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Evolution Of Smart Glass and its role to redirect Architectural Buildings

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Abstract
High technology is nowadays leading many aspects of life, like industrialization, education, innovations, and other fields. Moreover, high technology has gained the power to convert materials into smart ones that are not only self-adaptable and self-sensing but can also react to external environmental stimuli, whether by strengthening and embracing all wanted features or by expelling the unwanted ones. Unfortunately, architects are not aware of most of the technologies that can be implemented in building construction and finishing materials, so they squander all opportunities to produce a sustainable building and increase energy performance. The paper undertakes many phases to help architects understand and use smart materials in general and smart glass in particular. These phases start by revealing how materials can be converted into smart ones, followed by the characteristics of smart materials, their importance, types, applications, and advantages in architecture. Smart glass is presented to architects as one of the most significant examples of smart materials that play an important role in building envelopes. Therefore, all types of smart glass will be presented using a comparative analytical method to explain their benefits and features that can assist architects in applying sustainable principles in architecture. Moreover, the research suggests a methodology to assist architects in utilizing smart glass and choosing the most convenient according to surrounding stimuli.

1. Introduction

The main desire of buildings in architecture is to create spaces that provide comfort and satisfaction to inhabitants; in return, this will increase their production level and reinforce the function of

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buildings. The previous can be sustained through a smart building envelope that can sense any changes in external climate and thus has the ability to react to external stimuli and expel undesired light, glare, and heat.

An envelope can be sufficiently designed by combining materials together in a way to gain their full potential from one side and to react with external climatic changes from the other side. Unfortunately, architects don't have sufficient information about material properties to make the right decisions while designing building envelopes. Therefore, they simply use conventional windows and force inhabitants to use curtains, blinds, air conditioners, and many other treatments that don't only block the view and waste energy but also generate a sense of constant discomfort for inhabitants. Therefore, it is necessary to help architects briefly understand the meaning of the word "material" and its types and behaviours in order to examine their conversion into smart ones [1][2].

The term "smart materials" will appear rapidly, followed by a definition showing the difference between their passive and active types. In addition to many explorations about their return to their original shape and characteristics when the external stimuli are removed, the time needed for this return varies from one material to another and according to the type of stimuli.

2. Objective

The paper attempts to encourage architects to replace traditional windows with smart glass in all buildings after generating tables that illustrate and explore all types of smart glass, showing their potential to control different climatic conditions while achieving safety, security, and many other technological features. Also, a comparison will be held between different types of smart glass, showing their advantages and features, to help architects implement the suitable smart glass to achieve the desired purpose by the best means.

3. Methodology

In order to fully understand smart building envelopes, some introductory sections will first explain some important factors: the materials historical background, the classification of materials and smart materials, the industrial revolution, the birth of smart glass, and the analysis of its different reactions to external stimuli.

Moreover, an analytical comparison is undertaken in the paper to differentiate between different features of smart glass types and their design potentials to help the architect choose the suitable type of smart glass and understand their potentials while designing sustainable, clean buildings.

4. Materials

In order to gain the maximum potential of any material used in building construction, it is important to understand and study its properties and its reaction to changing surrounding conditions [3].

According to the definition in the Cambridge dictionary, materials are the physical substances or objects that things can be made from. In other words, the materials of a building can be the stones that formed it, or the materials of a curtain can be the cloth that sewed it [4].

Materials come from nature in three basic categories: metals, ceramics, and polymers. In addition to a fourth category called "composites," which is derived from the combination of two or more of the

previous three basic material categories, Besides, there is another functional classification in Table 1 that considers materials as advanced ones, like high-technology applications, electronic materials, biomaterials, smart materials, and others that depend on nanotechnology [5].
The industrial revolution changed the function of materials from just a cover or separating surface without any effect on building systems to the most important sensors and controllers in building performance. Therefore, this led to a massive change in the use of building materials through the years, as in the past, materials were chosen for their availability in local areas and for their ability to be shaped into ornaments. But nowadays, materials are chosen for their ability to increase the building's performance under different climatic and environmental conditions. Moreover, the industrial revolution and nanotechnology allowed the materials to change their characteristics, which therefore led to the appearance of smart materials [3].

Table 1: Types and classifications of materials [6]

<table>
<tr><th colspan="2">Metals</th><th colspan="2">Ceramics</th><th colspan="2">Polymers</th><th colspan="2">Composites</th></tr>
<tr><td colspan="2">Has one or more metallic elements and often non-metallic elements</td><td colspan="2">Compounds between metallic and non-metallic elements.</td><td colspan="2">Include the familiar plastic and rubber materials. Many of them are organic compounds</td><td colspan="2">Combination of two or more of metals, ceramics, and polymers</td></tr>
<tr><td colspan="2">Example: Iron, aluminium, copper, titanium, gold, and nickel. Carbon, nitrogen, and oxygen</td><td colspan="2">Example: some of the common ceramic like glasses, clay products, cements, and refractories</td><td colspan="2">Example: Carbon, hydrogen, and other non-metallic elements</td><td colspan="2">Example: Mud bricks, wood, fiberglass, and plastics.</td></tr>
<tr><th colspan="8">Functional Classification of materials</th></tr>
<tr><th>Structural</th><th>Aerospace</th><th>Biomedical</th><th>Electronic</th><th>Smart</th><th>Optical</th><th>Magnetic</th><th>Energy technology</th></tr>
<tr><td>Have mechanical properties, as opposed to their electronic, magnetic, chemical, or optical specification</td><td>Metal alloys have exceptional performance, strength & heat resistance.</td><td>Engineered to interact with biological systems or replace damaged tissue for a medical purpose</td><td>Has electrical properties, considered core elements in a variety of device applications.</td><td>changes its properties in response to external stimuli</td><td>Their function is to alter or control electromagnetic radiation in the ultraviolet, visible, or infrared spectral regions.</td><td>Produces magnetic field and interacts with magnets.</td><td>dedicated to publishing high-quality materials related to cleaner energy and environment.</td></tr>
<tr><td>Example: steels, concrete, fiberglass, plastics, wood, aluminium alloys</td><td>Example: Al-alloys, Amorphous silicon</td><td>Example: Titanium, shape-memory alloys, stainless steel</td><td>Example: Si, GaAs, Ge, PZT Al, Cu, W, conducting polymers</td><td>Example: PZT, Ni-Ti shape-memory alloys, MR fluids, Polymer gels.</td><td>Example: SiO2, Glasses, Al2o3, YAG, ITO</td><td>Example: Fe, Fe-Si, NiZa, MnZn ferrites</td><td>Example: UO2, LiCoO2, Amorphous Si:H Solar & fuel Cells, Catalysts, Batteries</td></tr>
</table>

5. Smart materials: Definition and Classification

There are many synonyms for the word "smart," like clever, sharp, intelligent, and bright, but when the word smart is followed by material, it means that this material has special features like being active, self-adaptable, and self-sensing and has multiple functionalities that allow it to sense changes and conditions surrounding them in the environment. Accordingly, smart materials consist

of sensors that sense changes in the surrounding environment and an actuator that acts and responds to undesired stimuli by changing their shape, position, natural frequency, or mechanical characteristics [7].
Smart responsive materials are the type of material whose external or internal behaviour slightly changes by altering and effecting its structure, function, or stability. This happens in response to different environmental conditions surrounding the material itself. The material characteristics are switched in response to environmental stimuli like temperature, stress, heat, light, moisture, chemical compounds, bio-stimuli, pH (potential of hydrogen), electric field, magnetic field, mechanical stress, and ionic strength [1].
Any material can be considered smart if it can be [3].

- Transiency: to react to various environmental states.
- Selectivity: their reaction is expected and discrete.
- Self-actuation: the material itself is smart.
- Directress: The fact that the reaction is local means that the response is similar to the activating event.
- Immediacy: the response is instant [2].

The classification of smart materials depends on the characteristics and responsive methods of the material itself (Fig.1). Moreover, the structure of each material and its synthesis degree grabs it towards being a smart material with superior characteristics [1]. Smart materials are classified into two main types: those that just sense any surrounding changes and transfer energy without changing properties, so they are called passive smart materials, like fibre optic materials [8].
The second type senses and responds interactively to external environmental conditions or stimuli in predetermined manners, so they are called active smart materials. This response takes place by changing their geometrical shape or property under the application of electric, thermal, or magnetic fields. Piezoelectric materials, SMAs, ER fluids, and magnetostrictive materials are examples of active smart materials [8] [9].

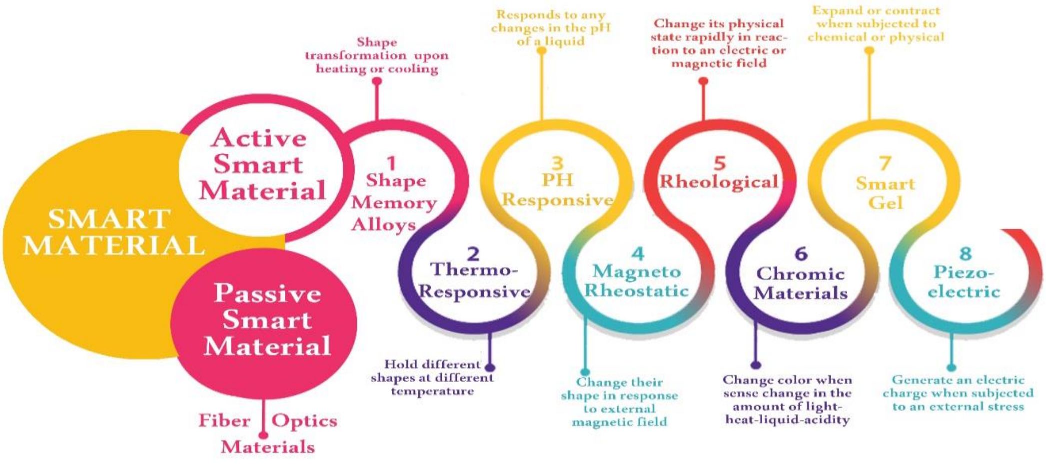


Fig.1: Smart Materials classification [6]

Active smart materials also have many types that sense different stimuli and respond to them in various manners according to the following classification:

5.1 shape memory alloys

Shape memory metals are kinds of metals in which large deformations can be induced and recovered through temperature changes or stress changes. They also have the ability to revert to their original shape and properties when the temperature returns to normal. A shape memory alloy is a kind of shape memory metal in which its deformation is a transformation to any shape upon heating or cooling. In addition, alloys have the ability to remember their original shape and return to it [10]. These materials can be transformed into any shape, but on heating or cooling, they will remember their original shape and get transformed into the original shape when the temperature is retained to their original status. Therefore, shape memory alloys are called "intelligent "materials," and "smart wire" is considered an example of shape memory alloy wire that remembers its shape, so when it is subjected to an electrical current, it becomes smart. The smart wire can be shorter, then return to its length and original shape when the current is off. Scientists use the smart-shape memory alloy in robotic hands for robots or for artificial motion [8] [9].

5.2 Thermo-responsive

Thermo-responsive is a shape memory polymer, which is considered the second type of shape memory metal that has the ability to hold different shapes at different temperatures. Shape memory polymers have many advantages that make them preferable in architectural usage, like their light weight, wide flexibility in shape deformation, and their ability to recover themselves [11]. Thermo-responsive materials have many applications in architecture and especially in a building’s outer skin due to their high elastic deformation and high flexibility in changing their form or state in response to a variation in temperature [12].

5.3 PH sensitive/responsive

They are commonly used and developed, especially those that are polymer-based, due to their various applications in many fields. A pH-responsive polymer is a material that responds to any changes in the pH of a liquid by undergoing structural and property changes such as solubility, surface activity, volume, and chain structure formation [5].

5.4 Magneto rheostatic

Magnetic-sensitive smart materials are those materials that can easily sense any external magnetic field near them and also respond to this field by changing their shape. Moreover, it is a reversible process that can return to its original status when the magnetic field subjection is ended [8]. Therefore, magnetorheological materials are considered a type of magnetically sensitive material that changes immediately, endlessly, and reversibly in response to it. Magnetorheological materials (MR) have several types, like MR fluids, MR elastomers, and MR gels, which can change their viscosity or solidification when subjected to the magnetic field [13].

5.5 Rheological

A rheological material is a material that can change its physical state rapidly in reaction to an electric or magnetic field. These electric rheological (ER) and magnetic rheological (MR) materials are subjected to physical change by converting themselves from liquid to solid states and vice versa. Therefore, these materials have many uses concerning safety, and they are frequently used in brakes, cars, and dampers on bridges (Fig. 2) [14].

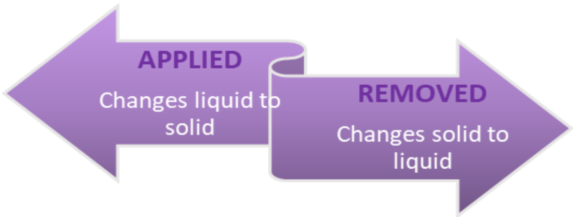


Fig. 2: Electric/Magnetic field [6]

5.6 Chromic Materials

The word "chromic" means the ability to change colour; therefore, chromic materials are those that change their colour in response to external stimuli like heat, light, water, acidity, and an electric field. Chromic materials are classified into (i) thermochromic materials. (ii) photochromic materials; (iii) halochromic materials. (iv)Hydro chromic

(i) Thermo-chromic: Thermo = heat, Chromic = colour

They are materials that change their colour temporarily in response to temperature changes, then return to their normal colour when they gain their own temperature back. Thermos-chromic materials are widely used in many fields and industries, like manufacturing special ink and thermochromic coatings with high reflectivity during high temperature seasons [9].

(ii) Photochromic materials

Photochromic materials are colourless materials that sense increased light absorption when light rays fall on it. They have many uses and can be used in the manufacturing of optical glasses, plastic materials, and windows.

Photochromic materials have the ability to transmit most light if it is not too bright, and on the other side, they get increasingly dark when exposed to sunlight [15].

(iii) Halochromic materials

They change their colour as a result of changing acidity. These materials can be used in the manufacturing of paints that can change colour to indicate corrosion in the metal beneath them [9].

(iv) Hydro-chromic Materials

Hydro-chromic materials change colour as a response to sensing an amount of liquid and can be used in manufacturing inks [16].

5.7 Smart gel

Smart gels by nature contain liquid, which is usually water; therefore, when they are subjected to chemical or physical stimuli like changes in temperature, light strength, electric, or magnetic forces, they expand or contract by several orders of magnitude. These smart gels can be used in the manufacturing of food, drugs, and chemical processing [14].

5.8 Piezoelectric materials

They are materials that have the ability to produce and generate a voltage or electric charge when subjected to external stress. Also, the previous is in a reversible manner; therefore, these materials can bend, expand, or contract when a voltage is applied [8]

In conclusion, by revealing the mysteries of different types of smart materials and understanding their function and how they can be used in architecture, this will allow architects to use smart materials and mix them together in structures, building envelopes, construction materials, and many other inventions. All the previous will work together to create a smart system that increases the performance and life cycle of the structures, decreases the cost and energy consumption, and finally controls light and heat to create a safe atmosphere and physical comfort for users. Therefore, their performance levels will be highly fulfilled, and spaces will operate efficiently, leading to the creation of a smart, sustainable community with a high quality of life.

Smart glass is considered one of the most widely used examples of smart materials that are selectively used in critical components of a structure, which is the façade or building screen. It promises higher performance, more durability, and better economic feasibility, and it is considered the best method to control external weather stimuli compared to conventional glass. To understand the variable strengths and functions that can be offered by smart glass, it is important to define the word "smart glass" and sense the great evolution in the production of smart glass by emerging science and technology to create new features that enhance architecture and communities [8].

6. Smart glass

All of the previous smart materials had made a major revolution in the industry field to increase the performance of all materials and elements used in building, such as structure, windows, glass, furniture, and many materials in the field of materials science. In general, using smart materials instead of conventional mechanisms will allow a huge development in architecture and guarantee the birth of smart architecture that senses and responds to any surrounding changes. Furthermore, it opens up new possibilities, such as for glass that gains the ability to control and interact with surrounding environmental changes and also repair, clean, and allow existing technology to be improved [17].

6.1 Definition:

Smart glass is a type of glazing product that adjusts its light-control characteristics in response to an external input. Smart glass is a relatively new class of high-performing glazing with important clean technology qualities. It is also referred to as switchable glazing, dynamic glazing, and chromogenic. A variety of conventional products, including windows, doors, skylights, dividers, sunroofs, sun visors, and more, can be made with smart glass [18].

7. Passive and Active Smart glass:

Smart glass is composed of two major types that depend on controlling the quantity of light, glare, and heat passing through the facades and windows. The previous control can be done manually or automatically if it is an active smart glass, which is considered the first and most common type. The other type is passive smart glass that cannot be manually controlled (Fig. 3). The use of air cooling and heating throughout the summer and winter is reduced by glass facades using smart glass technology. It is advantageous and exceptional to be able to alter the glass instantaneously to maximize daylight when it is truly needed and to provide adjustable solar shading when light levels are at their highest [9].

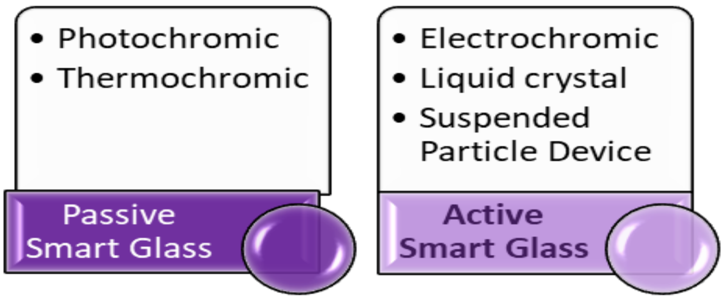


Fig. 3: Smart glass classification [6]

7.1 Passive smart glass

Passive smart glass is the type of glass that makes a reaction to surrounding non-electrical stimuli such as light and heat. Therefore, it is made of chromic materials, like photochromic and thermochromic, that react to changes in light and temperature by changing their colours or light-control properties. For example, thermochromic windows are tinted in the summer and clear in the winter; they switch according to the temperature of the outside air. Finally, passive smart glass cannot be manually controlled [9].

7.2 Active smart glass

Active smart glass is the type of glass that makes a reaction to surrounding electrical stimuli, and therefore it is controllable by the user manually or automatically. It has three primary types, which are electrochromic (EC), polymer dispersed liquid crystal (PDLC), and suspended particle device (SPD). Each of these types has its own performance characteristics and chemistry, and that will be explained briefly in the following [19]:

7.2.1 Electrochromic smart glass

It uses electricity to offer solar control and light transmission levels from clear to dark. The visible light transmission in the darkest state can be less than 3%. When the glass is subjected to low-voltage electrical charges, the electrochromic layers in the glass will be activated to change the glass colour from clear to dark. Moreover, the electric current can be applied manually by the user or automatically with the help of light intensity sensors that spot any changes in light and send an order to the glass to change its colour. Unfortunately, to apply electrochromic glass to an existing building, the old conventional window needs to be removed and replaced with smart glass because commercial film is not available to be added to the old glass [19].

7.2.2 Polymer dispersed liquid crystal

Smart glass is primarily used for interior partitions in architectural applications because of its great ability to switch between translucent and transparent. Therefore, liquid crystal glass diffuses incoming light and thus provides a privacy benefit in its translucent form but provides very little in the way of shading [18].

With the flip of a switch, smart glass immediately changes from clear to opaque, offering instant privacy. This effect is the reflection of applying electricity to microscopic liquid crystals. The electrical current causes the liquid crystal molecules to simultaneously align when the power is turned on. This makes the glass clear and allows light to enter. Similar to conventional glass, switchable glass can be placed by any glazier and wired by an electrician. Any type of glass, including pressure-rated and bulletproof glass, can be made switchable [20].

7.2.3 Suspended particle device

The light transmission levels of smart glass can be adjusted to any point between opaque and transparent. A level 20 to 40 times darker than conventional window tints, SPD smart glass can block at least 99.4% of incoming light when it becomes entirely dark. Light transmission through SPD smart glass is similar to that of a conventional, non-tinted window when it is in its clear state. No matter how big the glazing is, all adjustments to light transmission levels occur in a matter of seconds [18].

8. Smart Glass leading the future Architecture

8.1 Advantages of smart glass

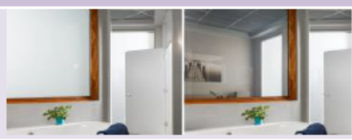
Smart glass has many advantages that are increasing day after day, allowing it to lead the market, like the following:

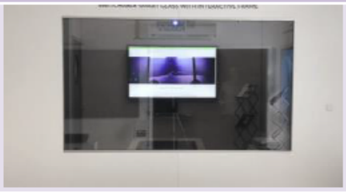
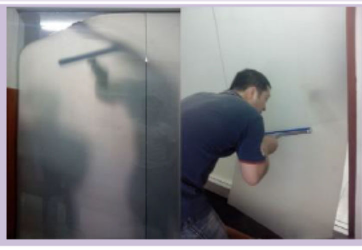
- Energy Efficiency: It acts as a heat insulation screen; therefore, it optimises the temperature inside the spaces, leading the users to give up the usage of air conditioners and thus saving energy.
- Energy performance: It can result in significant expense reductions for heating, lighting, ventilation, and air conditioning. Additionally, it reduces the demand for artificial light while blocking UV and infrared rays.
- Versatility: It has multiple applications, such as in advertising fields and information communication, as the building façade can be converted by a click into a display screen.
- Enhanced Security: Achieve the highest security levels, as it makes it difficult to see through buildings and spaces.
- Sun Protection: It blocks up most ultraviolet rays while only allowing needed visible light to get through.
- Environmentally Friendly: It is designed to contribute to environmental protection efforts by decreasing pollution and being friendly to all surrounding weather conditions.
- Sound Insulation: It helps to block out audible sound and keeps the noise locked out.
- Cost-Efficient: Although it is mistakenly thought to be more expensive than conventional glass, it is financially cheap in return for the multiple benefits it provides.
- Increase Market Value: Using smart glass indicates how significant the building is and thus increases the value of the building in general.
- Modern Appeal: it is considered a futuristic technology and a symbol of modernity used in the building [21].

8.2 Directing architects to smart glass

The technology of smart glass is increasing every day, leading architecture to sustainability and allowing the spread of green buildings. Unfortunately, architects need assistance to understand all types and their potential to be used properly in different spaces and building screens. Therefore, most smart glass types are represented in Table 2 with an explanation of what they can offer to designers and a picture to fully explain their system.

Table 2: Types of smart glass used in buildings [6]

Smart Glass Types	Definition	Image
1. **Switchable Dark**	It is a laminated glass with a liquid crystal interlayer; it can switch between transparent and opaque as a full blackout. Therefore, it ensures privacy and safety, blocks ultraviolet rays, and reduces noise.	
2. **Switchable mirror**	They combine both switchable and mirrored surfaces, working together to offer a display solution.	
3. **High Reflective Switchable Glass**	High Reflective Switchable Glass is a unique product that combines switchable technology with a highly reflective coating, producing a mirrored switchable effect. Ideal for retail or high-end displays	

4. Voice activated Switchable Glass	Glass switches from transparent to opaque according to voice commands and is mainly used in automation systems and houses.	
5. Switchable Front Projection Screen	Due to the limitations of PDLC technology, switchable projection products have traditionally been rear projection-based, which allows us to produce an effective front projection switchable screen.	
6. Interactive switchable screen	It brings the power of touch to switchable technology. Standard rear projection switchable projection screens are ideal for meeting rooms and information points.	
7. Sound Insulating Acoustic Switchable Glass	It provides sound insulation without having to compromise on style or effect. It is useful in designing spaces that need audio privacy.	
8. Fire Safety Switchable Glass	Thick concrete walls are no longer needed to achieve fire safety regulations, as fire safety glass can do the job perfectly. It minimizes the damage and helps to contain any fire.	
9. Colored Switchable Glass	Many manufacturing processes are used to add colour to switchable glass, including laminating with a colour resin or applying special transparent tints.	
10. Battery Powered Switchable vision panels	It is powered by a replaceable AA battery pack concealed within the door. The glass works independently of mains power, which allows flexibility and little disruption during installation.	
11. Self-Adhesive Switchable Film	It offers retrofit switchable technology to customers at an affordable price without the need for specialist installation tools. It provides a simple and cost-effective alternative way to retrofit existing glass into switchable smart glass.	

Furthermore, a comparison is held between active smart glass types in Table 3 to show the advantages of each type and the features that distinguish one. Therefore, the following will allow architects to choose the suitable types of smart glass that fulfil the required needs.

Smart glass will lead to a commercially successful product as those that are made of switchable glass can be used for at least 100,000 hours. The lifespan of smart glass is now 15-20 years on average. Because smart glass will use less energy and resources overall, there is a significant possibility for increased sustainability in the future. It is the perfect option for both homes and businesses because of its capacity to regulate light and heat and create a secure environment.

Table 3: Comparison between Active smart glass types [6]

Architectural Design Considerations	Electrochromic smart glass	Suspended particle device	Polymer dispersed liquid crystal
Glass is transparent when switched on	X	YES	YES
In continuous state between transparent and opaque	YES	YES	X
It requires power to maintain the state	X	YES	YES
Low energy needed to operate & power needed	YES 12 V DC	YES 65-110 V AC	YES 65-110 V AC
Shading Benefit	YES	YES	Nominal
Time for Switching	3-5 minutes	Several seconds	Milliseconds
Privacy achieved	Medium	High	High
Light degrees levels form dark to clear	2 levels	Unlimited	2 levels
Forms variety between rectangle, square, trapezoid or triangle	YES	YES	YES
Tints	Blue, Green	Blue, Green	Blue, Green
Expenses	Lowest	Highest	Medium
lifespan	>30 years	>30 years	>30 years
Can be controlled by Wall switch, Remote control, Movement sensor, Light and heat sensor, Timer	YES	YES	YES
Obvious Light Diffusion (Bright)	60%	65%	Up to 75%
Obvious Light Diffusion (Shady)	1%	0.5%	50%
Cost efficient	YES	YES	YES
Modern appeal	YES	YES	YES
Environmentally Friendly	YES	YES	YES
Best place for usage	Large or small facade windows where instant shade is not required	Skylights, facade windows, cars, trains and aeronautics, TV Studios, ultrasound rooms, and galleries where art can be damaged by sun exposure	Indoor: Interior privacy partitions and transparent displays Outdoor: Exterior windows, interior glass walls, and interior privacy partitions

The previous tables will allow the mystery of smart glass to be revealed, thus helping architects explore sustainable architecture through smart glass and envelopes.

9. Conclusion

Sustainable and smart materials are required to help buildings react dynamically to external stimuli to capture the benefits of natural light with the least energy consumption. In the global push towards sustainability, active smart glass will become increasingly significant. Smart glass may be integrated into projects in ways that provide control over incoming light, glare, and heat because it uses very little electricity to function.

Sustainable living is about to reach new heights thanks to clean technologies. Such significant advancements are required now, when energy costs are rising, and environmental concerns are becoming more pressing. Smart glass can assist the architectural community in achieving its sustainability goals by cutting cooling costs, reducing electricity consumed to power interior lighting, and enhancing the health and well-being of inhabitants when used as a component of a daylighting strategy.

One of the main purposes of smart glass systems is to create a comfortable and healthy interior atmosphere, which accounts for about a third of all energy consumption. In addition to making significant improvements in efficiency, new technologies for heating, cooling, and ventilation can also improve the way building systems satisfy the needs and preferences of occupants by giving users more control, minimizing undesirable temperature changes, and raising indoor air quality.

Moreover, smart glass can be used to develop climate-adaptive building shells that provide advantages including natural light adjustment, visual comfort, UV and infrared blocking, lower energy consumption, thermal comfort, resistance to extreme weather conditions, and privacy. Some intelligent windows have the ability to self-adjust to heat or cool for building energy conservation. Blinds, shades, and other window treatments may not be necessary with smart windows.

References

[1] Saleh, T., Fadillah, G., & Ciptawati, E. (2021). Smart Advanced Responsive Materials, Synthesis Methods And Classifications: From Lab To Applications. Journal Of Polymer Research, Https://Doi.Org/10.1007/S10965-021-02541-X.

[2] Lefebvre, E., Piselli, A., Faucheu, J., Delafosseb, D., & Curto, B. D. (2014). Smart Materials: Development Of New Sensory Experiences Through Stimuli Responsive Materials. A Matter Of Design|Proceedings Of The 5th STS Italian Conference, (Pp. 367-382). Italy.

[3] Modin, H. (2014). Adaptive Building Envelopes. Göteborg, Sweden: Department Of Civil And Environmental Engineering, Division Of Building Technology, CHALMERS UNIVERSITY OF TECHNOLOGY.

[4] Cambridge Dictionary. (2023, April 1). Materials. Retrieved From Cambridge Dictionary: Https://Dictionary.Cambridge.Org/Dictionary/English/Material

[5] Balasubramanian, A. (2017). Classification Of Materials. University Of Mysore, 10.13140/RG.2.2.12792.34567.

[6] Researcher, 2023

[7] Shehata, N., Abdelkareem, M. A., Sayed, E. T., Egirani, D. E., & Opukumo, A. W. (2022). Smart Materials: The Next Generation. Elsevier Science Direct, 288-299 - Https://Doi.Org/10.1016/B978-0-12-815732-9.00062-0.

[8] Damodharan, J., Sreedharan, A., & Ramalingam, T. (2018). A Review On Smart Materials, Types And Applications. International Journal Of Engineering Technology Science And Research, 649-653.

[9] Arthur, E. K. (2020). Functional Materials. Retrieved From Wepep Site (Faculty): Https://Ekarthur.Wordpress.Com/Second-Semester/

[10] Elyasian, I. (2015). Smart Materials And New Technologies. Sid International Conference On Modern Research In Civil Engineering, Architectural And Urban Development. Iran.

[11] Yoon, J., & Bae, S. (2020). Performance Evaluation And Design Of Thermo-Responsive SMP Shading Prototypes. Sustainability, Doi:10.3390/Su12114391

[12] Yoon, J. (2019). SMP Prototype Design And Fabrication For Thermo-Responsive Façade Elements. Journal Of Facade Design And Engineering , 41-61 - DOI:10.7480/Jfde.2019.1.2662.

[13] Xu, Y., Liao, G., & Liu, T. (2020). Magneto-Sensitive Smart Materials And Magnetorheological Mechanism. In M. S. Kandelousi, & S. Ameen, Nanofluid Flow In Porous Media. Intechopen: DOI: 10.5772/Intechopen.84742.

[14] Vaidkar, S. (2021, May 25). Smart Materials. Retrieved From Medium: Https://Sushantvaidkar.Medium.Com/Smart-Materials-4c6def928b6b

[15] Paschotta, R. (2022). Photochromic Materials. Retrieved From RP Photonics: Https://Www.Rp-Photonics.Com/Photochromic_Materials.Html

[16] SFX. (2016). What Are Smart Materials? Retrieved From Special Fix Creative: Https://Www.Sfxc.Co.Uk/Blogs/Sfxc-Specialfxcreative-Blog/What-Are-Smart-Materials#:~:Text=Hydrochromic%3A,Changes%20colour%20in%20the%20rain!

[17] Postnote. (2008, January). SMART MATERIALS AND SYSTEMS. Retrieved From Parliamentary Office Of Science And Technology,: Www.Parliament.Uk/Parliamentary_Offices/Post/Pubs2008.Cfm

[18] Sottile, G. M. (2008). Cleantech Daylighting Using Smart Glass: A Survey Of LEED® Accredited Professionals. Clean Technology Proceedings, 201-204 , Hynes Convention Center, Boston, Massachusetts, U.S.A.

[19] Quesada, S. (2016, August 1). Smart Glass - Passive And Active Technologies. Retrieved From Linkedin: Https://Www.Linkedin.Com/Pulse/Smart-Glass-Passive-Active-Technologies-Stacey-Quesada

[20] Aggour, M. M., & Soliman, O. A. (2010). SMART MATERIALS – TOWARD A NEW ARCHITECTURE. First International Conference On Sustainability And The Future FIDC2010. Cairo: The British University In Egypt.

[21] Chiefway. (2023). 9 Benefits Of Smart Glass For Building Facades And Commercial Architecture. Retrieved From Chiefway SMART GLASS - WAY GLASS: Https://Chiefway.Com.My/Benefits-Of-Smart-Glass-For-Building-Facades/

تطور الزجاج الذكي ودوره في إعادة توجيه المباني المعمارية

الملخص بالعربي

تقود التكنولوجيا العالية في الوقت الحاضر العديد من جوانب الحياة، مثل التصنيع والتعليم والابتكارات وغيرها من المجالات. علاوة على ذلك، اكتسبت التكنولوجيا المتقدمة القدرة على تحويل المواد إلى مواد ذكية ليست فقط قابلة للتكيف الذاتي والاستشعار الذاتي، بل يمكنها أيضًا التفاعل مع المحفزات البيئية الخارجية، سواء من خلال تعزيز واحتضان جميع السمات المطلوبة أو عن طريق طرد السمات غير المرغوب فيها. ولسوء الحظ، فإن المعماريين ليسوا جميعهم على دراية بمعظم التقنيات الحديثة التي يمكن تنفيذها في تشييد المباني ومواد التشطيب، لذلك يهدرون كل الفرص لإنتاج مبنى مستدام وزيادة أداء الطاقة.

ويمر البحث بمراحل عديدة لمساعدة المعماريين على فهم واستخدام المواد الذكية بشكل عام والزجاج الذكي بشكل خاص. تبدأ هذه المراحل بالكشف عن كيفية تحويل المواد إلى مواد ذكية، يليها خصائص المواد الذكية وأهميتها وأنواعها وتطبيقاتها ومزاياها في الهندسة المعمارية.

يتم تقديم الزجاج الذكي للمهندسين المعماريين باعتباره أحد أهم الأمثلة على المواد الذكية التي تلعب دورًا مهمًا في بناء الأغلفة. ولذلك سيتم عرض جميع أنواع الزجاج الذكي باستخدام أسلوب تحليلي مقارن لشرح فوائدها وميزاتها التي يمكن أن تساعد المهندسين المعماريين في تطبيق المبادئ المستدامة في الهندسة المعمارية. علاوة على ذلك، يقترح البحث منهجية لمساعدة المعماريين في استخدام الزجاج الذكي واختيار النوع الأنسب حسب المحفزات المحيطة.