Zurich, June 15-17 2016
Sustainable Built Environment (SBE) Regional Conference

Expanding Boundaries:
Systems Thinking for the Built Environment

NANOTECHNOLOGY AND ITS IMPACT ON SUSTAINABLE ARCHITECTURE

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Abstract

Diminishing natural resources, increasing levels of carbon emissions from the transformation of raw materials into products, and the growing demand for consumable materials are factors that raise the question “how can a balance between the need for development and the protection of natural resources be created”? As a large share of the energy consumption is related to buildings, analysing the role of advanced materials in architecture and its contribution to sustainability is essential. This paper discusses nanotechnology’s promise of lower energy and raw material consumption, reduced waste, greater safety and a healthier environment in the context of sustainable architecture.

Nanotechnology is an expanding and innovating area of research and in architecture, it will greatly impact construction materials since the fundamental properties of materials like surface-to-mass ratio, elasticity, conductivity and strength can be controlled at nano-scale. Products like high-insulating panels, self-cleaning and heat-absorbing windows will influence the building industry as such materials have the potential to improve the energy efficiency, durability, economy and sustainability of the built environment.

Nano insulating coatings are more efficient than traditional insulators and have a lesser environmental impact. As they can be used for the renovation of existing buildings, they increase the potential of reuse without the aesthetic and functional compromises often required by thick layers of insulation.

This paper investigates the application areas of nanomaterials in the construction industry, illustrated with case studies. Investigating the opportunities and challenges provides the basis for the successful implementation and development of these materials.

Keywords:
Sustainability; Nanotechnology; Nanomaterials; Energy efficiency

1 INTRODUCTION

The building and construction industry are an important consumer of energy resources and materials. The current demand for more sustainable practices has imposed a tremendous pressure on this field to develop and utilize new environmentally friendly materials [1] [2].

The definition given by the German Federal Ministry of Education and Research summarises nanotechnology as "Nanotechnology refers to the creation, investigation and application of structures, molecular materials, internal interfaces or surfaces with at least one critical dimension or with manufacturing tolerances of less than 100 nanometres" [4].

Nanotechnology provides the possibility to create new materials with unique and enhanced properties that can respond to specific functions or implementing qualities and performances in existing materials [5][6].

Nanotechnologies contribution to construction industry:

- Reduction in the consumption of raw materials, energy and CO_2 emissions
- Enhancing the properties of existing products
- Reduction in weight and/or volume
- Reduction in the number of production stages [4]

Nanomaterials are perceived by some as potential health hazards but by most as a way of reducing them. Environmental concerns and sustainability issues range from embodied energy used for production all the way through to recycling. Moreover, economic concerns, including both initial and long-term costs are present. On the other hand, nanomaterials could greatly extend the durability and lifespan of materials, thus reducing maintenance and replacement costs and improving energy efficiency [3] [4] [7].

2 NANOSTRUCTURED MATERIALS

Nanomaterials are materials with at least one dimension below 100 nm (1 nm = 1× 10^{-9} m) (fig. 1). A nanostructured material can be defined as a traditional material (steel, concrete, glass...) blended in mass or surface with nanomaterials or correcting and improving the chemical and physical structure of materials at nanoscale (production process does not require the use of nanomaterials) [5].

In both cases, the original characteristics of the materials are modified and optimized in order to obtain specific performances, usually not comparable to those shown by the original materials. Therefore, enabling to produce a high variety of materials with different functions [5][6].

3 NANOMATERIALS IN CONSTRUCTION

The potential of nanotechnology in construction as pointed out in RILEM TC 197-NCM report:

- Increasing the strength and durability of concrete
- Production of cheap corrosion-free steel
- Production of very effective thermal insulators
- Production of multifunctional coatings and thin films [8]

Table 1 shows nanomaterials being utilized in the construction industry.

3.1 Concrete

Concrete is the most widely used manufactured construction material. Energy use, carbon emissions and waste are all major environmental concerns connected with concrete production and use. Therefore, finding ways to overcome durability issues, is a crucial step in concrete sustainability [3] [7] [8].

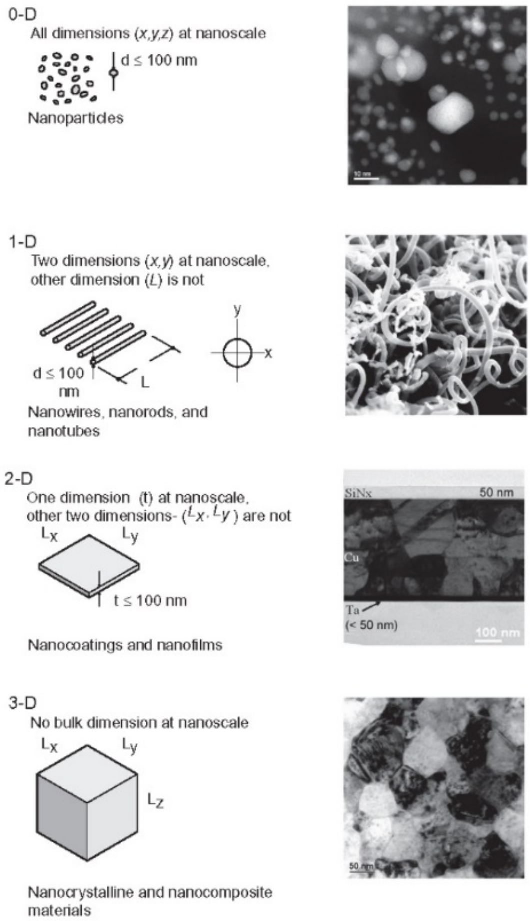

Fig. 1: Classification of nanomaterials [7].

Manufactured nanomaterials	Architectural/Construction materials	Expected benefits
Carbon nanotubes	Concrete Ceramics	Mechanical durability, Crack prevention Enhanced mechanical and thermal properties
SiO_2 nanoparticles	Concrete Ceramics Window	Reinforcement in mechanical strength Light transmission, Fire resistant Anti-reflection, Flame retardant
TiO_2 nanoparticles	Cement Window Coating/Paint	Self-cleaning, Rapid hydration Super hydrophilicity, Anti-fogging Self-cleaning, Antimicrobial properties
Fe_2O_3 nanoparticles	Concrete	Abrasion-resistant, Increased strength
Cu nanoparticles	Steel	Weldability, Corrosion resistance
Ag nanoparticles	Coating/Paint	Antimicrobial properties

Table 1: Example of nanomaterials in construction [1].

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Nanosilica improves the hydration process of cement due to their large reactive surface area, increase the viscosity of the fluid phase of concrete, improve bonds between pastes and aggregates, fill the voids between cement grains and finally reduce calcium leaching in water. All factors that lead to enhancement in strength, flexibility, durability and workability of concrete [2] [3] [7].

Addition of Titanium dioxide (TiO_2) nanoparticles increases the rate as well as the peak of the hydration process. Self-cleaning concrete is produced by utilizing the photocatalytic and hydrophilic (water-attracting) properties of TiO_2 (fig. 2) [3] [7] [8] [9].

Fig. 2: Church Dives in Misericordia, Rome, Italy (Product: Self-cleaning concrete) [4].

3.2 Steel

Steel is a major component in reinforced concrete construction as well as a primary construction material. Nanotechnology improves the corrosion resistance of steel. MMFX Steel (brand) is manufactured using nanoscale processes. The steel produced has a unique laminated structure (plywood effect) that makes it very strong and corrosion resistant [3].

Nanocoatings can help protect stainless steel surfaces against corrosion and metal oxide staining. The addition of magnesium and calcium nanoparticles reduces the size of heat affected zone (HAZ); as a result, weld toughness is increased and less material is used to keep stresses within allowable limits [3].

3.3 Wood

Wood is a renewable building material that can be recycled and regenerated. Low conductivity of wooden structures reduces the heating and cooling loads. Additionally, wood has the ability to reduce carbon emissions by converting CO_2 into oxygen. However, wood must be protected from water, pests, mold and UV radiation [3].

Nanotechnology has the potential to improve the performance and functionality of wood-based products; for example, nanosensors can identify mould, decay, and termites, nanocoatings can make self-cleaning wood surfaces [3].

Hydrophobic nanocoatings protect the wood against weathering and slow down the discoloration process. Nanoscale UV absorbers added to coatings reduce the degrading effects of UV radiation. Nanotechnology is expected to produce the next generation of bio-products that have higher performances and longer lifespans by giving scientists control over bonding at the nanoscale [3][4].

3.4 Thermal Insulation

Thermal insulation has a great impact on saving energy and reducing emissions by decreasing the amount of energy required to sustain a comfortable environment in buildings. Nanotechnology promises to provide more efficient building insulation (fig. 3) [3] [4].

3.4.1 Aerogel

Aerogel or ''frozen or solid smoke" is a well-known nanoscale material with high insulating properties (fig. 4) and less thickness compared to traditional materials. Aerogel is a light foam like structure that contains more than 95% air and less than 5% silica nanoparticles and has the lowest thermal conductivity and weight of any solid [3][4][5][7].

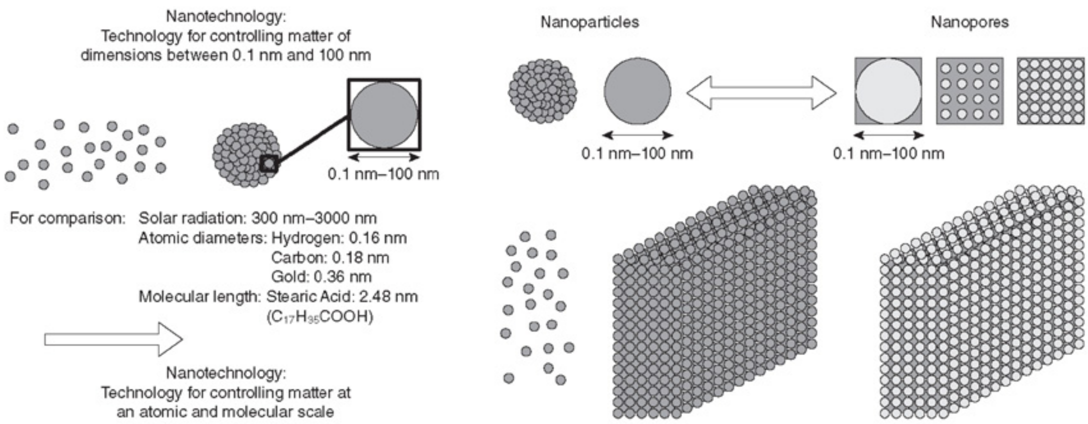

Fig. 3: Nanotechnology application in thermal insulation [10].

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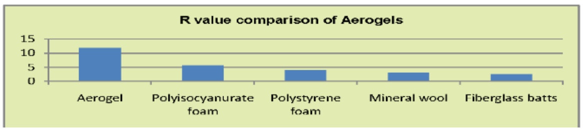

Fig. 4: R value comparison of aerogel [2].

Aerogel particles are used as high performance insulation additives in composite insulation boards and plasters, as well as stand-alone blown-in or poured-in insulation for cavity fill applications. Aerogel-filled panels are translucent, exhibit good light transmission and spread a glare-free soft light, obviating the need for shading systems and artificial lighting during the day as seen in figure 5. Aerogel, also acts as a sound insulator which makes aerogel panels suitable not only for facades but also for interiors, for example around conference rooms [3] [4] [7] [11].

3.4.2. Insulating coatings

Nanocoatings improve the insulating values of conventional materials due to the fact that they can be applied directly to external surfaces in the form of spray or paint. These coatings provide an insulation function by trapping air at the molecular level [3] [7].

3.4.3. Vacuum insulation panels (VIPs)

Vacuum insulation panels (VIPs) provide good thermal insulation whilst consuming less space. New thinner VIPs use aerogel or fumed silica within a vacuum and have up to 10 times smaller thermal conductivity than conventional insulation panels. The thin construction and high insulating performance of VIPs make them suitable for renovation [4] [7] [11].

Fig. 5: Sports hall, Carquefou, France (Product: Multi-wall panels with nanogel filling) [4].

VIPs are recyclable after their useful life. A problematic issue concerning VIPs is the degradation of thermal resistance (aging) initiated by penetration of gases (especially water vapor) into the seal. Many factors contribute to this problem, including relative humidity, the type of building envelope, the amount of vacuum and the correct installation of the product [4] [7].

3.4.4. Latent heat storage (PCM)

Latent heat storage, also known as phase change material (PCM), can be used for temperature regulation. The thermal retention of PCM can be used for levelling out temperature fluctuations and reducing peak temperatures. In addition to conserving energy by reducing the energy demand for heating and cooling, PCMs are also recyclable and biologically degradable [4].

PCMs are commonly made from paraffin and salt hydrates. Small paraffin balls with a diameter of between 2 and 20 nm are enclosed in a sealed plastic layer and integrated into typical building materials (around 3 million in 1 cm²) [4].

PCM is able to retain heat and use it to liquefy the paraffin allowing the indoor environment to remain cooler for longer. The same principle also functions in the other direction; during a phase change PCMs are able to store heat as well as cold. PCMs can be integrated into conventional building materials such as plasters, gypsum board and concrete [2] [4].

3.5 Nanocoatings

Nanocoatings have the greatest market potential for any nano-based product. Nanomaterials are quite expensive, but nanocoatings use small quantities of nanoparticles and exhibit many of the properties with minimal production cost. Additionally, the coatings are quite thin and cover large areas [7].

Nanocoatings are produced by nanoparticles bonded to conventional materials or directly integrated into the base material. The aim is to improve the characteristics and add new functional properties. Surfaces treated with nanocoatings exhibit multifunctional properties such as self-cleaning, antimicrobial, antifogging, UV protection, scratch-resistant, corrosion-resistant, air-purification, solar protection, etc. [3] [4] [7].

Fig. 6: Sonnenschiff Centre, Freiburg, Germany (Product: Vacuum insulation panel and PCM) [4].

3.5.1. Self-cleaning nanocoatings

Self-cleaning can be achieved in several ways based on hydrophobic (water-repellent), hydrophilic (water-attracting) or photocatalytic properties; these approaches can be combined in a variety of ways [4].

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Lotus effect

Lotus leaves (fig. 7) exhibit a microscopically rough water-repellent (hydrophobic) surface. Due to this structure water forms tiny beads and rolls off taking dirt with it [3] [4] [7] [8].

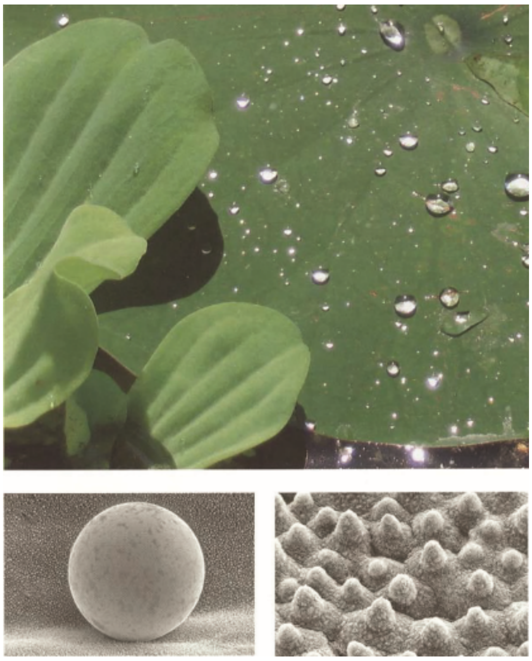

Fig. 7: The surface is covered with nanostructured 5-10 micrometer high knobbles with waxy tips [4].

Artificial lotus effect is produced by nanosurfaces with roughness characteristics that serve the hydrophobic function. Lotus effect is used in Ara Pacis Museum in Rome to retain the whiteness of travertine as shown in figure 8. Hydrophobic coatings can be used in wood, metal, masonry, concrete, leather and textiles. Hydrophilic self-cleaning involves extremely smooth surfaces with low surface energy; forming a thin film of water that aids in cleaning [4][7].

Photocatalytic self-cleaning is a natural process that happens when certain nanomaterials are subjected to ultraviolet (UV) light. The absorbed UV ray initiates the catalytic reaction that oxidizes and decomposes foreign particles so that the loosened particles can be washed away. Since TiO_2 and ZnO are economical and respond well to UV light they are usually used. In self-cleaning glasses, thin TiO_2 coatings exhibit photocatalytic and hydrophilic properties as shown in figures 9 and 10 [3][7].

Another advantage of this process is reduction in the lighting cost due to the fact that daylight is less obscured by surface dirt. In addition to self-cleaning, the surfaces also exhibit antimicrobial, antifogging and air-purification properties. So any advances in this field not only saves energy and labour costs, but could also aid reduce hazardous substances and be beneficial for the environment [4][7].

Fig. 8: Ara Pacis Museum, self-cleaning nanocoating (Lotusan) is invisibly integrated into the surface [4] (http://quotesgram.com/richard-meier-quotes).

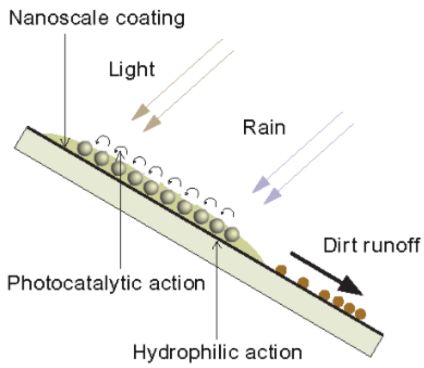

Fig. 9: Thin titanium dioxide coating [7].

3.5.2. Antimicrobial coatings

Bacteria and fungi production on surfaces is one of the main factors responsible for materials degradation and the health problems experienced by building occupants. Several approaches are available to create surfaces with antibacterial or antimicrobial properties using nanomaterials. One method is to use nanocoatings embedded with copper or silver nanoparticles. Another way is to integrate nanoparticles directly on the surface of the base material. Both procedures are already being used in floor coverings, panels and paints [4] [7] [8].

Photocatalytic action can also be used to achieve antibacterial or antimicrobial surfaces and since this process depends on UV light it can be applied to products exposed to natural or artificial UV light (fig. 11). One of the architectural applications of this method is in large tents and other types of membrane structures to prevent discoloration or staining caused by bacteria growth [7] [8].

3.5.3. Anti-fogging nanocoatings

The main aim of creating fog-free clear appearance is preventing the formation of water droplets and creating a thin transparent film. This can be achieved by nanocoatings with hydrophilic properties [4].

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Fig. 10: G-Flat, Tokyo, photocatalytic self-cleaning glass coating (Product: Sagan Coat) [4].

Fig. 11: Operating theatre, Berlin, Germany (Product: "Hydrotect" tiles, photocatalytic surface with antibacterial effect) [4].

3.5.4. Nanopaints

The addition of TiO_2 and SiO_2 nanoparticles adds scratch resistance, self-cleaning, glossiness, air-purifying, antimicrobial and fire resistance properties to paint [7] [12].

3.6 Solar Radiation

Glass plays a major role in the energy performance of buildings by controlling daylight and solar heat gain. Studies show nanotechnology has four approaches regarding solar radiation:

(i) Nanocoatings: spectrally sensitive coatings filter out unwanted infrared frequencies and reduce heat gain
(ii) Thermochromic technologies: provide thermal insulation (heat protection) whilst maintaining adequate lighting (light transmission adapts to temperature)
(iii) Photochromic technologies: reacting to changes in light intensity by increasing absorption
(iv) Electrochromic technologies: reacting to changes in applied voltage and becoming more opaque

Electrochromic glass is most effectively used in high-latitude zones where heat gain is not a concern [3] [7] [13] [14].

3.7 Challenges

Despite the many benefits nanomaterials exhibit as described in the previous paragraphs, it is important to mention also some important issues facing the widespread application of these products.

The biggest obstacle is the cost of nanomaterials and new processing technologies. Other important issues are the lack of availability of nanomaterials in large volumes, potential risks and health hazards, absence of awareness in the construction industry about novel products and uncertainty about long-term reliability of nanomaterials properties.

Further scientific research is required to define the hazardous impact of nanomaterials with the aim to reach an adequate risk assessment [15].

4 SUMMARY AND FUTURE PROSPECT

Nanomaterials contribute to sustainable construction by providing high insulating and multifunctional properties that improves energy efficiency in buildings. Furthermore, by reducing the amount of energy and raw materials required in the production process, it contributes to the conservation of resources, and reduction of carbon emissions. Nanotechnology increases the robustness of materials through enhanced resistance to corrosion, fatigue, wear, and abrasion.

Businesses that choose to employ nanotechnology will have to face challenges related to material cost, construction industry awareness and potential health risks.

This paper is a basis for an in-depth research on the role of nanomaterials in advanced glazing systems, examining their energy efficiency, lifecycle cost and environmental impact.

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