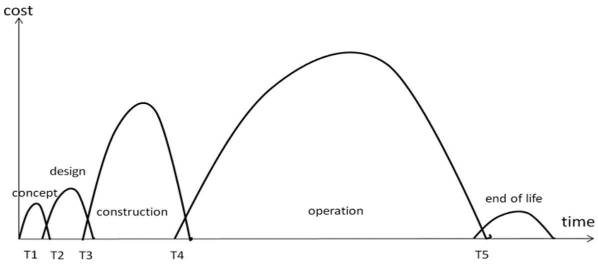



**Fig. 4:** Project Main Phases and Its Relation With Time And Cost

### 1.4.7. LCC calculation

To more understand the LCCA economic elements, we must keep in mind some factors affecting the initial and future costs which are calculated in the LCCA, they are:

1. Study Period/Project Time Frame, It is the period of time over which ownership and operations expenses are to be evaluated, it can range from 10, 20 to 40 years or more, depending on the building's technical parameters, expected time of operation (from the stakeholder's point of view) and the stability of the building function.
2. Initial Costs, it can be categorized into Land acquisition, Design team fees and associated costs, Construction cost as labor, material, equipment etc, in their real cost.
3. The running costs/Future cost, includes Maintenance costs, Operation costs and Replacement cost, by discounted to their present value at the base date of study.
4. Disposal Cost/End of Life Costs, include the construction disposal (removal and transport to recycling), as it's unpredictable it can be assumed = 0.

ISO 15686-5 states The money spent on the present and future is calculated in LCC analysis. All future expenditures must be converted to their present value before being included to calculate the overall LCC. When the Net Present Value (NPV) for each alternative is computed, comparisons become more simple because the best alternative is simply the one with the lowest total LCC or NPV, the following is the LCC Standard Equation as per ISO 15686-5.

$$TLCC = IC + RC_{PV} + DC_{PV}$$

Where;

1. TLCC is the total life cycle cost;
2. IC is the Initial Cost / Construction costs (Pre-Operation Costs) includes:
   - Purchasing cost
   - Installation cost
   - Transportation Cost
3. RCpv is Running Cost (Post- Construction Cost) / Future Cost includes:

- specified functional performance Operation Cost (Energy Cost)
- Maintenance Cost commonly interpreted to mean all costs incurred in ensuring the continued of the asset, includes:
  - The agent annual maintenance cost
  - Soft Maintenance (Cleaning Materials & Manpower)
- Replacement Cost
- Temporary Replacement Cost

4. DCpv Is Net Disposal Cost = 0

## 2. CASE STUDY - CREDIT AGRICOLE EGYPT (CAE)

LCC is a method for measuring the cost performance of different alternatives building facade material by single sum representing the sum of capital cost and future cost with the goal of facilitating options and those alternatives differ not just in their initial costs but also in their later Running and End of life Cost. To make a meaningful smart facade material comparison based on LCC Method, an Crédit Agricole Egypt (CAE) office building in New Cairo, Egypt was chosen as a case study, main building description was descriped in **Table 5**:

**Table 5:** Building General Description

| | |
|---|---|
| **Glazing System** | Saint Gobain / COOL SKIN 154-145II |
| **Certificates** | Platinum LEED v3 BD + C (LEED-NC) |
| **Climatic Zone** | Arid zone - hot desert climate |
| **Type** | Commercial / Administrative Building |
| **No. Of floors** | 2 Basements + Garden Floor Level + Ground Floor + 3 Typical Floors + Roof |

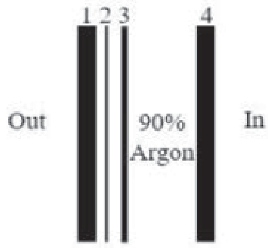
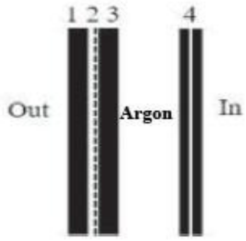
### 2.1. Building Façade

Glazing (Glass windows and Curtain Walls) is about 44 – 40% of total building façade material as shown in **Table 6**, two types of smart materials were used beside the existing façade , COOL-LITE SKN 154/154, to compare them: SageGlass (Electrochromic Glass) – Electromic and Photovoltaic smart material with their system Smart material system Glass. A conventional Clear Double-Glazing System was used as a basic scenario for comparing the alternatives (**Table 7**).

**Table 6:** The Existing Glazing Materials in CAE building facade

| | |
|---|---|
| **Glass Windows with Aluminum Frame** | Saint Gobain COOL-LITE® SKN 154/154 II<br>South facade: 375.5 m2<br>North façade: 322 m²<br>External East façade: 315.5 m²<br>External West 1 façade: 316 m²<br>Internal East Façade: 252 m²<br>Internal West façade: 181.5 m² |
| **Aluminum structural glazing curtain wall** | Saint Gobain COOL-LITE® SKN 154/154 II<br>West façades and 30% south façade with Total project area: 720m²<br>North, East and 70% south with Total project area: 1450m², 2265m² ground floor and 256m² inside facade<br>Full glazed façade with Total project area: 745m² |

**Table 7:** The Alternatives Specifications

| Types | COOL-LITE SKN 154/154 Existing Glass | SageGlass (Electrochromic Glass) –Alternative 01 | Photovoltaic Smart Glass material system Alternative 02 |
|---|---|---|---|
| **No. of Pane** | Double Pane | Double Pane | Double Pane |
| **Cross Section** |   |   |   |
| **Configuration** | External 6mm glazing panel (COOL-LITE SKN 154/154 II) + 16mm filled with 90% Argon + Internal 6mm glazing panel (PLANICLEAR / the latest generation of clear glass) | External 6mm glazing panel (+ 0.89mm Sentry Glass+ 2.2mm SageGlass (Electrochromic Glass)) + 10mm filled with 90% Argon + Internal 6mm glazing panel (optional low-e coating can be provided on the outer surface of the inner lite) | (6+3+6) mm amorphous silicon Photovoltaic smart material with their system |
| **U-Value** | 1.3 | 1.61 | transparency 20% + 12mm argon |
| **LT (Light Transmission)** | 0.52 | Range from 0.03 – 0.95 depending on the surrounding Environment and BMS | chamber + 6 mm tempered glass |

## 2.2. Case Study Parameters

In this study, the total LCC includes all the initial costs, which include; (the glazing unit Purchasing cost, installation cost, and transportation cost) in their real cost. Then, the running costs, that's includes; (the Operating energy cost for cooling and lighting, maintenance, and Temporary replacing cost) by discounted to their present value at the base date. Finally, the disposal costs indicate; (demolition, transportation, and resale value) but this is very uncertain data, accordingly in our case study we will assume the End of Life Costs = 0, All these calculations must be identified in a study period / Period of Analysis that we assume to be 60 years from the base date 2022, with expected lifetime of the three materials to be estimated 25 years, which indicates that, during the building service lifetime, the materials must be replaced two times at year 25 and 50.

## 2.3. Life Cycle Cost Calculation

### 2.3.1. LCC calculation considerations

1. Average Discount Rate / Interest Rate in Egypt According to Central Bank of Egypt (1991-2023) = 11%
2. Average Escalation Rate / Inflation Rate in Egypt According to WB (1960-2022) = 9.7%
3. Study Period = 60 Years

### 2.3.2. Initial cost

The initial costs of each alternative are calculated based on the rate of each 1 m2 of the glazing system, includes with its purchase, transportation from its home country location to Egypt, 5th setlement , and installation costs as per the specifications and also the façade marina cleaning system, This calculation can be viewed below **Table 8**:

$$IC = P + T + I$$

Where;

- IC is the initial cost;
- P is the purchase cost;
- T is the transportation cost,
- I is the installation cost.

**Table 8:** Initial Cost Calculations

| Description | Unit | Qty | Rate/m² | Actual cost | Rate/m² | Actual cost | Rate/m² | Actual cost |
|---|---|---|---|---|---|---|---|---|
| | | | COOL-LITE SKN 154/154 | | SageGlass (Electrochromic Glass) | | Photovoltaic Smart Glass material system | |
| Glass Window with Aluminum Frame | m2 | 2,024 | 6,676 | 13,512,995 | 13,248 | 26,813,952 | 14,016 | 28,368,384 |
| Aluminum Structural Glazing Curtain Wall | m2 | 2,076 | 6,676 | 13,860,167 | 13,248 | 27,502,848 | 14,016 | 29,097,216 |
| Façade Cleaning System | Item | 1 | 1,090,575 | 1,090,575 | 1,090,575 | 1,090,575 | 1,090,575 | 1,090,575 |
| **Total Initial Cost** | | | | **28,463,737** | | **55,407,375** | | **58,556,175** |

For SageGlass (Electrochromic Glass) – Alternative 01 and Photovoltaic smart glass material system– Alternative 02, the installation cost increased due to the additional electrical connections and the sensors installed.

### 2.3.3. Running cost

As previously stated, operating costs include energy costs, maintenance costs, and replacement costs for the glass system. During the glazing system lifetime study period, these expenditures will be paid on a regular basis. As a result, the costs that will be paid in the future must be assessed in terms of present values. For this calculation, the energy, maintenance, and replacement costs are multiplied by the Present Value Factor (PVF), which considers the Time Value of money by using the Escalation Rate to get first the future value of money then the discount rate to get the present value of money both are used with the study period, the following is the General Running cost;

$$RCpv = (EC_{Fv}\ x \sum_{n} \frac{1}{(1+r)^{n}}) + (MC_{Fv}\ x \sum_{n} \frac{1}{(1+r\ )^{n}}) + \ (RC_{Fv}\ x \sum_{n} \frac{1}{(1+r\ )^{n}})$$

Where;

- **RCpv** : Running Cost in the Present Value
- **ECFv** : Energy Cost in the Future Value
- **MCFv** : Maintenance Cost in the Future Value
- **RCFv** : Replacement Cost in the Future Value
- **Fv** : Future Value
- **r** : Discount Rate / Interest Rate
- **n** : Study Period Life cycle / Number of Years

While The PV is calculated as follows:

$$Pv = Fv(\frac{1}{(1+r)^n})$$

Where;

- **Pv** : Present Value
- **Fv** : Future Value
- **r** : Discount Rate / Interest Rate
- **n** : Study Period Life cycle / Number of Years
- $\frac{1}{(1+r)^n}$ : Present Value Factor

And the Future Value equation is as follows:

$$Fv = Pv\ (1+e)^n$$

Where;

- **Fv** : Future Value
- **Pv** : Present Value
- **e** : Escalation Rate / Inflation Rate
- **n** : Study Period Life cycle / Number of Years
- $(1+e)^n$ : Future Value Factor

- **Energy Cost**

For each scenario, the cooling and lighting loads were calculated following the below steps:

1. Getting the actual cost of the of the existing and alternatives glazing façade materials for the 60 years' study period, by getting the average energy cost for year 2021 from CAE operation department and assuming that it's the actual cost for the rest of the years, and the summing of these costs during the 60 years is the net actual cost for energy consumption.

   Then, Obtain the future value for each scenario for every year as the following example:

$$Fv = Pv\ (1+e)^n$$

   Fv for energy consumption in year 20 = 7,002,979 $x$ $(1 + 9.8\%)^{20}$

   Fv in year 20 = 45,428,631 EGP

2. After that, Calculating the present value for each year during the 60 years' study period, as the following example:

$$Pv = Fv(\frac{1}{(1+r)^n})$$

   Pv for energy consumption in year 20 = 45,428,631 $x$ $\frac{1}{(1+11\%)^{20}}$

   Pv in year 20 = 5,634,690 EGP

In **Table 9**, The electrical and gas consumption cost used for cooling and lighting for existing façade material, obtained from CAE Operation Department, and for the two alternatives façade material, in which for alternative 01 Following the specification obtained from Sanit Gobain Company, the consumption used for cooling and lighting is decreased by 25% when using Sage Glass, while in alternative 02 Following the specification obtained from Company and recommended by [4], PV glazing with a power conversion efficiency as low as 7% to 15% energy conversion efficiency, reduces energy use by more than 30% - 43%, and by taking that it will save 40% as an average, accordingly, for electrical consumption it will save up to 25.5% as it increased the energy consumption for lighting by 14.5% according to [4], while in gas consumption we assumed that it will save up to 40% in cooling.

**Table 9:** Energy Cost Calculations

| Description | Actual Value | Future Value | Net Present Value |
|---|---|---|---|
| **COOL-LITE SKN 154/154 / Existing Facade** | | | |
| **Electrical Cost** | 326,308,350 | 16,572,948,596 | 238,405,484 |
| **Gas Cost** | 93,870,420 | 4,767,605,994 | 68,583,053 |
| **Total** | **420,178,770** | **21,340,554,590** | **306,988,537** |

| Description | Actual Value | Future Value | Net Present Value | Actual Value | Future Value | Net Present Value |
|---|---|---|---|---|---|---|
| **SageGlass (Electrochromic Glass / Alternative 01** | | | | **Photovoltaic smart glass material system** | | |
| **Electrical Cost** | 244,731,263 | 12,429,711,447 | 178,804,113 | 243,099,721 | 12,346,846,704 | 177,612,085 |
| **Gas Cost** | 70,402,815 | 3,575,704,496 | 51,437,290 | 56,322,252 | 2,860,563,596 | 41,149,832 |
| **Total** | **315,134,078** | **16,005,415,943** | **230,241,403** | **299,421,973** | **15,207,410,301** | **218,761,917** |

- **Maintenance Cost**

The maintenance cost covers both the annual fees of the maintenance agency as well as the costs of soft maintenance, for the existing glazing facade material the maintenance annual cost were obtained from CAE operation department, and the data for the alternative glazing facade material 01 / SageGlass (Electrochromic Glass) is obtained from their brochure, which mentions that their maintenance is the same as any traditional glazing facade maintenance, while for alternative 02 – Photovoltaic smart glass material system, have an annual maintenance rate of 1% of the purchase cost [4], and according to the purchase cost of Photovoltaic smart material with their system façade system per m2 = 730 $, accordingly with the dollar exchange rate in 2021, the maintenance cost for m2 will be = 4100 Egyptian Pound, **Table 10**.

**Table 10.** Maintenance Cost Calculations

| Description | COOL-LITE SKN 154/154 / Existing Facade | SageGlass (Electrochromic Glass) / Alternative 01 | Photovoltaic smart glass material system / Alternative 02 |
|---|---|---|---|
| **Total Maintenance Cost / 60 Years** | 9,468,759 | 9,468,759 | 9,834,884 |

- **Replacement Cost**

It was stated that All glazing systems must be replaced after 25 to 30 years, according to the manufacturer's requirements. [4] The reason for this is that maintenance becomes unprofitable after this time of service. Furthermore, the performance of glass, coating, and PV film is at its lowest, which is insufficient to conserve or generate energy, The total cost of the replacement stage has been determined and converted to present value.

Replacement costs are divided into two major categories, essential replacement for the whole glazing system assuming that it will be after 25 years and temporary replacement used as a risk factor for unpredictable loses for glazing panels assuming that this temporary replacement will take place each 3 years and calculated for 1 m2 as shown in **Table 11**.

For the existing glazing facade, the rate of annual replacement for m2 is equal to 33,550 EGP as stated in the below table, obtained from CAE operation department, while for alternative 01 – and alternative 02 –the annual replacement calculated as follows:

$$TRC = ICm^2 \; x \; \$e \; x \; RF$$

Where;

- **TRC** : Temporary Replacement Cost
- **ICm²** : Initial Cost for glazing façade / $M^2$
- **$e** : Average Dollar Exchange to EGP in 2023 (1 $ = 35 - 40 EGP)
- **RF** : Risk Factor (Assuming 1.4)

The whole replacement stage costs must be calculated and converted to the present value as the following:

$$Rpv = (RC_{Fv} \; x \sum_{n} \frac{1}{(1+r)^n}) + (TRC_{Fv} \; x \; \sum_{n} \frac{1}{(1+r\,)^n})$$

Where;

- **Rpv** : Replacement Cost in the Present Value
- **RCFv** : Replacement cost after each intervals of 25 years in the Future Value
- **TRCFv** : Temporary Replacement Cost each 3 years in the Future Value
- **r** : Discount Rate / Interest Rate
- **n** : Study Period Life cycle / Number of Years

**Table 11:** Replacement Cost Calculations

| Description | COOL-LITE SKN 154/154 / Existing Facade | SageGlass (Electrochromic Glass) / Alternative 01 | Photovoltaic smart material with their system Smart / Alternative 02 |
|---|---|---|---|
| **Total Replacement Cost / 60 Years** | 37,240,858 | 73,493,609 | 77,754,108 |

## 2.4. Life Cycle Cost Analysis

In **Table 12**, the use of Photovoltaic smart material with their system has the lowest total LCC although it has the highest initial cost due to it installation and transportation cost, the reduction in the Life cycle cost came from the saving energy obtained from Photovoltaic smart material with their system material as it's helps in generate electricity used in the building cooling & lighting which affect in a lower cooling loads used by from the normal electrical way. While SageGlass (Electrochromic Glass)is the second recommended material to be used after Photovoltaic smart material with their system , although it's initial cost is lower than Photovoltaic smart material with their system Smart material system but it's total LCC is greater than it, and the existing glass façade has the lowest initial cost but it's LCC is the highest of them all, Photovoltaic smart material with their system is economically feasible; in converse, SKIN LITE 154 – 154 II has a negative total LCC due to the high running costs, which cannot be recovered during the 60-year study period. This result is in line with previous research results.

Using alternative 02, the investor will save approximately 17,254,805 EGP over the study period, which is approximately 4.5% of the total life cycle cost of the existing façade, whereas using alternative 01 will save approximately 13,550,744 EGP over the study period, which is approximately 3.5% of the total life cycle cost of the existing façade.

**Table 12:** Life Cycle Cost Analysis

| Description | COOL-LITE SKN 154/154 / Existing Facade | SageGlass (Electrochromic Glass) – Alternative 01 | Photovoltaic smart material with their system Smart / Alternative 02 |
|---|---|---|---|
| **Total Initial Cost** | 28,463,737 | 55,407,375 | 58,556,175 |
| **Total Operation Cost / 60 Years** | 306,988,537 | 230,241,403 | 218,761,917 |
| **Total Maintenance Cost / 60 Years** | 9,468,759 | 9,468,759 | 9,834,884 |
| **Total Replacement Cost / 60 Years** | 37,240,858 | 73,493,609 | 77,754,108 |
| **Total Life Cycle Cost / 60 Years** | **382,161,890** | **368,611,146** | **364,907,085** |

# CONCLUSION & RECOMMENDATIONS

This Case study aims to shed light on the smart materials used in the facades of the administrative buildings for its high efficiency and its impact on the life cycle cost of the projects, moreover to implement the projects to meet the global trends toward the sustainability and zero carbon vision, Based on the experimental results and the above discussions, the following conclusions can be derived:

1. The existing facade skin lite 154 - 154 II employed has a 49% lower initial cost than alternative 01 - SageGlass (Electrochromic Glass)and a 51% lower initially cost than alternative 02 - Photovoltaic smart material with their system system. The transportation have a significant impact on the initial cost. Skin Lite 154-154 II imported from UAE while SageGlass (Electrochromic Glass)& Photovoltaic smart material with their system system from USA & Spain respectively.
2. The LCC calculation revealed that energy costs are the greatest impact on the building's life cycle cost. According to studies, the energy used in lighting and cooling is closely related to the building's façade, particularly to the type of glass employed. As a result, Sage Glass saves 25% of the overall building energy and Photovoltaic smart material with their system Smart material system save 35% - 45% based on the energy generated by this system, which are the same percentages that are meant to be saved from the building's energy cost throughout the study period.

## Recommendations:

It is advised that designers and other relevant parties increase the application of smart materials technologies in building facades due to their ability to respond to external stimuli, preserve the interior environment of the building, and enhance occupant comfort.

Furthermore, by incorporating life cycle cost analysis techniques, not only are the initial cost calculations made, but the entire life of the project—from the start of the project stage to the operation stage and finally to the disposal life—is calculated. This helps enforce recommendations for maintaining the building's interior environment with suitable materials, which prevents resources from being wasted and protects the surrounding environment, which lowers energy consumption, carbon emissions, and harmful gas emissions.

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