SMART MATERIALS AND ADAPTIVE BUILDING ENVELOPES AS AN APPROACH FOR REDUCING ENERGY CONSUMPTION IN EGYPT: A LITERATURE REVIEW

SAMAR AWAD ABDELHAMED SOLIMAN, IBRAHIM ELSAYED MAAROUF IBRAHIM & MAI MOHAMED ABDO IBRAHIM
Architecture Department, Faculty of Engineering, Alexandria University, Egypt

ABSTRACT

In the last 10 years, a quantum leap occurred in Egypt in the field of architecture that led to the consumption of large quantities of energy during implementation. It was noted that most of the buildings were designed to mimic the technological development in the architectural formations' trends globally, without considering the environmental impacts in Egypt or the resources availability in the future to operate these buildings. Therefore, the research was built on the premise that the operating cost will be prohibitively expensive, which requires offering solutions that can be applied during or after implementation in the operating stage that can help to control the cost of the building life cycle. The initial hypothesis of the research was about finding a solution for energy consumption percentages and controlling cost throughout using different types of smart materials that being used in the building envelope and its effect on the building performance, especially public utility buildings. Other reasons for this research are to help in protecting natural resources and achieve more adaptation for the building envelope throughout performing alternative materials characteristics, and to achieve Egypt Vision 2030 (SDS) and the global vision SDGs.

Keywords: material characteristics, energy consumption, operating cost, Egypt vision, building envelope, performance, numerical simulation.

1 INTRODUCTION

Architectural design is moving toward the integration of building technology and equipment in response to the desire for building envelope designs that can reduce energy demand. The ultimate goal is to produce a "smart envelope" that can undertake new jobs in addition to performing better than a typical building shell. Numerous studies show that the construction sector has the ability to increase energy efficiency at a reasonable cost.

The envelope deals with the building parameters including the skeleton of the building, construction materials Characteristics, cladding options design and the relation between all this parameters and energy efficiency for building performance.

This operation systems account for 70% to 80% of the total energy consumed in buildings. Energy costs roughly account for about 30% to 40% of the total operating cost of a typical building. Improving energy efficiency in buildings is essential to achieving the goals set by the Egyptian government in the Sustainable Development Strategy (SDS), Agenda (Egypt Vision 2030) and the international vision in sustainable development goals (SDGs) [1] as it reduces the energy consumption and consequently the emission of greenhouse gases without jeopardizing human comfort [2].

Taking into consideration the economic status in Egypt in recent years, especially the investment sector will demonstrate the enormous increase in construction sector, which would create massive energy consumption that was never in proportion with the growth in generated power in Egypt.

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1.1 Sustainability international vision

1.1.1 Egypt Vision 2030 (Sustainable Development Strategy (SDS))

The Sustainable Development Strategy (SDS): Egypt Vision 2030, which draws inspiration from ancient Egyptian culture and connects the present to the future, is a step toward equitable development. Consequently, supporting economic and social fairness as well as revitalising Egypt's position as a regional leader would lead to prosperity.

SDS stands for a strategy for achieving competitive advantage in order to fulfil Egyptians' hopes and desires for a respectable and decent existence [1].

The SDS was created through a participatory strategic planning methodology, in which a variety of civil society groups, national and international development partners, and government organisations worked together to establish all-encompassing goals for the nation's pillars and sectors [1].

The SDS has adopted the sustainable development principle as a general framework for enhancing welfare and quality of life while taking into account the rights of future generations to a prosperous existence. This involves dealing with the three main dimensions of the economic, social, and environmental spheres. The main strategic visions of SDS pillars are: the economic dimension, the environmental dimension, the social dimension) (Fig. 1). the research will focus on one dimension and will take tow pillars of this dimension [1].

- The economic dimension:
  - A) Energy pillar (improving the efficiency of building sector, applying environmental standards and accurate measurements).
  - B) Knowledge, innovation, scientific research (increase environmental sustainability sub-index of the global innovation (rank) from 65 to 30).

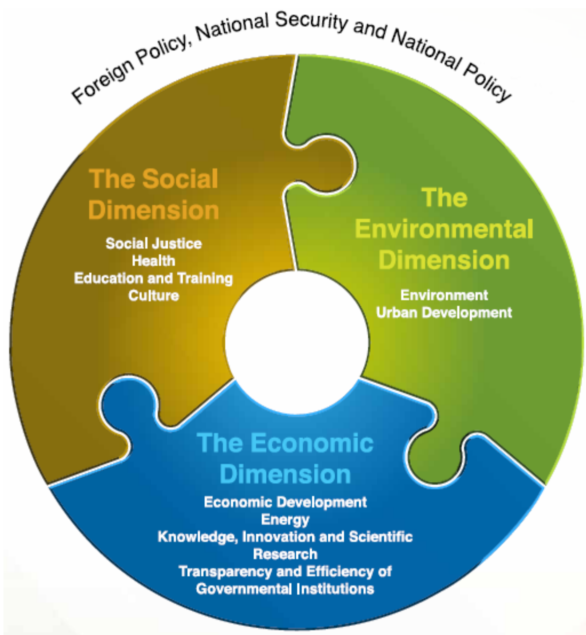


Figure 1: Strategic visions of SDS [1].

1.1.2 The international vision in sustainable development goals (SDGs)

The sustainable development goals are a global call to action to end poverty, protect the earth's environment and climate, and ensure that people everywhere can enjoy peace and prosperity. These are the goals the UN is working on in Egypt (Fig. 2) [2].

Figure 2: The international vision in sustainable development goals [2].

The research will focus on the "7. Affordable and Clean Energy" goal in SDGs and link it with the SDS 2030 [2].

1.2 Problem statement

Design and construct a building that fulfil all operational requirements of the users and reduce energy consumption through building life cycle is an unprecedented challenge for our times. Most of the buildings in Egypt are designed to mimic the technological development in the architectural formations' trends globally, without considering the environmental impacts in Egypt.

New approaches have appeared in the field of materials and its characteristics such as performative materials and smart materials that could enhance building performance but not applied yet in with wider scale. Researchers, practitioners are faced with enormous challenges due to the need to take account of various dynamic processes around us such as: global climate change and growing occupant needs and comfort expectations.

1.3 Research hypothesis

Smart materials and adaptive building envelope is the gate for reducing energy consumption through building life cycle. Cost is an important factor for the success of architectural design, and by studying it, the design can be converted into a real building.

1.4 Scope

This research will focus on the relation between material type especially smart materials, building envelope response in the scope of energy consumption and how these factors will affect Egypt Vision 2030 (Sustainable Development Strategy (SDS)) economically.

2 PERFORMANCE AND MATERIAL

2.1 High performance building "from traditional to integrated"

Prior to the industrial revolution, building efforts were often directed throughout design and construction by a single architect a method called the master builder model. The master builder alone bore full responsibility for the design and construction of the building, including any details required [2]. With the means of supplying heat, light, water, and other building services frequently being tightly integrated into the architectural parts, this paradigm lent itself to a building being built as a single system [3].

Lately, integrated design process appeared to design building with high performance strategy, buildings that used this integrated design approach frequently have high performance and sustainability.

This transition wasn't random or intentional; rather, it was brought on by the expanding variety of tools and technologies employed in design and construction as well as the complexity of those tools and technologies [4].

2.2 High performance building characteristics

Concern over the use of energy and water resources has made high-performance buildings particularly apparent, but it also encompasses other, larger issues like indoor environmental and air quality, material utilisation, well-thought-out development and design, and so on.

There are currently statutory rules and/or voluntary certification programmes for green buildings in several nations across the world [3].

Many different terms are used in the discussion of building design and performance. Green is one of those words that can have many meanings, depending on the circumstances. Like green, sustainable is primarily focused on environmental impact. High-performance is the preferred term used in this text when discussing buildings. Minimizing impact on the environment is one component of a high-performance building, but the building must also simultaneously provide a healthy, comfortable indoor environment [3].

2.2.1 Life cycle assessment (LCA) of high-performance building

A building designated as high-performance is one that is successful, over its full life cycle, in the following areas:

- Minimizing natural resource consumption
- Optimizing the quality of the indoor environment
- Reducing unwanted effects on the construction site
- Improving how well the new construction project is integrated into the general built and urban environment.
- Minimizing the discharge of solid waste and liquid effluents.

In addition to addressing the potential for energy use, a high-performance building makes sure that its function (occupant productivity) is not affected [3].

2.3 Materials in high performance buildings (energy efficiency approach)

> Materials are physical. they are available to our senses through perception.
> Materials are seen, touched, even smelled and tasted.
>
> Tim Ingold, Social Anthropologist

The materials form the cornerstone of building construction, and current technologies are anticipated to benefit them [4]. Traditionally, material has been a follower of form; it mostly alters the final appearance of the architectural product but does not participate in the initial stages of design. In fact, it appears that the design process is controlled by the hierarchical sequence "form–structure–material" when viewed from the perspective of building systems [5]. Both professionally and academically, the study of material structure and its function in creative design has grown in importance.

The study of and understanding of material function in design has grown to be a significant component of the field of architecture and one of its research topics.

The methods for modifying representations of material structures are also included in these study fields [4], and to raise awareness of developments in material applications (Fig. 3).

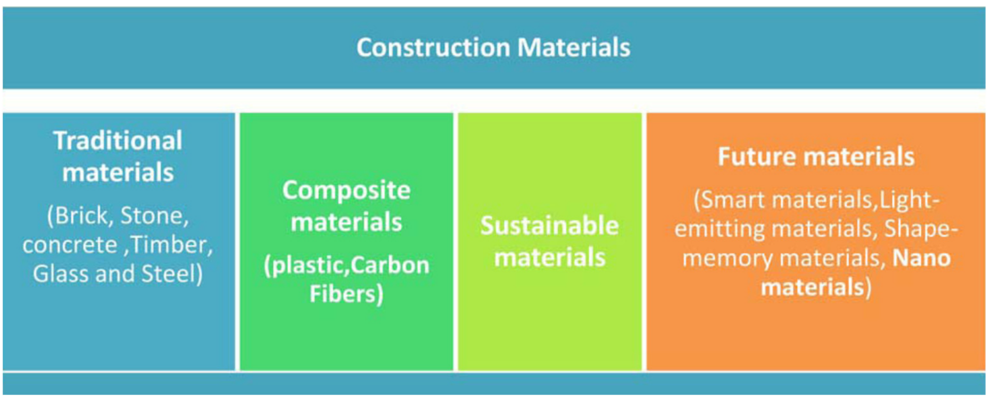


Figure 3: Material types [4].

In the rapidly changing building sector, planners, architects, engineers and builders are looking for new materials to adopt in future constructions that benefits like energy efficiency [4]. The development of new smart materials in the field of architecture, which we can control and adapt in terms of their thickness, pattern density, stiffness, colour, flexibility, and translucency, emphasises this design philosophy and offers us new possibilities and potentials that have an impact on our thinking, as shown in Fig. 4 [4].

2.4 Traditional building materials classification

Depending on the classification goal, building materials can be categorised in a variety of ways. Construction's primary classification systems primarily focus on composition, technical characteristics, environmental sustainability, and the function provided by a building system or size scale (Table 1). Building materials are often categorised into the following primary classes based on their composition [4].

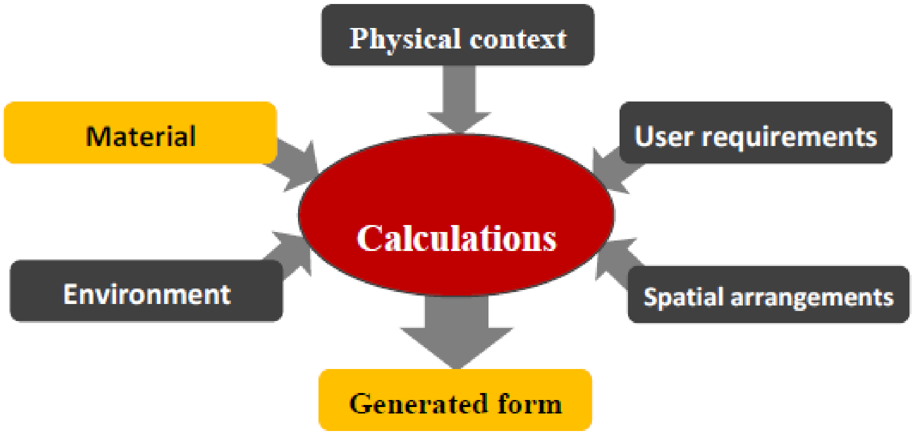


Figure 4: The development materials [4].

Table 1: Traditional building material classification [4].

Category subcategory	Category subcategory
Composition	• Metallic materials, ceramic materials, polymeric materials, composite materials.
Technical properties	• Mechanical, thermal, electrical, optical, acoustic, magnetic, chemical, radioactive.
Sustainability	• Renewability, recycled content, embodied energy, absence of toxic substances, compo stability, degradability, recyclability, reusability, durability, easy maintenance, global warming potential, ozone depletion potential, acidification potential.
Function	• Materials for use in the construction industry include but are not limited to the following: Binders and aggregates for mortars and concrete, structural components, load-bearing elements, windows, thermal and acoustic materials, water- and vapor-proofing materials, paints, primers, solvents, and adhesives.

2.5 Advanced materials

Advanced materials are those that are specifically created to have new or improved technical properties (structural or functional) or environmental features in comparison to materials that are typically used to carry out the same functions. These materials can be both new and derived from modifications of existing materials [6]. The use of cutting-edge materials in construction is significantly improving buildings' energy and environmental performance throughout their lifespans and bringing about significant improvements in every aspect of the construction process, from planning to execution.

In fact, advanced materials are a critical enabling technology for many other technologies, and they play a significant role in enabling advanced/high-value manufacturing and tackling society's major socioeconomic concerns, such as climate change and increased resource efficiency [6].

2.5.1 Smart materials definition

"Smart materials" are similar to living beings in that they have the ability to perform both sensing, actuating functions and are capable of adapting to changes in the environment. By utilizing these materials, a complicated part in a system consisting of individual structural, sensing and actuating components can now exist in a single component.

In the field of building, smart materials and their manufacturing techniques may provide a variety of advantages, including [5]:

- Superior toughness, ductility, and strength.
- Increased service life and durability.
- Enhanced resistance to chemicals, corrosion, abrasion, and fatigue.
- Lifecycle and initial cost efficiencies.
- A better ability to react to catastrophic situations like fires and natural catastrophes.
- Ease of production and use or installation.
- Compatibility with the surroundings and aesthetics.
- The capacity for structural control, self-healing, and diagnosis.

These advantages show how the design and construction sector can think outside of the box, The following is a previous advantages classification of smart materials Fig. 5 [6].

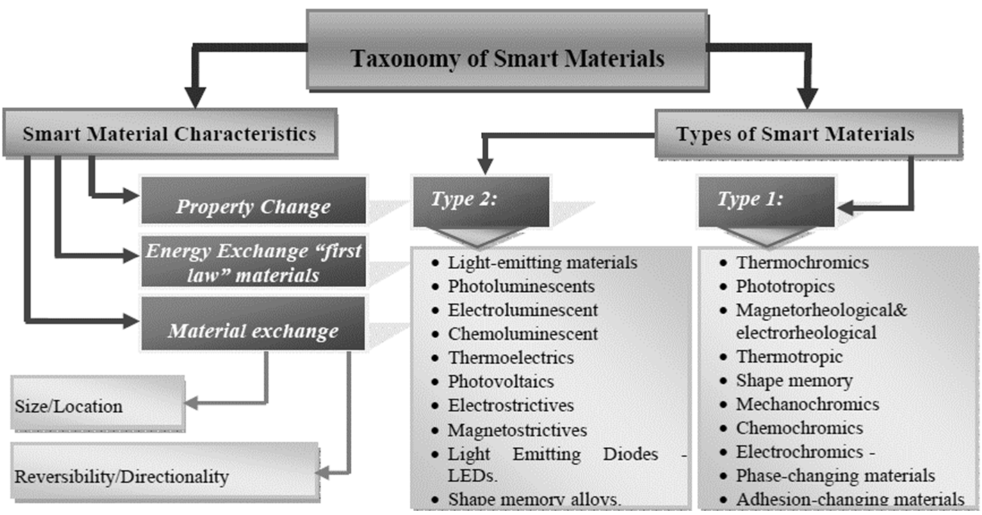


Figure 5: Classification (taxonomy) of smart materials [6].

2.5.2 Smart material characteristics

1. Property change: In reaction to a change in the environment, these materials experience a change in one or more of their properties, including chemical, thermal, mechanical, magnetic, optical, or electrical [7].
2. Energy exchange: These substances, which are also referred to as "first law" materials, convert an input energy into an output energy in line with the first law of thermodynamics. The potential usefulness of the energy is substantially bigger even

though smart materials like photovoltaics and thermoelectric typically convert energy at much lower rates than do conventional energy conversion technologies [7].

3. Material exchange:
   - Size/location.
   - Reversibility/directionality.

2.5.3 Types of smart materials

Smart materials and systems could be divided into two classes:

Type 1 Materials undergo changes in one or more of their properties (chemical, electrical, magnetic, mechanical, or thermal) in direct response to a change in external stimuli in the surrounding environment. The energy input to a material affects the internal energy of the material by altering the material's microstructure (Table 2) [8].

Type 2 Smart materials transform energy from one form to another. The energy input to a material changes the energy state of the material composition but does not alter the material, it stays the same, but the energy undergoes a change Applications of smart materials in architecture (Table 3) [5].

Table 2: Materials undergo changes in one or more of their properties [8].

Type 1	
Thermochromics	An input of thermal energy changes the material's color
Phototropic	Materials that change color when exposed to light.
Magnetorheological and electrorheological	The application of a magnetic field (or for electro-rheological – an electrical field) causes a change in micro-structural orientation, resulting in a change in viscosity of the fluid.
Thermotropic	An input of thermal energy (or radiation for a phototropic, electricity for electro tropic and soon) to the material alters its microstructure through a phase change. In a different phase, most materials demonstrate different properties, including conductivity, transmissivity, volumetric expansion, and solubility.
Shape memory	An input of thermal energy (which can also be produced through resistance to an electrical current) alters the microstructure through a crystalline phase change. This change enables multiple shapes in relationship to the environmental stimulus.
Mechano-chromic	Materials that change color due to imposed stresses and/or deformations
Chemo-chromic	Materials that change color when exposed to specific chemical environments.
Electro-chromic	Materials that change color when a voltage is applied. Related technologies include liquid crystals and suspended particle devices that change color or transparencies when electrically activated.
Phase-changing materials	Use chemical bonds to store and release heat.
Adhesion-changing materials	Change the attraction forces of adsorption or absorption of atoms or molecules when exposed to light or electrical field.

Table 3: Smart materials transform energy from one form to another [5].

Type 2	
Light-emitting materials	That convert an input energy to an output of radiation energy in the visible spectrum.
Piezoelectric	(An input of elastic energy – strain produces an electrical current. Most piezoelectric are bi-directional in that the inputs can be switched and an applied electrical current will produce a deformation – strain).
Thermoelectric	An input of electrical current creates a temperature differential on opposite sides of the material.
Photovoltaics	An input of radiation energy from the visible spectrum produces an electrical current.
Electro-strictive	The application of a current produces' elastic energy – strain which deforms the shape of the material.
Magneto-strictive	The application of a magnetic field produces elastic energy – strain which deforms the shape of the material.

2.5.4 Application on smart materials

By focusing on phenomena rather than the physical artefact, the use of modern technologies based on smart materials has the potential to dramatically increase the sustainability of buildings [9]. By responding locally, discreetly, and only, when necessary, energy consumption may be decreased. Then a wider variety of designs for both new construction and building retrofit may take use of many of the benefits provided by these technologies [10]. Either molecular structure or microstructure governs a material's qualities (Fig. 6).

3 ADAPTIVE BUILDING ENVELOPE

Adaptive building envelopes are referred to as a building skin that has the ability to change its characteristics and regulate a variety of aspects. These adjustments are made in response to changing climatic loads or the interior environment, which can improve comfort for the occupants [11].

The modification might be made in a number of ways, for as by relocating parts, adding airflows, or changing a material's chemical composition.

It's not a novel concept to modify a building's skin's performance, which depends on both the intended inside climatic conditions and the exterior climate. The concept of adaptable building skin is linked to biomimicry, intelligent structures, and intelligent materials [11].

3.1 Characteristics and properties of sustainable high-performance facades

High-performance facades could be described as the external building envelopes that consume the minimum amount of energy to retain a convenient indoor environmental quality, which improves the well-being and productivity of people inside the building. The properties of these building envelope include: (1) permit penetrating of natural light inside the building spaces; (2) stop undesired solar heat from penetrating the interior spaces; (3) stop heat transference through enhanced insulation; (4) blocking air and moisture from penetrating through the building; and (5) permitting natural ventilation to enhance the internal room temperature and air quality. These properties depend mostly on climate, in addition to the

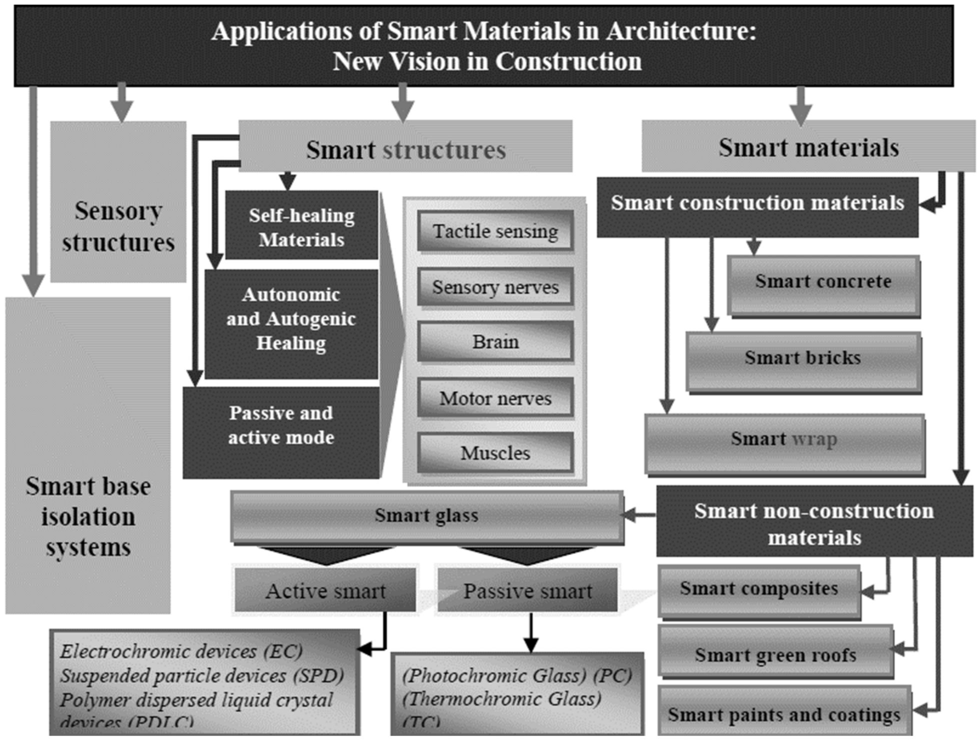


Figure 6: Application of smart materials [10].

building's operations, residence basis, orientation, and energy burden of equipment, moreover, the façade type [12].

3.2 Smart materials and adaptive envelope applications in the field of energy consumption reduction

Table 4 shows case studies with (high performance, smart material, adaptive envelope), it shows the reduction in energy consumption [10], [12].

4 DISCUSSION AND CONCLUSION

Smart materials will have an increasing range of applications and the underlying sciences in world. It must be maintained at a standard which helps achieve technological objectives which mean that smart materials and system must solve engineering problems and provide an opportunity for creating new products and could have an important role in sustainability architecture. From the data collected in this research regarding material function/system, this will speed the development of new materials for the use in different applications.

Smart materials and systems are able to sense and respond to the environment around them, they have the potential to improve existing technology and add new functionality to products.

In addition, smart materials are considered as "building envelope of the future" that combines various wall functions into a single product.

Table 4: Comparison table for case studies [10], [12].

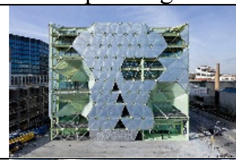
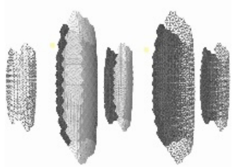
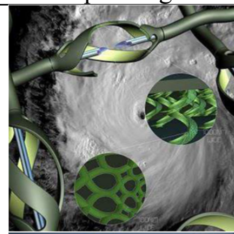
Building	Envelope design	Envelope type	Energy reduction
The Barcelona Media-ICT building		Smart materials in adaptive building envelope	ETFE material, the building generates 20% less in energy consumption. ETFE: (Ethylene Tetrafluoroethylene) Polymer This decreases the solar factor (SF) by four times, from 0.45, as accepted by the building Code, to 0.10.
Al Bahar Towers by Aedas	 	Responsive facade system in adaptive building envelope	Decrease solar gain by more than 50% and decreases the usage of air conditioning. In addition, its capability to filter and reduce the direct solar gain to a maximum of 400 W per linear meter.
Qatar National Convention Center, by Jorge Chapa		Energy exchanging smart material	The building will feature 3,700 square meters of solar panels, which will provide around 12% of the building's total power. The previous systems are using type 2 energy exchanging smart materials.
Geotube, Dubai by Faulders Studio		Smart material	Photovoltaic panels consider the application of smart material/system type 2.

Table 4: Continued.

Building	Envelope design	Envelope type	Energy reduction
Nano vent skin demonstrated in Concept Tower, Agustin Otaegui	 	Nano – smart material and skin	Nano vent skin (NVS) is a building skin that uses organic photovoltaics to capture sun and micro-wind turbines to capture wind. NVS is just acting as a merger of different means and approaches into energy absorption and transformation, which will never happen in nature.
Shanghai World Expo 2010, UK Pavilion by Thomas Heatherwick	 	Recyclable material	Steel and timber composite structure pierced by 60,000 fiber optic filaments, 20mm square in section, which pass through aluminum sleeves.

It became evident that the use of smart materials in the adaptive envelopes for buildings contributed to lowering the amount of energy used in the operating stage based on the aforementioned and prior analyses of buildings as well as the analysis of the types of smart materials and their use and relation to the performance of the building.

Additionally, based on the international vision (SDGs) (Affordable and Clean Energy goal) and Egypt's 2030 Vision (Sustainable Development Strategy (SDS)) and according to the Egyptian Ministry of Electricity and Energy 2022 study, buildings account for 40% of Egypt's yearly energy consumption. To address this urgent economic need, the researcher argues for the use of smart materials in building envelopes, particularly in public buildings. This will be done in future studies. The amount of energy savings will be calculated based on geographical location, the type of smart material utilised, and the material's life cycle assistance.

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