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RESEARCH ARTICLE

TOWARDS NANO ARCHITECTURE:NANOMATERIAL IN ARCHITECTURE - A REVIEW OF FUNCTIONS AND APPLICATIONS

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ABSTRACT

This paper provides a comprehensive review of the use of nanotechnology in architecture that reflects the global technological movement towards a better built environment. It focuses on the applications and functions of nanomaterial in architecture. Many products involving nanotechnology are already available, and the future applications seem endless in various areas, including energy and material design. Together with architecture, it makes up the nano architecture style, which is the use of nanotechnology in architecture by either the new customized materials or the new shapes and forms of buildings. This paper presents some examples for the use of new nanomaterial in existing buildings, which show the limitless feasibility of the application of the technological inventions of the nano sciences. The findings of this research indicate the importance of promoting the state-of-the-art technologies to the architects of the 21st century to make them aware of such contemporary issues, and to help maintain the currency and sustainability of newly designed buildings.

INTRODUCTION

Nanotechnology is one of the new emerging technologies of the contemporary time, as a result of the international focus on nano sciences. Such technology has made it possible to manipulate the matter on an atomic basis; this is expected to transform and revolutionizes the way of live. The nano world is a convergence of a real mix of scientific and technological domains which once were separate [1].

Nanotechnology is an exciting area of scientific development which promises more for less. It offers ways to create smaller, cheaper, lighter and faster devices that can do more and smarter things, use less raw materials and consume less energy.

The applications of nanotechnology include almost all aspects of our life, in medicine, industry, communications, transportation, and building façades. The application of nanotechnology in architecture is wide and varies from the early stages of sketching up to the final touches of finishing, especially in materials selection, which will not only be reflected on the design, but also has a great impact on the methodology of thinking of architects according to the new vast options that the nanotechnology offers.

It may change the way the architect think of the forms to design buildings, and help the earth to combat the pollution and reduce the global warming effects. There are many examples of the application of nanotechnology in the designing the built environment. It offers a variety of applications, either in designing new materials with new properties, nano-sensors that can help inspect the surrounding environment, nanobots that might replace the human labor reducing building time and cost. There are nano-coatings which can repel dirt and reduce the need for harmful cleaning agents, or prevent the spread of hospital-borne infections to improve indoor- air quality.

Nano architecture is the integration of nanotechnology in architecture, by using nano-products, nano-materials, nano-telecommunication, or even nano-shapes. In introducing nanotechnology to architecture, one should examine the benefits it can bring, such as additional functionality, value added, and market demand with regard to product development. Good design is based on demand, and the contributions to the evolution of both nanomaterial and the resulting nano-product in the long term.

The materials and products for which there is a demand will become established, whereas others will disappear from the market. Therefore, the use of nanotechnology in architectural engineering is not an end by itself, but follows an ongoing demand for scientific innovations worldwide. Following sections presents a background on nanomaterial, followed by some examples of applications of nanotechnology in architectural engineering. Analysis of these examples is provides, followed by some conclusions and recommendations.

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Nanomaterial

Historical Background

Nanomaterial exists naturally in many forms, including nanostructures of seashells and skeletons, clay particles, and smoke particles. The first scientific report is the colloidal gold particles synthesized by Faraday as early as 1857. Nanostructured catalysts have also been investigated for over 70 years. By the early 1940's, precipitated and fumed silica nanoparticles were being manufactured and sold in USA and Germany as substitutes for ultrafine carbon black for rubber reinforcements[2].

Nanosized amorphous silica particles have found large-scale applications in many consumer products, ranging from coffee creamer to automobile tires, optical fibers and catalyst supports. In the 1960s and 1970s metallic nano powders for magnetic recording tapes were developed. (Figure.1) shows the timeline for materials. In 1976, nano crystals were produced by the inert- gas evaporation technique by (Granqvist and Buhrman). Recently it has been found that the maya blue paint is a nanostructured hybrid material. The origin of its colour and its resistance to acids and bio corrosion are still not understood but studies of authentic samples from (Jaina Island) show that the material is made of needle-shaped palygorskite clay crystals that form a super lattice with a thickness of 1.4 nm, with intercalates of amorphous silicate substrate containing inclusions of magnesium nanoparticles. The beautiful tone of the blue colour is obtained only when both these nanoparticles and the super lattice are present, as has been shown by the fabrication of synthetic samples.

At the present, nano phase engineering expands in a rapidly growing number of structural and functional materials, both (inorganic and organic), allowing to manipulate mechanical, catalytic, electric, magnetic, optical and electronic functions. The production of nano phase or cluster-assembled materials is usually based upon the creation of separated small clusters which then are fused into a bulk-like material or on their embedding into compact liquid or solid matrix materials. For example, nano phase silicon, which differs from normal silicon in physical and electronic properties, could be applied to macroscopic semiconductor processes to create new devices [2].

Nanoscale

The nanoscale, based on the nanometer (nm) or one-billionth of a meter (10^{-9} m), exists specifically between 1 and 100 nm as shown in (Figure.2). General sense, materials with at least one dimension below one micron but greater than one nanometer can be considered as nanoscale materials [3]. To properly appreciate the diversity of nanomaterial, some form of categorization is required. The most typical way of classifying nanomaterial is to identify them according to their dimensions [5], as zero-dimensional (0-D), one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D), Table 1. This classification is based on the number of dimensions confined to the nanoscale range (<100 nm). As categories of nanomaterial move from the 0-D to the 3-D configuration, categorization becomes more and more difficult to define as well [6].

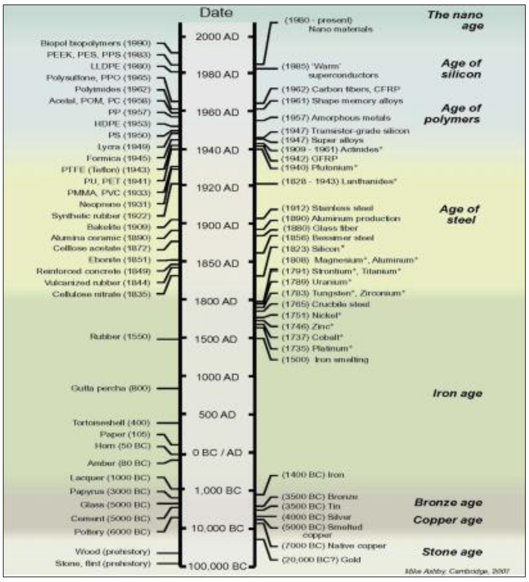

Figure 1 The Materials Timeline, Ashby (2007) [3]

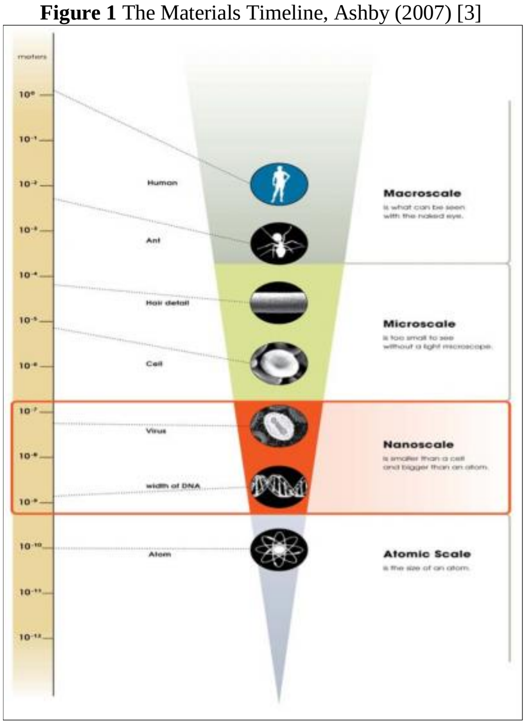

Figure 2 Scale Ladder diagram showing the size of the nanoscale [4]

Nanomaterial in Architecture

The building construction and operation is one of the most valuable industries worldwide, so it is expected that nanomaterial and nanotechnology will play an increasing role in the architectural engineering. Dozens of building materials incorporate nanotechnology, from self-cleaning windows to flexible solar panels, Wi-Fi blocking paint, self-healing concrete, materials to block ultraviolet and infrared radiation, smog-eating coatings, and light-emitting walls and ceilings. Nanotech is also starting to make the "smart home" a reality, which enables sensors to monitor temperature, humidity, and airborne toxins [8].

In architecture two different design approaches prevail when dealing with materials and surfaces: *Honesty of Materials* (what you see is what you get), and the *Fakes* (artificial surfaces that imitate natural materials) [9]. The former is favored by those architects for whom authenticity is a priority and who value high-quality materials such as natural stone or solid woods. The latter is chosen for economic reasons. Wood, whether in the form of veneer or synthetic wood-effect plastics, is considerably cheaper than solid wood. Even concrete or venerable walls can get plastic surface. Artificial surfaces are brought to perfection the grain can be tailored to appear exactly as desired; the color matches the sample precisely and does not change over the course of time. More and more "patinated" surfaces are being created that exhibit artificial aging: instant patinas precisely controllable. Certain design approaches prefer the provocation of deliberate artificiality. In future, a third option will be available (Functional Nano surfaces, emancipated from underlying materials) [9]**.** The properties of such ultra-thin surfaces can differ entirely from the material they enclose and can be transparent and completely invisible. Also Nano composites with new properties are possible. Nanoparticles or nanomaterial are integrated into conventional materials so that the characteristics of the original material are not only improved but can exhibit new functional properties or even be made multifunctional. Surface materials that are customized to have specific functional properties are set to become the norm, heralding a switch from catalogue materials to made-to-measure materials with definable combination of properties – a perfectly modular system.

The use of nanomaterial in architecture will present new opportunities to solve problems and lead the building structure and architecture to an optimum level by improving significantly the nature of building structure and efficiency and the way buildings relate to the environment [10]**.** Nanomaterial can expand design possibilities for both interior and exterior spaces. Their use can open up new possibilities for sustainable design strategies and provide a new array of functions that would help interaction between the occupants and the building. The development of carbon nanotubes and other breakthrough nanomaterial will affect building design and performance.

These nanomaterial can add functional characteristics and novel sensing properties such as structural health monitoring, increased tensile strength, self-cleaning capacity, fire resistance, and many other capacities like heat absorbing windows and energy coatings taking building materials (coatings, panels and insulation) to a maximum capacity of performance in terms of energy, light, security and intelligence [10]. The most compelling argument for using nanotechnology in architecture is for greater energy efficiency. Nanotechnology offers a new technological means with which to tackle climate change and help reduce greenhouse gas emissions in the foreseeable future.

To help achieving a more sustainable environment, nanomaterial can be used in also makes excellent filters for trapping heavy metals and other pollutants from industrial wastewater, water desalination and purification, wastewater treatment, waste remediation, and pollution control [11].

Applications And Functions

General

The use of nanotechnology in architecture is strongly linked to sustainability, to improve energy efficiency and reduce greenhouse gases. Architects are to find innovative solutions for climate changes, by combining ambitious architecture with energy efficiency [9]. The use of materials and surface properties that have now become possible through nanotechnology offer architecture, interior architecture and related disciplines a mean of achieving greater energy efficiency and sustainable architectural design through innovations.

The use of nanomaterial in architecture requires openness towards innovation and a willingness to employ new technologies, and coordination between the architect and the client on this issue. This is because of the longevity of building constructions and the liability period of the architects, which last longer than the outlook for the development of new products by manufacturers, which is typically 15 to 20 years. Architects will still be liable in the coming few decays for the buildings they designed today.

The following selections provide representative examples of innovative applications of nanotechnology to serve various functions in the built environment. The selected recent projects, from architects around the world, incorporate nanomaterial or nano-surfaces. These examples are intended to help recognize new developments in the field, and to provide a better visualization of how this technology can be employed. They represent a strong foundation for future developments, and provide a promising outlook on an exciting field [9].

An overall impression of each project has been provided rather than focusing solely on the isolated aspects of the nano-applications, as context matters in the design. An understanding of the context is also important in order to convey how products are implemented in the practice of designing our environment. Architects and interior designers are concerned with real and visible applications [9].

Following are some examples of the application of nanotechnology in various aspects of architecture, including coatings, insulations, air-purification, fire-proof and scratch-proof.

Coatings

Coatings (Finishing Materials) are an area of significant research in nanotechnology and work is being carried out on concrete, glass, and steel. Much of the work involves chemical vapor deposition (CVD), dip, meniscus, spray and plasma coating in order to produce a layer which is bound to the base material to produce a surface of the desired protective or functional properties. Researches cover experiment and modeling of coatings [12].

Nanotechnology is applied to paints for improving insulation properties, by the addition of nano-sized cells, pores and particles, giving very limited paths for thermal conduction (currently available R values are double of those for insulating foam). This type of paint is used, at present, for corrosion protection under insulation since it is hydrophobic and repels water from the metal pipe and can also protect metal from salt water attack. These nanoparticles coating can be used in stone based materials, and provide better adhesion and transparency than conventional techniques [12].

In addition to the self-cleaning coatings for glazing, the remarkable properties of TiO_2 nanoparticles are being put to use as a coating material on roadways. The TiO_2 coating captures and breaks down organic and inorganic air pollutants by a photo-catalytic process. A coating of 7000 m2 of road in Milan gave a 60% reduction in nitrous oxides. This research opens up the intriguing possibility of putting roads to good environmental use [12].

self-cleaning surface [9]. An example of the use of Lotusan, self-cleaning paint (lotus-effect), is the Strucksbarg housing, Hamburg, Germany, which has a facade area of 3,685 m² in 2007 [9].

Strucksbarg housing, Hamburg, Germany[9]	
Architecture	Renner Hainke Wirth Architekten, Hamburg, Germany
Client	Joint ownership Martens per Schumann Immobilien KG
Product	Lotusan, self-cleaning paint (Lotus-Effect)
Manufacture	Sto
Opened	2007
Area	3,685 m² facade area

With earlier renovation projects, the architects chose to use self-cleaning facade coatings for their renovation of a 1970s housing estate. The self-cleaning function is emphasized because Hamburg has a lot of rain. The estate consists of a high-rise block as well as a number of multi- story terraced housing blocks. The renovated elevations are clad in a composite thermal insulation system with a pigmented render coating in light beige and red.

Table 2 gives a comparison between types of nanomaterial coatings in terms of properties, specifications, and usage. Additional information about these materials are provided below for self-cleaning, easy-to-clean, anti-graffiti, and anti-bacterial [13]

	Coatings			
Product:	**Self-cleaning: Lotus-Effect**	**Self-cleaning: Photocatalysis**	**Easy-to-clean (ETC):**	**Antibacterial**
Properties:	Hydrophobic - water trickles off.	Hydrophilic surfaces. Deposited dirt is broken down and lies loose on the surface.	hydrophobic, i.e. water-repellent and often also oleo phobic Surface repellence without using the Lotus-Effect.	Bacteria are targeted and destroyed.
Specifications:	Microscopically rough, not smooth. Well suited for surfaces that are regularly exposed to sufficient quantities of water	A water film washes dirt away. UV light and water are required. Light transmissions for glazing and translucent membranes are improved.	Smooth surfaces with reduced surface attraction. Surfaces have a lower force of surface attraction due to a decrease in their surface energy	The use of disinfectants can be reduced. Silver nanoparticles reduce the amount of cleaning time necessary.
Usage:	For better optimal use and low maintenance façades (self-cleaning).	Reduces the extent of dirt adhesion on surfaces.	Are most commonly found in interiors, but can also be employed outdoors for better weather protection.	Supports hygiene methods especially in health care environments.

Figure 3 Strucksbarg housing façade**,** Hamburg, Germany [9]

Self-cleaning: Lotus-Effect

Self-cleaning surfaces were investigated in the 1970s by Barthlott, who examined a self-cleaning effect that can be observed not only in Lotus leaves. Such surfaces exhibit a microscopically rough water-repellent (hydrophobic) surface, which is covered with tiny knobbles or spikes so that there is little contact surface for water to settle on. Due to this microstructure, surfaces that are already hydrophobic are even less wettable. The effect of the rough surface is strengthened further by a combination of wax (which is also hydrophobic) on the tips of the knobbles on the Lotus leaves and self-healing mechanisms, which results in a perfect, super-hydrophobic,

As part of the redesign, window recesses were given color highlights, the house entrances were made more prominent, wired glazing was replaced with transparent clear glass, bathrooms were given windows and the undersides of balconies were painted in color. The differentiated coloring of the new facades is most apparent. Warm colors in a palette between yellow and red lend the entire estate a pleasant and unified appearance (Figure 3) [12].

Self-cleaning: Photo catalysis

Photo-catalytic self-cleaning is probably the most widely used nano-function in building construction.

There are numerous buildings around the world that make use of such a function. Its primary effect is that it greatly reduces the extent of dirt adhesion on surfaces [14]. An example of the use of Ever Fine Coat, TiO_2 photo-catalytic self-cleaning membrane, is the Narita International Airport of Tokyo, Chiba, Japan, with an area of 6,250 m² [14].

Narita International Airport of Tokyo, Terminal 1, Chiba, Japan[14]	
Architecture	Nikken Sekkei Ltd., Japan
Client	Narita International Airport Corporation
Product	Ever Fine Coat/Ti02 photocatalytic self-cleaning membrane
Manufacture	Taiyo Kogyo Corporation
Opened	2006
Area	6,250 m²

In 2006, the Narita International Airport in Tokyo underwent comprehensive renovation, (Figure 4). In the process large sections were covered with textile roofing. Membranes offer protection against the weather, and therefore improve comfort for passengers. As the membranes are equipped with a photocatalytic self-cleaning coating, the cost of cleaning and maintenance is kept to a minimum. In central areas of Tokyo, the use of self-cleaning awnings has been common practice for several years and they have proven to remain much cleaner than the conventional ones. Although conventional surface coatings, glass, PTFE or ETFE materials are also self-cleaning, they are not able to stop dirt deposits from accumulating [9].

Figure 4 Narita International Airport of Tokyo, Terminal 1, Chiba, Japan [14]

Easy-to-clean (ETC)

Easy-to-clean (ETC) surfaces are water-repellent and accordingly are often confused with other self-cleaning functions such as the Lotus-Effect. However, unlike the latter, easy-to-clean surfaces are smooth, and have a lower force of surface attraction due to a decrease in their surface energy, that reduces surface adhesion. This causes water to be repelled, forming droplets and running off. Easy- to-clean surfaces are therefore hydrophobic, and often also oleophobic. This function is used for coating ceramic sanitary installations and shower cubicle glazing. Wood, metal, masonry, concrete, leather as well as textiles are likewise candidates for hydrophobic coatings. The benefits of Easy-to-clean surfaces includes: less susceptibility to dirt accumulation (dirt repellent), stress free, and saves time and costs of cleaning [9].

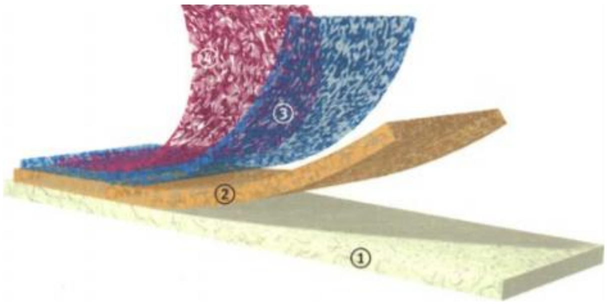

Figure 5 "Roll-out marble"- Impact-resistant, fire-retardant, vapor permeable and yet water-repellent and easy-to-clean [9]

The product consists of four layers [9]:

1. a flexible polymer matting as backing
2. colored ceramic material is applied
3. optional printing
4. creamiest top coat

Modem Classicism, Shanghai, China[15]	
Architecture	MoHen Design International, Shanghai, China
Client	MoHen Design International
Product	Sp-II, Energy Conservation Paint
Manufacture	Shanghai Pujin Macromolecule Material Science and Technology Development Ltd. Co., Apex Group
Product	Nano-stone panels with hydrophobic treatment
Manufacture	Sunny Win Light Ray Nano Technology Co. Ltd. in cooperation with (ITRI)
Opened	2006
Area	498 m²

This Chinese office interior combines classical and contemporary design elements such as specially designed chandeliers made of acrylic glass and floral wall panels made of a white acrylic material. Stainless steel sliding doors conceal everyday work equipment and form the rear wall of the office space. The color scheme is a combination of primarily black, white and steel with the dominant lines playfully governing the design. Most elements have a decorative character, and are augmented in their function with the help of nanotechnology: MoHen chose special wall coatings for their antibacterial, easy-to-clean and warming properties. The natural stone stairs have likewise been given hydrophobic coating for aesthetic and self-cleaning reasons and to improve their durability [15]

Anti-Bacterial

Photo-catalytic surfaces have an antibacterial side effect due to their ability to break down organic substances in dirt. With the help of silver nanoparticles for its antimicrobial properties, it is possible to manufacture surfaces specifically designed to be antibacterial or germicidal. Various products are already commercially available and the product palette ranges from floor coverings to panel products and paints to textiles with an innovative finish that renders them germ-free.

Figure 6 Modem Classicism (internal details) [15]

The antibacterial effect of silver results from the ongoing slow diffusion of silver ions. The very high surface area to volume ratio of the nanoparticles means that the ions can be emitted more easily and therefore kill bacteria more effectively [9].

Operating theatre, Goslar, Germany[16]	
Architecture	Schweitzer + Partner, Braunschweig, Germany
Client	Harzkliniken, Goslar
Product	"Hydrotect" tiles, photocatalytic surface with antibacterial effect
Manufacture	Agrob Buchtal Architectural Ceramics, Deutsche Steinzeug AG
Opened	2005

In both operating theatres, the floors and walls have been clad in photocatalytic tiles. Hygiene is of primary importance in operating theatres and antibacterial tiling contributes to lessening the risk of infection. In the Klinikum im Friedrichshain, the architects have gone one step further and minimized the amount of tile joints, lessening weak points where bacteria can settle and lending the room a calmer appearance. Large format tiling is more difficult to lay, and a conventional tile format was chosen for the high-tech antibacterial tiles used in the Harzkliniken. The light-colored grouting contrasts pleasantly with the fresh green tiling [9].

Figure 7 Operating theatre, Goslar, Germany [16]

Anti-Graffiti

Anti-graffiti coatings, which are applied to surfaces to reduce the adhesion of graffiti, have been on the market for a while but have two major disadvantages: the protective coating cannot be removed and the material it is applied to is sealed and therefore forfeits its permeability [9].

Insulation (Energy Saving Materials)

Insulating materials are used to keep the temperature constant in an enclosed space to protect the environment through the reduction of CO2, NO2 and greenhouse gases. Substantial quantities of energy are wasted daily in both homes and industry because of poor insulation. Advances in insulation will help reduce both energy demand and cost.

The basic requirement for thermal insulation is to provide a significant resistance path to the flow of heat through the insulation material. Insulating materials can be adapted to any size, shape or surface. Current materials used for insulation include fiberglass, rock wool, and slag wool. While these materials are renewable, nanotechnology can offer better alternatives. One form of insulation is to fill in airspaces in materials by using air or liquid. Most insulating materials are therefore porous. Nanotechnology has contributed to this area in the form of aerogels [9].

Table 3 gives a comparison between types of nanomaterial insulations in terms of properties, specifications and usage. Additional information about these materials are provided below for VIPs, Aerogel and PCMs [13]

Insulations			
Product:	Thermal Insulation: Vacuum insulation panels (VIPs)	Thermal Insulation: Aerogel	Temperature regulation: Phase change material (PCMs)
Properties:	Maximum thermal insulation. Minimal insulation thickness.	High-performance thermal insulation. Effective sound insulation.	PCMs are invariably made from paraffin and salt hydrates.
Specifications:	An enveloping skin made of plastic foil or of stainless steel. The fill material takes the form of foam, powder or glass fibers.	Light and airy nanofoam. Aerogel contributes towards energy efficiency.	Reduced heating and cooling demand. Passive temperature regulation.
Usage:	Used both for new building constructions as well as in conversion and renovation work and can be applied to walls as well as floors.	Nanogel-filled glass panels are suitable for use in Façades but also for interiors.	Conserving energy by reducing the energy demand for heating and cooling.

Thermal insulation: Vacuum insulation panels (VIPs)

Vacuum insulation panels (VIPs) are ideally suited for providing very good thermal insulation with a much thinner insulation thickness than usual. In comparison to conventional insulation materials such as polystyrene, the thermal conductivity is up to ten times lower. This results either in much higher levels of thermal resistance at the same insulation thickness or means that thinner insulation layers are required to achieve the same level of insulation. In other words, maximum thermal resistance can be achieved with minimum insulation thickness.

Sonnenschiff Center, Freiburg, Germany[17]	
Architecture	Rolf Disch, Freiburg, Germany
Art	Erich Wiesner, Herbert Dreiseitl
Client	Solarsiedlung GmbH
Product	Vacuum insulation panel (VIP) and phase change material (PCM)
Opened	2005
Area	6,500 m² residential and commercial floor area

Vacuum insulation panels can be used both for new building constructions as well as in conversion and renovation work and can be applied to walls as well as floors. The panels are constructed as follows: an enveloping skin made of plastic foil (often coated with aluminum) or of stainless steel encloses the fill material in a vacuum. The fill material takes the form of foam, powder or glass fibers and is always porous, resists pressure and can be evacuated [9].

The mixed-use residential and commercial center is situated next door to a solar housing estate and provides new amenities that were previously not locally available. The Sonnenschiff's forward-looking concept combines an economic and efficient use of energy with the use of regenerative energy sources, to the extent that the building produces more energy than it consumes. Solar and wind energy as well as geothermal warmth are utilized and natural, regenerative and recyclable building materials are employed vacuum insulation panels have been used for insulation and phase change material (PCM) latent heat storage systems for regulating indoor temperatures - both highly energy efficient systems. The V1Ps constitute the insulation of the external walls and window parapets as well as the ventilation flaps on the main facade. Compared with other insulation materials of the same thickness, they offer ten times better insulation. PCMs in the walls and roof construction store ambient heat as they change material state. As such they help keep rooms cool and passively regulate the indoor air temperature. The concept is rounded off by an ingenious light, ventilation and heating concept. The implementation of a colorful artistic concept gives the building an eye-catching appearance [17].

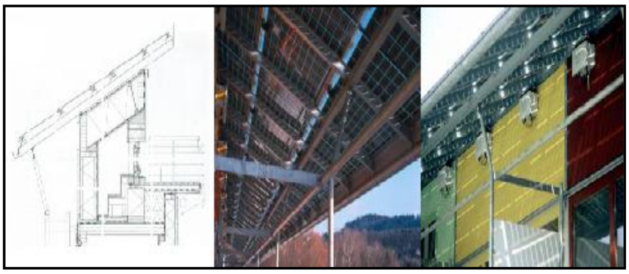

Figure 10 Row of inverters [17]

Thermal insulation: Aerogel

Aerogel currently holds the record as the lightest known solid material and was developed back in 1931. It is relatively banal: it is simply ultra-light aerated foam that consists almost 100% of air. The remaining foam material is a glass-like material, and silica. The nanodimension is of vital importance for the pore interstices of the foam: the air molecules trapped within the minute nanpores –each with a mean size of just 20nm – are unable to move, lending the aerogel its excellent thermal insulation properties.

It is used as an insulating fill material in various kinds of cavities – between glass panes, U-profile glass or acrylic glass multi-wall panels – and is therefore well suited for use in external envelopes of buildings. That way aerogels can help reduce heating and cooling costs significantly. Because it is translucent, aerogel exhibits good light transmission, spreading light evenly and pleasantly. In addition to its thermal insulating properties, aerogel also acts as a sound insulator according to the same basic principle. With its above-average thermal and sound insulation properties aerogel contributes towards energy efficiency, which is its primary functional property. It is an extraordinary high performance insulator and a comparatively new product on the market. A further advantage is its good light transmission and daylight transmittance. From an aesthetic point of view, its light weight makes homogeneous and slender façade constructions possible – all in all a whole catalogue of advantages with great potential [9].

Sports hall, Carquefou, ZAC du Souchais, France [18]	
Architecture	Agence MA, Murail Architectures, Nantes, France
Client	City of Carquefou
Product	Multi-wall panels with Nanogel filling
Manufacture	Cabot Corporation
Opened	2006
Area	3,360 m²
Façade Surface	1,450 m²

All elevations of this sports complex have been clad with aerogel-filled multi-wall polycarbonate panels. With this construction the architects voluntarily comply with the guidelines set down by the French "green" environmental initiative Haute Qualite Environnementale (HQE). Additional solar protection is unnecessary, allowing a clean and unified appearance uninterrupted by brise-soleils or louvers. Natural daylight provides an even and glare-free illumination of the indoor space and additional indoor lighting is not necessary during the day. There are no cast shadows that could be distracting for certain sports. The thermal insulating effect of the aerogel panels also reduces the heat demand: a 25 mm thick panel has a U-value of 0.89 W/ m² K and is available in 1.05 m wide panels of up to 6 m in length [9].

Figure 11 Sports hall, Carquefou, ZAC du Souchais, France (internal and external view) [18]

Temperature regulation: Phase change material (PCMs)

The good thermal retention of PCMs can be used both in new and existing buildings as a passive means of evening out temperature fluctuations and reducing peak temperatures. It can be used both for heating as well as cooling. As PCM is able to take up energy (heat) without the medium itself getting warm, it can absorb extremes in temperature, allowing indoor areas to remain cooler for longer, with the heat being retained in the PCM and used to liquefy the paraffin.

Energy is stored latently when the material changes from one physical state to another, whether from solid to liquid or from liquid to gaseous. The latent warmth or cold, which effectively fulfills a buffer function, can be used for temperature regulation.

The predefined, so-called switching temperature, in which the phase changes from one physical state to another occurs in latent heat storing materials designed for construction, is defined as 25^{o}C, as above this temperature the indoor air temperature is generally regarded as being unpleasantly warm. Depending upon the PCM used, to regulate a 5^{o}C increase in temperature only 1mm of phase change material is required in comparison to 10-40mm of concrete. The PCM has a far greater thermal capacity: a concrete wall warms up much more quickly whilst the temperature of a PCM remains unchanged. In the meantime, PCMs have become available in the form of additives that can be integrated into conventional building materials such as plaster, plasterboards or aerated concrete blocks with specific retention properties. In addition to conserving energy by reducing the energy demand for heating & cooling, PCMs are also recyclable and biologically degradable [9].

"Sur Falveng" housing for elderly people, Domat/Ems, Switzerland [19]	
Architecture	Dietrich Schwarz, GlassXAG, Zurich, Switzerland
Client	]urgen Schwarz
Product	Latent heat storing glass, phase change material (pc), GLASSX crystal
Manufacture	GlassX
Area	148 m² GlassXcrystal glazing

An experienced architect, who is also a scientist, developed a latent heat storing glass, which was followed soon after by the founding of a start-up company under the name GlassX AG. Among the projects realized using this glass is a building with 20 disabled-access sheltered flats in the Swiss Alps. All flats have large expanses of south-facing glazing and, depending on the season, the flats are heated actively or from passive solar gain. The central of three cavities of an 8 cm thick composite glass element contains a salt hydrate fill material that functions as a latent heat store for solar heat and protects the rooms from overheating. The latent heat store has a thermal absorption capacity equivalent to a 15 cm thick concrete wall. The glass panel is transparent when the fill material has melted and milky-white when frozen. The material's change of state is therefore immediately reflected in the building's appearance - function and aesthetics are inseparably connected. The buffer function of the latent heat store enables the indoor temperature to be regulated mostly passively, resulting in significant energy savings for heating (and cooling) [19].

Figure 12 "Sur Falveng" housing for elderly people' Domat/Ems, Switzerland [19]

UV protection

There are two kinds of UV protection, both of which are organic and employ additives. Both are typically used in combination: one variant involves the use of UV absorbers that filter out the harmful rays in sunlight before they come into contact with the material itself. As such they need to be on an upper layer and are typically applied in the form of a protective lacquer.

The second approach uses so-called free-radical scavengers, which in contrast to the first approach take effect at a later stage. A prerequisite of protective coatings is that they are transparent so that the coloring and structure of the material beneath is preserved. To achieve this, the individual inorganic UV-absorbing particles in the formulation must be smaller than 15nm in size. Below this size they no longer scatter visible light and become effectively visible [9].

Solar protection

The advent of nanotechnology has provided a new means of integrating electchromatic glass in buildings. The primary difference to the earlier product is that a constant electric current is no longer necessary. A single switch is all that is required to change the degree of light transmission from one state to another, i.e. on switch to change from transparent to darken and a second to change back. The electrical energy required to color the ultra-thin nanocoating is minimal and the switching process itself takes a few minutes. Photochromatic glass is another solution for darkening glass panels. Here the sunlight itself causes the glass to darken automatically without the switching.

Nanotechnology has made it possible to provide an energy-efficient means of solar protection that can also be combined with other glass functions [9].

Figure 13 Electrochromic windows

Air-purifying

Though not able to completely purify air, the use of nanomaterial makes it possible to improve the quality of air. It enables unpleasant odours and pollutants to be eradicated. Healthy air is a fundamental and ever more important resource that at the same time is becoming ever more precious. Legislation was initially introduced to reduce the level of outdoor air pollution; the need to improve indoor air quality followed later.

The air-purifying properties of nanomaterial are beneficial in both cases and play an important role both for indoor as well as increasingly for outdoor environments [9].

Jubilee Church, La Chiesa del Dio Padre Misericordioso, Rome, Italy[20]	
Architecture	Richard Meier & Partners, NewYork, NY, USA
Client	Vicariato di Roma
Product	TX Millenium, TX Active, photocatalytic cement
Manufacture	ltaIcementi
Opened	2003

Three giant sails reaching up to 36m into the sky give this church and community center its unmistakable appearance. Made of prefabricated high-density concrete, their white color is achieved by adding Carrara marble and titanium dioxide to the mixture. The photocatalytic self-cleaning additive enables the architect to achieve his trademark white coloring in an urban environment that is heavily polluted by car exhaust gases. The building not only remains clean, the large surface area of the sails also helps combat pollution by reducing the amount of volatile organic compounds and nitrogen oxide in the air considerably [20].

Figure 14 Construction of the Church (sails) [20]

Figure 15 Church in Rome – Internal view [20]

Fire-proof

In the nano-scene, a relatively small company from Switzerland, Interver Special Glass Ltd., has made headlines with its fire safety glass. A thickness of only 3 mm of a functional fill material between glass panes is sufficient to provide more than 120 minutes of fire resistance against constant exposure to flames of a temperature of over 1000°C. The product was developed in cooperation with the German chemical concern Degussa, which has produced particles of "between 4 and 20 millimicrometres" under the name Aerosil for over half a century and is a major producer in the field. The raw material Aerosil, a pyrogenic silicic acid, is produced by Degussa and used for a number of purposes including in the paint industry. The pyrogenic silicic nanoparticles, or nano-silica, are only 7 nm large and due to their relatively large surface area highly reactive.

Depending on the desired duration of fire-resistance, the highly effective fill material is sandwiched between one or more panes of glass. The size of the fill particles can be modified and is given in terms of its surface area in square meters per gram. Standard products are generally between 90 and 380 m² per gram.

The main advantages are the comparatively light weight of the glass, the slender construction and accompanying optical appearance as well as the long duration of fire-resistance. These provide benefits for building construction, installation, transport, aesthetics and last but not least the security of the users and the fire service.

In the event of fire, the fire-resistant layer expands in the form of foam preventing the fire from spreading and keeping escape routes accessible for users and firemen alike. The additional layer does not exhibit any clouding, streaking or fractures and is practically invisible.

An additional side effect is improved noise insulation. The ambitious product fulfills international testing criteria, norms and regulations and is certified for use around the world - currently it is installed in Dubai's newly constructed Dubai International Airport [9].

Waverley Gate, Edinburgh, Scotland [21]	
Architecture	SMC Hugh Martin Architects, Edinburgh, Scotland
Client	Castlemore, Development Company
Product	SGG Contraflam fire safety glass
Manufacture	Vetrotech Saint Gobain
Opened	2005
Area	20,000 m²

Waverley Gate is a complex in Edinburgh's central commercial and business district offering state-of-the-art premium office space with all the necessary facilities.

Not only does it offer the largest contiguous office space in the city, it also has low running costs thanks to energy- efficient planning. The roof of the building has an unusual rooftop garden and an atrium provides additional daylight for the interiors, lending it a spacious and airy atmosphere. High-performance fire safety glass, enhanced with nanotechnology, is used around the perimeter of the office spaces to ensure the safety of those working inside [21].

Figure 16 Waverley Gate, Edinburgh, Scotland (internal view) [9]

Scratchproof and abrasion-resistant

Nanotechnology makes it possible to improve scratch resistance whilst maintaining transparency. Scratch resistance is a desirable property for many materials and coatings can be applied to materials of different kinds such as wood, metal and ceramics. There is no ideal coating, rather two basic principles apply: self-healing layers, which are less susceptible to scratching, or glass-like hard scratch-resistant layers [9]. Materials are generally subject to wear and tear by abrasion, e.g. from being walked on, from scrubbing and cleaning or similar. The science of how materials behave under friction and wear is known as tribology. Nanotechnology has made so-called tribological coatings possible, which offer abrasion-resistance or low friction and are therefore resistant against wear and tear and also corrosion.

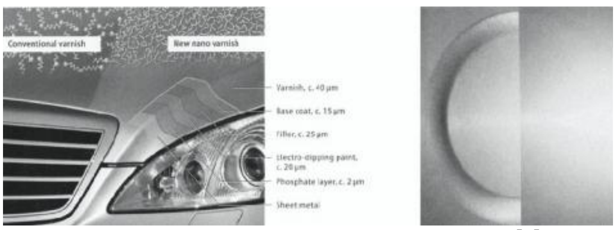

Figure 17 Applying new nano varnish for car body [9]

Table 4 shows the types of materials which have been used and its classification, as well as projects names and its locations around the world

Application	Classification	Project	Location
Coatings	Self-cleaning: Lotus-Effect	Ara Pacis Museum	Rome, Italy
Coatings	Self-cleaning: Lotus-Effect	Commercial building	Pula, Croatia
Coatings	Self-cleaning: Lotus-Effect	Private residence	Aggstall, Germany
Coatings	Self-cleaning: Lotus-Effect	Strucksbarg housing	Hamburg, Germany
Coatings	Self-cleaning: Photocataly	Muhammad Ali Center MAC	Louisville, Kentucky, USA
Coatings	Self-cleaning: Photocataly	Hyatt Regency Garden Chapel	Osaka, Japan
Coatings	Self-cleaning: Photocataly	Narita International Airport of Tokyo, Terminal 1	Chiba, Japan
Coatings	Self-cleaning: Photocataly	AKT - Am Kaiser's TXirm	Heilbronn, Germany
Coatings	Self-cleaning: Photocataly	East Hotel	St. Pauli, Hamburg, Germany
Coatings	Self-cleaning: Photocataly	G-Flat	Tokyo, Japan
Coatings	Self-cleaning: Photocataly	Kurakuen private residence	Nishinomya, Hyogo, Japan
Coatings	Self-cleaning: Photocataly	Senri New Town private residence	Osaka, Japan
Coatings	Self-cleaning: Photocataly	House in Creek	Hiroshima, Japan
Coatings	Self-cleaning: Photocataly	Disabled-access housing for elderly people	Frick, Switzerland
Coatings	Self-cleaning: Photocataly	MSV Arena soccer stadium	Duisburg, Germany
Coatings	Self-cleaning: Photocataly	Children's playground in the Mannou National Government Park	Kagawa, Japan
Coatings	Easy-to-clean (ETC)	Science to Business Center Nanotronics & Bio	Marl, Germany
Coatings	Easy-to-clean (ETC)	Kaldewei Kompetenz-Center (KKC)	Ahlen, Germany
Coatings	Easy-to-clean (ETC)	Private residence	Erlenbach, Switzerland
Coatings	Easy-to-clean (ETC)	Modem Classicism	Shanghai, China
Coatings	Easy-to-clean (ETC)	Urban lounge / Light bubbles	St. Gallen, Switzerland
Coatings	Antibacterial	Housing estate	Duisburg, Germany
Coatings	Antibacterial	Operating theatre	Goslar, Germany
Coatings	Antibacterial	Operating theatre	Berlin, Germany
Coatings	Antibacterial	Patient's hospital room prototype	Berlin, Germany
Coatings	Anti-graffiti	New Centre Ulm	Ulm, Germany
Coatings	Anti-graffiti	Homager Palais	Berlin, Germany
Insulations	Thermal Insulation: Vacuum insulation panels (VIPs)	Sonnenschiff centre	Freiburg, Germany
Insulations	Thermal Insulation: Vacuum insulation panels (VIPs)	Seitzstrasse mixed-use building	Munich, Germany
Insulations		County Zoo	Milwaukee, WI. USA
Insulations	Thermal Insulation: Aerogel	School extension	London, England
Insulations	Thermal Insulation: Aerogel	Sports hall	Carquefou, ZAC du Souchais, France
Insulations	Thermal Insulation: Aerogel	Factory	Zaisertshofen, Germany
Insulations	Temperature regulation: Phase change materials (PCMs)	"Sur Falveng" housing for elderly people	Domat/Ems, Switzerland
Air-purifying	Environmental Material	Atelier and villa for a calligrapher	Ymanashi, Japan
Air-purifying	Environmental Material	Paving for Leien Boulevard	Antwerp, Belgium
Air-purifying	Environmental Material	Jubilee Church, La Chiesa del Dio Padre Misericordioso	Rome, Italy
Fire-proof	Environmental Material	Deutsche Post headquarters	Bonn, Germany
Fire-proof	Environmental Material	Waverley Gate	Edinburgh, Scotland

For architectural applications, recently developed scratch-resistant stainless steel coatings are of particular interest and are available in transparent or colored form. Scratchproof lacquers are a standard feature of certain car models. The protective layer preserves the gloss of a vehicle's paint, avoiding damage from quartz dust hitting a car while driving or scratching in the car wash.

In the architectural context, scratchproof paints and varnishes are desirable, for instance to protect the varnished surfaces of parquet flooring or the surfaces of other gloss lacquered surfaces. Consumers who associate patina with negative connotations such as a "lack of care" and "old and worn" will value a durable gloss that maintains its original appearance. Not everyone shares the love that many architects have for authentic patina [9].

Furthermore, there are another applications and functions for nanomaterial in architecture such as self-healing, anti-fogging, anti-reflective, anti-fingerprint, scratch proof, abrasion-resistant, fragrance capsules and smart material which focus on specific desired material behaviors, such as color changing or shape changing.

Analysis and Summary

In view of above-mentioned examples of applications that have been gathered from several sources, we found it is concentrated in certain directions such as paints (finishing materials) with different types (Self-cleaning: lotus-effect, Self-cleaning: photocataly, Easy to Clean (ETC),Antibacterial and Anti-graffiti), this area granted the bulk of the attention where spotted 27 cases, another field is insulating material (energy-saving materials) and spotted 7 cases with different types (Thermal insulation: VIPs, Thermal insulation: Aerogel, Temperature regulation (PCMs), UV protection and Solar protection) , also cases for air purification applications , furthermore some miscellaneous applications such as fire-proof, anti-fogging, anti-reflective, anti-fingerprint , scratch proof and abrasion-resistant.

Herein a rose diagram (figure.18) that shows interesting positions of global trend towards nanotechnology application, it is also explain the variation in the degree of interest in such different applications, where we see that the application of paints got the bulk followed by insulation applications and then other applications.

While we missed those applications to some of our needs in the Middle East in general and in the Arab countries in particular, such as searching for materials to address extreme variance in temperature in winter between night and day in the desert areas, and high humidity in the coastal areas, causing rust and corrosion of some materials, as well as address the problem of desertification, which we hope to find solutions to them in the near future through Nanotechnology.

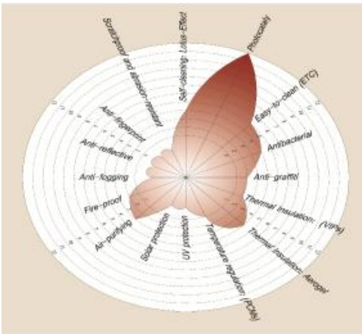

Figure 18 shows interesting positions of global trend towards nanotechnology applications (The Searcher)

Nanotechnology, the manipulation of matter at the molecular scale, promises to transform architecture in ways we can hardly imagine today. The nanotech revolution can bring dramatic improvements in building performance, energy efficiency and sustainability to building projects. The aim of this research is to bring to light the applications offered by nanomaterial in a particular sector and to examine the new materials from the point of view of architects, interior designers and designers which can vary widely from early stages of design to the final touches of finishes and throughout the building's lifetime.

Architects and designers need to know what engineers and scientists require. There are, for example, several challenges that arise from (e.g., nanomechanics and nanofluidics) at the nanoscale. Such integrated nanotechnologies are expected to impact our world, disciplines and multiple length-scales are the key to success, and require special buildings to house processes and procedures.

We draw a distinction between common types of nanomaterial properties and functional behaviors that might be the intention or application of a particular type of nanoproduct and the actual form of the nanoproduct itself. In the first instance, we have both property characteristics (e.g., mechanical, optical) and functional descriptors (e.g., self-cleaning or antimicrobial). In the second instance of product form, we have descriptors such as nanocoatings, nanofilms, nanopaints, nanotextiles, and others. Obviously, different product forms can be described in terms of basic properties as well as possess one or more of the functional behaviors noted. Many nanoproduct forms, such as nanotextiles, possess multiple functional qualities—for example, antistaining and antimicrobial. There is considerable difficulty and redundancy in describing various nanoproducts and functions in this way because of their overlapping and often ambiguous nature—for example; one person's coating is another's thin film.

The figure illustrates common characteristics and functionalities in relation to typical product forms. The vertical axis shows normal attribute or property characteristics of nanomaterial, that is, mechanical (strength, stiffness, etc.), thermal, optical, sound, chemical, and electromagnetic, and various functionalities (antibacterial and other).

The horizontal axis of (Figure.19) shows various common product forms that can be obtained in bulk sizes and that can be used in various engineering, architecture, and product design applications.

At left on the horizontal axis are primary forms of nanocomposites, in the middle are surface-oriented films and coatings, and on the right are special product forms. Not all product forms are shown. In particular, forms of nanoparticles or nanotubes that are fundamental constituents of other nanocomposite types, such as nanopowders or nanoclays, are not shown. These are indeed product forms, but they are essentially ingredients in more complex bulk forms that have immediate applications and are not treated here.

The chart suggests that different product forms, such as nanopaints, can be described in terms of both their primary properties and intended functionalities. The color intensities on the chart do nothing more than broadly suggest common relationships as a guide for thinking about relationships. Thus, we have self-cleaning nanopaints or antimicrobial nanotextiles. The color variations on the chart are meant to be suggestive of the intensity of relationships only.

Thus we see that the exploitation of optical properties and phenomena are naturally done with nanoproducts that are primarily surface oriented, such as nanofilms; or, alternatively phrased, the purpose of many surface-oriented nanoproducts has to do with optical properties—self-cleaning, antimicrobial, and so forth. It can be seen also that primary strength properties are normally a less important consideration in nanocoatings than are other properties.

Nano-Architecture would be the upcoming new architectural trend of the contemporary time. The impact of such new technology will exceed those of the precedent technologies because the intensity of the impact of any phenomenon is positively correlated with its pervasiveness. The circumstances indicate that the possible impacts of nanotech will exceed even those of the revolt against classicism some three centuries ago.

Designing buildings to house nanotechnology research presents a multitude of well recognized challenges to architectural and engineering design teams, from environmental control to spatial arrangements to operational functionality. These technical challenges can be solved with relative ease on projects with large budgets: designers have the option of selecting leading-edge systems without undue regard for their expense. This is reflected in the construction cost of many nanotechnology research facilities that run well into the hundreds of millions of dollars.

Nanomaterial makes opportunities to have smart buildings. Traditionally, the design and construction of building envelopes involve the use of multiple layers of different materials to achieve a wide array of functionalities, including strength, light filtering, thermal insulations, sound insulations, weather resistance and architectural appearance .How ever this layering approach introduce inefficiencies and also create a number of joint and interface, which ultimately act as weak links in the building envelope causing durability problems. Surely new materials and fields of use will bring new forms and functions to designs and there will be new dimensions in human structure environment relations. Architects who have come to be familiar with nanotechnology use products and systems that are lighter but stronger , environment friendly and those that can clean both themselves and the air , and so can design more sustainable buildings.

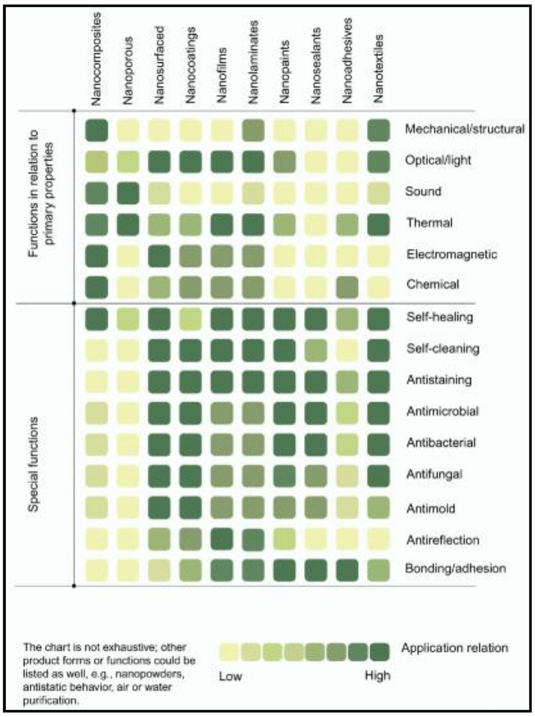

Figure 19 shows typical relationships among common nanoforms, nanoproducts, properties, and functionalities that are important to designers and engineers [6]

CONCLUSION AND RECOMMENDATION

Buildings and life in our buildings have changed over the last 25 years. Apart from a few exceptions, it is not spectacular buildings and housing types that define our times, it is above all the changes in building technology and automation. Through the development of innovative materials, products and constructions, the move to endow buildings with more functions, the desire for new means of expression, and ecological and economic constraints, it is now possible to design buildings that are clearly different from those of previous decades[22].

In the future, the environment will interact with occupants in ways hardly imaginable today, creating what a 2005 United Nations report calls “an internet of things.” Tiny nanosensors embedded in building materials will soon be able to track movement and detect temperature changes, humidity, toxins, weapons—even money. Sensors will pick up on users' preferences and attributes, which will then trigger responses in the intelligent objects around them, dimming the lights, altering the temperature, or—as is already happening with “push” technology that marketers use to blitz cell phones—alerting them to nearby sales and events[23].

Soon, the design and construction of buildings will incorporate a rich network of interacting, intelligent objects, from light-sensitive, photochromic windows to user-aware appliances. Buildings will not be static but will change constantly as their components continuously interact with users and each other. These dynamic environments will be almost organic in their ability to respond to changes, so architects will need to learn to design for change [23].

As materials gain such transient features, architectural design and construction will evolve.

By transforming the essential properties of matter, nanotechnology will be able to change the way we build. For instance, structures will be constructed from the bottom-up because materials like carbon nanotubes can self-assemble [24].

Green nanotechnology

Green nanotechnology is the development of clean technologies, to minimize potential environmental and human health risks associated with the manufacture and use of nanotechnology products, and to encourage replacement of existing products with new nanoproducts that are more environmentally friendly throughout their lifecycle [24].

Green Nanotechnology has two goals: [24]

- Producing nanomaterial and products without harming the environment or human health, and producing nano-products that provide solutions to environmental problems. It uses existing principles of Green Chemistry and Green Engineering to make nanomaterial and nanoproducts without toxic ingredients, at low temperatures using less energy and renewable inputs wherever possible, and using lifecycle thinking in all design and engineering stages. In addition to making nanomaterial and products with less impact to the environment, green Nanotechnology also means using nanotechnology to make current manufacturing processes for non-nanomaterial and products more environmentally friendly. For example, nanoscale membranes can help separate desired chemical reaction products from waste materials. Nanoscale catalysts can make chemical reactions more efficient and less wasteful. Sensors at the nanoscale can form a part of process control systems, working with Nano-enabled information systems. Using alternative energy systems, made possible by nanotechnology, are another way to "green" manufacturing processes.
- The second goal of Green Nanotechnology involves developing products that benefit the environment either directly or indirectly. Nanomaterial or products directly can clean hazardous waste sites, desalinate water, treat pollutants, or sense and monitor environmental pollutants. Indirectly, lightweight nanocomposites for automobiles and other means of transportation could save fuel and reduce materials used for production; nanotechnology-enabled fuel cells and light emitting

diodes (LEDs) could reduce pollution from energy generation and help conserve fossil fuels; self-cleaning nanoscale surface coatings could reduce or eliminate many cleaning chemicals; and enhanced battery life could lead to less material use and less waste. Green Nanotechnology takes a broad systems view of Nanomaterial and products, ensuring that unforeseen consequences are minimized and that impacts are anticipated throughout the full life cycle [24].

Sustainable Nano-Architecture (SNA)

The use of nanotechnology offers ecological and economic advantages for energy efficiency and the conservation of resources.

Technologies that help reduce climate change are in demand more than ever before. In future, ecology and the economy will become inseparably connected, as preventive measures will be cheaper on the long term than remedying the damage caused. Ecology pays off and climate protection pays off - provided one is open to technological possibilities and the conditions of use they involve.

Environmentally friendly production methods, energy efficiency, reduced environmental pollution and the conservation of resources are chances which nanotechnology offers. Ideally emphasis should be given to the overall eco-balance across the entire life cycle of a product or building rather than one individual aspect [9].

Sustainability is essential; buildings are often planned with 20-30 year cycles, which can make it difficult to incorporate coatings with 2-3 years durability. There are, however, some firms that provide a 10-year guarantee for their nanotechnology-based products. Production processes can also be made more efficient and more cost-effective with the help of nanotechnology, by reducing the amount of energy and raw materials required to a minimum - either directly or indirectly [9].

Nanotechnology revolution is bringing dramatic improvements in building performance, energy efficiency, environmental sensing, and sustainability, leading the way to greener buildings. The nanotech and building sector have to get to know each other a lot better in order to realize the dramatic benefits awaiting each of them. The nanotech community needs to be explored. It should explain the enormous economic opportunities in Green Building Design, Construction and Operation and demonstrate to Architects, Building Owners, Contractors, Engineers and others in the $1 trillion per year global building industry that nanotech is at this moment beginning to fulfil its promise of healthful benefits for people and the environment [9].

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