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# The Function of Smart Material's behavior in architecture

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**Abstract.** Smart materials are those objects that sense environmental events, process that sensory information, and then act on the environment. Fundamental characteristics, which distinguish Smart materials from most traditional materials that use in architecture, are transiency, selectivity, immediacy, self-actuation and directness.

Smart materials are materials that receive, transmit, or process a stimulus and respond by producing a useful effect that may include a signal that the materials are acting upon it. The effects can manifest themselves by a color change, a volume change, a change in the distribution of stresses and strains, or a change in index of refraction. This ability to producing a useful effect to respond the stimuluses has rendered smart materials a considerable materials to the architectural design since buildings are always confronted with changing conditions.

With a look to characteristics of smart materials, we discover that they directly focus on their actuation events and the ability of prognosis, immediate response to the environmental conditions. With applying this we can group smart materials into:

- Property change capability
- Energy exchange capability
- Discrete size/location
- Reversibility

Smart materials are the answer for the 21st century's technological needs. Use of smart materials in architecture moreover dramatically reduce the energy and material cost of the buildings, enables the human to design of direct and discrete environments that providing better conditions in space for human occupants.

The purpose of this article is the development of a generic familiarity with the characteristics and behaviors that distinguish smart materials from the more commonly used architectural materials, and speculation into the potential of these characteristics and behaviors when deployed in architectural design, and consider the functionality of these materials in architecture and building.

This paper is the result of a comprehensive research based on descriptive argumentation as research method and the final results show the significance of smart materials in future architecture.

**Keywords:** Smart Materials, Function of Materials, New Technologies, Smart Architecture, New Materials

## 1. Introduction

An inextricable link has existed historically between a building's characteristics form, appearance, function and the characteristics of the diverse materials that were available and suitable for construction. As

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exemplified by historical building traditions in stone and wood, early architects sought to understand intuitively the intrinsic physical behaviour of commonly available materials to exploit their properties in designing and constructing buildings. Conversely, later innovations in the type and availability of materials strongly impacted the development of new architectural forms as architects began to respond to changing societal demands and new building functions emerged. [1]

The world has recently undergone two materials ages, the plastics age and the composite age. In the midst of these two ages a new era has developed. This is the smart materials era. According to early definitions, smart materials are materials that respond to their environments in a timely manner. The definition of smart materials has been expanded to materials that receive, transmit, or process a stimulus and respond by producing a useful effect that may include a signal, which the materials are acting upon it. Some of the stimuluses that may act upon these materials are strain, stress, temperature, chemicals (including pH stimuli), electric field, magnetic field, hydrostatic pressure, different types of radiation, and other forms of stimuli. The effect can be caused by absorption of a proton, of a chemical reaction, of an integration of a series of events, of a translation or rotation of segments within the molecular structure, of a creation and motion of crystallographic defects or other localized conformations, of an alteration of localized stress and strain fields, and of others. The effects produced can be a colour change, a change in index of refraction, a change in the distribution of stresses and strains, or a volume change. [2]

Today, architects are beginning to look forward to using the developments in smart materials to bring new solutions to long-standing problems and also to exploit the potential of smart materials in developing new building functions, forms, and responses. The wide variety kinds of smart materials available have great potential for use within the field, but, in this area, their applications remain only marginally explored. [1]

## 2. Characteristic and Behavior of Smart Materials

Smart materials may be discussed as a substitute for traditional materials in many components and functions because of their features and characteristics distinguished them from the most traditional materials used in the architecture. These properties and features include transiency, selectivity, immediacy, self-actuation and directness that with more accurate to characteristics and properties of these materials and focus on their actuation events and how they response these events and environmental conditions can take capabilities and different behaviours of these materials as result. There are four fundamental capabilities and behaviour of smart materials used in architecture: Property change capability, Energy exchange capability, discrete size/location, Reversibility. These features can potentially be exploited to either optimize a material property to better match transient input conditions or to optimize certain behaviours to maintain steady state conditions in the environment. [3]

The capability to property change causes these materials have the ability to respond environmental conditions change. Materials with the energy exchange capability having many applications in architecture can also receive an input energy and according the thermodynamic law, change to another form of energy used depending on conditions and situations. Materials, having the property mentioned can also show reversibility property at the same time. Materials having this ability, if required, can return to themselves initial state (marked with the ⇔ in Table 1). Position and the discrete size allow smart materials with internal regulation placed and act in the most efficient positions. [1]

| TYPE OF SMART MATERIAL | | INPUT | OUTPUT |
|---|---|---|---|
| **Property-changing** | Thermomochromics[2] | Temperature difference | Color change |
| | Photochromics[3] | Radiation (Light) | Color change |
| | Mechanochromics | Deformation | Color change |
| | Chemochromics | Chemical concentration | Color change |

2. Thermochromic materials absorb heat that this heat creates color change on the materials by a chemical reaction.
3. For more information about Photochromic refer to the book "Organic Photochromic and Thermochromic Compounds", Page 2.

| | | | |
|---|---|---|---|
| | Electrochromics[4] | Electric potential difference | Color change |
| | Liquid crystals | Electric potential difference | Color change |
| | Suspended particle | Electric potential difference | Color change |
| | Electrorheological | Electric potential difference | Stiffness/viscosity change |
| | Magnetorheological | Electric potential difference | Stiffness/viscosity change |
| **Energy-exchanging** | Electroluminescents[5] | Electric potential difference | Light |
| | Photoluminescents[6] | Radiation | Light |
| | Chemoluminescents[7] | Chemical concentration | Light |
| | Thermoluminescents | Temperature difference | Light |
| | Light-emitting diodes | Electric potential difference | Light |
| | Photovoltaics[8] | Radiation (Light) | Electric potential difference |
| **Energy-exchanging (reversible)** | Piezoelectric[9] | Deformation | Electric potential difference |
| | Pyroelectric[10] | Temperature difference | Electric potential difference |
| | Thermoelectric | Temperature difference | Electric potential difference |
| | Electrorestrictive | Electric potential difference | Deformation |
| | Magnetorestrictive | Magnetic field | Deformation |

Table 1: Sampling smart materials in relation to input and output stimuli. [3]

## 3. Material Considerations in Architecture

Selection of materials for use in architecture is always based on various criteria. Performance and Cost have obvious role in this selection, but final selection are often done based on appearance, beauty and aesthetic, ease of construction with regard to human resource skills, availability of local or regional, as well as materials used in the building which are in the near place. [4]

Many progressive materials have emerged for preparing the fastest visual appearance and thus providing appropriate tools for interior and exterior of buildings. Thus modern architects often think about materials as a part of the composition of design through which materials can be selected and accepted as level of structure or combination and visual. It is in such an atmosphere and environment that many people reached to the approaches of using smart materials. [4]

## 4. Smart Materials in Architecture

Smart materials are often considered to a logical extension of the trajectory in materials development toward more selective and specialized performance. For many centuries, architect had to accept and work with the properties of a standard material such as wood or stone, designing to accommodate the material's limitations, whereas during the 20th century architect could begin to select or engineer the properties of a high performance material to meet a specifically defined need. Smart materials allow even a further specificity because their properties are changeable and thus responsive to transient needs. [1] For example, photochromic materials change their colour (the property of spectral transmissivity), when exposed to light: the more intense the incident light, the darker the surface. This ability to respond to multiple states rather than being optimized for a single state has rendered smart materials a seductive addition to the design palette since buildings is always confronted with changing conditions. As a result, we are beginning to see many proposals speculating on how smart materials could begin to replace more conventional building materials.[5]

4. Electro chromic windows, for example, will be bright or dark electronically (by applying a small voltage). Refer to the book "Smart Materials and New Technologies", Page 87.
5. For more information about Electroluminescents refer to the book "Smart Materials and New Technologies", Page 99.
6. This material may twist radiations, which has already absorbed them to become light. [6]
7. Chemiluminescence during a chemical reaction, emitting self light that these emissions would not be associated with heat production. [6]
8. For more information about Photochromic refer to the book "Materials for Architects and Builders", Page 323-325, and the book "Architecture in a Climate of Change", Page 45.
9. Featuring some crystals when the voltage applied to them are under pressure or when exposed to mechanical pressure, produce a voltage. Refer to the book "Nanoengineering of Structural, Functional, and Smart Materials", Page 368-370.
10. For more information about Pyroelectrics refer to the book "Handbook of Material Selection", Page 403.

On the whole, Cost and availability have restricted widespread replacement of conventional building materials with smart materials, but the stages of implementation are tending to follow the model by which new materials have traditionally been introduced into architecture: initially through highly visible showpieces (such as thermochromic chair backs and electrochromic toilet stall doors) and later through high profile 'demonstration' projects such as Diller and Scofidio's Brasserie Restaurant on the ground floor of Mies van der Rohe's seminal Seagram's Building. Many architects further imagine building surfaces, walls and facades composed entirely of smart materials, perhaps automatically enhancing their design from a pedestrian box to an interactive arcade. [1] Indeed, terms like interactivity and transformability have already become standard parts of the architect's vocabulary even insofar as the necessary materials and technologies are far beyond the economic and practical reality of most building projects. [7]

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 contexts. While using a smart material we should do consider that what we want that material to do not what it want to seem. Understanding smart materials should be more of simplicity and superficial understanding of material properties. In addition, it must exist complete and satisfactory knowledge of physical and chemical reactions of these materials with the environment surrounded them. [8]

Fig. 1: Interior view of Diller and Scofidio's Brasserie Restaurant. [9]

Fig. 2: Mies van der Rohe's seminal Seagram's Building. [9]

## 5. Smart Materials Mapping For Architectural Requirements

One of the major difficulties in incorporating smart materials into architectural design is the recognition that a little amount of materials and systems are under single environmental influences. For example, the use of a smart material to control conductive heat transfer through the building envelope may adversely impact daylight transmission. Furthermore, because most systems in a building are highly integrated, it is difficult to optimize performance without impacting the other systems or disrupting control system balancing. [1]

| **Architectural Requirement** | **Relevant Material Characteristic** | **Smart Material Application** |
|---|---|---|
| Control of solar radiation transmitting through the building envelope | Spectral absorptivity/transmission of envelope material<br><br>Relative position of envelope material | Electrochromics<br>Photochromics<br>Liquid crystal displays<br>Suspended particle panels<br>Louver control systems<br>• exterior radiation sensors(photovoltaics)<br>• interior daylight sensors(photoelectrics) controls (shape-memory alloys[11]) |

11. For more information about Shape-memory alloys refer to the book "Intelligent Materials".

| | | |
|---|---|---|
| Control of conductive heat transfer through the building envelope | Thermal conductivity of envelope material | Thermotropics[12]<br>Phase change materials |
| Control of interior heat generation | Heat capacity of interior material<br>Relative location of heat source<br><br>Lumen/watt energy conversion ratio | Phase change materials<br>Fiber-optic systems<br>Thermoelectrics<br>Photoluminescents<br>Light-emitting diodes |
| Secondary energy supply systems | Conversion of ambient energy to electrical energy | Photovoltaics |
| Optimization of lighting systems | Daylight sensing<br>Illuminance measurements<br>Occupancy sensing<br>Relative location of source | Photovoltaics<br>Photoelectrics<br><br>Fiber optics<br>Electroluminescents |
| Optimization of HVAC systems | Temperature sensing<br>Humidity sensing<br>Occupancy sensing<br>CO2 and chemical detection<br>Relative location of source and/or sink | Pyroelectrics<br>Hygrometers<br>Photoelectrics<br>Biosensors<br>Thermoelectrics<br>Phase change materials |
| Control of structural vibration | Euler buckling<br>Inertial damping<br><br><br>Strain sensing | Piezoelectric<br>Magnetorheological<br>Electrorheological<br>Shape-memory alloys<br>Fiber optics |

Table 2: Mapping of Smart Materials to Architectural Requirements. [1]

## 6. The Contemporary Design Context

Although the common belief is that architects design space, the reality is that architects make (draw) surfaces. This privileging of the surface drives the use of materials in two profound ways. First is that the material is identified as the surface: the visual understanding of architecture is determined by the visual qualities of the material. Second is that because architecture is synonymous with surface – and materials are that surface – we essentially think of materials as planar. The result is that we tend to consider materials in large two-dimensional swaths: exterior cladding, interior sheathing. Most current attempts to implement smart materials in architectural design maintain the vocabulary of the two-dimensional surface or continuous entity and simply propose smart materials as replacements or substitutes for more conventional materials. For example, there have been many proposals to replace standard curtain walls glazing with an electrochromic glass that would completely wrap the building facade. [3]

One major constraint that limits our current thinking about materials, is the accepted belief that the spatial envelope behaves like a boundary. Also we consider the building envelope to demarcate and separate the exterior environment from the interior environment. The presumption that the physical boundaries are one and the same as the spatial boundaries has led to a focus on highly integrated, multifunctional systems for facades as well as for many interior partitions such as ceilings and floors. [2]

Our building systems are neither discrete nor direct. For example, Something as apparently simple as changing the temperature in a room by a few degrees will lead to continous processes in the HVAC system, affecting the operation of equipment throughout the building. The concept of directness, however, goes beyond making the HVAC equipments more streamlined and local. The majority of our building systems, whether HVAC, lighting, or structural, are designed to service the building and hence are often referred to as 'building services'. [1]

Excepting laboratories and industrial uses, though, buildings exist to serve their occupants. Only the human body requires management of its thermal environment, the building does not, yet we heat and cool the

12. For more information about Thermoelectrics refer to the book "Smart Materials and New Technologies".

entire volume. The human eye perceives a tiny fraction of the light provided in a building, but lighting standards require constant light levels throughout the building. If we could begin to think of these environments at the small scale – what the body needs – and not at the large scale – the building space – we could dramatically reduce the energy and material investment of the large systems while providing better conditions for the human occupants. The advent of smart materials now enables the design of direct and discrete environments for the body, but we have no road map for their application in this important arena. [3]

## 7. Conclusion

An intelligent element, is the element which without the support infrastructure element acts as a clever system and does not stop performance of peripheral systems. Since the architectural design always involve integrated systems and materials traditionally –making coverage of building depends on the building structural system, HVAC system of building is subject to a cover structure– then the biggest potential application of smart materials will result in to separate the specific components (The development of smart materials will be involved in a variety of components such as sensors, actuators, the shape-memory alloys and etc.), behaviors or indoor environment.

This brief article discusses the relationship between the needs of today's intelligent architecture and proposed materials. On the one hand, Smart materials are proposed as a substitute for traditional materials and otherwise, are recommended to improve the performance of standard building systems. According to the characteristics and behaviors of smart materials, the impact of participation in these materials can be remarkable to standard architecture efforts, particularly with regard to energy efficiency and building performance; but considering the use of smart materials as the fundamental element in the design concept, Instead of just for used to improving exist elements, will create greater appealing potential.

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