Enrico Ercolani
Department of Industrial Engineering
Via del Politecnico 1, 00133, Rome, Italy
enrico.ercolani@uniroma2.it
Contents

- What's Nano?
- NanoTechnology
- NanoArchitecture
- NanoMaterials
- Nanoscale
- Functions and applications
- Costs
- The Holistic Application of Nanosurfaces in Interiors
- Conclusions
- References
Nanotechnology

"IBM" written out of 35 xenon atoms onto a nickel surface
What’s NANO

One Nanometer (nm) Is One Billionth, Or \(10^{-9}\) Of A Meter

At The Nanoscale:

1- Quantum mechanical effects come into play at very small dimensions and lead to new physics and chemistry 

2- A defining feature at the nanoscale is the very large surface-to-volume ratio of these structures
Nanotechnology (NT)

Nanotechnology, shortened to "nanotech", is the study of the control of matter on an atomic and molecular scale. Generally nanotechnology deals with structures of the size 100 nanometers or smaller in at least one dimension, and involves developing materials or devices within that size.

Nanotechnology and nanoscience got started in the early 1980s with two major developments:
1- the birth of cluster science
2- the invention of the scanning tunneling microscope (STM)
This development led to the discovery of fullerenes in 1985 and carbon nanotubes a few years later.
NanoArchitecture

Nanotechnology Can Make A Concrete Contribution To The Following Areas:

• 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.

And as a direct result:

• Reduction in the consumption of raw materials and energy and reduced CO2 emissions that will affect good in environment.
• Conservation of resources.
• Greater economy.
• Comfort.

The shiny surface that nanocubes display under the microscope holds its promise. An ideal medium for storing hydrogen, its nanopore structure means that 2.5 grams have an interior surface area equivalent to the size of a soccer field. They could potentially be used as energy stores for fuel cells for powering mobile electronic equipment.
Dozens of building materials incorporate nanotechnology, from *self-cleaning windows* to *flexible solar panels* to *Wi-Fi blocking paint*, and many more are in development, including *self-healing concrete*, *materials to block ultraviolet and infrared radiation*, *smog-eating coatings* and *light-emitting walls and ceilings*. Example are:

1. Carbonfiber
2. Energycoating
3. Heat absorbing windows
4. Nanocoatings
5. INSULADD,® QuantumSpheres, and Nano aluminium powders.
7. Nanosensors.
Ultra Low Energy High Brightness Light (ULEHB)

Lighting will produce the same quality light as the best 100 watt light bulb (Sustainable Energy), but using only a fraction of the energy and last many times longer.

These new ultra low energy lighting devices will be fabricated using carbon nanotube organic composites which will significantly reduce energy running costs, thus reducing carbon dioxide emissions at power generating stations.

Potential uses such as variable mood lighting over a whole wall or ceiling opens up a range of exciting applications. ULEHB is also expected to have wide uses in signage, displays, street lighting, commercial lighting, public buildings and offices.
Nanosensors can monitor temperature, humidity, and airborne toxins, vibration, decay and other performance concerns in building components, from structural members to appliances.

The **Nano Vent-Skin** is a zero-emission material that takes a tri-partite approach (*sunlight, wind, CO2*) towards energy efficiency.

1. The outer skin of the structure absorbs sunlight through an organic photovoltaic skin and transfers it to the nano-fibers inside the nano-wires which then is sent to storage units at the end of each panel
2. Each turbine on the panel generates energy by chemical reactions on each end where it makes contact with the structure. **Bioengineered organisms** are responsible for this process on every turbine’s turn
3. The inner skin of each turbine, made of bioengineered organism, works as a filter absorbing CO2 from the environment as wind passes through it
Nanomaterials

The pattern of the building shell of the Watercube, the National Swimming Centre for the 2008 Olympic Games in Beijing, China, resembles oversized buckybails.
The use of nanotechnology in construction is strongly linked to **sustainability**. The first phase of the Kyoto Protocol ends in 2012 and **CO2 emissions** across the world must be **halved by 2050**. Energy efficient construction is therefore imperative, particularly as construction is a major producer of CO2 emissions.

Nanotechnology offers a new technological means with which to:

- Tackle climate change.
- Help reduce greenhouse gas emissions in the foreseeable future.

Nanotechnology offer architecture, interior architecture and related disciplines a means of achieving **greater energy efficiency and sustainable construction** through **innovation**.
Nanomaterials

In architecture there are two different design approaches for materials and surfaces:

1- Honesty of Materials – “what you see is what you get”
Authenticity is a priority; high-quality materials such as natural stone or solid woods.

2- Fakes/artificial surfaces that imitate natural materials
For the most part, fake materials are chosen for cost reasons. Artificial surfaces are brought to perfection; the grain can be tailored to appear exactly as desired; the color matches the sample precisely and does not change over the course of time.

Certain design approaches prefer the provocation of deliberate artificiality.
Nanomaterials

In future, a third option will be available:

3- Functional Nanosurfaces, emancipated from underlying materials

The properties of such ultra-thin surfaces can differ entirely from the material they enclose and can be transparent and completely invisible.

Also possible are nanocomposites with new properties:

- Nanoparticles or other Nanomaterials are integrated into conventional materials so that the characteristics of the original material are not only improved but can be accorded new functional properties or even be made multifunctional.

- Surface materials that are customized to have specific functional properties are set to become the norm, switching from catalogue materials to made-to-measure materials with definable combination of properties – a perfectly modular system.
Nanoscale Materials reduced to the nanoscale can show very different properties compared to what they exhibit on a macroscale:

- Opaque substances become transparent (*copper*)
- Inert materials attain catalytic properties (*platinum*)
- Stable materials turn combustible (*aluminum*)
- Solids turn into liquids at room temperature (*gold*)
- Insulators become conductors (*silicon*)
Nanoscale

A Nanomaterial is an object that has at least one dimension in nanometer scale

<table>
<thead>
<tr>
<th>Nanomaterial Dimension</th>
<th>Nanomaterial Type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>All three dimensions &lt; 100 nm</td>
<td>Nanoparticles, Quantum dots, nanoshells, nanorings, microcapsules</td>
<td><img src="image1" alt="Example" /></td>
</tr>
<tr>
<td>Two dimensions &lt; 100 nm</td>
<td>Nanotubes, fibres, nanowires</td>
<td><img src="image2" alt="Example" /></td>
</tr>
<tr>
<td>One dimension &lt; 100 nm</td>
<td>Thin films, layers and coatings</td>
<td><img src="image3" alt="Example" /></td>
</tr>
</tbody>
</table>
Nanoscale

One-dimension: thin films, layers and surfaces:
One-dimensional Nanomaterials have been developed and used for decades in fields such as electronic device manufacture, chemistry and engineering.

Two-dimension: tubes and wires
• *Carbon nanotubes (CNTs)* are extended tubes of rolled graphene sheets. They are mechanically very strong, flexible (about their axis), and can conduct electricity extremely well. CNTs are used in reinforced composites, sensors, nanoelectronics and display devices.
• *Nanowires* are ultrafine wires or linear arrays of dots, formed by self-assembly. Nanowires demonstrated remarkable optical, electronic and magnetic characteristics and have potential applications in high density data storage.
Three-dimension: nanoparticle and fullerens

- **Nanoparticles** are often defined as particles of less than 100nm in diameter. They exhibit new properties (such as chemical reactivity and optical behavior) that compared with larger particles of the same materials. Titanium dioxide and zinc oxide become transparent at the nanoscale, however are able to absorb and reflect UV light, and have found application in sunscreens. For most applications, nanoparticles will be fixed, for example attached to a surface or within in a composite

- **C60 (buckminsterfullerene)** are spherical molecules about 1nm in diameter, comprising 60 carbon atoms arranged as 20 hexagons and 12 pentagons: the configuration of a football.
## Coatings

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Properties:</strong></td>
<td>Hydrophobic - water trickles off.</td>
<td>Hydrophilic surfaces. Deposited dirt is broken down and lies loose on the surface.</td>
<td>hydrophobic, i.e. water-repellent and often also oleophobic. Surface repellence without using the Lotus-Effect.</td>
<td>Bacteria are targeted and destroyed.</td>
</tr>
<tr>
<td><strong>Specifications:</strong></td>
<td>Microscopically rough, not smooth. Well suited for surfaces that are regularly exposed to sufficient quantities of water.</td>
<td>A water film washes dirt away. UV light and water are required. Light transmissions for glazing and translucent membranes are improved.</td>
<td>Smooth surfaces with reduced surface attraction.</td>
<td>The use of disinfectants can be reduced. Silver nanoparticles reduce the amount of cleaning time necessary.</td>
</tr>
<tr>
<td><strong>Usage:</strong></td>
<td>For better optimal use and low maintenance façades (self-cleaning).</td>
<td>Reduces the extent of dirt adhesion on surfaces.</td>
<td>Are most commonly found in interiors, but can also be employed outdoors for better weather protection.</td>
<td>Supports hygiene methods especially in health care environments.</td>
</tr>
</tbody>
</table>

*Chemical Vapor Deposition, Dip, Meniscus, Spray, Plasma*
Self-cleaning: Lotus-Effect®

✓ Microscopically rough, not smooth
✓ Hydrophobic: water trickles off

The Lotus plant with its natural self-cleaning qualities lends its name to the "Lotus-Effect".

A microscopic view of a water droplet resting on a superhydrophobic and visibly knobbly surface.

The surface is covered with 5-10 micrometre high knobbles, here enlarged, which themselves are covered with a nanostructure and have waxy tips.
Self-cleaning: Lotus-Effect®

The visualisation illustrates how the basic principle of the Lotus-Effect works: the knobbly structure combined with reduced surface contact and low surface adhesion makes water form droplets that run off, washing away dirt deposits.
The diagrams show clearly the difference between conventional surfaces and the Lotus-Effect.
Self-cleaning: Lotus-Effect®

To summarise, *in all areas not subject to mechanical wear and tear*, the Lotus-Effect drastically reduces the cleaning requirement and surfaces that are regularly exposed to water remain clean. The advantages are self-evident: a cleaner appearance and considerably reduced maintenance demands.
Self-cleaning: Lotus-Effect®
Ara Pacis Museum, Rome, Italy

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Richard Meier &amp; Partners, New York, NY, USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>Comune di Roma, Rome, Italy</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Lotusan, self-cleaning paint (Lotus-Effect)</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>Sto</td>
</tr>
<tr>
<td>OPENED</td>
<td>2006</td>
</tr>
</tbody>
</table>

Here a self-cleaning coating has been invisibly integrated into the white surfaces to ensure the durability of their color. In the heavily polluted city, it would not otherwise have stood much chance of remaining white for long.
The intensity of the pure white surfaces is protected against dirt with the help of a Lotus-Effect facade coating. **Dirt simply washes off the rough surface together with the rain.** The self-cleaning function should persist for at least five years without needing to be renewed.
Self-cleaning: Lotus-Effect®
Private residence, Agstall, Germany

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Hild und K Architekten, Andreas Hild, Dionys Ottl, Munich, Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>Barbara Gross, Dr. Bertold Schwarz</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Lotusan, self-cleaning paint (Lotus-Effect)</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>At the time of construction Ispo, now Sto</td>
</tr>
<tr>
<td>COMPLETION</td>
<td>2000</td>
</tr>
<tr>
<td>AREA</td>
<td>approx. 300 m²</td>
</tr>
</tbody>
</table>

The facade creates a play of shadow and reflection and is coated with a traditional plaster slurry, into which a self-cleaning paint with Lotus-Effect has been mixed.
Self-cleaning: Lotus-Effect®
Strucksberg Housing, Hamburg, Germany

The differentiated colouring of the new facades is most apparent. Warm colours in a palette between yellow and red lend the entire estate a pleasant and unified appearance. As regards the self-cleaning function, Hamburg proves to be an ideal location as there is no lack of rain.
Self-cleaning: Photocatalysis

✓ Hydrophilic surfaces.
✓ Deposited dirt is broken down and lies loose on the surface.
✓ A water film washes dirt away.
✓ UV light and water are required.
✓ Reduces maintenance requirement.

Photocatalytic self-cleaning is probably the most widely used Nano-function in building construction, with Japan leading the field. Its primary effect is that it greatly reduces the extent of dirt adhesion on surfaces. The term "self-cleaning" in this context is misleading and does not mean, as commonly assumed, that a surface need not be cleaned at all. Fewer detergents are required, resulting in less environmental pollution and less wear and tear of materials. A further advantage is that light transmission for glazing and translucent membranes is improved as daylight is obscured less by surface dirt and grime. Energy costs for lighting can be reduced accordingly.
Self-cleaning: Photocatalysis

Before and after:
On **conventional tiles**, water forms droplets that dry leaving behind dirt deposits.

On the hydrophilic surfaces of **photocatalytic tiles**, water forms a film that runs off taking any loose dirt deposits with it.
For the function to work, UV light, oxygen and air humidity are required. The level of UV light present in normal daylight is sufficient to activate the photocatalytic reaction. Organic dirt on the surface of a material is decomposed with the help of a catalyst - usually titanium dioxide (TiO₂, and the particularly reactive derivative Anatase). The nanoscalar dimension of TiO₂ makes it a highly reactive catalyst, speeding up the decomposition process rapidly without being used up so that the effect is lasting, and appears no longer white but transparent. As the UV component of light with a wavelength of less than 390 nm is considered essential, photocatalytic self-cleaning surfaces are generally speaking more effective outdoors than indoors. The method is predestined, for example, for use on building facades.
Surfaces are *hydrophilic* (water-attracting), which means that water runs off from any inclined surface in a film rather than in droplets. In comparison to Lotus-Effect surfaces, this coating is transparent and can be applied to glass invisibly. In combination with photocatalytic coatings silicon-free must be used and film-forming detergents must also be abandoned because the oils they contain transfer to the glass and are incompatible with the surface coating, rendering it partially hydrophobic.
TiO2 and PVC coated white membranes in weathering tests. The difference is readily apparent: after five months the former is still white, the latter grey and unsightly.
Self-cleaning: Photocatalysis
Muhammad Ali Center MAC
Louisville, Kentucky, USA

To maintain a consistently good appearance and to keep down the cost of cleaning, the ceramic tiles are equipped with a photocatalytic self-cleaning surface coating. The coating is baked onto the glaze of the tiles and is therefore indefinitely durable. In addition the surface is also air-purifying, breaking down pollution and exhaust gases from vehicles and industry in the surrounding atmosphere.
Self-cleaning: Photocatalysis

Hyatt Regency Garden Chapel
Osaka, Japan

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Obayashi Corporation, Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>Hyatt Regency Osaka</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Taiyo Kogyo Corporation</td>
</tr>
<tr>
<td>Completion</td>
<td>2001</td>
</tr>
<tr>
<td>Area</td>
<td>50 m²</td>
</tr>
</tbody>
</table>

Without its photocatalytic self-cleaning surface, the white of the membrane would not have lasted long without having to be cleaned regularly or even replaced at intervals.
Self-cleaning: Photocatalysis
Narita International Airport of Tokyo, Terminal 1. Chiba, Japan

Membranes offer protection against the weather and therefore improve comfort for passengers. As the membranes are equipped with a photocatalytic self-cleaning coating, the cost of cleaning and maintenance is kept to a minimum.
A photocatalytic self-cleaning glass was specified to ensure the best possible view without incurring excessive cleaning costs. The project illustrates how nanotechnology-based high-tech surfaces can also be of benefit for historic monuments.
Self-cleaning: Photocatalysis
east Hotel
St. Pauli, Hamburg, Germany

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Jordan Mozer &amp; Associates Ltd., Chicago, IL, USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>east Hotel und Restaurant GmbH</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Pilkington Activ, photocatalytic self-cleaning glass</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>Pilkington Deutschland AG/Pilkington Group</td>
</tr>
<tr>
<td>COMPLETION</td>
<td>2005</td>
</tr>
</tbody>
</table>

The self-cleaning function of the glass is therefore especially useful for hard-to-reach locations such as overhead glazing or glazed external walkways.
Self-cleaning: Photocatalysis
G-Flat, Tokyo, Japan

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Koh Kitayama + architecture Workshop, Tokyo, Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT</td>
<td>Sagan Coat, photocatalytic self-cleaning coating</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>SYK Corporation Inc.</td>
</tr>
<tr>
<td>COMPLETION</td>
<td>2006</td>
</tr>
<tr>
<td>AREA</td>
<td>2,636 m²</td>
</tr>
</tbody>
</table>

A photocatalytic self-cleaning glass coating helps the glass stay clean and is transparent due to its nanoscalar qualities.
Self-cleaning: Photocatalysis
Kurakuen private residence
Nishinomya City, Hyogo, Japan

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Casa Akira Sakamoto Architect &amp; Associates, Osaka, Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>Private</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Hydrotect, photocatalytic self-cleaning paint</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>Toto Ltd.</td>
</tr>
<tr>
<td>COMPLETION</td>
<td>2005</td>
</tr>
</tbody>
</table>

The architectural office responsible for both these houses has specified self-cleaning photocatalytic colour coatings for most of its projects since 2002.
Self-cleaning: Photocatalysis
Senri New Town private residence
Osaka, Japan

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Casa Akira Sakamoto Architect &amp; Associates, Osaka, Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>Private</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Hydrotect, photocatalytic self-cleaning paint</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>Toto Ltd.</td>
</tr>
<tr>
<td>COMPLETION</td>
<td>2006</td>
</tr>
</tbody>
</table>

In these projects, the photocatalytic self-cleaning outdoor coating is more than simply practical; it helps preserve the buildings’ aesthetics.
Self-cleaning: Photocatalysis
House in Creek
Hiroshima, Japan

Photocatalytic self-cleaning systems are ideal for such waterside locations where water and light are plentiful as both of these components are essential for the self-cleaning function of the coating.
# Self-cleaning: Photocatalysis

## Disabled-access housing for elderly people, Frick, Switzerland

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Walker Architekten AG, Brugg, Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>Verein für Altersbetreuung im Oberen Fricktal (VAOF) Frick AG</td>
</tr>
<tr>
<td>Product</td>
<td>Insulight Active, photocatalytic self-cleaning solar protection glazing</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Pilkington Glas Wikon, Switzerland</td>
</tr>
<tr>
<td>Completion</td>
<td>2004</td>
</tr>
<tr>
<td>Area</td>
<td>4,585 m²</td>
</tr>
</tbody>
</table>

The facade has to be cleaned from outside by "skyworkers“ and the longer cleaning intervals made possible by the self-cleaning coating help reduce the building's running costs.
Self-cleaning: Photocatalysis
MSV Arena soccer stadium
Duisburg, Germany

By using a photocatalytic self-cleaning glass, the cleaning interval could be lengthened considerably. In addition to its self-cleaning function, the glass wall also offers solar protection and noise insulating properties.
Self-cleaning: Photocatalysis
Children's playground in the
Mannou National Government Park
Kagawa, Japan

By using a photocatalytic self-cleaning coating, it was possible to choose a light colour for the membrane. Even in poor weather conditions, the UV light required to initiate the photocatalytic reaction is sufficient so that rain can wash off the dirt deposits lying loose on the membrane.
Easy-to-clean (ETC)

✓ *Smooth surfaces with reduced surface attraction.*
✓ *Surface repellence without using the Lotus-Effect.*

ETC surfaces are smooth rather than rough. These surfaces have a lower force of surface attraction due to a decrease in their surface energy, resulting in reduced surface adhesion. This causes water to be repelled, forming droplets and running off.

ETC surfaces are therefore **hydrophobic** and often also **oleophobic**, making them well suited for use in bathrooms. Water that runs off inclined ETC surfaces forms droplets, washing away surface grime in the process. It is therefore necessary to consider where and how the easy-to-clean function should best be employed. As a rule, *suitable surfaces should be inclined and exposed to sufficient quantities of water.*

ETC surfaces are most commonly found in interiors, but can also be employed outdoors for better weather protection.
Easy-to-clean (ETC)

"Roll-out marble" - Impact-resistant, fire-retardant, vapour permeable and yet water-repellent and easy-to-clean. The product consists of four layers:
1) a flexible polymer matting as backing
2) coloured ceramic material is applied
3) optional printing
4) ceramised top coat

A comparison of ceramic surfaces – left without ETC coating, right with ETC coating.
Flexible ETC ceramic wall coverings, similar to wallpapers, can withstand direct exposure to water, such as that in a shower cubicle, thanks to their highly water-repellent surface.
Various parts of the interior feature a particularly robust nanoceramic wall covering. It is flexible, impact-resistant and is vapor permeable whilst at the same time water-repellent. It can be applied similar to a normal wallpaper and is available in rolls. Beyond conventional applications, it can also be used in areas where conventional wallpaper would be inappropriate, for instance as a replacement for wall tiles in toilet areas.
The enamelled facade panels are coloured in the company's typical colour palette and are partially equipped with an easy-to-clean coating. This coating is otherwise used in the manufacture of bathtubs to further improve the ease with which one can clean the already low-maintenance material.
To protect the wood against weathering and to slow its gradual grey discoloration, the wood has been given a hydrophobic treatment. Rather than sealing the wood with a varnish-like film, the wood is impregnated transparently allowing it to breathe. The high-tech hydrophobic coating does not obscure the natural grain of the wood.
MoHen chose special wall coatings for their antibacterial, easy-to-clean and warming properties. The natural stone stairs have likewise been given a hydrophobic coating for aesthetic and self-cleaning reasons and to improve their durability.
The surface is covered with a dirt, snow and ice-repellent coating, which is ultra-thin, transparent and unaffected by UV light. Its anti-adhesive function ensures that dirt, which with time would impair the intensity of the light, is washed away with the rain. The lights are also equipped with fan heaters, a "plan B" for melting snow and ice. The coating has a limited lifetime, and must be renewed after several months.
Antibacterial

✓ Bacteria are targeted and destroyed.
✓ The use of disinfectants can be reduced.
✓ Supports hygiene methods - Especially in health care environments.

With the help of silver nanoparticles it is possible to manufacture surfaces specifically designed to be antibacterial or germicidal. Whether in the form of ultra-thin and invisible coatings or materials to which the particles have been added, these have an effect stronger than antibiotics. The antibacterial effect of silver results from the ongoing slow diffusion of silver ions. The very high surface area to volume ratio of the nanoparticles means that the ions can be emitted more easily and therefore kill bacteria more effectively. Bacteria have no chance of survival as the ions firstly hinder the process of cell division, secondly destabilise the cell membrane, walls or plasma and thirdly interrupt the enzyme's transport of nutrients. In this way, bacteria can be lastingly eradicated without the use of chemicals. The antibacterial effect itself is also permanent - it does not wear off after a period of time.
Silver nanoparticles of on average 10-15 nm in size lend the paint antimicrobial properties that remove the basis for mould and mildew. The particles are chemically stable and firmly anchored in the paint. The antimicrobial agent therefore cannot be washed out and the antibacterial function remains intact for many years. Three years later, no mould infestation is to be seen. The use of nanotechnology in this case offers an environmentally friendly and effective solution without the need for strong chemicals, and prevents further damage to the elevations.
Antibacterial Operating theatre
Berlin, Germany

The floors and walls have been clad in photocatalytic tiles. Largeformat tiling is more difficult to lay, and a conventional tile format was chosen for the high-tech antibacterial tiles used in the Harzkliniken. The light-coloured grouting contrasts pleasantly with the fresh green tiling.
Pleasant upholstered fabrics are used and still remain clean due to the antibacterial and dirt-resistant properties of nano silver particles. Light switches or floor surfaces, which are both subject to greater exposure to germs, are treated similarly. Quality wood veneers can be used thanks to antibacterial varnishes.

<table>
<thead>
<tr>
<th>Architectural Feature</th>
<th>Manufacturer</th>
<th>Product Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Architecture</strong></td>
<td>100% interior Sylvia Leydecke, Cologne, Germany</td>
<td></td>
</tr>
<tr>
<td><strong>Client</strong></td>
<td>succidia Verlag</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Capasan, air-purifying wall paint</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Caparol</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Drapilux air, air-purifying textiles</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Drapilux</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Accent Wood, antibacterial floor covering</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Tarkett</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>antibak, antibacterial wood varnish</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Clou</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Microcare, antibacterial and dirt-repellent upholstery fabrics</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Microcare</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>AS 500 antibacterial, antibacterial light switches</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Jung</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>ccflex, water-repellent, scratch-resistant and vapour permeable ceramic wallcovering</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Degussa, Evonik</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Jasba Centino with Hydrotect treatment, self-cleaning floor tiles</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Jasba, Deutsche Steinzeug</td>
<td></td>
</tr>
<tr>
<td><strong>Product</strong></td>
<td>Subway with Ceramicplus treatment, easy-to-clean WC</td>
<td></td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Villeroy &amp; Boch</td>
<td></td>
</tr>
<tr>
<td><strong>Completion</strong></td>
<td>2006</td>
<td></td>
</tr>
</tbody>
</table>
# Insulation

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

- Maximum thermal insulation
- Minimal insulation thickness

The historical precursor to vacuum insulators is the thermos flask: *low thermal conductivity is achieved by evacuating the air entirely* and the cylindrical form withstands the high pressure created by the vacuum. This approach is more difficult for flat insulation layers as they are unable to withstand the pressure. The solution to the problem is the use of an extremely fine fill material with a nanoscalar porosity of around 100 nm. A comparatively low pressure is then sufficient to evacuate the air making it possible to construct panels that can be used in building construction. The thickness of these VIPs ranges from 2 mm to 40 mm.
Thermal insulation: Vacuum insulation panels (VIPS)

The panels are constructed as follows: an *enveloping skin made of plastic foil (often coated with aluminium)* or of stainless steel encloses the fill material in a vacuum. The fill material takes the form of a *foam, powder or glass fibres and is always porous, resists pressure and can be evacuated*. The hermetically weld-sealed ends protrude on each side and are usually folded back and stuck to the panel. *For the panels to function correctly, it is imperative that the vacuum-enclosing skin is not pierced.*

Careful planning is necessary in order not to impair the insulating effect of the VIPs. *Gaps between neighbouring panels must be minimised* as far as possible to avoid cold bridges (heat leaks) resulting when the gap is too large.

VIPS are *more expensive than conventional insulation materials* and today are not necessarily conceived as a general replacement for conventional insulation. The lifetime of modern panels is generally estimated at *between 30 and 50 years*. 

---

[Image of vacuum insulation panels]
The VIPs constitute the insulation of the external walls and window parapets as well as the ventilation flaps on the main facade.
VIPs

Seitzstrasse mixed-use building
Munich, Germany

**ARCHITECTURE**
pool architekten, Martin Pool, Munich, Germany

**CLIENT**
Joint ownership

**PRODUCT**
Vacuum insulation panel (VIP)

**MANUFACTURER**
Va-Q-tec, Würzburg, Germany

**COMPLETION**
2004

**AREA**
1,250 m²

The first building of a substantial size to be fully clad with vacuum insulation panels
Thermal insulation: Aereogel

- High-performance thermal insulation.
- Light and airy nanofoam.

Aerogels in combination with glass
Opaque nanogel pearls.
Translucent nanogel granulate.
Heaps of aerogel
Aerogel currently holds the record as the lightest known solid material and was developed back in 1931. The gel is a globular granulate and appears milky, translucent and somewhat cloudy. It is simply an ultralight aerated foam that consists almost 100% of nothing other than air (the exact figure varies between 95% and 99.9%). The remaining foam material is a glasslike material, silicon dioxide, also known as silica. The nanodimension is of vital importance for the pore interstices of the foam: the air molecules trapped within the minute nanopores - each with a mean size of just 20 nm - are unable to move, lending the aerogel its excellent thermal insulation properties. In addition to its thermal insulating properties, aerogel also acts as a sound insulator according to the same basic principle. Because it is translucent, aerogel exhibits good light transmission, spreading light evenly and pleasantly.
The installation of aerogel-filled glass panels, which provide glare-free natural daylight whilst ensuring greater energy efficiency.
Aereogel

School extension, London, England

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Jacobs UK Ltd., Glasgow, Scotland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>Buckinghamshire County Council</td>
</tr>
<tr>
<td>Product</td>
<td>Kalwall+ Nanogel glazing</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Stoakes Systems Ltd.</td>
</tr>
</tbody>
</table>

The south elevation, behind which classrooms, the assembly hall, an internet cafe and a dance studio are located, is clad entirely in translucent 70 mm thick aerogel-filled panels.
Aereogel
Sports hall
Carquefou, ZAC du Souchais, France

<table>
<thead>
<tr>
<th>Architecture</th>
<th>Agence MA, Murail Architectures, Nantes, France</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>City of Carquefou</td>
</tr>
<tr>
<td>Product</td>
<td>Multi-wall panels with Nanogel filling</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Cabot Corporation</td>
</tr>
<tr>
<td>Completion</td>
<td>2006</td>
</tr>
<tr>
<td>Area of sports halls</td>
<td>3,360 m²</td>
</tr>
<tr>
<td>Façade surface</td>
<td>1,450 m²</td>
</tr>
</tbody>
</table>

All elevations of this sports complex have been clad with aerogel-filled multi-wall polycarbonate panels.
**Aereogel Factory**

**Zaisertshofen, Germany**

<table>
<thead>
<tr>
<th><strong>Client</strong></th>
<th>Ruf Maschinenbau GmbH &amp; Co KG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product</strong></td>
<td>Aerogel-filled multi-wall polycarbonate panels</td>
</tr>
<tr>
<td><strong>Manufacturer</strong></td>
<td>E.M.B. Products AG Licht- und Lufttechnik GmbH</td>
</tr>
</tbody>
</table>

16mm thick translucent aerogel-filled multiwall polycarbonate panels were installed in the skylights to provide uniform glare-free natural illumination in the workspace beneath.
Temperature regulation: Phase change materials (PCMs)

✓ **Passive temperature regulation.**
✓ **Reduced heating and cooling demand.**

PCMs are invariably made from paraffin and salt hydrates. Minute paraffin globules with a diameter of **between 2 and 20 nm** are enclosed in a sealed plastic sheathing. These can be integrated into typical building materials (plasters, plasterboards or aerated concrete blocks), whereby around 3 million such capsules fit in a single square centimetre.

An image of minute paraffin-filled capsules in their solid state, taken using light microscopy. They exhibit an exceptionally high thermal capacity and during a phase change turn to liquid.
During a phase change, the warmth is retained latently for as long as is required to change from one physical state to another. As PCM is able to take up energy (heat) without the medium itself getting warm, it can absorb extremes in temperature, allowing indoor areas to remain cooler for longer, with the heat being retained in the PCM and used to liquefy the paraffin.

As the temperature rises, melting the waxy contents of the microcapsule, the paraffin changes from solid to liquid. The same principle also functions in the other direction: rooms that are cooling down stay warm for longer, while the molten paraffin gradually hardens, before losing warmth. The temperature level of the materials remains constant. The predefined temperature is defined as 25°C.
PCMs
"Sur Falveng" housing for elderly people
Domat/Ems, Switzerland

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Dietrich Schwarz, GlassX AG, Zurich, Switzerland</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>Jürgen Schwarz</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Latent heat storing glass, phase change material (PCM), GLASSXcrystal</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>GlassX</td>
</tr>
<tr>
<td>AREA</td>
<td>148 m² GlassXcrystal glazing</td>
</tr>
</tbody>
</table>

The central of three cavities of an 8 cm thick composite glass element contains a salt hydrate fill material that functions as a latent heat store for solar heat and protects the rooms from overheating. The latent heat store has a thermal absorption capacity equivalent to a 15 cm thick concrete wall. The glass panel is transparent when the fill material has melted and milky-white when frozen.
Air-purifying Indoors

- **Pollutants and odours are broken down into their constituent parts**
- **Does not replace ventilation, but improves air quality**

Nanotechnology makes it possible to chemically decompose odours into their harmless constituent parts. Here the molecules are cracked, giving off steam and carbon dioxide.

Air-purifying curtain materials can simultaneously be equipped with antibacterial properties.
Air-purifying Indoors

To function adequately, the air-purifying surface area must be sufficient with regard to the volume of the room. Only surfaces that are exposed to the air, i.e. those not concealed by furniture, are relevant. For processes based on oxidative catalysis, normal air circulation is sufficient. **Nicotine or formaldehyde** molecules can also be cracked and filtered out of the indoor air.

The European headquarters of Hyundai Motors Europe in Offenbach, Germany, is lined with air-purifying plasterboard panels – an interesting combination for a car manufacturer.
Air-purifying Outdoors

The air-purifying capacity of photocatalytic concrete for example provides a possible means of combating existing pollutants. Applications are air-purifying paving stones, road surfaces and paints. Depending on the respective conditions, it was possible to eradicate between 20% and 80% of airborne pollutants. Pedestrians walking in the vicinity of treated walls breathed in fewer airborne pollutants.
Air-purifying Atelier and villa for a calligrapher, Yamanashi, Japan

**Architecture**  Kazuyasu Kochi, Kochi Architect's Studio, Tokyo, Japan

**Product**  Moiss, air-purifying building board

**Manufacturer**  Mitsubishi

**Completion**  2004

**Area**  62 m²

By using unvarnished wood and air-purifying building boards that eliminate airborne contaminants, the architect was able to reduce the problem of poor air.
Air-purifying Paving for Leien Boulevard Antwerp, Belgium

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>51N4E Space Producers, Antwerp, Belgium</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>City of Antwerp</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>Air-purifying paving tiles</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>With integrated technology from Mitsubishi</td>
</tr>
<tr>
<td>AREA</td>
<td>48,000 m²</td>
</tr>
</tbody>
</table>

The paving element, which was not realised for this project, is equipped with further functionality: with the help of sunlight and oxidative catalysis, it is able to convert environmental pollutants such as nitrogen oxide into inert nitric acid ions.
Air-purifying Jubilee Church
Chiesa del Dio Padre Misericordioso
Rome, Italy

<table>
<thead>
<tr>
<th>ARCHITECTURE</th>
<th>Richard Meier &amp; Partners, New York, NY, USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLIENT</td>
<td>Vicariato di Roma</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>TX Millenium, TX Active, photocatalytic cement</td>
</tr>
<tr>
<td>MANUFACTURER</td>
<td>Italcementi</td>
</tr>
<tr>
<td>COMPLETION</td>
<td>2003</td>
</tr>
</tbody>
</table>
Solar protection

✓ No blinds necessary.
✓ Glass darkens automatically or is switchable without the need for a constant electric current (memory effect).

The advent of nanotechnology has provided a new means of integrating electrochromatic glass in buildings. The primary difference to the earlier product is that a constant electric current is no longer necessary. A single switch is all that is required to change the degree of light transmission from one state to another (from transparent to darkened).

Photochromatic glass is another solution for darkening glass panels. Here the sunlight itself causes the glass to darken automatically without any switching.
Fire-proof

✓ Highly efficient fire protection.
✓ Light and transparent.

A thickness of only 3 mm of a functional fill material between glass panes is sufficient to provide more than 120 minutes of fire resistance against constant exposure to flames of a temperature of over 1000°C. The pyrogenic silicic nanoparticles, or nano-silica, are only 7 nm large and due to their relatively large surface area highly reactive. Depending on the desired duration of fire-resistance, the highly effective fill material is sandwiched between one or more panes of glass. The size of the fill particles can be modified and is given in terms of its surface area in square metres per gram.

In the event of a fire the nanosilicate forms an opaque protective layer against the fire, which also protects against heat radiation.
A fire safety glass with a particularly slender profile was selected for the project.
High-performance fire safety glass, enhanced with nanotechnology, is used around the perimeter of the office spaces to ensure the safety of those working inside.
Anti-graffiti

✓ Permeable surfaces with permanent anti-graffiti coating
✓ Highly hydrophobic and dirt-resistant.

They are highly effective and are used to make building materials water-repellent. Their extremely hydrophobic properties mean that graffiti can be removed more easily with appropriate detergents. Even porous and highly absorbent materials such as brick, lime sandstone, concrete and other similar materials can be protected efficiently using such nano-based coatings. Although the coating is effectively an impregnation, unlike other systems it does not close the pores of the material, allowing the material to retain its vapour permeability. The ultra-thin nanocoating lines the capillary pores without closing them.
In addition, the coating also reduces dirt accumulation significantly, making the coating applicable for use on floor surfaces too. The effect of the impregnated coating is a result of several layers of molecules. Within the coating, the self-organisation of the molecules it contains ensures that these are distributed evenly, stay together and have the same orientation. The upper layer fulfils a hydrophobic function, with a significantly reduced surface tension and molecular attraction. The lower layer ensures the entire coating adheres to the substrate it is applied to.

Noise barriers are ideal candidates for the use of anti-graffiti coatings.
Anti-graffiti
New Centre Ulm
Ulm, Germany

Both buildings have exposed concrete facades whose clean-cut forms are best appreciated when the surfaces are equally clean. For this reason the concrete surfaces have been coated with a nanoscalar high-tech coating. Such dirt-repellent anti-graffiti surfaces are well suited for use in urban environments where the potential for undesirable defilement is particularly great. Unsightly damage to buildings can be avoided as a result.
Anti-graffiti
Homager Palais
Berlin, Germany

**Architecture**
Hilmer & Sattler und Albrecht, Berlin, Germany; Walther Stepp, Berlin, Germany

**Client**
Groth Gruppe, Kondor Wessels Investa

**Product**
Faceal Oleo HD, Anti Graffiti

**Manufacturer**
PSS Interservice Group, Head Office, Switzerland

**Completion**
2006

**Area**
9,800 m² gross floor area

Its central location attracts graffiti-sprayers and it is only a matter of time before the first graffiti will appear on walls outdoors. An anti-graffiti coating was applied to guard against such damage, which protects the surface without clogging the capillary pores. The material itself is still permeable and able to breath. Pink stays pink.
Anti-reflective

✓ Improving solar transmission.

Transparent nanoscalar surface structures, where the particles are smaller than the wavelength of visible light, offer not only an innovative but also a cost-effective and efficient anti-reflective solution. Their structure consists of minute 30-50nm large silicon-dioxide (SiO2) balls. A single interference layer is applied by dipping the glass or plastic in the solution and functions across a broadband spectrum of light. The refractive index of the outer layer is very small and can be defined precisely, as can the thickness of the coating. A thickness of 150nm is regarded as ideal. The ratio of reflected light reduces from 8% to less than 1%.
anti-fingerprint

Steel and satin-finish glass surfaces are particularly affected by repeated touching. The coating alters the refraction of the light in the same way the fingerprint itself does so that new fingerprints have little effect. The light reflections on the coating make steel or glass surfaces appear smooth, giving the impression of cleanliness that many users have come to expect.

Functional principle of an anti-fingerprint coating (below) vs. an uncoated surface (above).
1- Nanoparticles for applications are already commercially available in a wide range of forms that can support a host of applications. Materials such as silver (Ag), gold (Au), aluminum (Al), and iron (Fe) are commonly available, as are many fundamental forms. A wide array of compounds (such as tungsten carbide, TiC) and oxides (such as titanium dioxide, TiO2) are also available.

2- Titanium dioxide (TiO2), widely used in its anatase form for photocatalytic applications (self-cleaning, antimicrobial), typically ranges from 5 to 20 nm, whereas in another of its forms (rutile) diameters are often larger (40–50 nm).

3- Nanoparticles can also come in varying levels of treatments. Various nanoparticles can be obtained that, for example, already have hydrophobic or hydrophilic properties useful in a wide range of applications.

4- Carbon nanotubes for applications are available in a wide variety of single-walled (SWNT) and multiwalled (MWNT) forms, including different lengths, diameters, and purities.
The holistic applications: Hotel room
The holistic applications: hospital room

So, how are we feeling today?
The holistic application of nanosurfaces in patient rooms of the future

Tiles: antibacterial
Sanitaryware: anti-fingerprint
Tiles: antibacterial
WC: easy-to-clean
Shower screen: easy-to-clean
Mirror: anti-fogging
Doorknobs: anti-fingerprint, antibacterial
Wall paint: air-purifying
Call-button, light switch, TV/radio buttons: antibacterial

TV: anti-reflective

antibacterial

Upholstery, carpets: air-purifying, oxidative catalysis
Table surfaces: anti-fingerprint, scratchproof

Curtains: air-purifying
Window: photochromatic or electrochromatic
Window: self-cleaning, photocatalytic
The holistic applications: bank office
Conclusions

- Nanomaterials are materials made from nanometer-scale substances has opened up possibilities for new and innovative functions.
- Nanotechnology is disruptive and offers the possibility of great advances whereas conventional approaches, at best, offer only incremental improvements.
- Nanotechnology is the opposite of the traditional top-down process of construction, or indeed any production technique, and it offers the ability to work from the “bottom” of materials design to the “top” of the built environment.
- Nanomaterials will produce buildings lighter, smaller and more robust which will save in the cost of construction and saves a flat earth for future generations.
- There are three main issues that might prevent the widespread use of the nanotechnology:
  - Lack of vision to identify those aspects that could be changed through its use.
  - Lack of skilled personnel.
  - Level of investment.

As with most major innovations, there are two principle obstacles to be overcome:

- Develop a sufficiently deep understanding of behavior to establish both the good and the bad, the benefits and the hazards, of the nanoscale.
- Nanomaterials are expensive and will remain so, at least for some time. Finding ways to cushion the transition to economic viability needs thought.
References