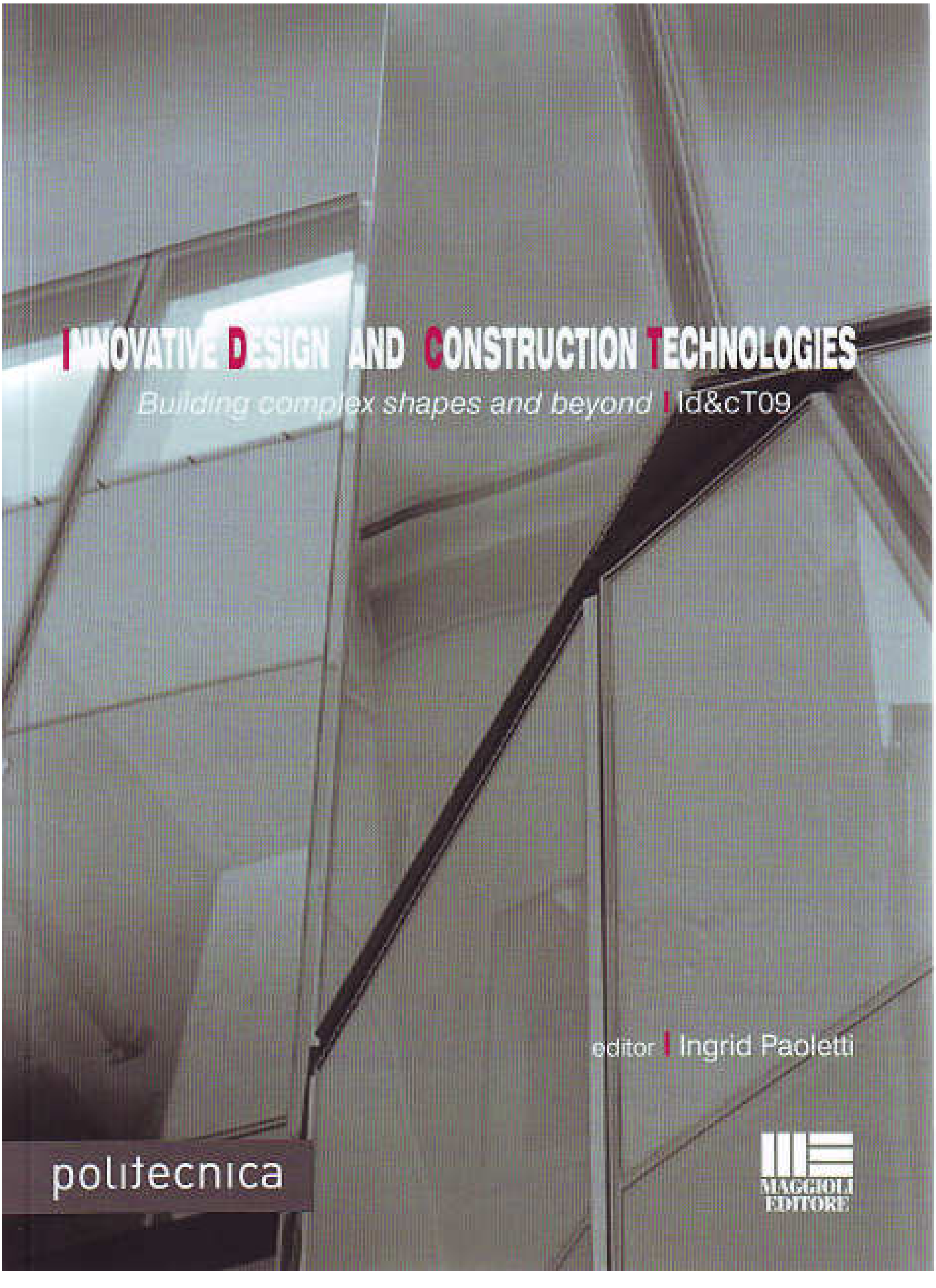

INNOVATIVE DESIGN AND CONSTRUCTION TECHNOLOGIES

Building complex shapes and beyond | Id&cT09

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Elena Magarotto, Maria Giovanna Romano

Ingrid Paoletti

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Building complex shapes & beyond

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INGRID PAOLETTI

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Nanotechnology and Construction Innovation Material for Architecture

Author:
C. Sposito (*cesare.sposito@unipa.it*)

Affiliation:
Università degli Studi di Palermo
Dipartimento di Progetto e Costruzione Edilizia

Nanotechnology is about the manipulation of matter at the nanoscale. A nanometre is a billionth of a metre (m=10-9 m). It is an 80.000th of a diameter of a hair. Nanotechnology opens up new possibilities in material design. Fundamental properties like strength, conductivity and elasticity can be designed in to create dramatically different materials. Nanotechnology is a growth market with a huge potential and numerous governments are funding nanotechnology initiatives. USA, Japan and Germany currently lead nanotechnological development.

China, South Korea and Russia are rapidly catching up and other nations such as India are mobilising. In 2006 Governments supported nanotechnology to the tune of 6.4 billion US dollars and the industry invested 5.3 billion US dollars worldwide in research and development. Few technologies have created so much hype and attracted so much funding globally as nanotechnology has over the last 5-10 years. There is a global race to take the lead in what many expect to be the next industrial revolution. The construction sector was among the first to be identified as a promising application area for nanotechnology back in the beginning of the 1990s.

The advent of nanostructured materials is relevant to the entire building, from the structure to the walls, from the lighting to energy production, and most important of all, it is considered decisive for the energy efficiency of buildings. The introduction of nanotechnology will help improve the performance of concrete and reduce energy consumption. The addition of nano-particles, for example, can contribute to improving the durability of concrete through the filling-in of pores, in the same way as the introduction of carbon nano-tubes can significantly improve the strength of concrete, since they have the potential to hinder effectively the propagation of cracks in the concrete. One of the basic problems linked to energy consumption in buildings is represented by winter heating and summer cooling. Heat-loss and gain are closely connected to the presence of glass surfaces and to the insulating capacity of the outer cladding. As regards glass surfaces, nanotechnology is reducing heat-loss and gain by using glass covered with layers of thin thermo-chromatic, photo-chromatic and electro-chromatic film. Another category of material that has received a great boost from the arrival of nanotechnology is that of coating with Vacuum Insulation Panels (VIP). Photo-catalytic cements are another category of very common nano-material.

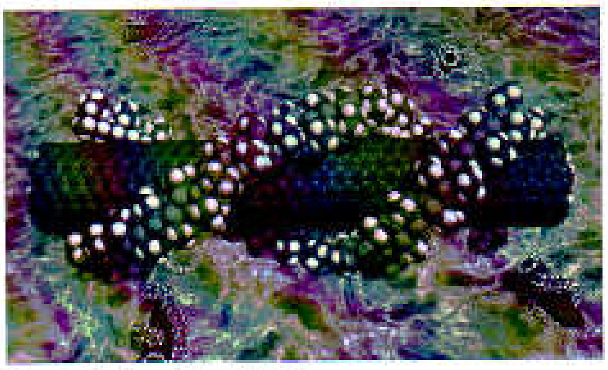

figure 1: Single-walled nanotubes

First of all we have concrete, one of the most widely produced materials in the world. Each year about one tonne of concrete is produced per human being (about six thousand million tonnes per year), releasing into the atmosphere 1.3 tonnes of CO_2 for every tonne of concrete produced. On the global scale, concrete production generates over 1.6 thousand million tonnes of carbon, which represent over 8% of total carbon dioxide emissions. There is also considerable waste, seeing as concrete accounts for two thirds of all waste from demolition, only 5% of which at present is re-cycled. The introduction of nanotechnology will help improve the performance of concrete and reduce energy consumption. The addition of nano-particles, for example, can contribute to improving the durability of concrete through the filling-in of pores, in the same way as the introduction of carbon nano-tubes, which have the potential to effectively prevent the spreading of cracks in concrete, can significantly improve its strength. The addition of a few carbon nano-tubes can improve resistance to compression and flexion (when compared to non-reinforced concrete) although the cost represents a considerable obstacle in its utilisation. Only with the injection of considerable resources on the part of industry, governments and the academic world, might costs be reduced, eventually making it an economically viable prospect. Chinese researchers have created sensors for monitoring reinforced concrete and these can be incorporated into concrete to enable the structure to be monitored throughout its life-span.

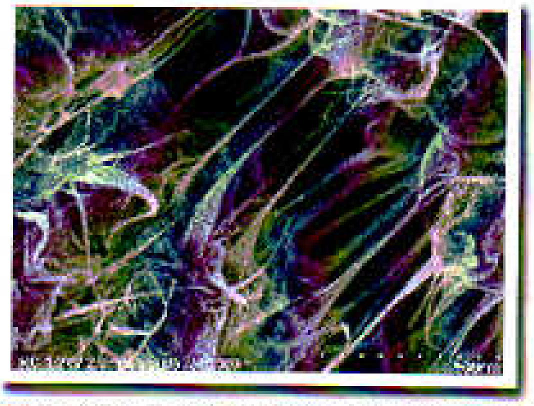

figure 2: Carbon nanotubes bridging cracks in a cement composite
(SEM – Scanning Electron Microscopy)

These nano-sensors can collect data regarding the performance of the material, from temperature to humidity; they can also monitor external conditions, such as seismic activity and the building's load, as well as the volume of traffic on the roads and the state of the roads. These are examples of smart materials, in which the micro-electro-mechanical devices are embedded directly in the concrete.
There is on-going experimentation with self-repairing concrete; when the latter starts to crack, a micro-capsule embedded in the material breaks and the material then releases into the damaged area a substance (agent), which then contacts a catalyzer, setting in motion polymerisation capable of sealing the crack. In tests carried out, the self-repairing compound retains over 75% of its original strength; it could increase the life-span of structural components two or three times over, when compared to present expectations. Nanotechnology can also contribute to improving resistance to corrosion in steel, although this has not had any noticeable effect on the market thus far; however there are various forms of steel available today, utilising nano-scale processes. One of these products is MMFX steel which proves to be five times as resistant to corrosion, and up to three times as strong, as conventional steel. MMFX steel products are used above all in North

America in structures such as bridges, motorways, car-parks, residential and commercial buildings.

Nanotechnology promises to improve the structural performance and serviceability of wood. "Employing nanotechnology with wood and wood-based materials could result in previously undreamed of growth opportunities for bio-based products. Nanotechnology will result in a unique next generation of bio-products that have hyper-performance and superior serviceability. These products will have strength properties now only seen with carbon-based composite materials. These new hyper-performance bioproducts will be capable of longer service lives in severe moisture environments. Enhancements to existing uses will include development of resin-free biocomposites or wood-plastic composites having enhanced strength and serviceability because of nano-enhanced and nanomanipulated fiber-to-fiber and fiber-to-plastic bonding. Nanotechnology represents a major opportunity for wood and wood-based materials to improve their performance and functionality, develop new generations of products, and open new market segments in the coming decades" (Winandy J E. 2005).

One of the basic problems in connection with energy consumption in buildings is represented by winter heating and summer cooling. Heat-loss and gain are closely linked to the presence of glass surfaces and to the insulating capacity of the outer cladding. As regards glass surfaces, nanotechnology reduces heat-loss and gain by using glass covered with layers of thin, thermo-chromatic, photo-chromatic and electro-chromatic film. Thermo-chromatic technology is capable of varying its own light absorption in function of its external surface temperature, becoming opaque above a certain critical temperature and then becoming transparent again with a fall in temperature. Photo-chromatic technology autonomously modifies its light transmission in function of the amount of incident light on its surface. Lastly, electro-chromatic coating gradually varies its own transmission in function of an electric signal; in order for the glass to become transparent again a new backward electrical impulse signal is required. All these applications are intended to reduce energy utilisation for heating and cooling buildings and might well contribute to reducing energy consumption in buildings.

Nanotechnology promises to make insulation more efficient. Manufacturers estimate that insulating materials derived from nanotechnology are roughly 30 percent more efficient than conventional materials. Aerogel is an ultra-low density solid, a gel in which the liquid component has been replaced with gas. Aerogel has a content of 5 percent solid and 95 percent air, and can support over 2,000 times its own weight. Aerogel panels are available with up to 75 percent translucency, and their high air content means that a 9cm (3.5") thick aerogel panel can offer an R-value of R-28, a value unheard of in a translucent panel. One of the greatest potential energy-saving characteristics of nanocoatings and thin films is their applicability to existing surfaces for improved insulation. Adding thermal insulation to existing European buildings could cut current building energy costs and carbon emissions by 42 percent or 350 million metric tons. They can be applied directly to the surfaces of existing buildings, whereas the post-construction addition of conventional insulating materials like cellulose fiber and polystyrene require partial demolition of wall. And unlike cellulose fiber, and polystyrene, nano-coatings can be made transparent. Their application to existing structures could lead to tremendous energy savings, and they do not appear to raise the environmental and health concerns attributed to fiberglass and polystyrene.

Another category of material that has received a great boost from the advent of nanotechnology is that of coating. Insulation coating represents a field of some importance for the application of nanotechnology; it heralds the creation of materials that are not only more slimline but have an insulating mechanism that is superior to conventional insulation. These elements characterise vacuum insulation panels (VIP), which are capable of guaranteeing the same thermic transmittance as traditional insulation with a thickness that is ten times inferior; they consist of a core of material of low thermic conductibility, which can stand up to high pressure, with a coating made from plastic, or extremely flexible and resistant metals. Apart from a need for great resistance to compression and low thermic conductibility, research has highlighted the need for the central core material to have a high degree of porosity, in order to facilitate the passage of air; therefore, importance must be given to the size of the pores, which must be less than 100 nanometres, in order to prevent phenomena of thermic gas conductibility.

It should be pointed out that buildings are responsible for a quarter of carbon emissions in the European Union, 70% of which stems from heating requirements. By saving on the heating of spaces through better insulation, the European Union could reduce carbon dioxide emissions by 100 million tonnes (of cubic metres) per year, and by so doing ensure that Europe alone might reach its goal of reducing carbon emissions by 25% by 2010. Nanotechnology promises to render insulation more efficient, less dependent on non-renewable resources and less toxic. Producers estimate that insulation materials deriving from nanotechnology will be about 30% more efficient than those from conventional materials. One of the most important characteristics of insulation nano-coating is the possibility of applying it to existing surfaces to improve insulation; it can be applied directly to the surfaces of existing buildings, whereas the integration of conventional insulation materials, such as cellulose, glass-fibre, polystyrene, post-construction, can be rather invasive. The application of nano-coating to existing structures may lead to huge savings in energy and it does not seem to pose a threat to the environment and health in the same way as glass-fibre and polystyrene.

Through nano-science and molecular biology we are learning more about natural systems, organisms and about the behaviour of materials, and nanotechnology and bio-technology provide us with the instruments not only to intervene in these systems, but also to create new ones. For example, by studying the molecular composition of lotus leaves scientists have managed to create a new generation of water-resistant materials. The so-called lotus-effect is the capacity, observed in lotus leaves, of a material to keep itself clean autonomously. Water never adheres to lotus leaves (in fact, the leaves are always dry), but runs off in numerous little drops that form as a result of the high surface tension on the leaf, and takes with it the dirt and small insects to be found on the leaf. This is possible because the lotus leaves have a layer of hydrophobic-wax crystals of nanometric dimensions. On this scale, rougher surfaces prove to be more hydrophobic than smooth ones, because the actual contact area between the drop of water and the underlying surface is 3% of the apparent one, and therefore the weight of the drop causes it to run off.

The roughness of the leaf's surface is also very useful for its self-cleaning effect, since the drops roll around, whereas on a smooth surface they would slide off, resulting in a less effective cleaning operation. Experts are applying the lotus-leaf's water-repellent properties in a wide range of products and materials, from self-cleaning windows to motor-car wax. Nature provides innumerable lessons that could be applied to future projects, processes and materials; for example, via a nanoscale examination of the structure of the gecko's feet scientists have created materials with extraordinary adhesive properties. All the lessons provided by nature will help us create more efficient systems, materials and devices than those available today. Photo-catalytic cements are another category of very common nano-material, photo-catalysis being a natural phenomenon, closely linked to chlorophyll synthesis. In fact, there is a substance called a photo-catalyser, which, through the action of natural or artificial light, sets in motion a vigorous oxidative process that results in the transformation of harmful organic and inorganic substances into absolutely harmless compost.

figure 3: Richard Meier's church in Rome

Photo-catalysis is therefore an accelerator of processes of oxidisation already existing in nature and it encourages a swifter decomposition of pollutants, preventing their accumulation. Self-cleaning surfaces have become widespread thanks to photo-catalytic coating containing nano-particles of titanium dioxide (TiO_2).

The principal effect of these coatings is a considerable reduction in the degree of adherence of dirt to surfaces. It is important to note that the term "self-cleaning" in this context is misleading and does not mean, as is often thought, that a surface should not be cleaner, but that the interval between the cycles of cleaning should be significantly extended, which is particularly important in the maintenance buildings.

figure 4: Rome, Ara Pacis Museum: self-cleaning paint.

This results in a reduction in the utilisation of detergents, with a consequent reduction in environmental pollution, less wear on materials and a saving on personnel costs. Therefore, generally speaking, self-cleaning photo-catalytic surfaces require less maintenance. A further advantage is that there is better light transmission through glass, since daylight is not obscured by dirt; consequently the costs of energy for lighting can be reduced. Photo-catalytic cements also have a purifying effect on the air; this effect has led to these cements being given the name smog-eaters, attracting considerable interest from the public. In fact, when applied to floors, road-surfaces and façades, they could provide a notable contribution to the fight against atmospheric pollution. These self-cleaning façade systems are to be found in several buildings, such as Richard Meier's church, Chiesa del Giubileo, in Rome, Hopkins Architects' Marunouchi Building in Tokyo, Herzog & de Meuron's Bond Street Apartment Building in New York.
Nor should we forget the role of anti-stain coating, as well as scratch-resistant, anti-misting, anti-frosting, anti-microbe and anti-corrosion coating . The other great factor in reducing carbon dioxide emission will probably be solar technology with organic thin-film, LED (Light Emitting Diode) and OLED (Organic Light Emitting Diode). Thin-film solar-cells can be produced on rolls of plastic, with

an important reduction in price when compared to traditional technology with sheets of glass. Moreover, flexible plastic solar-cells can be adapted to the façades of buildings much more easily than rigid sheets of glass, and the photo-voltaic panels can be integrated in buildings much better, thus making them more convenient as well as adaptable.

The energy saving from Light Emitting Diodes (LED) and Organic Light Emitting Diodes (OLED) will be substantial, given their clearly superior efficiency compared to conventional lighting. LED are a special type of diode, made from a thin layer of semi-conductor material. LED are used more and more frequently in the illuminating-engineering field in place of traditional light sources. As a result of noteworthy results achieved in the development of innovative techniques, they can today be utilised in domestic lighting in place of compact incandescent, halogen or fluorescent lamps.

OLED consent the production of colour displays with the capacity to emit their own light. Liquid crystal displays are quite different to OLED displays in that they do not require additional components in order to be lit up (liquid crystal displays are lit up by an external source of light), but produce their own light; this means that much slimmer displays can be produced, as well as flexible displays, and displays that can be rolled up, which need smaller amounts of energy in order to function. Although OLED technology has great advantages (low supply-tension, excellent contrast, colour brightness) it does still have certain limitations. Firstly, production costs are still high; secondly OLED screens do not last as long as liquid crystal screens and plasma screens. The organic material from which they are made does in fact tend to lose its capacity for emitting light after a few thousands hours of activity.

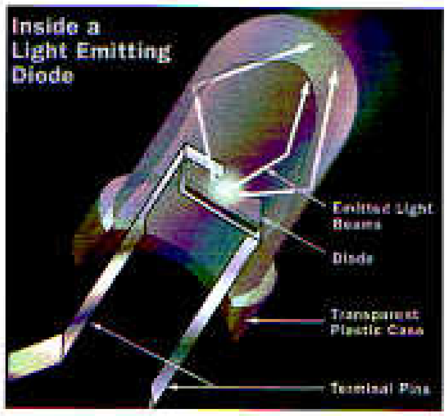

figure 5: Holey LEDs

The potential of nanotechnology in the construction industry, in particular in the development of the green building, is enormous. But, "the fragmented nature of the construction sector means that it is likely to have a low uptake, spread and development of such a new and advanced technology as nanotechnology unless careful action is taken" (Andersen, Molin 2007). The immediate adoption of nanotechnology into the building industry is being slowed by the mismatch between a short term cost-conscious industry and the high cost of most nano-products relative to conventional building materials. But with new materials and technologies come new concerns. Uncertainty surrounding the interaction of nanoscale particles with the environment and the human body has led to caution and concern about toxicology, worker health and safety, and regulation. A larger concern is the uncertainty surrounding public acceptance of nanotechnology. So far, the public has been largely positive about nanotechnology. However, a single instance of harm attributable to nanotechnology could be enough to quickly change public perception.

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