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Nanotechnology, a Step toward Sustainable Architecture

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Abstract: Global warming, thinning Ozone layer affected by increasing greenhouse gases and various pollutants, increasing environmental pollution and consequently extinction of biological species all lead to focus on environmental issues and ecology as the "sustainable environment" which have been studied extensively during the recent decades. Nanotechnology demonstrates amazing properties by taking control in molecular and atomic levels of materials. Regarding this matter, nanotechnology can be considered as one of the most efficient and innovative ways to achieve environmental sustainability goals. This technology enables us to produce materials, tools and new systems that lead to dramatic improvements in production, transmission, storage and consumption of energy. Firstly, this study points to the principles governing "Green Architecture", secondly, the achievements of nanotechnology and the satisfactory of this achievement in meeting the sustainable architecture goals that surely is conservation of nonrenewable resources, adaptation and utilization of natural environmental factors has been studied.

Key words: Green buildings, sustainable architecture, nanotechnology, smart building, smart materials, nanotube, nano-wire, repair and reconstruction, self-repairing materials

INTRODUCTION

In recent century, the new paradigm is one of saving and the intelligent use of available resources at an interconnected local level to keep the natural ecology in a safer mode. This crucial point will attain by achieving: resource efficiency, energy efficiency, pollution prevention, harmonization with environment and using long lasting materials. Aiming for this universal goal, architecture now faces a new responsibility of having to respond to these needs. Buildings should be able to isolate the life space from the changing climate of their surroundings. Designing inhabitable organisms that are capable of developing functions and integrating the processes of the natural world would be a basic requirement.

Nanotechnology is one of the brightest and most developed areas playing an important role in today's world's material development. Nanotechnology is a combination of Nano-science and Nano-engineering. This young and multidisciplinary science has spread in different areas and brings new materials and new possibilities to industries as diverse as electronics, medicine, energy and aeronautics. This technology progressively impactinfluencess different industries and caused a dramatic transformation in storage and consumption of energy. So, therefore, a new frontier is opening in building materials as nanotechnology introduces new products and new possibilities.

The above mentioned buildings that could cover the aforementioned requirements of today's needs is called "Sustainable Buildings" that should be constructed by using "Sustainable architecture" which surely is conservation of nonrenewable resources, adaptation and utilization of natural environmental factors. To approach this goal the assistance of nanotechnology could make a drastic improvement in architecture. Therefore, for the building industry to achieve its potential as the leader in sustainable development, new materials are urgently needed. Awareness of new materials and systems that are are producproducted with the aid of nanotechnology could be a great help in designing modern and more efficient buildings (Zhang and Li, 2011).

MATERIALS AND METHODS

Organization: This study is to suggest that the potential for energy conservation and reduced waste, toxicity, nonrenewable resource consumption and carbon emissions through the architectural applications of nanotechnology is significant. These environmental performance improvements will be ledled by current improvements in insulation, coatings, air and water purification, followed by forthcoming advances in solar and lighting technology and more distant potential in structural components, accessories and adhesives. In addition, new materials in this field, including: nano-glass, nano-coating board, aerogel, nano-silica, carbonic nano-tubes, etc. are introduced briefly (Table 1):

Table 1: The relationship between nano-materials and sustainable construction

Nano-material	Sustainable construction	Sustainable development
Using smaller and stronger silicon solar collectors improved by nanotechnology	Using clean energy (Biomass, Geothermal and renewable energies)	Resource efficiency
Using (NiFe204) nanoparticles in residential air conditioners	Using less energy	
Using fiber cement, light steel, stone sands and gas concrete improved by nano-silica, carbonic nano-tubes, etc	Using long lasting and lighter materials	
Using thermal insulation materials such as: aerogel, nano coating board, etc	Using kinds of insulation	Energy efficiency
Using accessory building improved by nanotechnology, like: LED, tiles, etc	Using long lasting and more efficient materials	
Using Self- cleaning, depolluting, Antimicrobial, UV protection, etc., materials	Using materials with natural structure and structure and materials	Pollution prevention

- The use of nanoparticles, carbon nanotubes and nano fibers to increase the strength and durability of cementations composites as well as for pollution reduction
- Production of cheap corrosion free steel
- Production of thermal insulation materials with a performance 10 times commercial current options
- Production of coats and thin films with self-cleansing ability and self-color change to minimize energy consumption
- Production of nano-materials with sensing ability and self-repairing ability

Here are some principle terms and definitions:

Green building: Environmental pollution, acidification, ozone depletion, fossil fuel depletion, global climate change and human health risks are all attributable in some measure to building construction and operation. Green building is a catch-allcatchall phrase encompassing efforts to reduce waste, toxicity and energy and resource consumption in buildings. Green building practitioners seek to implement sustainable development, development that meets the needs of the present without compromising the ability of future generations to meet their own needs, in the design, construction and operation of buildings. They strive to minimize the use of non-renewable resources like coal, petroleum, natural gas and minerals and minimize waste and pollutants. Energy conservation is critical to green building because it both conserves resources and reduces waste and pollutants (www.greenmillennium.com).

Sustainable construction/architecture: Sustainable construction is defined as the creation and responsible management of a healthy built environment based on resource efficient and ecological principles. Sustainably designed buildings aim to lessen their impact on our environment through energy and resource efficiency. It includes the following principles: Minimizing non-renewable resource consumption Reduction of the natural environment damage eliminating or minimizing the use of toxins (www.arch.hku.hk)

Sustainable building: "Sustainable building" can be defined as those buildings that have minimum adverse impacts on the built and natural environment in terms of the buildings themselves their immediate surroundings and the broader regional and global setting. "Sustainable building" may be defined as building practices which strive for integral quality (including economic, social and environmental performance) in a very broad way. Thus, the rational use of natural resources and appropriate management of the building stock will contribute to saving scarce resources, reducing energy consumption (energy conservation) and improving environmental quality. Five objectives can be identified for sustainable buildings:

- Resource efficiency
- Energy efficiency (including greenhouse gas emissions reduction)
- Pollution prevention (including Indoor air quality and noise abatement)
- Harmonization with environment (including environmental assessment)
- Integrated and systemic approaches (including environmental management system) (Elvin, 2007)

Nanotechnology: The speech of the physicist Richard Feynman entitled "There's plenty of room at the bottom" that took place in a Meeting of the American Physical Society in 1959 at Caltech is considered to be the beginning of the nanotechnology era. This last term was nonetheless presented in 1974 by Professor Norio Taguchi, meaning the processing of materials, atom by atom or molecule by molecule. A more accurate definition of nanotechnology was presented in 1981 by Drexler such as the production with dimensions and precision between 0, 1 and 100 nm. In medium terms nanotechnology involves the study at microscopic scale (1 nm = $1*10^{-9}$ m) (Pacheco-Torgal and Jalali, 2011).

Photocatalyst: Photo-catalyst produces surface oxidation to eliminate harmful substances such as organic compounds or nearby bacteria when it is exposed to the sun or fluorescent lamp. By applying this principle to water treatment, dissolving (NOx) in the air or room air purification, photo-catalyst can be used for various steps in purifying a contaminated environment. The most known application of nano-materials in the construction industry relates to the photo catalytic capacity of semiconductor materials. Several semiconductors materials such as TiO_2, ZnO, Fe_2O_3, WO_3 and CdSe, possess photo catalytic capacity; TiO_2 is the most used of all because of its low toxicity and stability (Elvin, 2007).

Clean energy: As mentioned above, green building and sustainable architecture is one of the most urgent environmental issues of our time. Meeting the goals of sustainable architecture, nanotechnologies are expected to reduce energy consumption in different ways. Some of these materials that are produced or improved by nanotechnology that are being or potentially used in architectural field are going to be introduced in the following paragraphs.

Silica aerogel: This material was developed by NASA in the 1950s and has been known as "solid/frozen smoke". It is composed by air (99.8%) and silica nanoparticles (0.2%) having the lowest thermal conductivity of any solid (between 0.004 and 0.03 W/mK). Recent investigation has tried to produce aerogel-based windows, allowing for future high insulation Windows (Scientifics, 2007). Here are some records held by some specially-formulated silica aerogels:

- Lowest density solid (0.0011 g cm^3)
- Lowest optical index of refraction (1.002)
- Lowest thermal conductivity (0.016 W $m^{\bullet 1}$ $k^{\bullet 1}$)
- Lowest speed of sound through a material (70 $mses^{\bullet 1}$)
- Lowest dielectric constant from 3-40 GHz (1.008)

RESULTS AND DISCUSSION

Nanotechnology (or nano-science or nano-material) is essentially, the study of the design, production and application of materials on the nano-scale which are materials that are on a scale of a few millionths of a millimeter (typically 1-100 nm in size). One nanometer (nm) is 10^{-9} m and about the same length as ten atoms in a line (a typical atom has a diameter of about 0.1 nm). In contrast, a human hair is about 80,000 nm thick. Rather than being a new subject in its own right, the nano-discipline is simply an extension of existing subjects (Physics, Chemistry, Biology, Engineering and Materials-Science) but concentrates on the behavior and use of substances on a tiny scale.

Table 2: A comparison of some properties of a few well-known materials

Material	Macro-scale property	Nano-scale property
Aluminum	Stable	Combustible
Copper	Opaque	Opaque
Gold	Solid at room temperature	Liquid at room temperature
Platinum	Inert	Reactive
Silicon	Insulator	Conductor

Nanoparticles are governed by van der Waals forces, atomic bonding (ionic, covalent and hydrogen bonding), electronic charge and quantum effects which means that they often display very different properties compared with the same materials on the macro scale. Some interesting examples of such contrast are given in Table 2 (Aston, 2011).

Nanotechnology can be used in the efficient production of green energy and in reducing our overall energy consumption by increasing efficiency (Wu *et al*., 2011).

Using nanothechnology for solar collectors: The best solar cells currently available are only 30% efficient and commercially available systems are even less efficient at only about 20%. Specially designed nanostructures have the potential to increase the efficiency of solar collectors dramatically and it may be possible to use coatings made from nano-materials to turn every rooftop into a solar energy collector (Wu *et al*., 2011).

Silicon solar collectors are improved by nanotechnology (thin-film solar nanotechnologies). The sun offers a free, renewable source of energy capable of meeting all our energy needs, if an efficient, economical means of converting solar to electrical energy can be found. Today silicon-based solar cell technologies is being used. By using nanotechnology the researchers developed a silicon nano-crystalline ink that could make flexible solar panels as much as ten times cheaper and stronger than current solutions while providing color options for improved aesthetics when integrated into building designs.

It includes curtain wall systems in which panels can be mounted vertically on an exterior wall. These transparent and semitransparent panels can also, be mounted on a roof, acting as a power-generating skylight. Organic thin-film or plastic solar cells that improved by nanotechnology use low-cost materials primarily based on nanoparticles and polymers. The other dramatic advantage of organic thin films is their flexibility which will enable their integration into far more building applications than conventional flat glass panels. This will open new architectural possibilities and overcome the aesthetic concerns some architects hold against rigid flat panels which can hardly be integrated into building facades. Using renewable energies in buildings, like solar energy could be a great help in decreasing of usage of non-renewable energy sources and this could cover one of the principle goals of sustainable buildings (Elvin, 2007).

A hot topic in terms of energy production at the moment is the hydrogen fuel cell. These could be used to generate electrical energy for use in the home. One big drawback with these fuel cells is the storage of the hydrogen prior to its use and this is where nanotechnology could offer a practical solution (Wu *et al*., 2011).

Using nanotchnology for inhancement the efficiency of fuel cells: Researchers are also, investigating the potential for nano-materials to increase the efficiency and lower the costs of fuel cells that use hydrogen and oxygen to produce electricity. Building fuel cells can be costly, especially, the platinum electrode material used inside the devices. By using nanoparticles of platinum, reactivity is increased. The reactivity of nanoparticles of platinum is greater than the reactivity of larger particles of platinum, more reactive atoms are exposed as the size of particles decreases and their relative surface area increases. By increasing the reactivity of platinum, researchers hope that less platinum could be used. This could reduce the costs of production. Researchers are also investigating whether or not it is possible to use Nano scale non-precious metal catalysts in place of the platinum.

Using nanotechnology in producing lighter and long lastin materials: Material strength is critical in a building, defining its structure, longevity and resistance to gravity, wind, earthquake and other loads that act to tear it down. A load-bearing structural material's strength/weight ratio is particularly important because stronger, lighter materials can carry greater loads. Nanotechnology promises significant improvements in structural materials. Concrete as the world's most widely used manufactured material and also, steel as the most important metals in construction industry have been studied and many researches are being made in the field of nanotechnology application in concrete structure. Nano-particles application in construction industry, the most important of which is Carbonic Nano-Tubes (CNT and TiO_2) generally, increase the mechanical properties of samples in main structures. That can lead to narrower and lighter section of materials with more resistance and durability that can form new structural systems (Elvin, 2007) (Fig. 1).

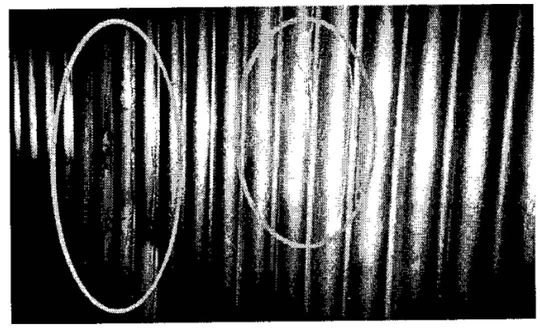

Fig. 1: Nano-copper coating shows no damage from erosion or corrosion (Elvin, 2007)

Using nanotechnology for better material construction cement and concrete: Concrete durability has attracted a lot of attention from many researchers because it has critical influence on the service life of concrete structure. The durability properties of concrete include many aspects such as permeability, impact resistance, abrasion resistance and frost resistance. Researchers are conducted several studies in using nanoparticles to increase the strength and durability of concrete and cementations composites. For instance, Porro *et al.* (2005) reported that the use of nano silica particles increases the compression strength of cement pastes (Porro *et al*., 2005). Sobolev *et al.* (2008) mentioned that nano silica addition led to an increase of strength by 15-20%. Also, Zheng (2010) reported that, permeability of concrete containing nano-particles (TiO_2 and SiO_2) refines the pore structure of concrete and enhances the resistance to chloride penetration of concrete.

Nano-materials such as carbon nanotubes offer tremendous strength for their size. The use of these in composites instead of carbon fibers could allow much larger, lighter structures to be built. This could include less bulky suspension bridges that could span larger gaps (Wu *et al*., 2011). Using lighter, long-lasting and more resistant concrete in building construction would be more efficient in constructing a more sustainable buildings.

Using nanotechnology for insulation: Heating and cooling use huge amount of energy Insulators trap air extremely high surface-to-volume ratios allow insulation made from nano-scale materials to trap air at the molecular level. This allows very thin applications to provide better insulation properties than much thicker layers of standard insulation such as fiberglass.

Silica aerogels: SiO_2 aerogels which are usually transparent could be used as highly efficient thermal insulation building material. In addition, Silica aerogels are sound and electricity insulators. Aerogel panels are available with up to 75% translucency. Aerogel glass has good thermal stability, thermal shock resistance and heat retention and could replace the common curtain wall glass, greatly reducing building weight and play a role in fireproofing the building. As an insulation brick, SiO_2 aerogel insulation composite material with Nano pore structure has lighter mass and smaller size compared with traditional insulation materials while achieving equivalent insulation effect. This great insulation leads to energy efficiency. Architectural applications of aerogel include windows, skylights and translucent wall panels.

Thin-film (coatings): Thermal bridging can also be reduced by using coatings because the coatings can be applied to surface areas where heat loss/gain is an issue due to conduction through materials. Thermal bridging occurs in building envelopes when relatively high thermal conductivity materials such as steel and concrete create pathways for heat loss. Insulation in coating form is easily applied over entire wall and ceiling surfaces, so, thermal bridging is either eliminated or greatly reduced.

Insulating nano coatings can also be applied as thin films to glass and fabrics. Massa Shade Curtains, for example are fiber sheets coated with a Nano scale stainless steel film. Thanks to stainless steel's ability to absorb infrared rays these curtains are able to block out sunlight, lower room temperatures in summer by 2-3°C more than conventional products and reduce electrical expenses for air conditioning, according to manufacturer claims. Thin film insulations are now being incorporated in some window curtains (Massa shade curtains) and in glass. The 3M has developed window film insulation they claim blocks out 99% of UV rays and 97% of IR light.

Using nanothechnology in residential air conditioner: Wang *et al*. (2010) presented a method that uses nanoparticles to enhance the energy efficiency of retrofitted residential air conditioners employing hydro-fluorocarbons as alternative refrigerants. The reliability and performance of residential air conditioner with nanoparticles in the working fluid have been investigated experimentally. New mineral based nano-refrigeration oil, formed by blending some nanoparticles ($NiFe_2O_4$) into naphthene based oil B_{32} was employed in the residential air conditioner using R_{410} a as refrigerant. They reported that the cooling/heating energy efficiency ratio of the air conditioner increased about 6% by replacing the Polyol-Easter oil VG $_{32}$ lubricant with MNRO (Wang *et al*., 2010). The result would be a great help in decreasing of energy consumption.

Using nanothechnology in self cleaning materials: Although, self-cleaning properties of catalysts materials are known, since, the 1960s, only recently they start to be used in a wide manner. Nanotechnology based super hydrophobic materials can repel water and prevent icing. This could protect structures and building surfaces from harsh weather and icing (General Electric 2009). The first application of self-cleaning concrete took place in the church "Dives in Misericord" in Rome (Fig. 2 and 3). This building was designed by the Arq-Richard Meyer and

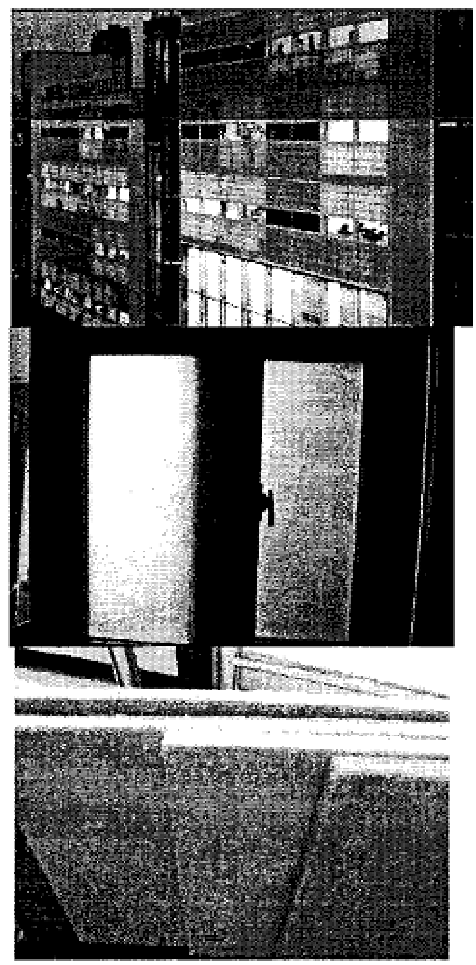

Fig. 2: The flower, the Mona Lisa of aerogel pictures, dramatically demonstrates the super insulating properties of silica aerogel by insulating a delicate, moist flower from the raging heat of a Bunsen burner (image credit Lawrence Berkeley National Laboratory) (www.aerogel.org)

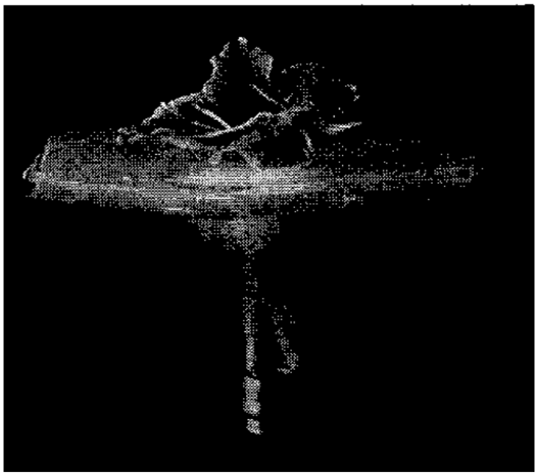

Fig. 3: a) Nano gel panels provide translucency and insulation; b) These kinds of Aerogel are super-low temperature thermal insulation material and c) These kinds of Aerogel synthesized by top quality FRP material and translucent nano-silica aerogels particles, film or plate materials. It possesses properties of light, thermal insulation, environment friendly, waterproof and fireproofs (Elvin, 2007)

officially opens in 2003. It is composed by 346 prestressed concrete blocks made with white cement and TiO_2 (binder 380 kg/m^3 and W/B = 0.38). Visual observations carried out 6 years after construction revealed only slightly differences between the white color of the outside concrete surfaces and the inside blocks.

Also, windows coated with Nano materials such as Nano titanium dioxide can repel dirt and self-clean, reducing cleaning costs. Nano materials such as titanium dioxide are also being promoted for their antimicrobial properties. Other Nano paints can protect buildings structures from dirt, cutting down on maintenance and cleaning.

Being a semiconductor with photo catalytic capacity when TiO_2 is submitted to UV rays (320-400 nm) in the presence of water molecules, it leads to the formation of hydroxyl radicals (OH) and superoxide ions (O_2-). Those highly oxidative compounds react with dirt and inorganic substances promoting their disintegration (Fig. 4 and 5).

Photo catalysis of TiO_2 is also, responsible for the reduction of the contact angle between water droplets and a given surface, leading to super hydrophobic or super-hydrophilic surfaces increasing their self-cleansing capacity. Water repellent surfaces are one of the features of natural systems as it happens in the leaves of the lotus plant (Fig. 6) whose microstructure allows self-cleansing ability.

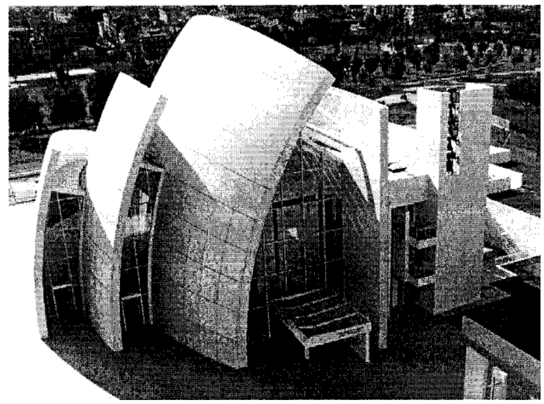

Fig. 4: Church "Dives in misericordia", Rome, Italy (Pacheco-Torgal and Jalali, 2011)

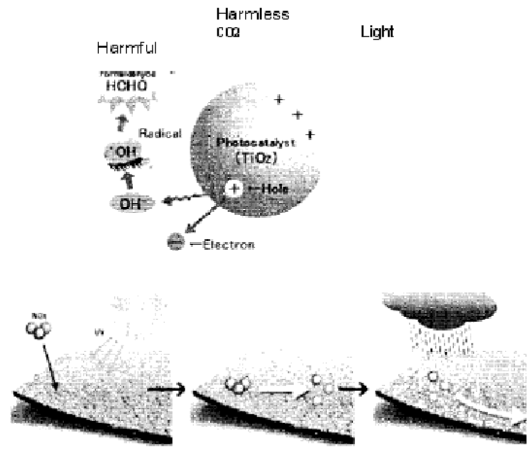

Fig. 5: Scheme of photo catalytic capacity of nano particles (Elvin, 2007)

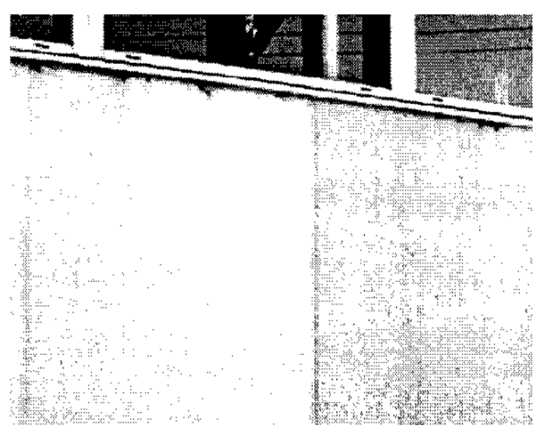

Fig. 6: Nano coatings containing titanium dioxide (left) can be self-cleaning as compared to untreated surfaces (right) (Elvin, 2007)

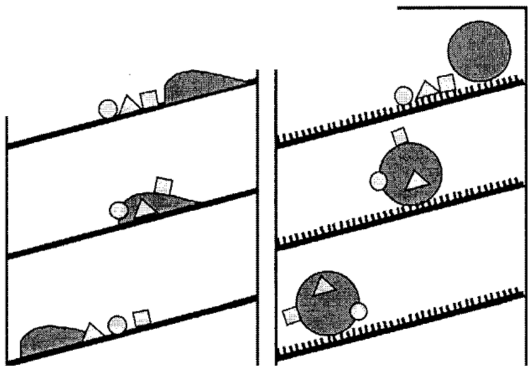

Fig. 7: Lotus effect (Pacheco-Torgal and Jalali, 2011)

The applications related photo catalysis cover five groups: self-cleaning, air-cleaning, anti-bacterial and anti-fogging and water treatment. So, thiscapacity may lead to a greatly less energy, waste, toxicity and carbon emissions materials, consumption that ends up in resource efficiency, energy efficiency and pollution prevention; the aims of sustainable building (Pacheco-Torgal and Jalali, 2011) (Fig. 7).

Using nanotechnology for accessories of building construction

Nano-SiO_2 in tile manufacturing: Various sludge ash tiles, introduced nano SiO_2 particles as strengthening additives in the clay-ISSA materials have been studied by Chen Chen has studied various sludge ash tiles, introduced nano SiO_2 particles as strengthening additives in the clay-ISSA materials at al. Several analysis including, Scanning Electron Microscopy (SEM) and characterization of chemical compositions with X-ray diffraction has been carried out. Consequently, results indicate that water absorption of porcelain and potter's clay-based tiles was reduced when samples were fired at the higher kiln temperature, dropping to <12% in porcelain tiles at a kiln temperature of 1100°C. Kiln temperature appeared to have less influence on the tiles made from potter's clay. With the addition of nano-SiO_2, additive, the bending strengths of both types of tiles were increased with the strengthening effect more pronounced in potter's clay tiles when compared to porcelain clay tiles (Chen and Lin, 2009).

Light-Emitting Diodes (LEDs): Light-Emitting Diodes (LEDs) based on nano-materials last much longer and are far more efficient than conventional light bulbs which only convert 5% of the electrical energy to light. Offering a tremendous energy saving they produce a very bright light and require far less maintenance (Aston, 2011).

Supplying energy to power laptop computers or mobile phones: Konarka Company is now offering nano solar panels (polymer fullerene on flexible plastic) for use on travel luggage, to power laptop computers or mobile phones. Thin film flexible panels installed on roofs or other building structures are very low in weight are not subject to wind lifting and can be walked on (with care).

Water purification: The photo catalytic capacity of nano-TO, Product, coupled with UV lights can oxidize organic pollutants into nontoxic materials such as CO_2 and water and can disinfect certain bacteria. This technology is very effective at removing further hazardous organic compounds (TOCs) and at killing a variety of bacteria and some viruses in the secondary wastewater treatment. Pilot projects demonstrated that photo catalytic detoxification systems could effectively kill fecal coli form bacteria in secondary wastewater treatment (www.greenearthnanoscience.com).

Using nanotechnology in air pollution reduction: Several studies have been conducted on using nanoparticles in air pollution reduction. All of them mentioned a high photo catalytic capacity for indoor air pollution reduction by using TiO_2 nanoparticles. Maier *et al.* reported a fast pollution reduction in indoor air by the use of gypsum plasters containing 10% TiO_2 as well. Energy conservation, reduced waste and toxicity are the result of applying this capacity of nano-material (Michael, 2006)

CONCLUSION

Nanotechnology has the potential to completely revolutionize the construction and building materials in the new world. Also, nanotechnology has the potential to transform the way we harness, use and store energy. Research has demonstrated its prospective value in decreasing energy consumption. Applying all the aforementioned capacities of nanotechnology in building constructions surly leads to resource efficiency, energy efficiency and pollution prevention which are the most demanding need today's world. However, still more research efforts are needed in order to find other applications of nanotechnology in the field of building and construction. Not to mention that a precautionary approach to nanotechnology is essential for all classes of nano products.

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