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TOWARDS SUSTAINABLE ARCHITECTURE WITH NANOTECHNOLOGY

Abdelrahman AbdelNaieem Abdellatif

Dear Prof.

I have the pleasure to inform you that your paper has been accepted for oral presentation during Al-Azhar Engineering Eleventh International Conference. Selected papers will also be published in a special issue of Journal of Al Azhar University Engineering Sector, JAUES

Thank you for your interest in AEIC 2010 and I look forward to seeing you in Cairo.

Sincerely,

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Abstract

Nanotechnology is the art of new sophisticated technological process, which based on using of very small particles of material either by themselves or by their manipulation to create new large scale materials which their physical, mechanical and chemical properties become more affected.

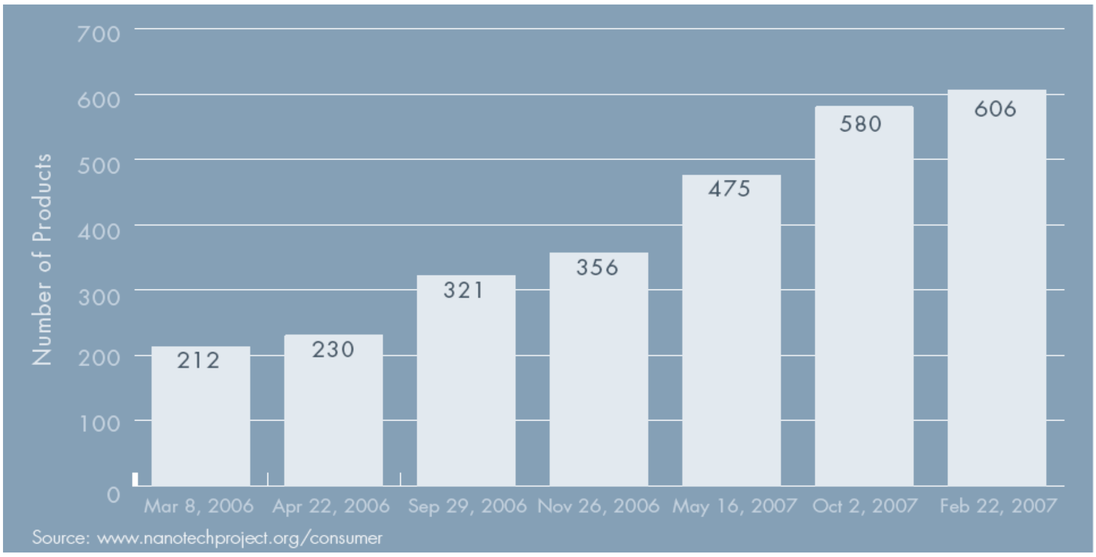
Nanotechnology introduces promising economical solutions and products to achieve reliable sustainable environment. The building sector shows a great potentiality to be beneficiary from this technology. Many distinguish applications have been established in construction business, for example improving the performance of traditional building materials, like concrete, steel and glass. Concrete is become stronger, more durable and more easily placed, steel tougher and glass self-cleaning. Increased strength and durability are also a part of the drive to reduce the environmental footprint of the built environment by the efficient use of resources. This is could be achieved prior to the construction process by a reduction in pollution during the production of materials (e.g. cement) and also in service, through efficient use of energy. Purification of water and reduction of air pollution are significant applications for water and air filtration (“nanofiltration”). Nanoapplications in the field of energy are introduced many environmentally friendly energy systems to reduce energy consumption or to produce renewable energy by production of improved solar cells.

However, on one hand Nanotechnology is likely to significantly changes in our modern way of life. On the other hand we must ensure that the benefits of nanotechnology are maximized and the risks are identified and controlled.

Introduction

Nanotechnology is a new technology that has been compared with the industrial revolution in terms of its impact on society. It is also important as a prototype of the technological opportunities and challenges that will characterize the 21st century.

Recently, there are more than 600 manufacturer-identified consumer products are available on the market using nanotechnology. Which is projected will enable 15 percent of globally manufactured goods worth $2.6 trillion by 2014.[8] The U.S. federal government budget for nanotechnology for fiscal year (FY) 2009 totals $1.5 billion. China, Japan, Korea and several European nations are competing with the United States for the lead in developing nanotechnology, and Russia recently announced a $5 billion for research and development program of nanotechnology (Elder 2007).[10]



(Fig. 1) development of total products listed for nanotechnology

The implications of nanotechnology on building sector are introducing new potentialities for used materials. They lend building materials and surfaces entirely new physical and mechanical properties. The key characteristic is not the material itself but the size of the particles. These are responsible for properties such as fire-resistance, durability and strength. Applications of nanotechnology range from controllable adhesion and grip, tribological aspects such as ultra-low friction, switchable magnetism or light absorption, conductive transparent surfaces, light diffusers and so on to insulation materials for buildings. The multitude of nanotechnological products in this area underlines the economic relevance of such new materials. *Nanotechnology is an "enabling technology". It helps to improve existing products rather than creating completely new products*. [4]

1.1 Problematic of study

As above mentioned nanothnology have huge impacts on the most applicable fields in our modern society, which compare with impact of industrial revolution on the 19 century. In fact recent architectural professions have the same attitude of their colleagues in the 19yh ct. towards new building technology. The main reasons which lead to the slow beneficiary of building sector from nano-technology could be concluded in the following:

- The majorities of architects especially in the developing country are not familiar with the applications of nanotechnology in building sector and they are ignorance with the huge potentiality of this technology to improve or introduce new building materials and related building systems.
- Unfortunately they are not active enough to explore the possibilities of developing new sustainable architecture based on the local context and applications of new technology.
- The slow progress of academic qualification process for architects need to be developed towards creation a new architecture, away from false copied style of paper architecture and imitating distinguish architectural works without understanding sciences and technology behind its creation.
- Finally the strong engagement to traditional building industry due to costs constrains, or to take the risk of probation the new material or technology against normal test of client.

1.2 The aim of study

The main objectives of this paper are:

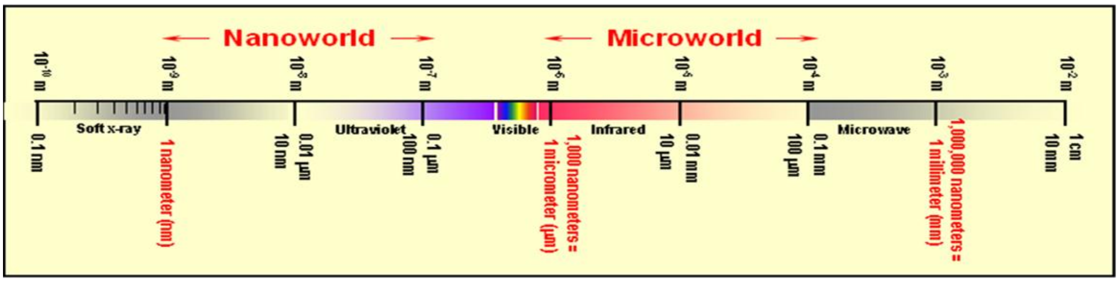
- Introduce for architects the nanotechnology as the technology of 21th ct., this affects all our modern life fields.
- Clarify the great potentiality of nanotechnology on building sector, through many applications, like innovative building materials and smart building systems.
- Discuss from the point of view of architects, interior designers and designers, whom concern with sustainable aspects in building sector, how to achieve sustainability through utilization nanotechnology in optimizing the use of building materials, improving the environmental conditions of buildings, reducing the consumption of energy, reducing air pollution and introducing renewable energy.
- Finally clarify the potential risks of nanotechnology which should be avoided through developing new appropriate standard and code for application of nanotechnology.

1. What is nano[1]-materials and nanotechnology?

Nanotechnology is the manipulation of matter at the scale of individual atoms and molecules. It includes processes for making materials, systems and structures. Some types of nano-materials exist in nature, but nanotechnology, the deliberate engineering of nanostructures and materials, largely began in the 1980s with the invention of new, more powerful types of microscopes. *"Nanotechnology is an enabling technology that allows us to develop materials with improved or totally new properties"* [7]

2.1 Nanoscale

Nanoscale[2] science, engineering, and technology are fields of research in which scientists and engineers manipulate matter at the atomic and molecular level in order to obtain materials and systems with significantly improved properties. Nanomaterials are usually defined as materials that have at least one dimension smaller than 100 nanometers. A nanometer is approximately 1/80,000th the width of a human hair or 1/7,000th the size of a single red blood cell. Materials at the nanoscale often exhibit physical, chemical and biological properties that are very different from those of their normal-sized counterparts. [4]



(Fig. 2) The Scale – Nanometers [16]

Resource: Office of Basic Energy Sciences, Office of Science, U.S. DOE Version 05-26-06

2.2 Nanoparticals

A nanoparticle is a microscopic particle whose size is measured in nanometres (nm). It is defined as a particle with at least one dimension less than 200nm. When brought into a bulk material, nanoparticles can strongly influence the mechanical properties of the material, like stiffness or elasticity. Such nanotechnologically enhanced materials will enable a weight reduction accompanied by an increase in stability and an improved functionality.

Two nano-sized particles that stand out in their application to construction materials are titanium dioxide (TiO_2) and carbon nanotubes (CNT's). [7]

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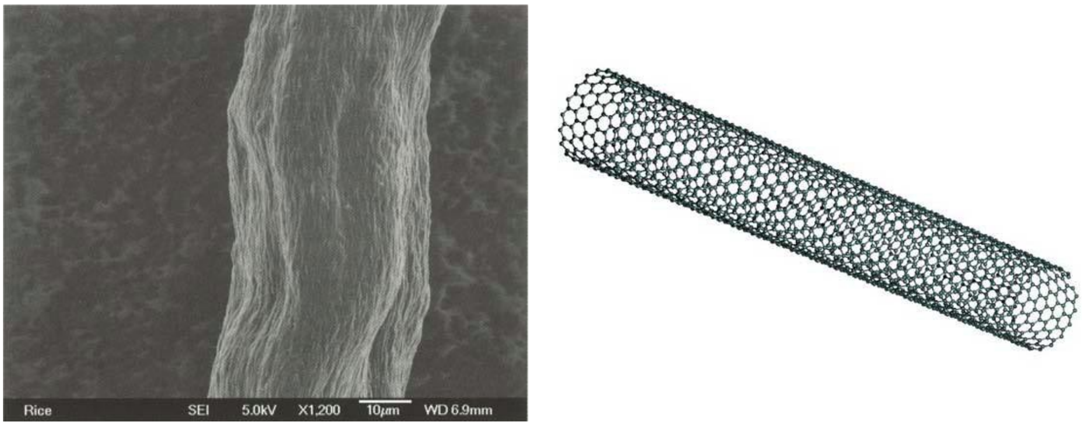
[1] "Nano" derives from the Greek word nanos (Latin nanus) meaning "dwarf", ibid p. 12[4]

[2] A nanometre (nm) is a millionth of a millimeter (1/1,000,000mm = IO-6mm) or a billionth of a meter (1/1,000,000,000m = IO-9m). The wavelength range of visible light is approximately 400 to 800 nm and as the light scattered by smaller particles reduces significantly, particles of such a small size become effectively invisible.[4]

2.2.1 Carbon nanotubes (CNTs)

The current stars of modern nanotechnology are the carbon nanotubes (CNTs).[3] They are cylindrical in shape, as shown in figure below, and their name comes from their nanometre diameter. They have a diameter of between one and a few nanometres and can be several nanometres long. Nanotubes can act as semiconductors or as conductors. Their key properties are great strength coupled with low weight. Nanotubes are always mixed with other materials or applied to surfaces. Additional work is needed in order to establish the optimum values of carbon nanotubes and dispersing agents in the mix design parameters.[4]



(Fig. 3) carbon nanotubes (CNTs)
(Single-walled carbon nanotubes can be extruded to form macroscopic fibers.)

The development of nanotubes is continually being optimized. High-quality nanotubes can now be produced much more cheaply and in large quantities. Although nanotubes can now be produced comparatively economically, they are still too expensive for use in large quantities.

2.2.2 Titanium Oxide (TiO2)

Titanium dioxide as nanoparticles is a widely used white pigment because of its brightness. It is normally can be used as an excellent reflective coating. It can breaks down organic pollutants, volatile organic compounds, and bacterial membranes through powerful catalytic reactions; therefore, It is incorporated, to paints, cements, windows, tiles, or other products for sterilizing, deodorizing and anti-fouling properties and when incorporated into outdoor building materials can substantially reduce concentrations of airborne pollutants. Additionally, as TiO2 is exposed to UV light, it becomes increasingly hydrophilic (attractive to water), thus it can be used for anti-fogging coatings or self-cleaning windows. Titanium dioxide (TiO2) is added to concrete to improve its properties. The resulting concrete has a white color that retains its whiteness very effectively unlike the stained buildings of the material's pioneering past.[7]

[3] Carbon nanotubes are a form of carbon that was first discovered in 1952 in Russia (and mostly ignored) and then re-discovered in 1991 by the Japanese physicist Sumio Iijima at the electronics concern NEC in Tsukuba, Japan. [4]

2. Building sustainability with Nanotechnology

Nanotechnology is an enabling technology that is opening a new world of materials functionalities, and performances. Therefore, it is opening also new possibilities in construction sustainability. It could lead to a better use of natural resources, obtaining a specific characteristic or property with minor material use. It can (also) help to solve some problems related to energy issues in building (consumption and generation), or improve internal environmental conditions to mention only a few matters. [7]

3.1 Sustainable Building materials

Nanotechnology has improved the productive capacities in the field of building materials. It has the potential to make it stronger, lighter, cheaper, safer, durable, easy to maintain and more sustainable.

3.1.1 Nanotechnology and Concrete

"CO2 emissions from the global cement industry are significant and they are increasing. … the global cement industry produces around 1.4 tonnes of CO2 each year. This represents about 6% of the total worldwide man-made CO2 production." [7]

(Fig. 4) Jubilee Church, Rome, Italy, Richard Meier, 2003,

(TX Millenium, TX Active, photocatalytic cement) [4]

In the field of cement and its derivatives, sustainability will be a major issue. The control of the cement hydration could lead to a new generation of products. Their production processes could be more environment-friendly. Nano-silica addition to cement based materials can lead to improvements in durability and the compressive strength of the refined material (3 to 6 times higher at different ages). Concerning the corrosion problems in concrete products, nanotechnology can offer smart solutions providing coatings that respond to external agents with a ‘response’ that can repair or prevent damage. Current research on the application of multifunctional materials such as nanoparticles and carbon nanotubes shows that, not only do these materials significantly increase the compressive strength of cement mortar specimens; they also change their electrical properties which can be used for health monitoring and damage detection. Self-Compacting Concrete (SCC)[4] is one that does not need vibration in order to level off and achieve consolidation. This represents a significant advance in the reduction of the energy needed to build concrete structures, and can offer benefits of up to 50% in labor costs, due to it being poured up to 80% faster and having reduced wear and tear on formwork that is therefore a sustainability issue. Nanoparticles are used to penetrate and close small cracks on the concrete surface and, in strengthening applications, the matrices form a strong bond between the surface of the concrete and the fiber reinforcement. The ability of the samples to sustain load after cracking is greatly improved by the carbon tows and both the matrix and the interface are durable under wetting and drying and scaling (scraping) conditions.

3.1.2 Nanotechnology and Steel

(Fig. 5) Seri Wawasan bridge, Putrajaya (Malaysia's administrative centre) [19]

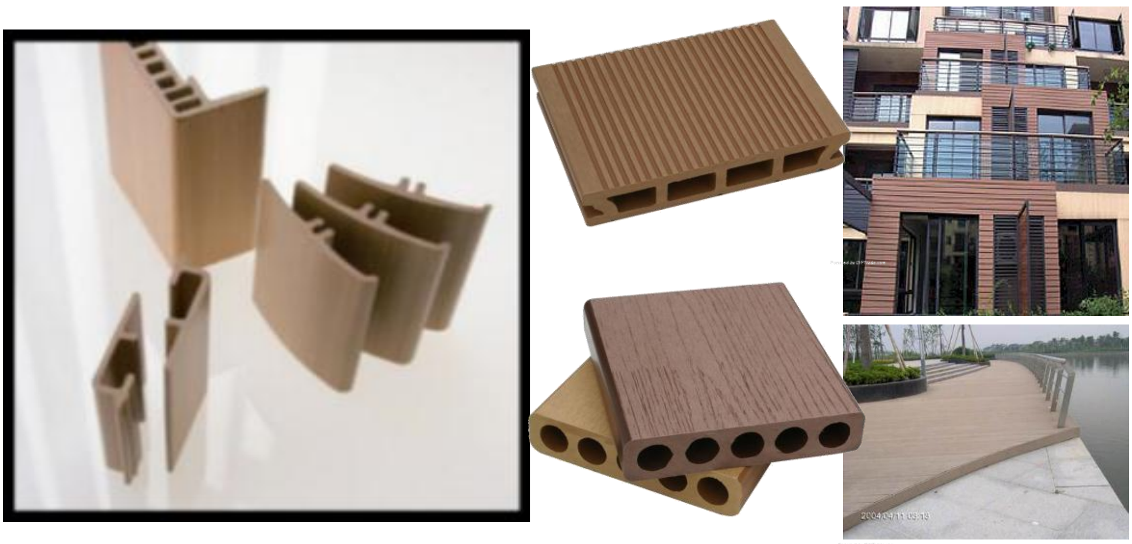
Research has shown that the addition of copper nanoparticles reduces the surface unevenness of steel which then limits the number of stress risers and hence fatigue cracking. Also research into the refinement of the cementite phase of steel to a nano-size has produced stronger cables. High strength steel cables are used in bridge construction and in pre-cast concrete Tensioning and a stronger cable material would reduce the costs and period of construction, especially in suspension bridges as the cables are run from end to end of the span. Nanoparticles are reducing the effects of hydrogen

[4] The material behaves like a thick fluid and is made possible by the use of polycarboxylates (a material similar to plastic developed using nanotechnology).

embrittlement and improving the steel micro-structure through reducing the effects of the inter-granular cementite phase. The addition of nanoparticles of magnesium and calcium makes the HAZ (Heat Affected Zone) grains finer in plate steel and this leads to an increase in weld toughness. Two relatively new products that are available today are Sandvik Nanoflex (produced bySandvik Materials Technology) and MMFX2 steel (produced by MMFX Steel Corp). Both are corrosion resistant, but have different mechanical properties and are the result of different applications of nanotechnology. Sandvik Nanoflex has both the desirable qualities of high strength and resistance to corrosion. MMFX2 steel has a modified nano-structure that makes it corrosion resistant and it is an alternative to conventional stainless steel, but at a lower cost. [7]

3.1.3 Nanotechnology and Wood

Wood is composed of nanotubes or “nanofibrils”; namely, lignocellulosic (woody tissue) elements which are twice as strong as steel. Harvesting these nanofibrils would lead to a new paradigm in sustainable construction as both the production and use would be part of a renewable cycle. Some developers have speculated that building functionality onto lignocellulosic surfaces at the nanoscale could open new opportunities for such things as self-sterilizing surfaces, internal self-repair and electronic lignocellulosic devices. These non-obtrusive active or passive nanoscale sensors would provide feedback on product performance and environmental conditions during service by monitoring structural loads, heat losses or gains, temperatures, moisture content, decay fungi, and loss of conditioned air. Due to its natural origins, wood is leading the way in cross-disciplinary research and modeling techniques which have already borne fruit in at least two areas. Firstly, BASF have developed a highly water repellent coating based on the actions of the lotus leaf as a result of the incorporation of silica and alumina nanoparticles and hydrophobic polymers. And, secondly, mechanical studies of bones have been adapted to model wood, for instance in the drying process. [7]



(Fig. 6) wood-plastic composites carbon nanofibers and nanoclayes improve stiffness and less-toxic alternative to traditional treated lumber

3.1.4 Nanotechnology and Glass

Many new glass products have been developed with nanotechnology. Titanium dioxide (TiO_2) is used in nanoparticle form to coat glazing since it has sterilizing and anti-fouling properties. The particles catalyze powerful reactions which breakdown organic pollutants, volatile organic compounds and bacterial membranes. In addition, TiO_2 is hydrophilic and this attraction to water forms sheets out of rain drops which then wash off the dirt particles broken down in the previous process. Glass incorporating this self cleaning technology is available on the market today. Fire-protective glass is another application of nanotechnology. This is achieved by using a clear intumescent layer sandwiched between glass panels (an interlayer) formed of fumed silica (SiO_2) nanoparticles which turns into a rigid and opaque fire shield when heated.[7]

Controlling light and heat entering through building glazing is a major sustainability issue. Nanotechnology offers four different strategic solutions to block light and heat coming in through windows. Firstly, thin film coatings are being developed which are spectrally sensitive surface applications for window glass. These have the potential to filter out unwanted infrared frequencies of light reduce the heat gain in buildings; however, these are effectively a passive solution. Secondly, (as an active solution) thermo-chromic technologies are being studied which react to temperature and provide thermal insulation to give protection from heating whilst maintaining adequate lighting. A third strategy, that produces a similar outcome by a different process, involves photo-chromic technologies which are being studied to react to changes in light intensity by increasing absorption. And finally, electro-chromic coatings are being developed that react to changes in applied voltage by using a tungsten oxide layer; thereby becoming more opaque at the touch of a button. All these applications are intended to reduce energy use in cooling buildings and could make a major dent in the huge amounts used in the built environment. .[7]

(Fig. 7) "Sur Falveng" house for elderly people, façade, Switzerland

Latent heat storing glass, phase change material (peM), GLASSXcrystal [1]

3.1.5 Nanotechnology and Coatings

Coatings are an area of significant research in nanotechnology and work is being carried out on concrete and glass as well as steel. Much of the work involves Chemical Vapour 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. Anther advanced application nano-coating is “Smart nano-dust”, which can be sprinkled (or even painted) on the surface or incorporated into the mix to provide wide-scale monitoring in a co-ordinated smart network. [4]

Better insulation and corrosion protection - protective coating surfaces are currently available, which produced by the addition of nano-sized cells, pores and particles, giving very limited paths for thermal conduction (R values are double 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. [7]

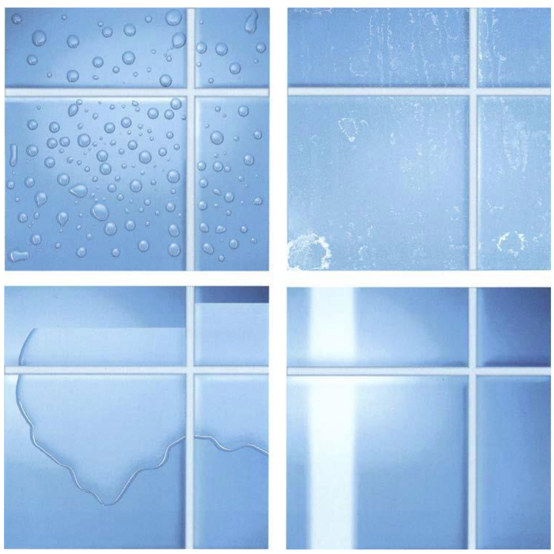
Better adhesion, transparency and self-cleaning - Nanoparticle based systems can provide better adhesion and transparency than conventional techniques. The remarkable properties of TiO2 nanoparticles are being put to use as a coating material on roadways in tests around the world. The TiO2 coating captures and breaks down organic and inorganic air pollutants by a photocatalytic process (a coating of 7000m2 of road in Milan gave a 60% reduction in nitrous oxides). This experience opens up the intriguing possibility of putting roads to good environmental use. [4]

Better fire Protection - Fire resistance of steel structures is often provided by a coating produced by a spray-on cementitious process. Current portland cement based coatings are not popular because they need to be thick, tend to be brittle and polymer additions are needed to improve adhesion. Nano-cement, which is achieved by the mixing of carbon nanotubes (CNT’s) with the cementious material to fabricate fiber composites, has the potential to be used as a tough, durable, high temperature coating material. Polypropylene fibers also are being considered as a method of increasing fire resistance and this is a cheaper option than conventional insulation. [7]

(Fig. 8) self-cleaning surfaces, before and after:

On conventional tiles, water forms droplets that dry leaving behind dirt deposits.

On the hydrophlllc surfaces of photocataiytic tiles, water forms a film that runs off taking any loose dirt deposits with it.



(Fig. 9): Lotusan, self-cleaning paint (Lotus-Effect)
Comune di Roma, Rome, Italy, Richard Meier, 2006 [4]

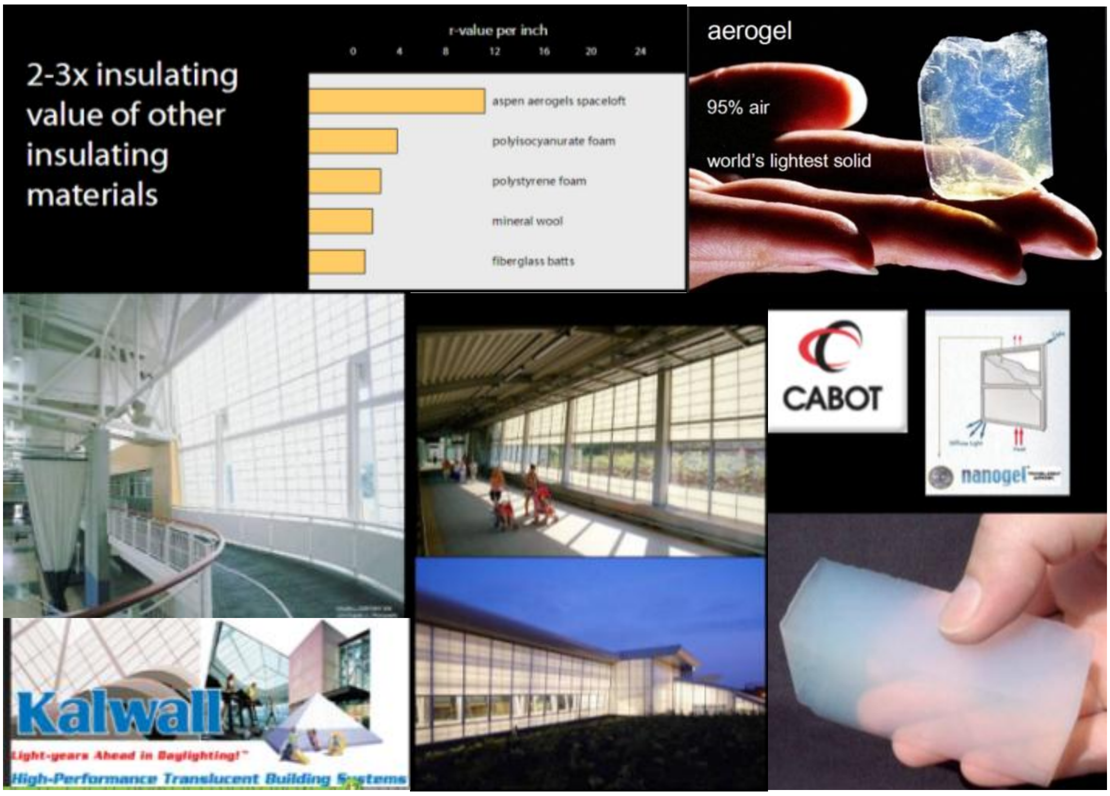
(Fig. 10) Hyatt Regency Osaka Sky Clear Coat fabric/TiO^2photocatalytic self-cleaning membrane [1]

3.2 Efficient use of energy

Another key aspect of sustainability is the efficient use of energy. The most advanced nanotechnology projects related to energy are: storage, conversion, manufacturing improvements by reducing materials and process rates, energy saving by better thermal insulation for example, and enhanced renewable energy sources like solar cells. Efficient use of energy in building can be achieved through the following aspects:

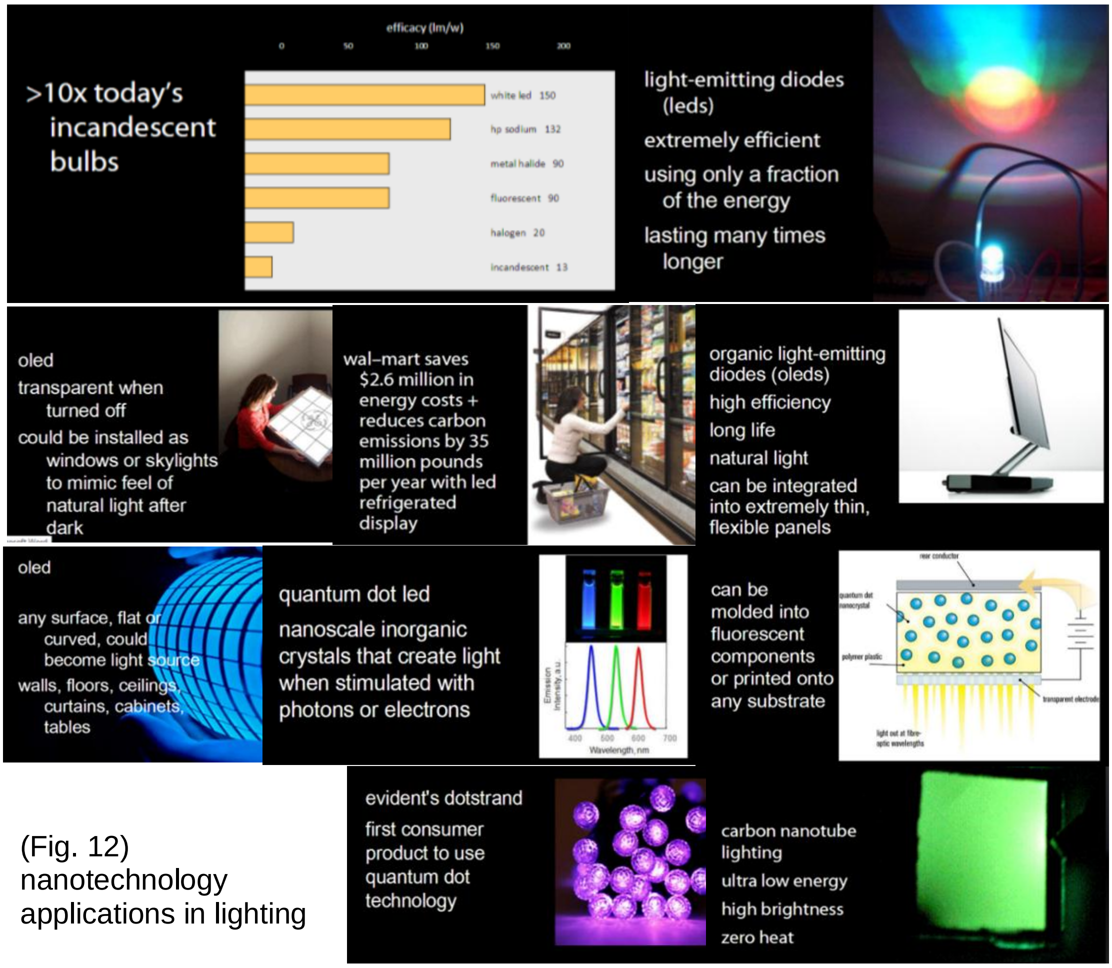
3.2.1 Reduction of energy consumption

Insulation - In the EU, over 40% of total energy produced is consumed by buildings. Insulation is an obvious solution to reduce some of this energy use; however, limited space for installation is a major problem for building renovation. As a possible remedy, work by Aspen Aerogels has produced an ultra-thin wall insulation which uses a **nanoporous aerogel** structure which is hydrophobic and repels water so it is mould free. Another intriguing application of aerogels is silica based products for transparent insulation, which leads to the possibility of super-insulating windows. [4]



(Fig. 11) aerogel – product different uses[6]

Lighting - Nanotechnological approaches like light-emitting diodes (LEDs) or quantum caged atoms (QCAs) could lead to a strong reduction of energy consumption for illumination. [15]



(Fig. 12) nanotechnology applications in lighting

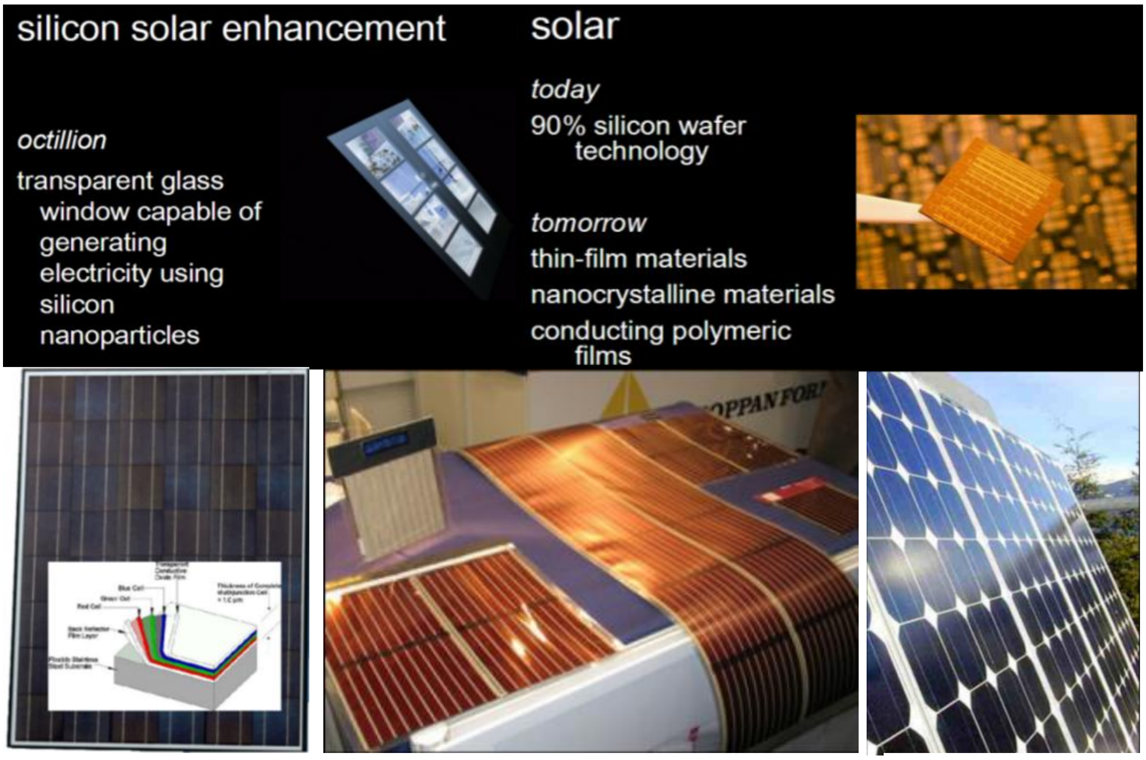
3.2.2 Energy production (Solar Cells)

Currently available nanotechnology solar cells are not as efficient as traditional ones; however their lower cost offsets this. In the long term nanotechnology versions should both be lower cost and, using quantum dots, should be able to reach higher efficiency levels than conventional ones. By using nanoparticles in the manufacture of solar cells have the following benefits:

- Reduced manufacturing costs as a result of using a low temperature process similar to printing instead of the high temperature vacuum deposition process typically used to produce conventional cells made with crystalline semiconductor material.
- Reduced installation costs achieved by producing flexible rolls instead of rigid crystalline panels. Cells made from semiconductor thin films will also have this characteristic.

Many Applications of using nanoparticles to produce more efficient solar cells are still under improvement and development – for example:

- Titanium dioxide nanotubes filled with a polymer to form low cost solar cells
- Carbon nanotubes, bucky-balls and polymers have been combined to produce inexpensive solar cells that can be formed by simply painting a surface.
- Hybrid solar cells, which using semiconductor nanoparticles applied in a low temperature printing process that results in low cost solar cells.
- Organic molecules to lower costs [18]



Solar amorphous silicon plastic substrate

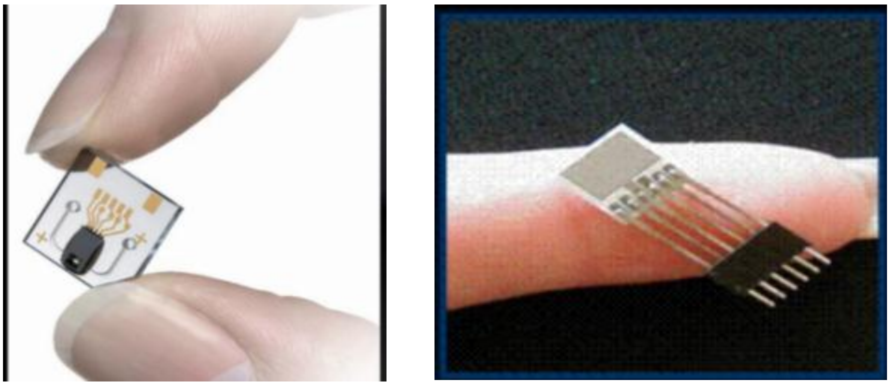
Thin-film solar nanotechnology

Solar crystalline silicon glass panel

(Fig. 13) products of nanotechnology solar cells [6]

3.2.3 Nano-ElectoMechanical System (MEMS or NEMS)

MEMS and NEMS are devices which use microfabrication methods to develop moving parts linked to electrical components for detection and action; they are often manufactured in a batch process. Micro or Nano Electomechanical Systems (MEMS or NEMS) also offer the possibility of monitoring and controlling the internal environment of buildings (through a potentially integrated network). This could lead to energy savings much in the way that current motion detectors switch on light only when needed. [7]



(Fig. 14) nanosensors – collect, process + transmit information
(light, temperature, pollutants, vibration ……) [6]

4. Architectural features of nano-materials & technology

(Fig. 15) The Nano Towers (Proposal), The new headquarters of the DuBiotech Research Park in Dubai, Allard Architecture, (imitating the form of carbon nanotubes)

Althoug the inovation in building materials and technology have great influnces one prograssive of architectural styles and trends, but that not always developed as an objective process. Unfortunlity, due to the permennent secientic deficiency in the

acdimic archiectural training, the majority of architects tend to be formalistic generatic new surprising forms or imitating the works of pioner or star architects as a new mode. The development process take some time until a character of modern arhitecture dependes on the real functional, aesthetical and economical values of the new inovative building materials and technology.
The new design area that will be influenced by nanotechnology is the smart building. Here, tiny embedded nanosensors will make architectural features responsive and interactive. Communication will occur between object and object, between occupant and object, between object and environment and between occupant and environment. As new materials gain more transient properties, objects and architectural features will impact the process of design by making “fields of interaction” a major focus. By working on “fields of interaction” architecture professionals will have some framework by which to design for dynamic environments. Since smart architecture will be changing states and communicating heavily, architects will likely focus on relationships as much as they focus on designed forms during the design stage. It is likely that both forms and their relationships will make up rule-based systems by which smart architectural spaces can function. [?] On the near horizon, it may take building enclosure materials (coatings, panels and insulation) to dramatic new levels of performance in terms of energy, light, security and intelligence. Even these first steps into the world of nanotechnology could dramatically alter the nature of building enclosure and the way our buildings relate to environment and user. The entire distinction between structure and skin, for example, could disappear as ultralight, super-strong materials functioning as both structural skeleton and enclosing skin are developed. . [5]

5. Conclusion and Recommendation

Potentiality - benefits and risks

A central aim of nanotechnology is to consistently use the minimum amount of raw material and energy: from an economic as well as an ecological point of view "nano" is a winning factor. From the point of view of the client or the user, the most realistic and sensible application of nanotechnology focuses on aspects of aesthetics, functionality, economy and sustainability.
The use of nanotechnologies in the design and construction disciplines usually involves the optimization of existing products or common materials. Nanotechnology brings us a step closer towards customized materials with specific individual properties and represents a shift away from the catalogue of standard materials. Surfaces emancipate themselves from the underlying material, developing clearly defined functions that can differ fundamentally from the substrate material. This helps make products and materials more economical and also conserves resources. The application of nanotechnology makes a concrete contribution in the field the construction industry to the following areas: [4]

- Optimization of existing products
- Damage protection
- Reduction in weight and/or volume
- Reduction in the number of production stages
- A more efficient use of materials
- Reduced need for maintenance (easy to clean, longer cleaning intervals) and/or operational upkeep.

Nanotechnology has a positive impact on many of the most important recent global problems. It can reduce dependence on oil, help to deal with global climate change, generate power, remedies for many of the world’s illnesses and improve the health system. As direct results for global issue of sustainability are:

- Reduction in the consumption of raw materials and energy and reduced CO_2 emissions
- Conservation of resources
- Greater economy

In spite of all these great advantages, many of the potential risks of nanoscale materials have already been identified. Therefore it's recommended that, Nanomaterials should be defined as “new” substances under the Toxic Substances Control Act (TSCA).[10]

The combination of poorly understood risks and increasing commercial product flow led the World Economic Forum to declare the risks of nanotechnology as one of the two major technological risks facing the planet. (The second risk is an attack on or a system failure of the global information infrastructure.) (World Economic Forum 2008, p. 51).

Because of their large surface-to-mass ratio, nanoparticles are more reactive than ordinary materials. Nanotechnology may produce materials that could have the same effect on lungs as asbestos, damage human DNA or wipe out bacteria necessary for the functioning of ecosystems. There is little or no effective oversight. Doing nothing is a dangerous option. Risk research is essential. In 2007, the Russians exploded the first bomb allegedly based on nanotechnology. It was reportedly the largest non-nuclear bomb ever tested (Elder 2007).[10]

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بسم الله الرحمن الرحيم
مؤتمر الأزهر الهندسي الدولي الحادى عشر
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Dear Prof.

I have the pleasure to inform you that your paper has been accepted for oral presentation during Al-Azhar Engineering Eleventh International Conference. Selected papers will also be published in a special issue of Journal of Al Azhar University Engineering Sector, JAUES

Thank you for your interest in AEIC 2010 and I look forward to seeing you in Cairo.

Sincerely,

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