BIRKHÄUSER

nano MATERIALS

in Architecture, Interior Architecture and Design

Sylvia Leydecker

With Forewords by Harold Kroto and Michael Veith

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and Contributions by Marius Kölbel and Sascha Peters

Birkhäuser
Basel · Boston · Berlin

The Medium is the Message – the accompanying sample has been provided courtesy of Evonik. It is an innovative, flexible ceramic wallcovering, which can be used as a durable and low-maintenance alternative to traditional wallpaper or tiling. Its ceramic structure makes it impact and scratch-resistant, water-repellent and resistant to chemicals, flame-retardant and UV-resistant. Sold by the roll, it is easy to handle and apply.

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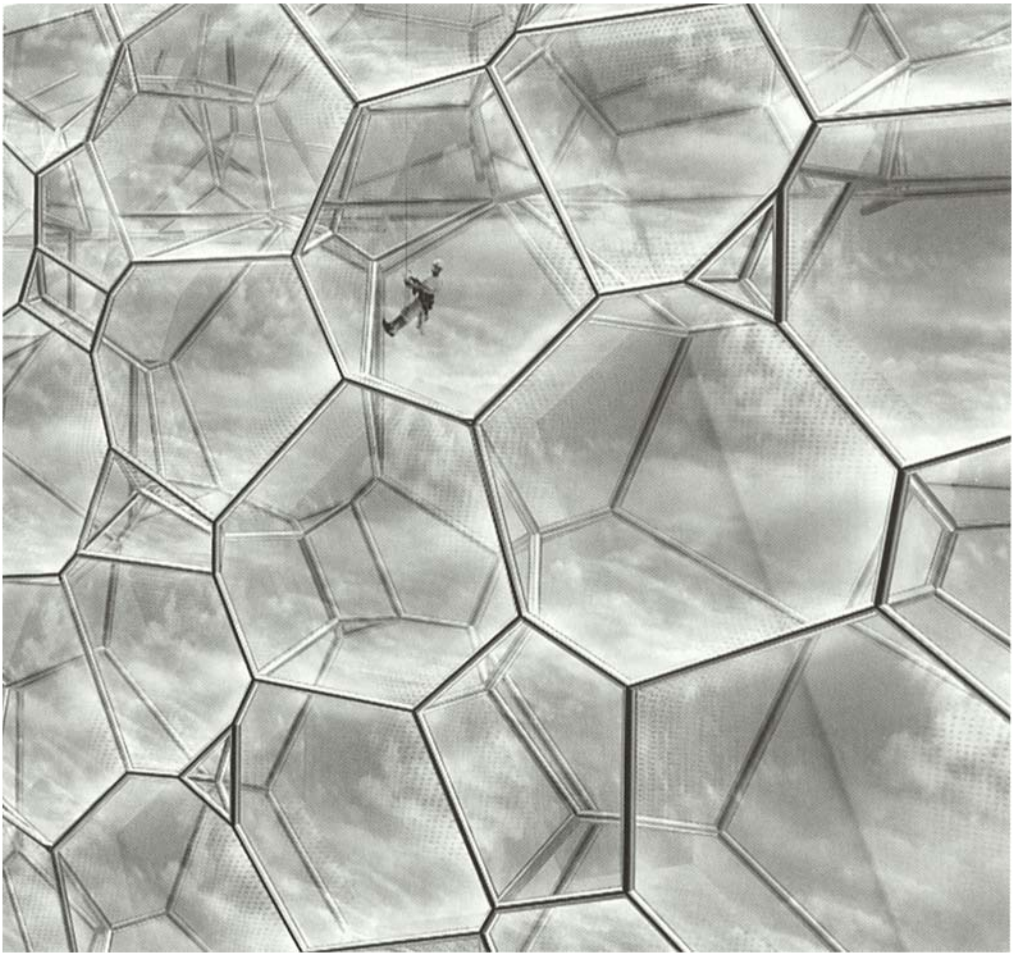
Contents

Hexagonal forms occur commonly throughout nature: whether in a tortoise's shell, in the internal structure of foams or in buckyballs. This formal structure is becoming increasingly evident in contemporary design and architecture, too. The façade of the Beijing 2008 Olympic Swimming Centre plays with its dimensions.



Foreword

by Harold Kroto

As the 21st century unfolds, chemistry-based, bottom-up approaches to the creation of materials with exactly specified atomic and molecular infrastructures have become more and more feasible while the top-down approach, which has served us so well, appears to be approaching some fundamental limits. The aim has been to access the promise that such materials hold of advanced behaviour, such as highly improved tensile strength and/or electronic and magnetic properties. As these new approaches to research in materials science have shifted more and more towards this intrinsic chemical perspective, the field acquired a new name, Nanoscience & Nanotechnology (N&N). It is not, of course, at all new as biology has constructed all living systems atom by atom, molecule by molecule on the basis of a DNA-based blueprint. At the same time that these new approaches were developing, a totally unexpected family of pure carbon cage molecules with fascinating properties was discovered, the Fullerenes and their elongated Nanotube (Buckytube) cousins. These species have properties that should be able to fulfil some of the exciting new developments promised by 21st century materials science and technology. The structures, which have also become the iconic images of N&N, are now the subject of intense study as they promise to play key roles in almost every possible area of future technology, from medicine and molecular electronics to civil engineering. In addition to carbon-based structures, the nanoscale behaviour of numerous other molecular and extended atomic array materials is being explored with similarly exciting prospects. Ingenious strategies for the creation of molecules with complex, exactly specified structures and functions are being developed – basically to make molecules that "do something". In fact, the cross-disciplinary field of N&N, which has resulted from deeper understanding and improved expertise in the application of the chemical principles that underlie condensed-matter physics, molecular biology and materials engineering may be considered "The Frontier Science of the 21st Century". Improvements in materials behaviour have already been achieved and if we can solve the problems of fine control over bottom-up chemical self-assembly then a paradigm shift in materials technology of all kinds will be achieved, with applications from molecular electronics to civil engineering. Such advances are vital if we are to develop the sustainable technologies that are necessary for survival of the human race.

Foreword

by Michael Veith

For a "nanophysicist" who looks into the world of quantum dots, the work of a "nanochemist" developing scratch-resistant surfaces seems quite foreign. The different views and fields of work of the professions involved render it impossible to make generalised statements about the current state of nanotechnologies. In the heads of scientists – and in the heads of journalists, too – fascinating ideas abound for ways of implementing new discoveries like carbon nanotubes. Whereas the mechanical and electrical properties of these carbon structures can in theory be predicted well, appropriate means for determining their material parameters in practice are still in their early phase. And although carbon nanotubes are already manufactured industrially, the creation of a cable of sufficient strength to convey an elevator into outer space, as visionaries say is potentially possible, is currently far beyond our technical capabilities.

In these as well as many other areas, the nanosciences are still in their infancy. By contrast, in other fields, such as the pharmaceutical and cosmetics industries, the use of nanotechnological substances and filler materials is so widespread that it is difficult to imagine these industries without them. We have grown used to sunscreen creams that despite a protection factor of 20 or 30 still appear transparent on the skin. This is made possible by titanium dioxide particles that are so small that they do not scatter light yet are able to absorb UV light. At the moment they do not seem to present a health hazard. The merits of liposomes as containers for cosmetic substances have been lauded by marketing experts for several years. This, too, is nanotechnology. But scientists are looking to achieve more than just anti-wrinkle creams. Using this approach they aim to encapsulate pharmaceutical agents and to treat the molecules on the surface of the liposomes in such a way that they release their medicine only to particular diseased cells in the body.

In the nano context, the most significant economic relevance is accorded to so-called "New Materials". These materials are not only new in terms of their dimensions; they can for example lend surfaces entirely new properties, that can be combined cumulatively. Applications range from controllable adhesion and grip, tribological aspects such as ultra-low friction, switchable magnetism or light absorption, conductive trans-

parent surfaces, light diffusers and so on to insulation materials for buildings which offer similar levels of insulation as conventional insulation materials at a tenth of the material thickness.
The multitude of nanotechnological products in this area underlines the economic relevance of such new materials. Research institutes such as the Leibniz Institute for New Materials (INM) are actively applying themselves to these technologies. In this context one should not forget that nanotechnology is an "enabling technology". It helps to improve existing products rather than creating completely new products. For instance, if the Chrome-VI content of a conventional anti-corrosive coating can be replaced by a non-toxic nanocoating, which is considerably thinner and therefore more sparing, this not only represents an economic advantage but also contributes towards sustainability. Likewise, the conservation of energy is a big issue.
There are few products whose properties cannot be usefully improved with the help of nanotechnology – refinements in design and feel inclusive. This message seems to be of central importance, and the competition for the best position is already well underway. However, although interest from businesses in the market place continues to grow, the notion that nanotechnology remains in the realm of university laboratories and that it has little to contribute to corporate competitive advantage is still widespread. Every attempt to explain nanotechnology and its applications is therefore to be welcomed.
The idea behind this book – to bring to light the applications offered by nanomaterials in a particular sector and to examine the new materials from the point of view of architects, interior designers and designers – is the right way to encourage people to examine a new technology more closely, both critically as well as enthusiastically, particularly when they would otherwise be unlikely to discover the field through scientific publications on nanosciences and technologies.
The examples shown here are just a beginning. In the Musée d'Art Moderne in Paris one can view 2 × 3 m metallic panels, an artwork whose colour changes according to where it is viewed from (it consists of very thin layers of paint). How long will it be before we can admire such nanotechnological layers on the façades of buildings?

What is nanotechnology?

Minute 100 nm and below.

Nanotechnology is currently all the rage. Accordingly, both the term and the concept are much over-used. Nevertheless few people, and even fewer designers, really know what nanotechnology actually is and what it is good for. It is, however, most definitely more than just a passing fashion. In fact, at present nanotechnology is still a fledging science but one that has been forecast an extremely promising future with the potential to change the world around us.

"Nano" derives from the Greek word nanos (Latin *nanus*) meaning "dwarf" – so begin many articles on nanotechnology and this book is no exception. A nanometre (nm) is a millionth of a millimetre (1/1,000,000 mm = 10^{-6} mm) or a billionth of a metre (1/1,000,000,000 m = 10^{-9} m). It is an 80,000th of the diameter of a hair (the figure varies between 50,000th and 100,000th) and is the same size as about five to ten atoms. Given that a billion nanometres equal a metre, it should be clear that we are concerned here with the most minute of dimensions. The wavelength range of visible light is approximately 400 to 800 nm and as the light scattered by smaller particles reduces significantly, particles of such a small size become effectively invisible. "Nano" cannot, therefore, be seen with the naked eye.

Comparisons help us to better comprehend the scale of the dimensions involved – a common comparison is that the proportion of a nanometre to a football is about the same as that of a football to the earth. If one were to spread a single drop of water over an area of 1 m² it would be 1 nm thick. Human fingernails grow at a rate of 1 nm per second.

In the famous film "Powers of Ten" by the designer-duo Charles and Ray Eames, a classic film in the field that has now attained cult status, the viewer is taken on a journey through the powers of ten of the cosmos, illustrating the differences in dimension. The film, made in 1977, is most worthwhile and can still be ordered from the Eames Office in the USA via the internet.

A clear and generally applicable description on an international level has not as yet been defined for the term "nanotechnology", but in most cases it serves as a general heading for all manner of analyses and material investigations at nanoscale. Generally speaking, nanotechnology therefore describes any activities at a magnitude of less than 100 nm. This threshold reflects the fact that at this point there is a "kink in nature". It is at this size that the properties of solid materials change, for example gold changes its colour to red. At 100 nm and below things start to become particularly interesting.

The definition given by the German Federal Ministry of Education and Research (BMBF) summarises nanotechnology as follows: "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 (typically) less than 100 nanometres. The decisive factor is that the very nanoscale of the system

The shimmering blue colour of butterfly wings is caused by light reflections rather than coloured pigments. The wings are covered with nanostructured scales that reflect light and through a process of interference cancel out all colours except blue. Such colourings are a product of the laws of physics and cannot fade. For this reason, researchers attempt to replicate this effect artificially with paints or coloured films.

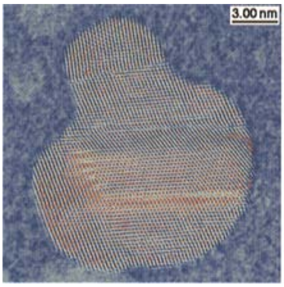
Gold nanoparticles are regarded as the ideal constituent material for nanostructures. Their unique optical, electronic and catalytic properties are especially interesting.

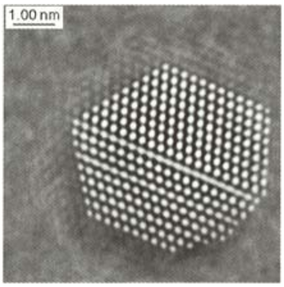
components results in new functionalities and properties for improving products or developing new products and applications."

Or in the words of the American Nanoscale Science, Engineering and Technology (NSET) Subcommittee of the U.S. National Science and Technology Council (NSTC, White House), which coordinates the National Nanotechnology Initiative (NNI):

"Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1–100 nanometer range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes manipulation under control of the nanoscale structures and their integration into larger material components, systems and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale. In some particular cases, the critical length scale for novel properties and phenomena may be under 1 nm (e.g., manipulation of atoms at ~ 0.1 nm) or be larger than 100 nm (e.g., nanoparticle reinforced polymers have the unique feature at ~ 200-300 nm as a function of the local bridges or bonds between the nanoparticles and the polymer)."

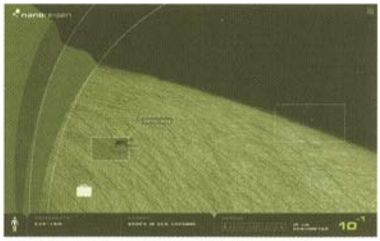
Nanoparticles measure only a few nanometres and can consist of just a few or several thousand atoms. The

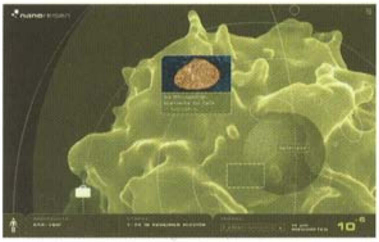




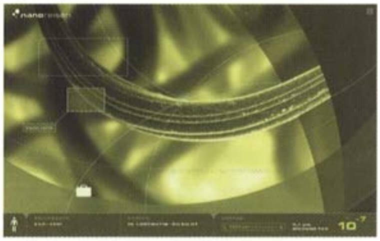
Home – Check-in – Welcome aboard!

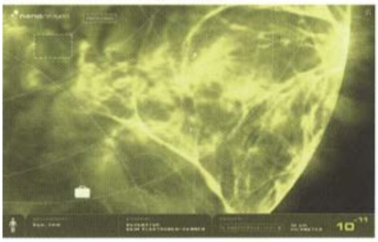

Start 10^{0} – Start of journey at a sidewalk café

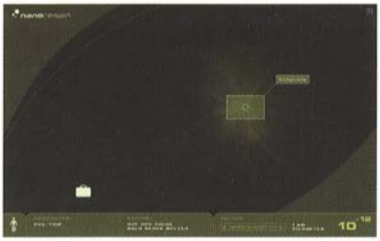

Ego-trip 10^{-1} – Rodeo in the Savannah

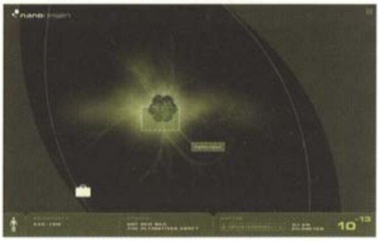

10^{-5} – T-26 on a secret mission


10^{-6} – Visit to the Central Station

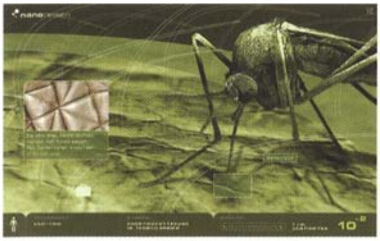

10^{-7} – In the Chromatin thicket


10^{-11} – Pit stop during the electron race


10^{-12} – In search of new worlds


10^{-13} – On the road to the ultimate force

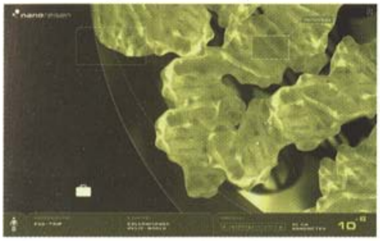
"Nano-journeys – adventures beyond the decimal" provides a virtual journey of discovery into the minute worlds of the micro- and nanocosmos. The filmstrip, published by the VDI Technology Centre (idea, concept and realisation by Lekkerwerken, if communication design award, gold, 2005), is available on CD or online.
On various routes, visitors can gradually "shrink themselves" into worlds normally invisible to us and investigate the smallest known dimensions of our universe.
The route described here is the so-called "Ego-trip".



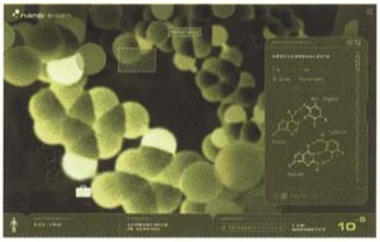
10^{-2} – Feeding beasts in Transylvania

10^{-3} – In the tropical hair forest

10^{-4} – Rush hour in the capillary system

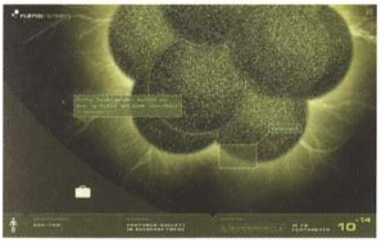


10^{-8} – Helix World Amusement Park



10^{-9} – Snorkelling in the gene pool (nano level)

10^{-10} – Weightless in the cloud orbital



10^{-14} – Proton ballet in a nuclear power plant

10^{-15} – Gala dinner with fireworks

10^{-16} – End of the ego-trip – "Take a journey to incredibly small worlds..."

Sand is a good example of how suspended solids gradually appear more transparent the smaller the particle size becomes. At the minute nanoscalar dimension (right) the particles are so small that a solution with 50% suspended solids appears transparent – even a laser beam can be seen through it.

The diagram illustrates the order of magnitudes by comparing different scales, from the metre to the nanometre.

material out of which nanoparticles are made is nothing out of the ordinary. The basic material of nanoparticles can be organic or inorganic, for example silver or ceramic. They can be elements such as carbon, or compounds such as oxides, or they can be a combination of different compounds and elements. The key characteristic is not the material itself but the size of the particles. In comparison to their size nanoparticles have a vast surface area. At this size, a relatively inert material can become highly reactive and therefore potentially interesting for many different uses, for example as a catalyst. In addition nanoparticles have a tendency to form agglomerations. Nanoparticles with less than 1000 atoms, i.e. very small nanoparticles, are called clusters.

Nanoparticles are invisible due to the fact that they are smaller than the wavelength of visible light and therefore unable to scatter light. For this reason, a solution that contains a 60% proportion of solids in the form of nanoparticles can still be transparent.

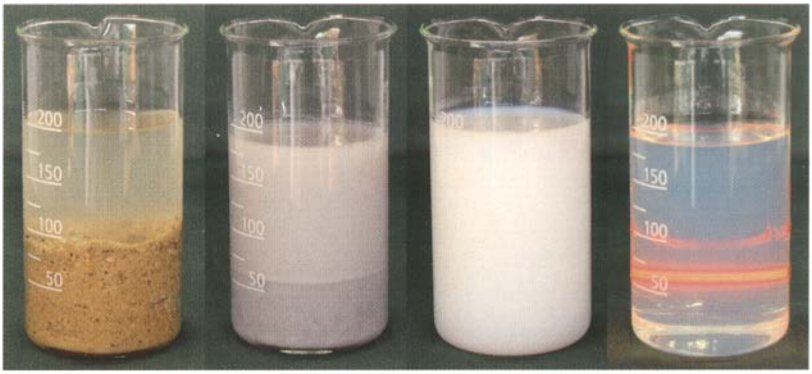
Aside from synthetic production, nanoparticles are also present in natural materials, for example in clay, a constituent of loam, which contains a high proportion of natural nanoparticles. These are responsible for properties such as frost-resistance, durability and strength. Another example from nature is mother of pearl, whose high durability is also attributable to its nanostructure.

The ultra-thin and invisible nanocoatings, whose applications are of particular interest to designers, generally have a thickness of 5–10 nm. The optimum thickness of each coating, for instance when spray-applied, comes about automatically, a phenomenon that is termed "self-organisation". Each square centimetre then contains billions of nanoparticles.

The manufacture of such ultra-thin coatings with the help of chemical techniques uses a so-called "bottom-up" approach, i.e. one develops from the smallest size to larger sizes, beginning with the atom and finishing with the desired product. By comparison, the conventional manufacture of raw materials generally uses a "top-down" approach, in which a material is reduced, for instance by grinding down, to the desired size. Nanotechnology in general, i.e. when used not solely for coatings, employs both such approaches.

Nanoparticles can be used in solutions, which despite a high proportion of solids appear transparent. Another application is the use of nanopowders. Nanocoatings can be applied using traditional means such as spraying and dipping.

In the building sector, nanotechnology is an "enabling technology", a fundamental technology that helps to make other technological developments possible. Various different scientific disciplines overlap and interdisciplinary work is becoming increasingly common, involving biology, physics and chemistry as well as engineering disciplines. In the architectural planning process it is necessary to bring together the knowledge of different specialist planners at an early stage. The use of nanotechnologies in the design and construction dis-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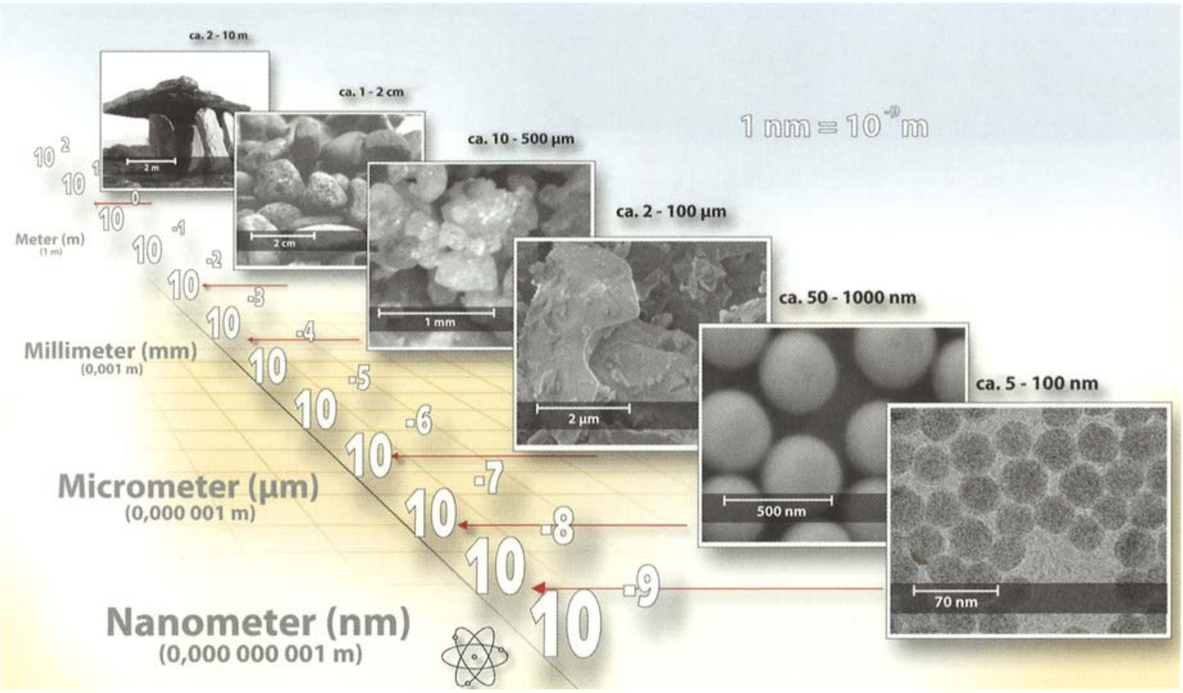
ca. 2 - 10 m
ca. 1 - 2 cm
ca. 10 - 500 µm
ca. 2 - 100 µm
ca. 50 - 1000 nm
ca. 5 - 100 nm
1 nm = 10^{-9} m
2 m
2 cm
1 mm
2 µm
500 nm
70 nm
Meter (m)
Millimeter (mm)
(0,001 m)
Micrometer (µm)
(0,000 001 m)
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ciplines usually involves the optimisation of existing products or common materials. Of particular interest is the development of new functionalities, i.e. properties that cannot be achieved without the help of nanotechnology, or indeed of multi-functionality. This helps make products and materials more economical and also conserves resources. Protection against damage can be a further potential benefit.

When introducing new technologies to a field such as the construction industry, one should always first examine the benefits it can bring. In the case of the application of nanotechnology we are talking about added value, additional functionality, as well as market demand with regard to product development. Good design in principle is always based on demand, and in this way contributes to the evolution of both nanomaterials and the resulting nanoproducts – in the long term the materials and products for which there is a demand will become established whereas others will disappear from the market. The use of nanotechnology is therefore not an end in itself but follows an ongoing demand for innovation – as such it can also be a marketing factor. Independent of marketing factors, nanotechnology can make a concrete contribution to the following areas:

- Optimisation 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

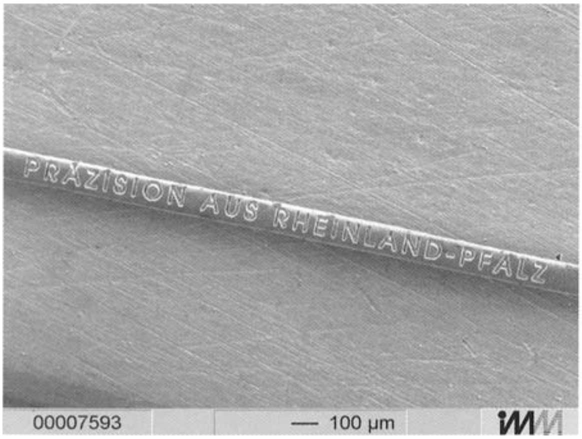
Microscopic image of a hair with inscription taken using a scanning electron microscope (SEM).

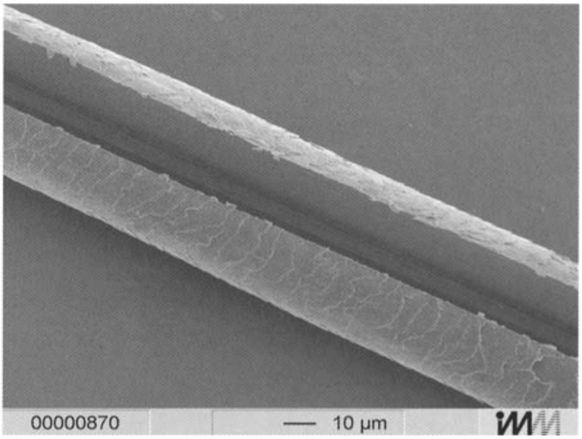
Splitting hairs taken to perfection – also taken with an SEM.

And as a direct result:

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

Nanotechnology brings us a step closer towards customised materials with specific individual properties and represents a shift away from the catalogue of standard materials. Surfaces emancipate themselves from the underlying material, developing clearly defined functions that can differ fundamentally from the substrate material. A central aim of nanotechnology is to consistently use the minimum amount of raw material and energy: from an economic as well as an ecological point of view, in the long term "nano" is a winning factor. However, one should have no illusions: the driving force behind development is not innovation itself but the cost factor. In practice it is not a matter of "nano" or not, but whether things work in real everyday conditions. Industrial standards, testing methods, long-term testing, quality indicators and their ongoing development help to ensure that this need is fulfilled. From the point of view of the client or the user, the most realistic and sensible application of nanotechnology focuses on aspects of aesthetics, functionality, economy and sustainability.





The development of nanotechnology

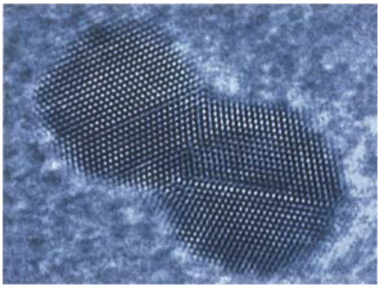
"There's plenty of room at the bottom"

From nature via historical examples, the scanning electron microscope, inscriptions written in atoms to buckyballs and nanotubes.

Nanoparticles are a natural phenomenon and it is therefore no surprise that their properties have been made use of throughout history. Among the earlier examples in which "nano" plays a role are the red colour of Roman glass trophies and the red colouring of stained glass in medieval church windows. The deep red colouring of the gold that was used for this purpose is partly responsible for the illustrious colour of the stained glass windows. The colour of gold particles changes depending on their size and form and can appear red, blue or violet. The Lycurgus Cup, also from Roman times, is another famous historic artefact that uses this effect. Exhibited in the British Museum in London, its colour changes from red to green depending upon the angle of incident light. The extremely hard Samurai swords are a further prominent example. Less well known is that the Damascene swords also contain carbon nanotubes (see p. 24 f.). Of course, at such times one was not aware of the presence of nanoparticles; one simply exploited the change in material properties without knowing where they came from.

The famous English physicist Lord Faraday, who was also trained in chemistry, was the first to investigate the colour effects of gold in the early 19th century. In 1926 the Austrian chemist Richard Zsigmondy was awarded the Nobel Prize for Chemistry for his research on the subject. Around the turn of the 20th century he examined gold ruby glass and in 1913 developed a microscope with which it was possible to see particles the size of a nanometre.

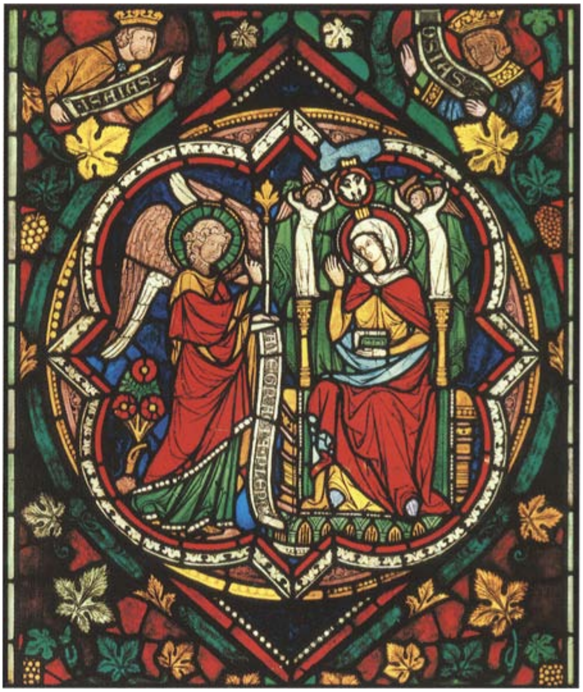
The story of current developments in nanotechnology has its legendary beginning in Christmas 1959. On 29th December the annual meeting of the American Physical Society convened in Pasadena, California at a leading private university, the California Institute of Technology (Caltech), where Richard P. Feynman, later to be awarded the Nobel Prize for Physics, held his now famous address "There's Plenty of Room at the Bottom". Exhibiting considerable prescience he noted, "It is a staggeringly small world that is below. In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction." His talk is full of pioneering ideas such as the direct manipulation and control of atoms, his assertion that it is conceivable to store the content of the Encyclopedia Britannica in a space as small as the head of a pin, the continuing reduction in size and with it a change in the laws that apply, the miniaturisation of computers and more. With his choice of title Feynman intended to emphasise not just the existence of space "down there" but also its expanse. Without going into details he went on to describe what he thought was possible: "I will not now discuss how we are going to do it, but only what is possible in principle – in other words, what is possible according to the laws of physics." His speech was first printed in the February 1960 edition of the journal *Engineering and Science*, published by Caltech, and one can read it on the Caltech website (http://www.its.caltech.edu/~feynman/plenty.html). Richard Feynman is rightly considered the "fa-



Minute detail with great effect: gold nanoparticles are responsible for the gold-ruby effect seen in medieval church windows. The atomic structure is clearly visible.

Church windows are a classic example of the early use of nanotechnology. Gold nanoparticles produce the ruby-red colouring of the glass, as can be seen in this example from Cologne Cathedral dating back to 1280.

ther of nanotechnology". With regard to the development of new materials, an aspect of particular interest also for architecture, he poses a fundamental question about the qualities that materials would gain from the controlled manipulation of their atoms. His deliberations marked the beginning of much innovation in the world of atoms and molecules and have subsequently opened up entirely new design possibilities. The "Feynman Prize in Nanotechnology" is awarded regularly to the present day. Feynman himself laid down the foundation for this by announcing in his speech two prizes to be awarded for the fulfilment of two tasks: the first was to represent the text of a page of a book at a scale of 1/25,000, readable with the help of an electron microscope, the second the development of an electric motor the size of 1/64 inch. The first task was solved only a year later in 1960 (Newman), the second not until 26 years later in 1985 (McLellan).



Feynman gave this speech again in an updated form in 1983 at the Jet Propulsion Laboratory (JPL) in Pasadena, California. The JPL is the NASA research and development centre for the robot-driven investigation of the solar system and is managed by Caltech. Feynman this time titled his talk "Infinitesimal Machines" and discussed the miniaturisation of computers. In 1993 this talk was re-discovered and reached a greater audience.

The term "nanotechnology" was coined in 1974 by Norio Taniguchi at the University of Tokyo in Japan. He used it to describe manufacturing methods with a tolerance

An ultra-fine coating of colloidal gold, which contains gold nanoparticles, is responsible for the different colouring of the halogen pin-type socket lamps and is able to withstand extreme heat.

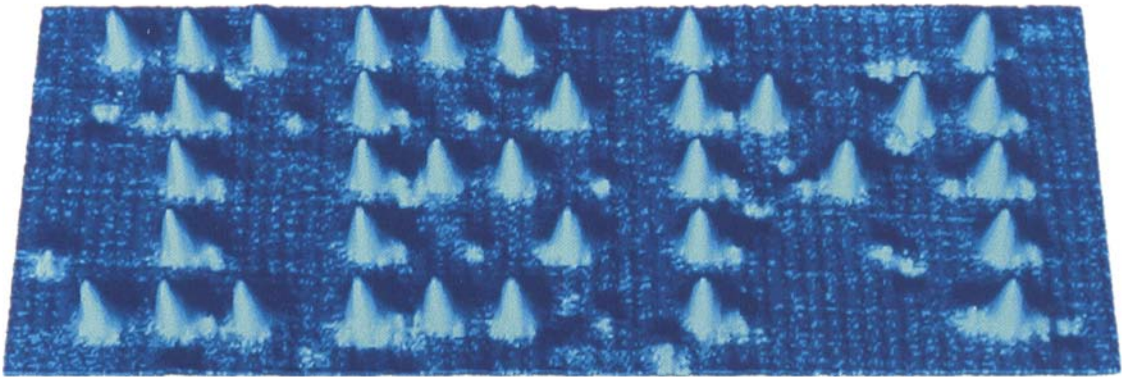
of less than a micrometer (a thousandth of a mm), which in comparison to today's technology seems rather coarse. The term was picked up again some 20 years later by K. Eric Drexler, the founder of the Foresight Institute. In his Sci-Fi bestseller from 1986 *Engines of Creation*, he paints a utopian vision of self-reproducing nano-robots ("assemblers") that populate the world in the form of "grey goo". Referring to this, Bill Joy, co-founder and former chief scientist of Sun Microsystems in Silicon Valley, USA, published an article in the leading IT-magazine *Wired* called "Why the Future Doesn't Need us" (2000), which can still be read on the Wired website (http://www.wired.com/wired/archive/8.04/joy.html). Joy calls for a cessation of certain kinds of research, reasoning, "the only realistic alternative I see is relinquishment: to limit development of the technologies that are too dangerous...". His article marks the beginning of a debate on nanotechnology that persists today.

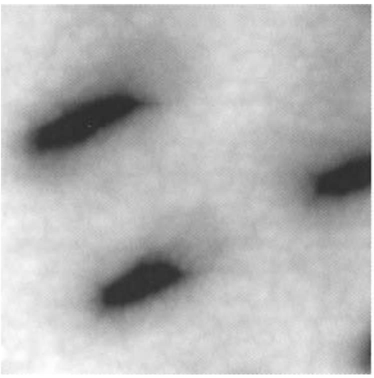
Feynman's call, voiced in his famous 1959 speech, for a much more powerful electron microscope as a suitable tool for his visionary ideas eventually became reality in 1981, paving the way for future developments. The researchers Gerd Binnig and Heinrich Rohrer developed the scanning tunnelling microscope (STM) in the Swiss IBM laboratory in Rüschlikon, with which one can discern individual atoms. In 1986 they received the Nobel Prize for their work. The STM enables one not only to make atoms and molecules visible, as one would expect, but also thanks to further developments to move them around individually. Since then further similar instruments for manipulating surfaces have been developed. Instruments for analysis and structuring such as the atomic force microscope (AFM), developed in the mid 1980s, further improve the ability to work at the nanoscale. In 1989 the letters "IBM" composed of 35 individual atoms made headlines around the world. The physicist Don Eigler 'wrote' them in the IBM laboratory at the Almaden Research Center, San José, USA. The instrument which first made it possible to accurately position atoms was the scanning tunnelling microscope (STM).

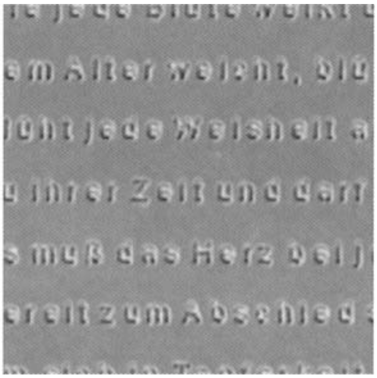
1985 also marks a further milestone with a direct relationship to architecture: the approx. 1 nm large (1 millionth of a mm) Buckminster fullerenes, affectionately known as buckyballs, named after the architect Richard Buckminster Fuller, were discovered by Robert F. Curl, Harold W. Kroto and Richard E. Smalley, also later recipients of a Nobel Prize. We shall examine these buckyballs that look like traditional black and white soccer balls in the following chapter (see p. 26 ff). In 1990 Donald Huffman (University of Arizona, Tucson, USA) and Wolfgang Krätschmer (Max Planck Institute for Nuclear Physics, Heidelberg, Germany) managed to produce several macroscopically visible grams of this molecule, i.e. quantities visible with the naked eye. Shortly afterwards, in 1991, the first large-scale production of buckyballs began, and its nomination as "molecule of the year" by the journal *Science* increased its popularity still further.

Atoms can be manipulated. An iconic image that caused a sensation in 1989: the letters "IBM" written out of 35 xenon atoms onto a nickel surface.

From tiny to minute. Both images were produced using a scanning tunnelling microscope (STM). The left image shows the topography of a digital versatile disc (DVD). The right image shows a "poetic miniature", a part of Hermann Hesse's poem "Stages" from "The Glass Bead Game" that was inscribed onto a polymethylmethacrylate plate using a STM. The latter is many times smaller than the data stored on the DVD.







Milestones of nanotechnology

29/12/1959	Feynman's lecture "There's Plenty of Room at the Bottom"
1974	The term "nanotechnology" is coined
1981	Invention of the scanning tunnelling microscope (STM)
1986	Invention of the atomic force microscope (AFM)
4/9/1985	Discovery of "buckyballs"
1989	The word "IBM" is written out of individual atoms
1990	First manufacture of buckyballs in macroscopic quantities
1991	Discovery of nanotubes
mid 1990s	Nations begin funding nanotechnology, primarily research and development
late 1990s	First products begin to appear on the market
2000	Article by Bill Joy "Why the Future Doesn't Need us" marks the beginning of the nanodebate
2007	The first worldwide certified seal of quality – NT Cenarios or "Certifiable Nanospecific Risk Management and Monitoring System" – developed by Tüv-Süd in Germany and the Innovationsgesellschaft mbH, St. Gallen, Switzerland

From macro to nano. The four images of parts of a Damascene sabre show what the blade is made of – carbon nanotubes are responsible for the extraordinary strength and flexibility of the steel.

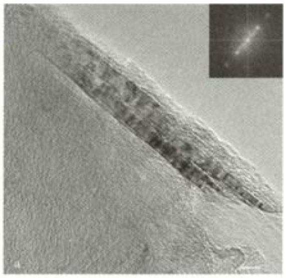
A Persian knife blade as we see it with the naked eye.

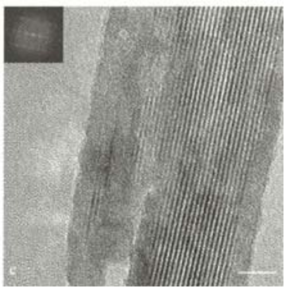
A close-up clearly showing the lighter carbide fields in the darker matrix of softer, low-carbon steel.

The other two images (right) were taken using electron microscopy. A small part of a Damascene sabre was dissolved in hydrochloric acid revealing the presence of nanotubes, in this example a multi-walled carbon nanotube. The striped patterning is formed by a contrast between the layers of carbon.

Cementite nanowire in a Damascene sabre encapsulated by a carbon nanotube, a leftover after dissolving the piece of sabre in acid.

The scale in the bottom-right of the lower image measures 5 nm.





The current stars of modern nanotechnology are the carbon nanotubes (CNTs), or simply "nanotubes", which were discovered in 1991 by the Japanese physicist Sumio Iijima at the electronics concern NEC in Tsukuba, Japan. They too are a form of fullerene, which because of their special properties have been forecast fantastic future prospects.

Since the end of the 1980s worldwide research into nanotechnology has increased rapidly. In addition to university-level research, high-tech firms, large concerns as well as small start-ups have taken up nano research. Research and development form the basis for usable products, and these are gaining increasing presence in the market place. In Germany, research began in the early 1990s, and since 1997 has received considerable funding from the Federal Ministry for Education and Research (BMBF).

New means of analysis extend our understanding of the properties of materials. In a 17th century Damascene sword, as mentioned earlier, researchers have discovered, with the help of an electron microscope, the presence of the much-vaunted carbon nanotubes (published by the Technical University Dresden in the journal *Nature*, 16th November 2006). This explains the special properties of the Damascene blades, which are legendary for their sharpness and shatter-resistance. Such knowledge can be used for the development of new materials.

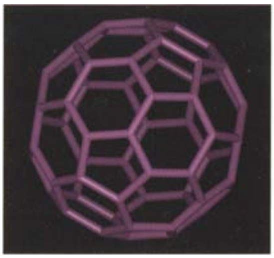
Carbon – new morphologies

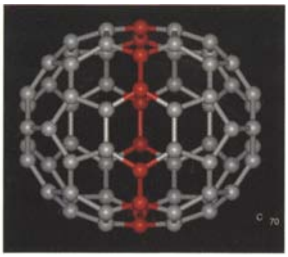
BUCKYBALLS AND NANOTUBES Minute particles with great effect.

Both of the nano raw materials described below have attained a form of cult status. Both represent, at different times, entirely new discoveries. Of the two it is nanotubes that today are of greater interest due to the vast innovation potential they promise for new products.

Buckminster fullerenes, buckyballs

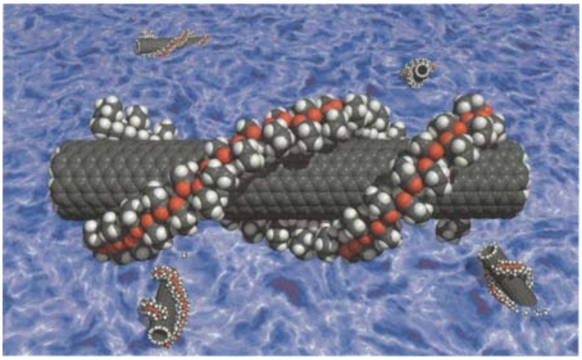
Today carbon is the nanomaterial with the greatest and most interesting innovation potential. It exists in two primary morphologies – in the form of diamonds, the hardest known natural material in the universe, and as graphite, a particularly soft material. The discovery of a third hitherto unknown morphology, carbon fullerenes, was a sensation. They are semi-conductive and as such can be regarded as lying in-between graphite, which is metallic and conductive, and diamond, which is isolating. They are also soluble in organic solutions. Harold W. (Harry) Kroto (University of Sussex, UK), Robert F. Curl and Richard E. Smalley (Rice University, Houston, USA) discovered in 1985, during an experiment designed for outer space, that nature itself produces C_{60} and C_{70} (carbon) molecules. The name "Buckminster Fullerenes" is derived from the formal similarity of the C_{60} carbon molecule to the geodetic domes constructed by the American architect Buckminster Fuller, the most famous of which was constructed for the Montreal Expo in 1967, and for which Kroto had a soft spot. C_{60} carbon molecules or "Buckminster Fullerenes" are also known colloquially as buckyballs.





The typical Buckyball is represented by a C_{60} carbon molecule. Its geodesic structure is reminiscent of a soccer ball as well as of Richard Buckminster Fuller's architecture, which provided the inspiration for its name.

There are several variants of buckyballs. The C_{70} carbon molecule is just one of these and exhibits a form more akin to an American football than a soccer ball.

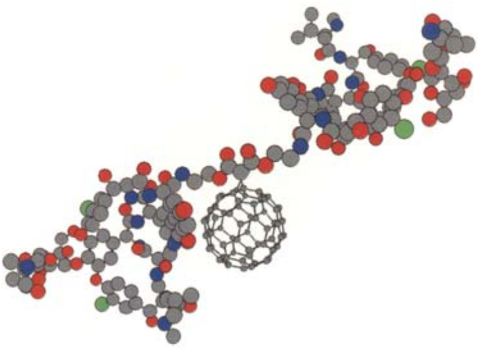


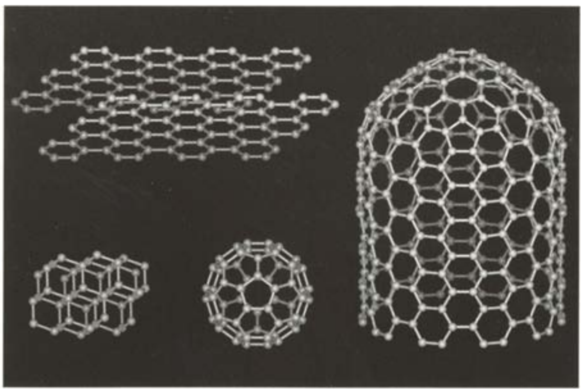
Single-walled nanotubes, when encapsulated in polymers, can be used as chemical containers in order to be placed on a functional substrate. The electrical and mechanical properties of carbon nanotubes are preserved yet their solubility properties are modified so that they become soluble.

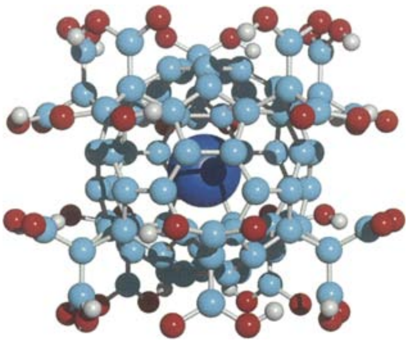
A new buckyball-enriched variant of the antibiotic Vancomycin has been developed to overcome resistance against the drug. Antibodies are supposed to dock onto the buckyballs to produce a targeted antibiotic and a potential new line of defence against biological weapons.

Until 1985 carbon was known only in two basic morphologies: graphite (top) and diamond (bottom left). The discovery of the Buckminster fullerenes (bottom centre) and carbon nanotubes (right) represents a third morphology.

Of those large molecules, the C_{60} is the most rounded and symmetrical. It consists of 60 carbon atoms and has a diameter of 0.7 nm. The spheroid shape, consisting of 12 pentagons and 20 hexagons, looks very similar to a black-and-white soccer ball. It is part of a family of so-called "fullerene" molecules with a large number of atoms, to which the ellipsoid C_{70} molecule also belongs.
In 1991 Wolfgang Krätschmer at the Max Planck Institute for Nuclear Physics in Heidelberg and Donald Huffman at the University of Arizona, USA, developed a technique for making buckyballs in large quantities. The easily recognisable buckyball was accorded the title "molecule of the year" by the journal *Science* in 1991. At the time, the buckyball was prophesied a similarly bright future to that of the nanotubes today, but it has







Scientists manipulate nanotubes at minute dimensions. A revolutionary class of contrast agents for magnetic resonance screening was developed in 2005. A single gadolinium atom is placed within the cage of a buckyball. Carboxylic groups are attached to the exterior of the buckyball, simultaneously making the material soluble and improving its efficiency as a contrast agent.

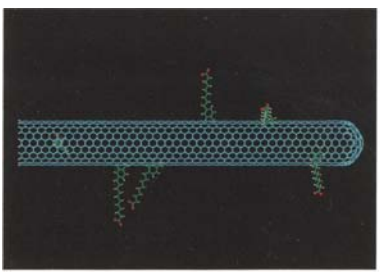
One way in which chemists manipulate carbon nanotubes is by creating nanotube derivatives – nanotubes that are decorated with extra molecules that give the tubes unique properties or act as chemical "handles" for further manipulation.

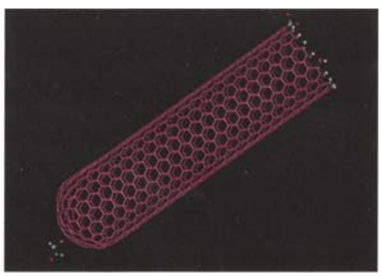
proved inferior in comparison to other possibilities. In 2007, however, a further interesting discovery was made in the field, as before also at Rice University: a Boron buckyball or so-called B80 B-fullerene was discovered with an additional atom in the centre of each hexagon, making it much more stable.

Carbon nanotubes

The current stars of the nano-world are another variety of the fullerenes known as carbon nanotubes (CNT), or simply nanotubes for short, and were discovered in 1991 by Professor Sumio Iijima at the electronics concern NEC in Tsukuba, Japan.

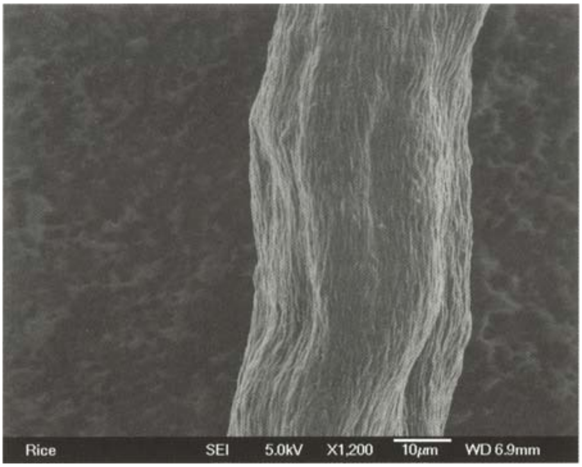
Nanotubes consist of single-walled (SWNTs) or multi-walled (MWNTs) carbon tubes of rolled layers of graphite. They have a diameter of between one and a few nanometres and can be several nanometres long. They have a tensile strength far in excess of steel, yet are flexible and lighter. Their thermal conductivity is also higher than any other known material, exceeding that of diamond. Their key properties – great strength coupled with low weight – are predestined for use in future composite materials. Nanotubes can act as semiconductors or as conductors. Their electric conductivity is excellent, and as such nanowires are of great interest for electronic applications such as minute circuits and a generally more efficient use of electricity. The mechanical properties described are, however, only attained when the atomic structure of the nanotubes is faultless. Any defects result in impaired performance. A particularly ingenious variant developed for certain applications are filled nanotubes.





Single-walled carbon nanotubes can be extruded to form macroscopic fibres.

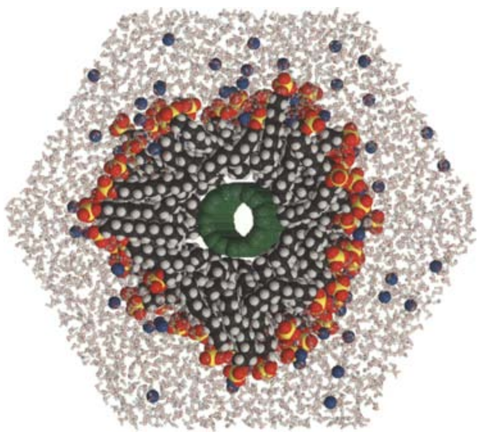
This image shows a single carbon nanotube isolated and enclosed in a molecule. Under particular conditions carbon nanotubes have been found to exhibit fluorescent properties. In the near-infrared range, light is absorbed and emitted.



Extremely stable, lightweight and conductive – ideal properties for a perfect raw material for the future. New application areas are constantly being discussed in the sciences and breakthroughs and new discoveries occur regularly. Nanotubes are always mixed with other materials or applied to surfaces. The company Hyperion Catalysis International, for example, mixes small quantities of electrically conductive nanotubes into plastics to facilitate electrostatic discharge. Plastics are likewise mixed with nanotubes to improve their mechanical properties considerably.

The development of nanotubes is continually being optimised. The cost for their production has fallen significantly since the initial high cost of manufacture. The company Carbon Nanotechnologies Inc., founded by Richard Smalley, one of the discoverers of the buckyball, produces nanotubes in large quantities. The Frontier Carbon Corporation FCC, founded in 2001 in Tokyo, produces fullerenes including nanotubes in vast quantities (1500 t per annum). With the development of the so-called "Baytubes" method (developed in 2005 by Bayer MaterialScience AG in cooperation with Bayer Technology Services GmbH in Germany), high-quality nanotubes can now be produced much more cheaply and in large quantities. Similarly, the NASA recently developed a method for the cost-effective mass production of nanotubes.

Although nanotubes can now be produced comparatively economically, they are still too expensive for use in large quantities, for example as additives for concrete. In order to be practical for the mass market, it is essential that they are to be obtained not only at a



consistently high quality and secured availability but also at a sufficiently low price. Before the production of nanotubes can become feasible for the mass market, it must also overcome some hurdles with regard to purity. Nevertheless, it seems as if it is only a matter of time before these problems will be overcome. From then on, the way is paved for highly stable materials for the construction of bridges (e.g. ultra-strong concrete) or of skyscrapers. The NASA is using nanotubes in its research for a truly visionary project – an elevator into outer space!

Due to their fibrous form (architects invariably think of asbestos), nanotubes are suspected of presenting a safety hazard, unlike the buckyballs. More on the issue of "risks and safety" can be read in the respective chapter (see p. 44 ff.).

Other nano raw materials

The chemical industry, which sits at the beginning of the chain as a supplier of raw materials for further processing, uses various raw materials. Nanoparticles can be produced from different substances. The most common nano raw materials include polymer emulsions, aerogels and zeolites, carbon black, dendrimers, nanosilica and metallic nanoparticles, titanium dioxide, ceroxide and aluminium oxide. The proportion of

The largest nanotube model in the world was produced by a team at Rice University in Houston, Texas.

The pattern of the building shell of the Watercube, the National Swimming Centre for the 2008 Olympic Games in Beijing, China, resembles oversized buckyballs, but has otherwise nothing in common with nanotechnology.

nanoparticles in a composite material or coating is comparatively small, so typically only small quantities are required. For example, the nano raw material is mixed into another raw material and then processed further, or a coating that contains nanoparticles is applied using conventional methods such as dipping or spraying using techniques such as CVD (chemical vapour deposition).

FUTURE Minute particles with a vast market potential.

According to several surveys, the predicted market development in the field of nanotechnology is enormous. Nanotechnology is a growth market with a huge potential. Business enterprises, banks and business consultancies outstrip one another in their estimation of the market potential of nanotechnology. Politicians are equally active and numerous governments are funding nanotechnology initiatives. The primary motivations are economic growth, better international competitiveness resulting from innovation and technological advantages, the creation and securing of jobs and the principle of tackling environmental problems through appropriate technology. Strategy plans are drawn up, such as the German government's "Nano-Initiative – Action Plan 2010", and exchanges between science, business and politics are intensified to help translate scientific know-how into marketable products.

On the international arena, the USA, Japan and Germany form a triumvirate of nanotechnological development and currently lead the field. China, South Korea and Russia are rapidly catching up and other nations such as India are currently mobilising. In Asia, Japan heads the field with Germany clearly occupying first place in Europe.

In the European context, the EU has provided almost 3.5 billion Euro through its "Cooperation" programme for nanotechnology, nanosciences, materials and new production techniques as part of the 7th EU Research Framework Programme (2007–2013). In Germany, the Federal Ministry for Education and Research (BMBF) has funded research in the field of nanotechnology since the late 1980s (146.5 million Euro in 2007) and since 1997 provides special funding for nano-enterprises.

In January 2000, the US government under President Clinton founded the "National Nanotechnology Initiative", which since then has been responsible for the sizeable financial funding of research and development activities. In December 2003, President George Bush signed the "21st Century Nanotechnology Research and Development Act" in the Oval Office, providing a further 3.7 billion US dollars of research and development funding between 2005 and 2008.

According to the New York business consultancy Lux Research, a total of 12.4 billion US dollars were invested worldwide in research and development in the field in 2006, with nanotechnology-based products already being responsible for a turnover in excess of 50 billion US dollars. Governments supported nanotechnology to the tune of 6.4 billion US dollars in 2006, 10% more than in 2005. The USA provides the most funding, followed by Japan and Germany. If one takes into account the comparative international purchasing power parity (PPP) in this context, then China also counts among the leading nations. On a critical note, very little of the respective countries' funding budgets are used to investigate the potential risks of nanotechnology.

In 2006, the industry invested 5.3 billion US dollars worldwide in research and development (19% more than in 2005) with China expanding its investments significantly (68% more than in 2005). Patent applications

in the field rose by 30% totalling more than 10,000 submissions. Of these, 6801 were registered in the USA, with Germany following in second place with 773 applications.
Just as it is difficult to comprehend the minute scale of the nanometre, so are the near-utopian figures quoted for the future by the world of finance. As small as "nano" may be, the market estimation for the field seems inversely proportionate. Lux Research estimates the global market volume for nano-based products in 2010 at 500 billion US dollars, with a projected 2.6 trillion US dollars in 2014. In short, in the time span between 2010 and 2015, nano-based products will have become commonplace and have achieved major market penetration.
According to the market research business Fuji Keizai in a study commissioned by the Ministry of Economy, Trade and Industry (Meti), the Japanese turnover of nano-based products will exceed 26 trillion Yen by 2030, in comparison to its current estimated market volume of 3 trillion Yen. According to the report "Half way to the trillion-dollar market?" compiled by the nano business consultancy Cientifica, the chemical industry will continue to dominate the global nano-market until 2012, before bio-related applications take over the lead. Cientifica estimate a worldwide market volume of 1.5 trillion US dollars (excluding semiconductors) or 2.95 trillion US dollars (including semiconductors) for nano-based products in 2015. According to Cientifica, however, the greatest profits will be accrued by those businesses offering innovative products and not the businesses that produce the (raw) nanomaterials.
The available figures that include the complete turnover of the respective products, i.e. not exclusively their nano-proportion, are gigantic. These figures are the source of considerable hype and seem quite exaggerated. Only a very small quantity of the specific raw material is required to create nanoproducts, and this lies in their very nature. The extremely high market volume prognoses describe the overall market value of the entire product and not its specific nano-proportion and it is important to bear this in mind before getting too impressed by the figures given.
At present the commercialisation of nanoproducts is still at an early stage. The general consensus is that by 2015 almost all business sectors will be influenced by nanotechnology, most notably automotive and electronics. Given such bright future prospects, the financial backing will continue unabated and the demand for venture capital will increase. The innovation potential is there and the competition for international market leadership is already in full swing.
Not so long ago, computers were regarded sceptically. Today most households own a computer, offices are unthinkable without them and before long it seems that nothing much will be possible without mobile pocket-size computers. In future, what today may seem the wonder of nanotechnology may quite simply be the standard, replacing conventional technologies – without a great fuss and for the benefit of everyone.

Branches From aerospace and electronics to automotive, medical and environmental technology to food.

If one is to believe current prognoses, by 2015 nanotechnologies will play a role in all branches of economic life. And it looks very much as if they could be right. In fact, new application areas and products are emerging all the time, although sometimes unnoticed by the public. The average person is relatively unaware and has little idea of what "nano" encompasses, although they may actually have come into contact with it, for instance in advertising for outdoor jackets in supermarkets or suits at a men's outfitter. What it actually means is largely unknown or is at best a nebulous idea. Similarly, the discussions on internet forums vary wildly between fact and fiction.

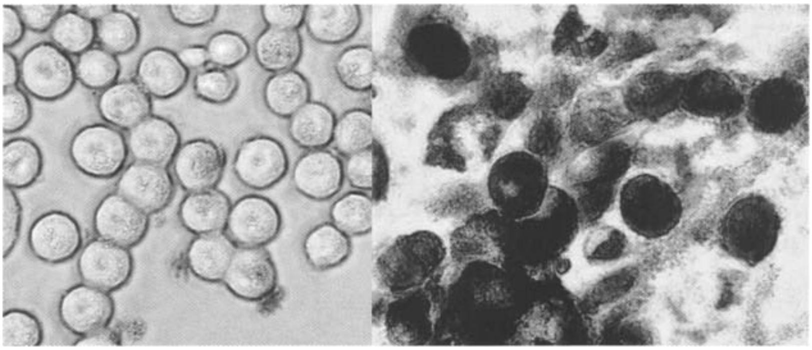
Many products are advertised using the label "nano", however some firms choose to leave this out quite deliberately, possibly for fear of negative press and the concomitant loss of reputation. A decision for or against explicit labelling is at present largely a matter of the respective marketing strategies. However, should the labelling of nano-based products become statutory, this would provide welcome clarification. In 2007, the nano-critical ETC Group (Action Group on Erosion, Technology and Concentration) held a competition for a nano symbol to stimulate further discussion on this issue, as at present no general regulation for how to handle nanotechnology exists.

Nanotechnology already plays a major role in many branches. The following represent a selection of applications in no particular order:

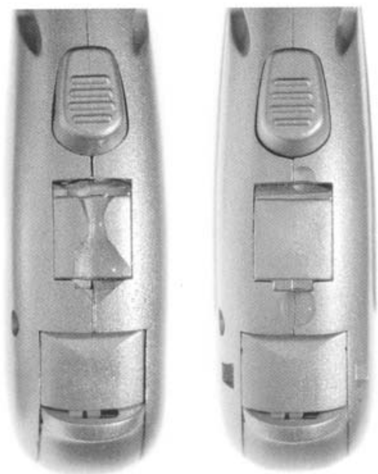
The shiny surface that nanocubes display under the microscope holds its promise. An ideal medium for storing hydrogen, its nanopore structure means that 2½ grams have an interior surface area equivalent to the size of a soccer field. They could potentially be used as energy stores for fuel cells for powering mobile electronic equipment.

Cancer cells before and (right) after the take-up of ironoxide nanoparticles. Set in motion using a magnetic field, they develop heat that irrevocably damages the cancer cells.

- The cosmetic industry, most notably haircare and skincare products as well as decorative cosmetics. For example, strong UV protection can be achieved using TiO_2 nanoparticles. Due to the nanoscalar size of the particles, they are invisible on the skin even when present in large quantities. If the particles were larger a cream of the same UV protection factor would have a visible white creamy appearance.
- Air and space travel, automotive and formula 1 – more so than most others, these branches are driven by innovation, often with extensive roadmaps for the development of new application areas such as ultra-light yet extremely stable materials, which for space travel reduce kerosene consumption and for formula 1 increase speed. By adding nanotubes to plastics, very light yet stable materials can be created. Lightweight and highly insulating aerogels protect space shuttles and rockets against the extreme heat and cold.
- Modern cars already make use of scratch-resistant paints that retain their gloss longer by protecting against scratching that can result from quartz dust when driving or against abrasion from car washes. Mirrors darken photochromatically as the light changes. Headlamp casings can be made self-cleaning with the help of photocatalysts.
- Medicine, life sciences and pharmaceutics benefit from nanotechnology, which for example help improve the reception of implants by the body. Advances in the treatment of cancer have been made possible by the ability to allow agents to target tumour cells



A special nanocoating applied to a hearing aid renders it water-, fat- and dirt-repellent.



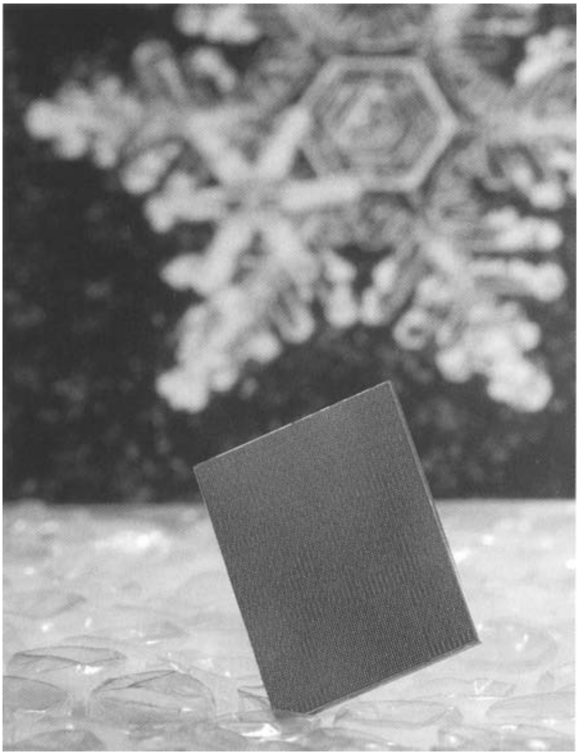
directly without damaging the entire organism in the process. Antibacterial hearing aids have significantly reduced the incidence of inflammation among wearers. Health insurers have recognised this and are willing to pay for such innovative equipment. Antifogging mirrors for stomatoscopes help dentists work more easily. Likewise antibacterial catheters contribute to a reduction in infections in hospitals.

- Information technology and electronics – nanotechnology contributes to the improved performance of computers whilst enabling components to become ever smaller. So-called "embedded systems", whose implementation is largely a factor of miniaturisation, can be found everywhere – from the coffee machine to the cash dispenser to the electronics in car dashboards. Minute transistors are manufactured with the help of nanotubes.
- In the print industry, the non-stick coating of print rollers reduces interruptions for cleaning, increasing efficiency and therefore profitability.
- Cling film helps keep foodstuffs fresh by preventing oxygen from reaching the food and moisture from

In the future computer chips at IBM will employ self-assembling nanotechnology. The natural pattern-creating process that forms seashells and snowflakes has been harnessed to form billions of identical holes to create insulating vacuums around the miles of nanoscalar on-chip wiring.

escaping. Nanotechnology allows ketchup to be dosed perfectly and nano-based additives help foodstuffs to stay fresh longer or to transport vitamins via micro-capsules in so-called "functional food".

- Environmental technology – energy, climate protection, water/wastewater and recycling – is a field of ever increasing importance. A central aspect is the conservation of water as the most valuable resource and global water provision. With the help of nanotechnology dirty water can be cleansed using photocatalysts, which contributes towards providing clean drinking water. Anti-reflective coatings improve the efficiency of photovoltaic systems, thereby reducing CO_2 emissions. Recycling can be simplified through the use of "debonding on command" systems that ease the separation of materials from one another for separate reprocessing. Bond-on-command systems contribute towards long-term heavy-duty adhesion between steel components, for example in the construction of wind farms.
- The defence departments of different countries are particularly interested in the advantages offered by



Nanoparticles in toothpaste can help alleviate pain felt by sensitive teeth.

nanotechnology for warfare. This applies both to high-tech clothing for soldiers or camouflage colouring on military equipment as it does to weaponry.

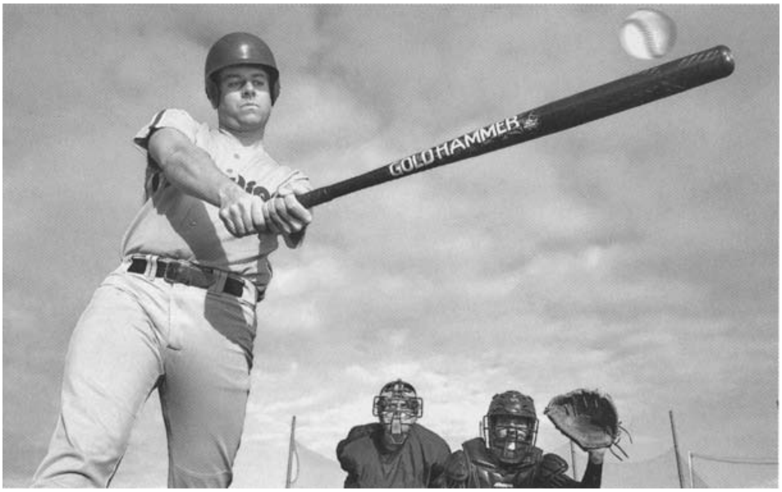
- Optics and light – energy-efficient lighting is continually being improved. Organic light-emitting diodes (OLEDs) produce light from a low source of energy. Ultra-thin lighting solutions, such as illuminated wallpapers, will soon become reality.
- In the textiles industry, so-called "smart textiles" are equipped with additional functionality. Self-cleaning membranes triggered by photocatalysts are now increasingly being used in architecture, for instance in airport buildings or sports arenas. Dirt-repellent suits can already be bought, as can water-repellent jackets or antibacterial socks that reduce unpleasant odours. Microcapsules anchored in textiles release perfumes, for instance seductive perfumes for lingerie.
- In sport and recreation, ultra-lightweight extra-robust tennis rackets or extremely smooth-running skis are already available. Motorcycle helmets with anti-fogging visors improve road safety for the rider and similar technology in sports goggles improves visibility for swimmers or snowboarders.

We could extend this list of applications indefinitely; they affect practically all realms of life.

The applications from the field of construction that follow in the next chapters range from scratch-resistant lacquers and antibacterial paints, dirt-repellent textiles and self-cleaning glass to air-purifying concrete, highly efficient insulation materials and easy-to-clean sanitary ceramics. According to Lux Research, in comparison to other products, such materials and surfaces come onto the market at a relatively early stage in their development but then need a long time to become established. Applications in electronics and IT come onto the market only once they are more fully developed but spread much more rapidly. As such, given we are in the early days in the overall development of "nano", the truly high-tech architectural visions await us in the future. An exciting period lies ahead.

Anti-fogging coatings on motorcycle helmets and sports goggles reduce fogging and ensure a clear view.

Through the integration of nanotubes (baytubes), this baseball bat is not only more robust but also lighter than other comparable conventional bats.



Form Follows Function?

NANO / NO NANO Truth and authenticity in the use of nanomaterials.

In architecture, two fundamentally different design approaches prevail when dealing with materials and surfaces:

Honesty of materials – "what you see is what you get".

This approach is favoured by those architects for whom authenticity is a priority and who value high-quality materials such as natural stone or solid wood.

Fakes – artificial surfaces that imitate natural materials.

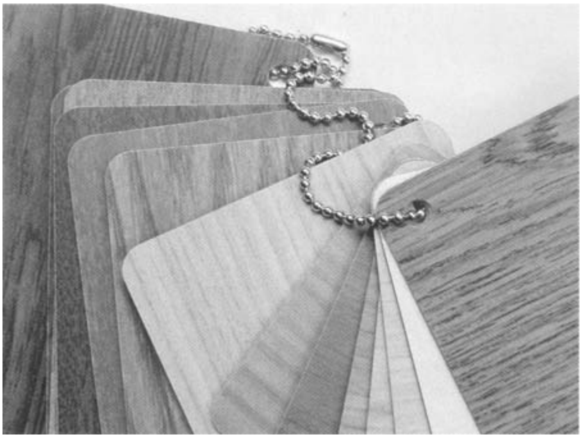
For the most part, "fake" materials are chosen for cost reasons. Wood, whether in the form of veneer or synthetic wood-effect plastics, is considerably cheaper than solid wood. Even concrete or venerable walls can be had *en plastique*. Artificial surfaces are "brought to perfection" – the grain can be tailored to appear exactly as desired, the colour matches the sample precisely and does not change over the course of time. More and more "patinated" surfaces are being created that exhibit artificial aging: instant patinas, precisely controllable. Certain design approaches prefer the provocation of deliberate artificiality.

In future a third option will be available:

Functional nanosurfaces, emancipated from the underlying material.

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: nano particles 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 customised to have specific functional properties are set to become the norm, heralding a switch from catalogue materials to made-to-measure materials with a definable combination of properties – a perfectly modular system. A danger is that surfaces invested with functionally improved properties may no longer age naturally, eliminating the patina that lends buildings and spaces their particular character and charm. However, the concurrent availability of perfect and "imperfect" or authentic materials should provide greater design freedom. With careful design, the use of perfect surfaces with a "cleaner" aesthetic can contrast effectively with the patina of natural surfaces. Nanomaterials extend our design possibilities. The aging process itself becomes a question of time frame – it can set in earlier or later according to the material chosen. Likewise, aesthetic, functional and emotional qualities can be expressed more easily – it is simply a matter of choice. As such "Form Follows Function" applies more than ever and for all kinds of building tasks.

However, the developments outlined are not without their hurdles. In the building sector, a large proportion of work concerns renovation, conservation work and



"Fakes" – laminates that simulate real materials. Real wood exhibits other haptic, acoustic and sensory properties than wood imitations.

building in existing fabric. In this field nano high-tech materials meet old, conventional materials and methods with which they should be compatible. The use of new materials derived from nanotechnology is not just a financial risk for those involved but also a legal risk. Many builders often do not like to offer guarantees in areas they do not know well, which explains why it is sometimes difficult to find a suitable firm for certain services. Likewise a good product can be compromised by poor installation or the difficulty involved in installing it. Finally, building products need to be certified by the building inspectorate, a hurdle that needs to be overcome for nanoproducts as well.

The question of authenticity also arises in the way that nanomaterials themselves are presented. In many cases the producing companies do not communicate well whether nanotechnology plays a role in the products they sell or not. A number of different phenomena can be observed in this context:

"Nano-Fake" It is not unknown for products to be marketed as "nano" (because "nano's always good...") even when the product has nothing to do with it – which is sometimes determined through laboratory analysis.

"Nano-Proof" There are also situations where companies are unwilling to provide detailed information about the individual products. Studies are not always freely available. Other producers, on the other hand, market products with a variety of quality marks or certificates. Some regard quality marks without a statutory basis as lacking impartiality – the commissioning client can influence the testing method and therefore the results and their assessment. Nevertheless, quality marks do offer consumers a degree of purchasing confidence that is better than none. Ideally, statutory prescribed testing methods should be established that are independent and precisely defined.

"No-Nano" Occasionally products appear in the "nano" context whose producers, when asked, assert that their products have been produced without the use of nanotechnology. Sometimes the confusion results from differences in the definition of "nano", although as mentioned previously no precise definition exists. It can also happen that "nano" is an aspect of a particular product but that this is not mentioned in the company's publicity communications or marketing for fear of negative publicity ("nano risk"), for example when the licensee of a nano patent intentionally declines to mention "nano" in its communications.

It can at times be difficult for architectural offices and designers to find appropriate partners for information on nano-based products and technology. Without such partners, the danger is that important details regarding the application of nanotechnology products are omitted, for example that hydrophilic glass is incompatible with silicone and should be used with alternative sealants. Interesting and competent partners are often to be found in the product development and technical departments of the producing companies, or even in their laboratories.

Ecology and economics

Environment Nanotechnology combines ecology and economy.

The use of nanotechnology offers ecological and economic advantages for energy efficiency and the conservation of resources. Technologies that help reduce climate change are in demand more than ever before. In future, ecology and the economy will become inseparably connected, as preventive measures will be cheaper in the long term than remedying the damage caused. Ecology pays off and climate protection pays off – provided one is open to technological possibilities and the conditions of use they involve.

Nanosurfaces are not an aim in themselves, but a response to a demand for innovation, also with regard to effective new marketing factors. However, the label "nano" on its own is no guarantee for innovation. Many a sound technological innovation has foundered on misguided marketing strategies and consumer disinterest – it is essential to communicate its purpose clearly and that whatever it may be actually works.

Innovations have a hard time breaking into the notoriously conservative construction sector. Cultural differences in the mentality of the different users worsen their chances still further – the willingness to risk something new varies considerably. Is a principle explored through "trial and error" or analysed and tested exhaustively before being realised? A decisive factor in this respect is the liability obligations of architectural offices, however this cannot be the sole reason for such inordinate caution. A further reason is that construction firms tendering for a contract may price themselves out of the competition if they wish to use more expensive nanotechnology-based products not offered by their competitors.

In the long term, sustainability is essential. Buildings are often planned with 20-30 year cycles, which can make it difficult to incorporate coatings with 2-3 years durability. There are, however, some firms that provide a 10-year guarantee for their nanotechnology-based products. Production processes can also be made more efficient and more cost-effective with the help of nanotechnology, by reducing the amount of energy and raw materials required to a minimum – either directly or indirectly. Direct reductions can result, for example, from the use of ultra-thin scratch-resistant lacquers, reducing both the number of production stages and material usage. Indirect savings can result, for example, from the use of highly efficient insulation, which not only actively helps to conserve energy but also uses less material in its manufacture and therefore reduces transport costs.

From an economic point of view, self-cleaning surfaces reduce the cost of cleaning. From an ecological point of view, it is also advantageous when the lifespan of ma-

Ecology and economics will become inseparably connected, as preventative measures will prove to be cheaper in the long term than remedying the damage caused.

terials can be extended – materials suffer less wear and tear from regular cleaning or aggressive detergents. Likewise, far fewer detergents pollute the environment. Both contribute towards conserving resources.

Photocatalytic surfaces are able to markedly eliminate many pollutants in the air through oxidative catalysis. Antibacterial surfaces can reduce the use of biocides. Highly efficient insulation saves energy. Photovoltaic elements are made more effective.

Environmentally friendly production methods, energy efficiency, reduced environmental pollution and the conservation of resources are chances which nanotechnology offers. Ideally, emphasis should be given to the overall eco-balance across the entire life cycle of a product or building rather than one individual aspect. The risks of environmental impact on air, water and the human organism are part of this, as we shall see in the following chapter. To a certain degree, there is always some apprehension when new technologies are introduced – this is a normal emotional reaction. Why should this be any different for nanotechnology when safety, jobs, environment and health may be at risk to a greater or lesser degree? So, nano or no-nano? What is more important is that we are aware of the risks. A number of different initiatives have been established that focus on aspects of safety, risks and the impact on health and the environment, undertaken by NGOs such as the nano-critical ETC-Group (Action Group on Erosion, Technology and Concentration) and Greenpeace as well as informative studies by governments and industry such as "NanoCare", INOS "Identification and assessment of the health and environmental impact of technical nanoscalar particles" (both initiatives by the German BMBF in conjunction with industry), the EU "Nanosafe" project with participants from science and business or the "Safer Nanomaterials and Nanomanufacturing Initiative" (SNNI, Nanoscience and Microtechnologies Institute and Air Force Research Laboratory, Oregon, USA). A possible criterion for the application of nanotechnology in future could be that the advantages of their use should significantly outweigh the possible associated risks. Likewise, not all nanotechnologies should be judged the same way. In principle, nanotechnology offers a chance to improve the environment, and whether or not "nano" is involved, the environment is still endangered. An openness towards the new technological possibilities could offer a ray of hope.

Is the devil in the dwarfs?

DEBATE On the risks of nanotechnology.

by Marius Kölbel

At the beginning of this book, the author mentions what makes nanoparticles so special: it is the fact that familiar everyday materials exhibit new, sometimes spectacular properties when they exist as particles of less than 100 nm in size. Below this magic threshold, particular physical laws come into effect that we don't otherwise see. One reason for this is the very high surface area to volume ratio for such minute particles and the accompanying electronic structures on their surface. Materials become invisible because they are so small that they no longer interact with light; gold when dissolved in water produces an intense coloured liquid; other substances develop a strong catalytic effect at such small sizes. The applications for these and other special physical properties are described in numerous examples in this book.

It does not take a great deal of thought before the question arises as to whether such changes in physical behaviour below a particle size of 100 nm are necessarily always positive. When familiar and unprepossessing materials suddenly become invisible, illustriously coloured or catalytically active at small sizes, is it not also possible that substances in the form of nanoparticles could also develop less welcome new properties, for example become toxic, carcinogenic or environmentally unsafe?

Anyone who has followed the developments in nanotechnology in recent years will know that this issue has sparked a turbulent debate. Potential users of such a new technology quite naturally also want to know what problems may be associated with it and how they may have to deal with them. This chapter aims to give a short overview of the possible risks associated with nanomaterials, the ongoing discussions and activities on this topic and the consequences one can expect these to have for users and consumers.

It is in fact the case that nanoparticles do exhibit properties that are not only beneficial, but could also have damaging effects – and this is not limited to nanoparticles of substances that are already toxic. Likewise, a "positive" effect such as greater catalytic activity represents just one side of the coin. It is not unlike weeds: weeds do not really exist, they are just plants in the wrong place. The catalytic effect of nanoparticles of a particular substance can be useful in many circumstances – they can accelerate or initiate reactions in the chemical industry, saving costs and energy, they can make it possible to dispense with polluting solvents, help reduce contamination and cleanse air and sewage. However, in the wrong place, for instance the human body, the same catalytic effect could have disastrous consequences. It can lead to inflammations or allergic reactions or even interfere with cellular and genome structures with possible carcinogenic or hereditary effects. It is imperative to protect the human organism against such particles. This is made all the more difficult due to the fact that minute particles can pass through the organism more easily than larger particles. They are so small that, in many cases at least, one can assume that they will not be stopped by the respiratory organ's natural filter systems. Once they have reached the bronchia and lungs, they may not only cause inflammations but can also very easily be transferred to other organs via the blood. Their small size makes it easier for them to pass through cell walls and other biological barriers such as the blood-brain barrier.

Such information helps little to promote trust in nanotechnology. However, irrational fears are uncalled for. It is more important to understand under which conditions nanoparticles can enter the human organism and to develop appropriate means to protect against these. In over 200 years the chemical industry has learnt how to live with hazardous substances. Many raw materials or secondary products used in the manufacture of plastics are anything but harmless, but the industry has learnt to handle them safely, and the final products that tradesmen or users eventually hold in their hands are free of such dangers. A similar principle applies for nanotechnology, especially where special surface qualities or composite materials are concerned. A differentiation between free-floating unbonded nanoparticles and those embedded in coatings or in substrate materials is of essence in the following discussion.

We should first note that nanotechnology is still a very young field and for this reason our knowledge of the potential dangers involved is as yet incomplete. The situation is improving constantly, and some issues that are unresolved at the time of writing will no doubt have been clarified by the time this book has been printed. However, until all uncertainties have been clarified, the general consensus in the field is that precautionary measures are advisable.

Nanoparticles did not first come about as a result of nanotechnology. In fact, they surround us on a day-to-day basis, resulting from different processes such as the combustion of fuels in motors, volcano eruptions or smoke from cigarettes. Nanoparticles are also present in the much-discussed fine dust pollution. The exact proportion depends on the source of the dust as well as other factors such as the distance from its source, temperature, wind speed and humidity. To put it crudely, one could say that perhaps more nanoparticles are already produced today as a result of natural or uncontrolled processes than may be synthetically produced in future.

The industrial manufacture of nanoparticles is also not as new as the media sometimes suggest. Common chemicals such as silicon dioxide, titanium dioxide or carbon black have been produced at nanoparticle scale in large quantities for decades. Safety methods for these processes have been in place for years, not least since the effects of asbestos and other hazardous dusts have become known. Likewise, young enterprises producing new nanoparticles take such protective measures often as standard practice.

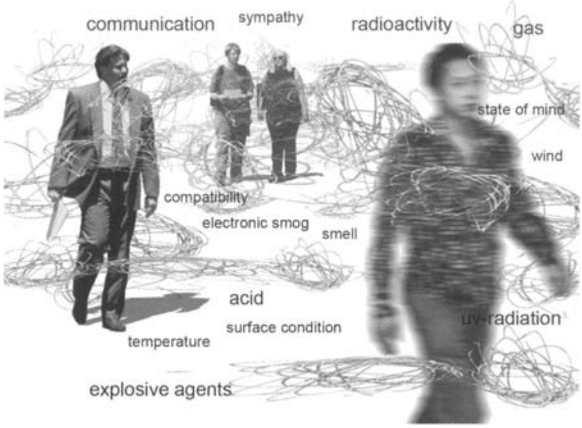
It is also important to know that free nanoparticles only exist for a short while. Nature appears to dislike minute particles, which have a very large surface area, and attempts to reduce their number as far as possible. By way of example, small droplets of water or mercury flow together whenever possible to form a larger droplet. Nanoparticles behave similarly: they have a very strong tendency to clump together in large agglomerations. For the synthesising scientist, this tendency is a hindrance and much research and know-how is required to overcome this behaviour, for instance through ingeniously conceived processes, surface modifications at particle level or the addition of stabilisers. From a safety point of view, however, this tendency is a blessing as it means that nanoparticles rarely exist for long. Even if there were to be an accident and nanoparticles were to escape from a production facility, one can reckon that within a short space of time a high proportion of the emitted substance would rapidly agglomerate not far from the point of escape into larger and therefore less hazardous structures.

A first conclusion is therefore that free-floating nanoparticles can occur through intentional as well as uncontrolled and natural processes. The detection and minimisation of dangers resulting from such particles is a task for environmental protection and occupational safety and health agencies.

For the most part, it is scientists and manufacturing staff who are exposed to free synthetic nanoparticles. Users of nanotechnological-based coatings or materials really only experience them embedded in a coating matrix or composite material.

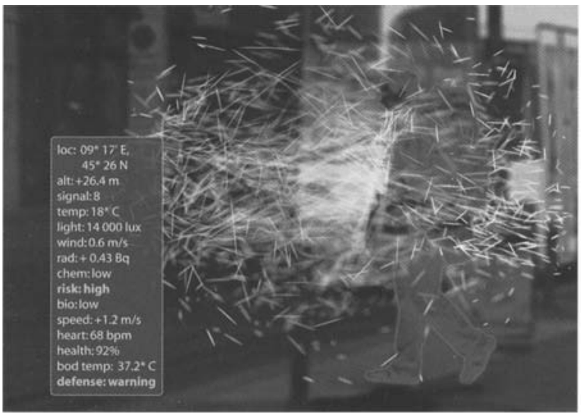
A coating matrix is typically created using the so-called sol-gel approach. A detailed explanation of this technique would exceed the scope of this chapter. Grossly simplified, it involves the application of a silicon-based chemical solution to a surface using a variety of con-

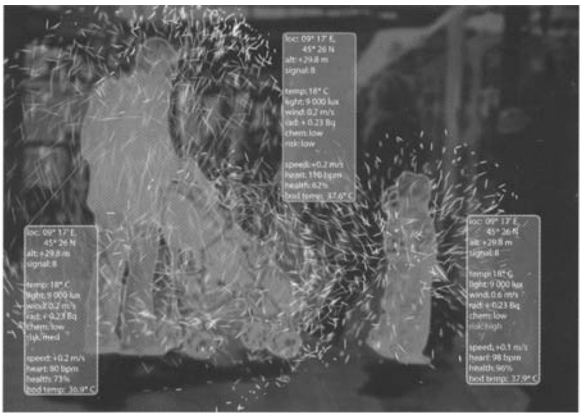
The fictional "smart dust sensory outfit" (design: Jürgen Mayer H.) is an intelligent dust cloud: The Body.Guards continually monitor the surroundings of the wearer for hazardous physical, biological, chemical or radioactive dangers and generate a protective shield in the form of an external immune system. The dust cloud is, of course, self-organising. This description calls to mind the nano-swarms in Michael Crichton's novel "Prey", although in the latter they are anything but protective, but rather the opposite: a deadly threat.



ventional techniques and subsequent hardening, in which the chemicals bond to form a stable matrix and in many cases also chemically bond to the underlying substrate material. Depending upon the composition of the coating solution, the surface can have a glass-like or plastic appearance. If the coating solution also contains nanoparticles, their properties can also apply to the resulting coating, for example ceramic hardness, abrasion resistance, decorative colouring or catalytic activity. In many cases the particles are bound chemically within the coating matrix or to the surface of the substrate and are not released into the surrounding atmosphere.

The question arises as to whether this is also the case when the material is treated or worked mechanically, for instance when broken, sawn, milled, filed, drilled, ground or sanded. Can one ensure that nanoparticles are not then torn out of the matrix and released into the air? To the best of our knowledge this can be ruled out. As previously mentioned, the manufacture of nanoparticles is a complex process that works against nature's resistance to small-sized particles. In most cases nanoparticles are made using a bottom-up process, i.e. one grows them from a molecular solution and stops growth at the desired size. The reverse method – the mechanical grinding down of larger objects to nanoparticles – was until recently regarded as practically impossible. Only very recently have researchers successfully managed to produce nanoparticles of particular materials through a process of grinding down. Again, here too the addition of surface modifiers and stabilisers is necessary. It is therefore highly unlikely that nanoparticles





are accidentally created or released as a result of grinding chippings. If this were so easily possible, we would have been confronted by the emission of nanoparticles since man began to saw and bore materials.

A further problem is not so easily dismissed, and that is the disposal of nano-based materials. In principle it is conceivable that over long periods of time, substrate materials or coating matrices disappear as a result of weathering (which could be intentional, for example for biologically degradable materials), leaving the embedded nanoparticles behind in the atmosphere or the soil. This possibility needs to be considered when nanocoatings and materials are being designed, and in some cases special disposal regulations will almost certainly be necessary. It is also necessary to consider what happens in the case of fire. However, as mentioned earlier, combustion processes lead to the emission of nanoparticles anyhow. Whilst in no way harmless, the application of nanoparticles in coatings will not seriously exacerbate the problem.

In all our deliberations, we should not forget that we are always talking about minute quantities. One of the major advantages of nanotechnology is the vast savings in material consumption. If one imagines a sugar cube broken down into nanoparticles, one could cover approximately the size of a football field with them. This example illustrates just how small the quantities involved are, should the worst come to the worst.

The second conclusion we can draw is that workmen and consumers of nano-based coatings are not subject to nanoparticle emissions, as the particles are firmly bound within a matrix, even when mechanically worked or worn. In some cases special disposal methods may be necessary at the end of the product's life cycle.

So far, special regulatory instruments do not exist for nanotechnology. The fact that familiar materials behave differently at the size of nanoparticles and are in fact to be seen as new chemicals has not yet found expression through laws and regulations. In many cases existing regulations will be sufficient for the certification of nanoparticles too. They will be categorised as new substances (even when the "parent material" is well-known) and as such will be subject to the same proofs and hazardous material classifications as other chemicals. The current Reform of the European Chemicals Regulation (REACH) does not include any special considerations for nanomaterials, however environmentalist and consumer protection activists have voiced major objections and may bring about a revision of the regulations in this respect.

It is to be welcomed that the debate on the dangers of nanotechnology has begun at such an early stage in its development. As has been seen with nuclear energy and more so with genetic engineering, public debate on the negative aspects of new technologies after such technologies have become widespread is highly counter-productive. In the case of nanotechnology, an intelligent consideration of potential risks is taking place for the first time parallel to the development and marketing of the first products. All relevant interest groups are involved from the outset: science, business, politics and non-governmental organisations are cooperating in an attempt to establish a common consensus as well as integrating input from the broader public. This process is taking place in many countries at a national level, but also on the European Union level and in international councils such as the ISO and OECD. In many states generous public funding has been made available for research projects that examine the possible risks of nanotechnology, stipulating that the findings are made available to the public.

Businesses that choose to employ nanotechnology for new products or to improve existing products will without doubt be confronted by challenges resulting from the ongoing debate on the risks of nanotechnology. In most cases it will also be necessary to invest time and financial resources in development. One can, however, expect that the later added value will more than outweigh this investment. Those who successfully implement nanotechnology today demonstrate not only their entrepreneurialism but will also enjoy a competitive advantage for a long time to come. The improved quality and functionality of materials together with a minimum of material input will convince consumers too.

Nanotechnology and product design

DESIGN CONCEPTS The creative industries discover a future market.

by Sascha Peters

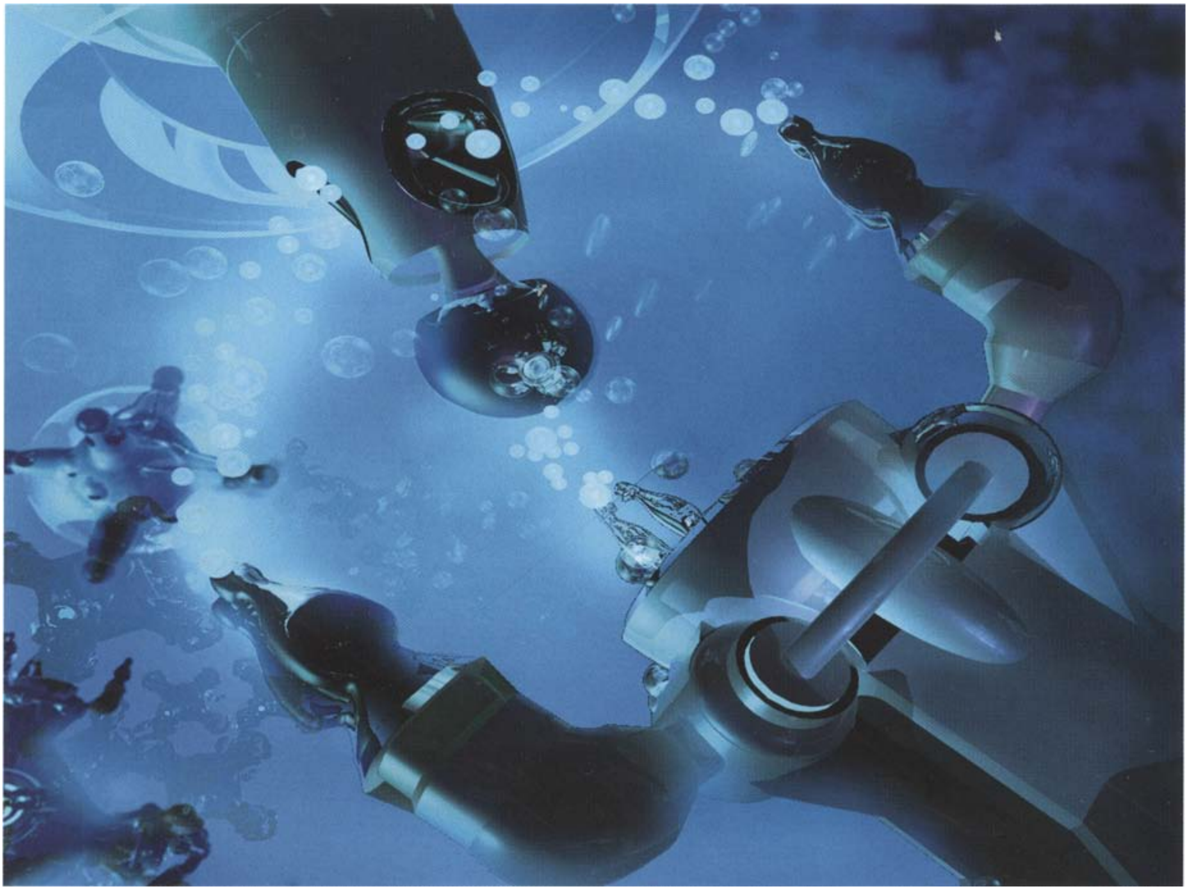
An imaginary scenario for the year 2015: the depletion of material and energy resources and accelerated global warming force the authorities to enforce stricter conditions for the automotive industry. In future, a vehicle must be 100% recyclable after a minimum lifespan of five years. Volkswagen reacts to the stricter statutory conditions by developing a new production process. To ensure their long-term competitiveness, they employ billions of nanomachines, each less than half a millimetre in diameter, which are able to automatically construct as well as dismantle the lightweight structure of a new car, the Nanospyder. Thanks to the additive and highly flexible production process, the Nanospyder is optimised in all respects – weight, performance and energy consumption. Intelligent self-deforming zones anticipate the effects of external force and ensure the highest possible degree of security.

Is this a promising vision or just science fiction? In most cases, this is the typical reaction to such visionary design concepts. An article in *Der Spiegel* from 30th October 2006 reporting on the results of a design competition at the Los Angeles Auto Show goes as far as to use the headline "Ideas for the compost heap" (Grünweg 2006). In fact, the competition entry featured in the article is based on current technological developments in the textile industry made in the Czech Republic. In late 2004, researchers at the Technical University of Liberec filed a patent for a machine for manufacturing nanoscalar fibres. The potential application areas for these fibres include medicinal technology (e.g. treatment of viral infections) and the building and automobile industries.

That the designers Patrick Faulwetter, Daniel Simon and Ian Hunter found the appropriate environment for developing technology-driven visionary scenarios for the automotive industry in the design centre of a leading German automobile manufacturer in California clearly illustrates a deficit in the German economic climate (Kerka et al. 2007). Although the number of patent applications in Germany ranks among the highest in the world, the marketing of such technological innovation usually takes place elsewhere. The iPod is a case in point. Although the Fraunhofer Institute, as the creators of the MP3 format, receives a multi-million figure in licence fees every year, it was an American concern that took the shopping shelves of the world by storm, and in the process transformed the way people consume music (Peters 2006).

In a recent study, the business consultants Booz Allen Hamilton listed Adidas as the only German company in their shortlist of current leading innovators. The reason given for their success: the early involvement of the

Nanospyder – a design study for the LA Design Challenge 2006: Nanospyder production using nanomachines.



"creative industries" (design, architecture, marketing, PR etc.) in the innovation process, i.e. the direction of research and development activities towards the market place. According to Heinz-Jürgen Gerdes, director of Bremer Design GmbH, "the creative industries imbue technological solutions with added value in that they turn an invention into a marketable product" (Peters 2007).

In this respect, the comparatively new field of nanotechnology offers good opportunities. Up to now, potential application areas have been put forward by researchers: "cars that can change their colour at the press of a button, clothes that fulfil bodily functions, or intelligent medicines that find their own way to where they are needed", are just some of the loose concept descriptions proposed (Oesterreicher 2006). Experts warn that not enough is being done to convert research findings into commercial products (Niesing 2006). Here the need to invest more in the creative industries becomes apparent.

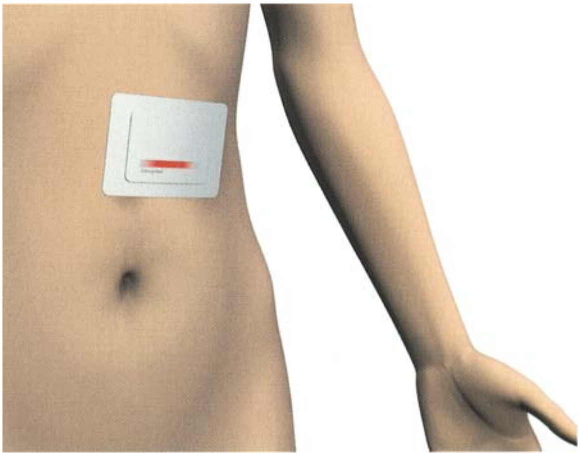
In addition to nano-enriched surfaces, information technology is another potentially vast market for nanotechnology. There is enormous potential for the miniaturisation of electronic components and a greater density of their arrangement. Today it is already possible to realise computer circuits on chips of a size of 90-130 nm and this is expected to sink to 23 nm by the year 2020: "microelectronics will become nanoelectronics" (Hartmann 2006). In the near future, the variety of different devices we currently employ (mobile phone, PDA, MP3-player, digital camera etc.) will probably merge into a single device – a challenging task for industrial

Nanospyder: LA Design Challenge 2006.

Reducing the risk of infection using nanosensors.

design! The computer concern Apple once again has made a first initiative with the iPhone: after the iMac, iTunes and iPod the fourth in a series of revolutionary developments from Apple in the last decade. It is no coincidence that the creative industries have traditionally enjoyed a central role at Apple and are involved in strategic decisions from an early stage.

Of particular interest for product designers are the possibilities offered by ever smaller electronic components in conjunction with textiles. "Smart textiles", intelligent clothing, is a term enjoying particular currency at present. Examples of products range from outdoor jackets in which an MP3-player or heating elements have been "woven-in" to organic light-emitting diodes (OLEDs) that will help improve night-time safety for fans of extreme sports (Peters, Kalweit 2006). Research projects are also



currently investigating textiles with integrated sensors that can monitor the health (e.g. blood sugar level) of the person wearing them (Halbeisen 2006).

The ability to monitor body functions and weather conditions was also the aim of a graduate from the University of Duisburg-Essen. In 2006, design students were asked to develop concepts for converting the potential of nanotechnology into marketable applications. Kevin Kreft devised a product called "Sensoa", an early-warning system for sportsmen and climbers to avoid exhaustion and inclement weather conditions. A further interesting concept, which again illustrates the potential the creative industries have to offer, is Martin Langhammer's "Nanoplast" concept, which detects infections in wounds through the use of nanosensors that react to certain characteristic proteins. A display that turns red warns the patient or carer of the possibility of potential health risks.

These examples demonstrate the far-reaching economic potential that a future nanotechnology market may have across all sectors. By involving creative industries in the innovation process from an early stage, the conversion of technological potential into marketable products can be spurred on.

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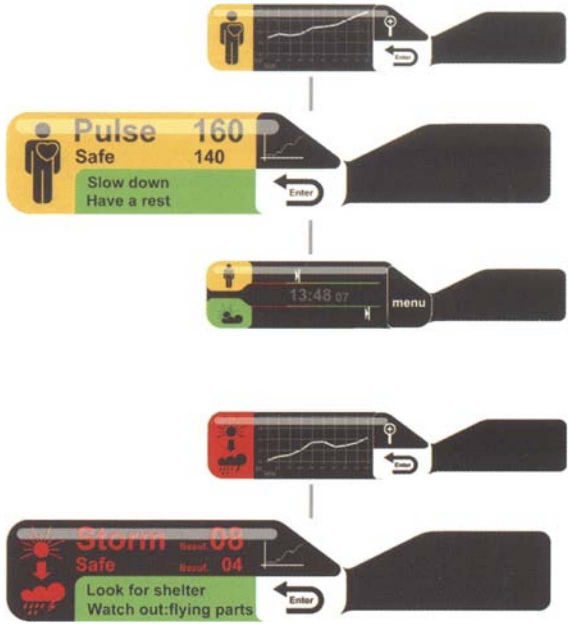
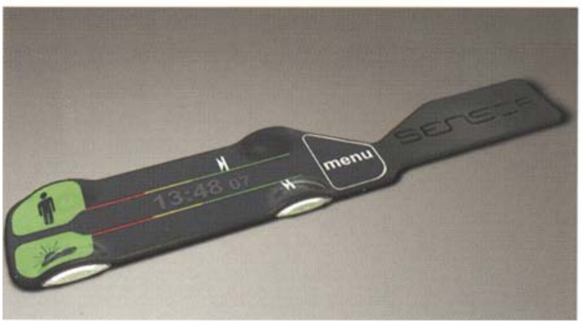
Body performance data for extreme athletes.





Functions and applications

By far the most compelling argument for using nanotechnology in architecture is for greater energy efficiency. Nanotechnology offers a new technological means with which to tackle climate change and help reduce greenhouse gas emissions in the foreseeable future. The use of nanotechnology in construction is strongly linked to sustainability. It is the declared aim of many nations to improve energy efficiency and reduce greenhouse gases. The first phase of the Kyoto Protocol ends in 2012 and a follow-on agreement will lay down further measures. CO_2 emissions across the world must be halved by 2050 and this is only possible with resolute and above all immediate action. Energy-efficient construction is therefore imperative, particularly as construction is a major producer of CO_2 emissions. Architects and planners are called upon to find innovative solutions for slowing climate change, to combine ambitious architecture with energy efficiency. The use of materials and surface properties that have now become possible through nanotechnology offer architecture, interior architecture and related disciplines a means of achieving greater energy efficiency and sustainable construction through innovation.

The use of nanotechnology is not about jumping on a bandwagon, about being part of a supposed "nano fashion" with the sole purpose of keeping up with the latest trend. "If you pick up on it quick, you can say you were there" sings Robert Smith in a song from The Cure, "Jumping Someone Else's Train". At the time he was referring to mod fashion at end of the 1970s in England, asserting that one should follow one's own ideas, but his text applies equally well to the oft-quoted "nano trend". When employed solely to convey the message, "we are nano", as a label quickly forgotten as soon as the next hype arises, this use of nanotechnology makes little worthwhile contribution.

If, however, it is about making the maximum use of functions provided by nanotechnology, and with its help to bring about innovation, then the use of nanotechnology is of lasting value – and entirely irrespective of arbitrary fashions. To comprehend the implications and potential for design, a basic knowledge of the different functional possibilities is essential. The following chapters have therefore been arranged according to the properties the nanomaterials and surfaces offer, such as air-purifying, self-cleaning and so on, rather than by the chemical or physical principles they are based on, such as photocatalysis. They illustrate the wide variety of different and innovative applications currently in use. The projects shown here prove that through nanotechnology greater energy efficiency is already possible today.

Visionary scenarios, particularly those that drive the development of new products by manufacturers, typically have an outlook of 15 to 20 years. Given the longevity of building constructions and the liability period of the architects, this outlook is comparatively short – in 15 years most architects will still be liable for buildings planned today. As such the use of nanosurfaces and nanomaterials in construction requires openness towards innovation and a willingness to employ new and forward-looking technologies, not only from the architect but also the client.

Not least for this reason, the following selection of representative case studies complements the description of the different nano-functions, providing concrete examples of innovative applications so that all participants have a better idea of how they can be employed. The built examples from architects around the world are intended to help recognise new developments in the field. The selection features forward-looking projects from a variety of countries, all of which were completed in recent years and incorporate nanomaterials or nanosurfaces. Together they represent a solid and tangible foundation for future developments, providing a promising outlook on an exciting field.

Wherever possible, an overall impression of each project has been provided rather than focussing solely on the isolated aspects of the nano-applications. A design or construction project is always a matter of context, i.e. it makes a difference whether an application is employed in a football stadium or a private villa. An understanding of the context is also important in order to convey how products are implemented in the practice of designing our environment. Without the context, a picture of a product, photographed in a warehouse, would have sufficed, or perhaps simply a description without illustrations, as "nano" is invisible to the human eye anyway. By contrast, architecture, interior design and related disciplines are concerned with real and visible applications.

Self-cleaning: Lotus-Effect®

Lotus-Effect	Microscopically rough, not smooth.
	Hydrophobic – water trickles off.

This is one of the best-known means of designing surfaces with nanomaterials. In other countries, for example Japan, photocatalysis is the more popular alternative. The name "Lotus-Effect" is evocative, conjuring up associations of beads of water droplets, and therefore the effect is often confused with "Easy-to-clean" surfaces or with photocatalysis, which is also self-cleaning.

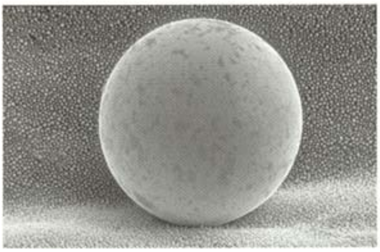
Self-cleaning surfaces were investigated back in the 1970s by the botanist Wilhelm Barthlott, who researched at the University of Heidelberg. He examined a self-cleaning effect that can be observed not only in oriental Lotus leaves but also in the European Nasturtium, the American Cabbage or South African Myrtle Spurge. Common to them all is that they exhibit a microscopically rough water-repellent (hydrophobic) surface, which is covered with tiny knobbles or spikes so that there is little contact surface for water to settle on. Due to this microstructure, surfaces that are already hydrophobic are even less wettable. The effect of the rough surface is strengthened still further by a combination of wax (which is also hydrophobic) on the tips of the knobbles on the Lotus leaves and self-healing mechanisms, which results in a perfect, super-hydrophobic self-cleaning surface. Water forms tiny beads and rolls off the leaf, taking with it any deposited dirt. If leaves should be damaged they heal on their own.

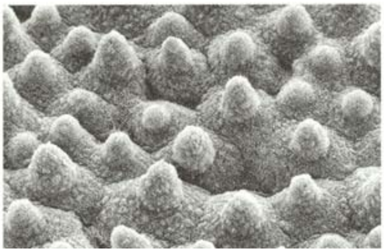
In the above description, "water" really means water. Other wet liquids such as shampoos or washing-up liquid prevent the beads of water forming – the tensides they contain destroy the hydrophobic effect. As such this approach is not advisable for use in areas con-

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 superhydrophic 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.





The micro-structure of the surface of a façade coated with a nanotechnology-engineered Lotus-Effect colour coating emulates that of its natural namesake.

Water channels formed by water droplets running off natural surfaces and a building façade.

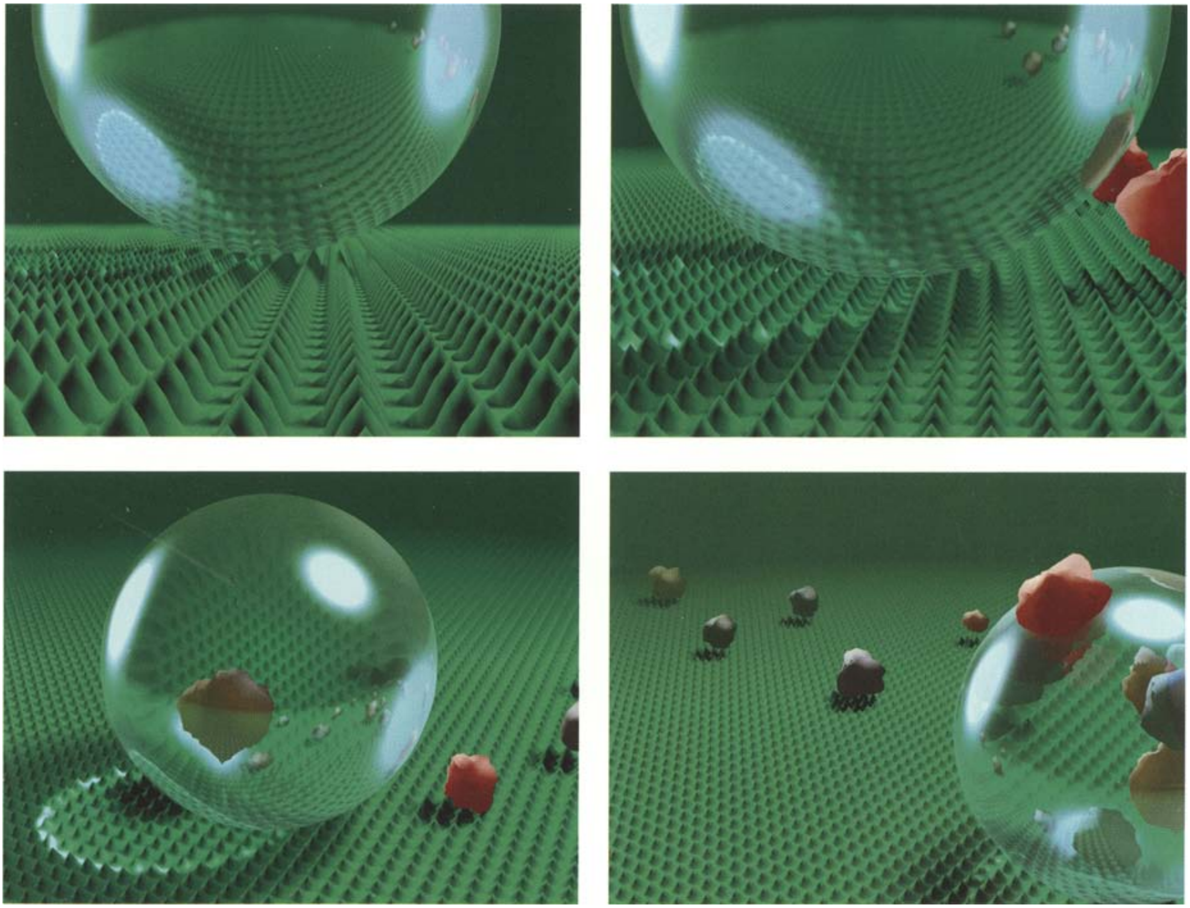
stantly exposed to such liquids. The effect is not lost forever – rinsing with water restores the hydrophobic effect.

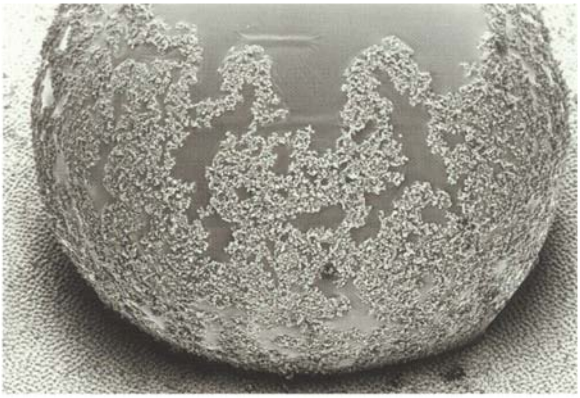
Artificial "lotus surfaces", created with the help of nanotechnology, do not as yet have any self-healing capabilities, but they can offer an effective means of self-cleaning when properly applied. The Lotus-Effect is most well suited for surfaces that are regularly exposed to sufficient quantities of water, e.g. rainwater, and where this can run off. Small quantities of water often lead to water droplet "runways" forming or drying stains, which may leave a surface looking dirtier rather than cleaner. Without the presence of water, the use of such surfaces makes little sense.

At present the structure of these surfaces cannot withstand extreme mechanical wear, and are therefore currently unsuitable for use on floors. Likewise for treated textiles, the mechanical wear caused by washing in a washing machine rapidly reduces its effect. The same applies for cleaning with abrasive cleaning agents, which should be avoided. In all other situations the Lotus-Effect is long lasting: five years later a painted façade remains as fully functional as ever.

Lotus-Effect products, despite the popularity of the term, are few and far between. The botanist Wilhelm Barthlott from the Nees Institute at the University of Bonn, Germany has been the owner of the patent and trademark for the "Lotus-Effect" since 1997 and in April

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.





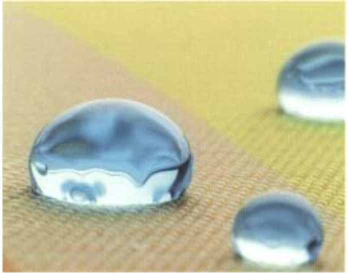
2006, together with the ITV German Institute for Textile and Fibre Research Denkendorf, developed a certification scheme for self-cleaning textiles based on the natural phenomenon. The scheme tests superhydrophobic properties, the surface structure and the existence of superimposed micro- and nanostructures.

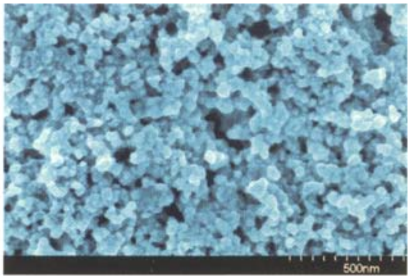
Various products (such as Lotusan façade coatings offered by Sto, formerly Ispo) are allowed to bear the name, as are some roof tiles that have been on the market for several years. The first roof tile products that came onto the market were coated using the Lotus-Effect but have since been replaced by photocatalytic self-cleaning systems and are marketed under a slightly modified name. Some products advertise demonstratively with pictures of lotus blossoms in order to awaken such associations. In many cases, however, these do not employ the Lotus-Effect but are simply Easy-to-clean surfaces – probably one cause of the misunderstandings outlined earlier.

Barthlott's team of researchers have since landed a new coup, a material that remains dry for up to four days underwater. In contrast, self-cleaning under water using

Wood can be given an extremely water-repellent self-cleaning surface. By creating nanostructures similar to those of the Lotus plant on the surface of the wood, the contact area between water and wood is minimised and surface adhesion reduced. Water rolls off instead of penetrating the wood.

Water droplets running off a superhydrophobic surface of a leaf wash away dirt deposits, as can be seen in this image of the cultivated oriental Colocasia esculenta plant. The fine knobbly structure of the leaf's surface is also clearly visible.





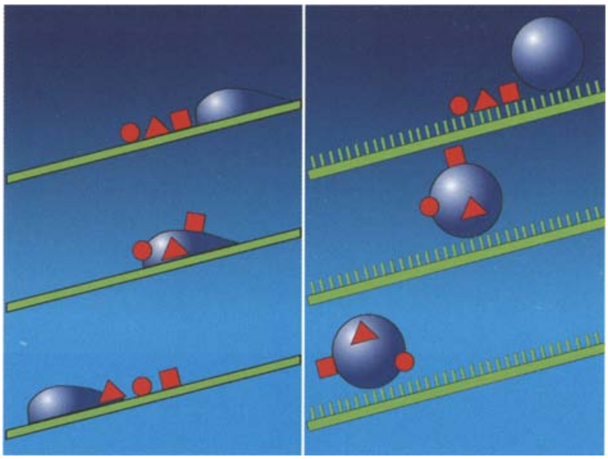
the lotus principle is not possible. At present no Lotus-Effect textiles are available on the market, although they are expected to launch soon. BASF have developed a product under the name of Mincor, for which at the time of writing a licensee is yet to be found.
To summarise, in all areas not subject 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.

Water droplets on a polyester textile.

This textile is more than 80% covered with a nanoporous coating.

Even when viewed under the microscope, a polyester textile treated with Mincor TX TT appears no different to conventional textiles.

The diagrams show clearly the difference between conventional surfaces and the Lotus-Effect.



Ara Pacis Museum

Rome, Italy

Architecture	Richard Meier & Partners, New York, NY, USA
Client	Comune di Roma, Rome, Italy
Product	Lotusan, self-cleaning paint (Lotus-Effect)
Manufacturer	Sto
Opened	2006

After ten years of construction and political debate, the Ara Pacis Museum is now home to an archaeological highlight in Rome. The Ara Pacis Augustae, a sacrificial altar that was inaugurated by the Emporer Augustus himself, was given a new container that remedies the environmental as well aesthetic deficits of the previous pavilion from 1938 in which the monument was formerly kept. A tripartite building complex has been created on the banks of the River Tiber, whose urban form now fits in with the historic centre of Rome, and which connects antiquity with the modern. The complex consists of an entrance gallery with an urban square in front, the main building with the exhibits, conference rooms and restaurant as well as further areas with space for temporary exhibitions, library and offices. The monument itself, the "Pax Augusta", is now contained within a transparent glazed part of the building and protected against damage from the environment. The remainder of the building is characterised by large blocks of travertine, typical for Rome, and surfaces clad in white, as is typical for Meier's architecture. Here a self-cleaning coating has been invisibly integrated into the white surfaces to ensure the durability of their colour. In the heavily polluted city, it would not otherwise have stood much chance of remaining white for long.

Commercial building

Pula, Croatia

Architecture	Rusan arhitectura, Andrija Rusan, Pula, Croatia
Interior Design	Dean Skira
Client	Lumenart d.o.o.
Product	Lotusan, self-cleaning paint (Lotus-Effect)
Manufacturer	Sto
Completion	2006
Area	745 m^2 gross floor area

The building for a lighting design company is clearly visible in its surroundings. Its extravagant sculptural form, a monolithic cubic arrangement coated all in white looks simple but not ordinary. The windows appear to be carved out of the volume of the building while the thick walls and the drawbridge-like entrance canopy remind one of a fortress.

Brilliant white dominates indoors and outdoors alike and is the sole colour of all surfaces. In the interior, it serves as background for the showroom, projections and light design, forming a light ambience. Outdoors, when seen from afar, its pure white colour makes the building look like a crystal or a light and is also reminiscent of the white architecture of Mediterranean hill towns. At night, the clean white cube with its subtle play of natural light is transformed into a colourfully illuminated eye-catcher.

The intensity of the pure white surfaces is protected against dirt with the help of a Lotus-Effect façade 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.

Private residence

Aggstall, Germany

Architecture	Hild und K Architekten, Andreas Hild, Dionys Ottl, Munich, Germany
Client	Barbara Gross, Dr. Bertold Schwarz
Product	Lotusan, self-cleaning paint (Lotus-Effect)
Manufacturer	At the time of construction Ispo, now Sto
Completion	2000
Area	approx. 300 m²

Where a dilapidated house once stood, a new house has been erected with a ridge-height and width stipulated to follow that of the old building. The design features an asymmetrical pitched roof and extended eaves on one side, reflecting the typology of houses in the region. The use of solid brickwork masonry, untreated recycled roof tiles, the plastered interiors and last but not least the impressively graphic brick ornamentation on the elevations reflect the tradition of craftsmanship. On the elevation, the irregularity of handcrafted workmanship is bound within a geometric pattern. The façade 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. The locally typical overhanging eaves are somewhat problematic for the Lotus-Effect as they protect the façade against rainwater. In this case they have been omitted so that the self-cleaning function of the paint can work uniformly.

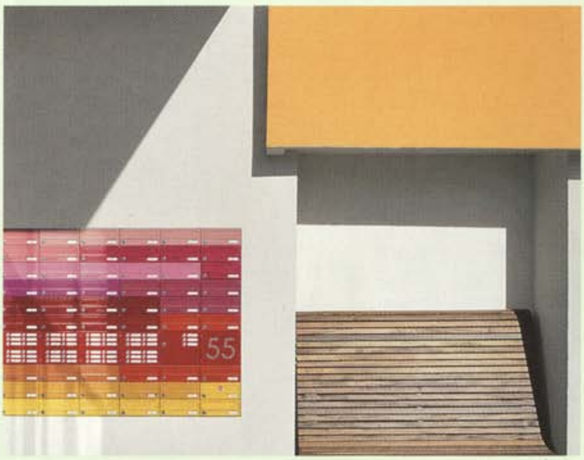
Struckbarg housing

Hamburg, Germany

Architecture	Renner Hainke Wirth Architekten, Hamburg, Germany
Client	Joint ownership Martens per Schumann Immobilien KG
Product	Lotusan, self-cleaning paint (Lotus-Effect)
Manufacturer	Sto
Completion	2007
Area	3,685 m² façade area

As with earlier renovation projects, the architects chose to use self-cleaning façade coatings for their renovation of a 1970s housing estate. The estate consists of a high-rise block as well as a number of multi-storey terraced housing blocks. The renovated elevations are clad in a composite thermal insulation system with a pigmented render coating in light beige and red. As part of the redesign, window recesses were given colour highlights, the house entrances were made more prominent, wired glazing was replaced with transparent clear glass, bathrooms were given windows and the undersides of balconies were painted in colour.

The differentiated colouring of the new façades 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.



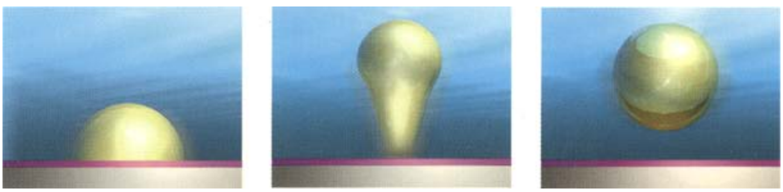
Self-cleaning: Photocatalysis

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. There are numerous buildings of all sizes around the world that make use of this function. Its primary effect is that it greatly reduces the extent of dirt adhesion on surfaces. It is important to note that 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. The interval between cleaning cycles can, however, be extended significantly, a fact that is particularly relevant in the context of facility management. Fewer detergents are required, resulting in less environmental pollution and less wear and tear of materials. Likewise reduced cleaning cycles lead to savings in personnel costs and the fact that the dirt adheres less means that it is also easier to remove. Generally speaking, photocatalytic self-cleaning is a low-maintenace and trouble-free solution.

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.

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 (TiO_2, and the particularly reactive derivative Anatase). The nanoscalar dimension of TiO_2 makes it a highly reactive catalyst, speeding up the decomposition process rapidly without being used up so that the effect is lasting. Since its discovery in 1908 TiO_2,

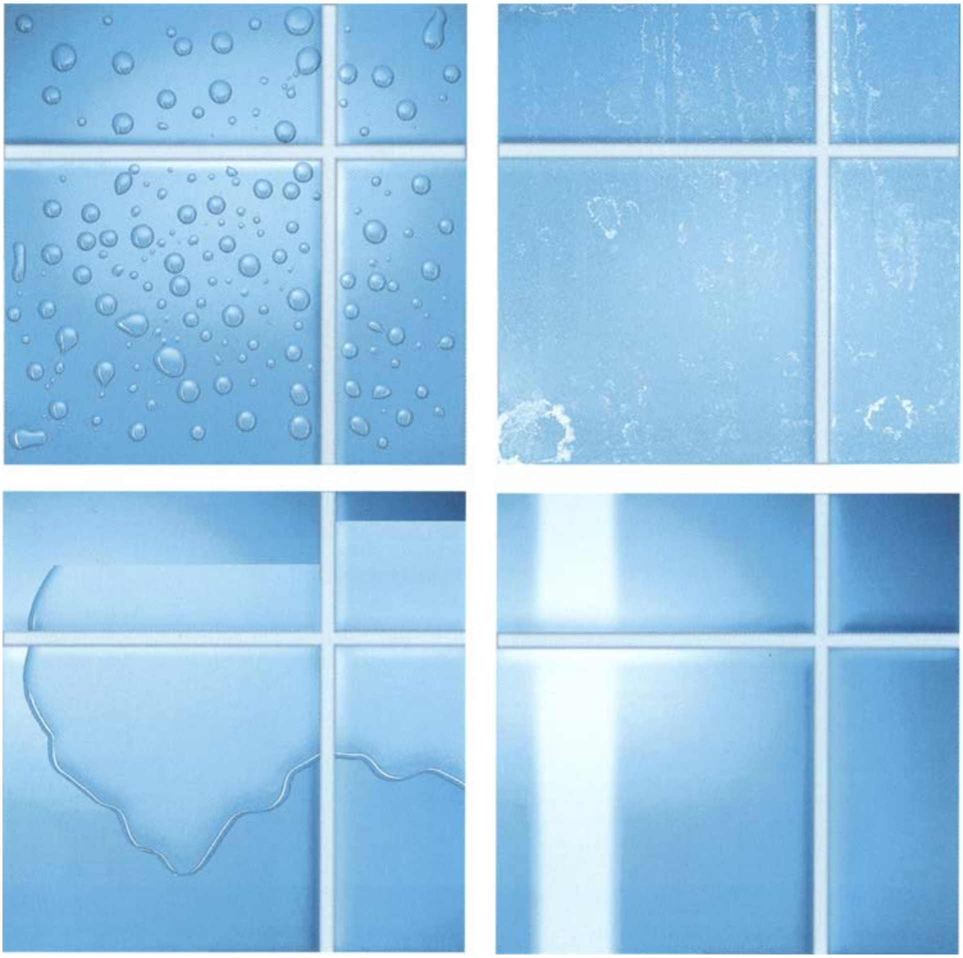


Oleophobic surfaces are resistant against oils and fats.

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.



The diagrams show the basic process:

Organic dirt and grime is broken down and "decomposed". Until now UV light, such as present in sunlight, is necessary to initiate photocatalysis.

When water impacts on the surface, it spreads to form a film washing away the loose dirt.

The result: clean surfaces!

also known as titanium white, has been used in all kinds of products from washing detergents to salami skin – the prosperity of a culture can be measured by its consumption of TiO_2. At a nanoscalar dimension, titanium appears no longer white but transparent.

The production of self-cleaning surfaces using photocatalysis originates from Japan. In 1967, the photocatalytic property of titanium dioxide was discovered by Akira Fujishima at the University of Tokyo. Together with his professor at the time a report was published on the phenomenon entitled the "Honda-Fujishima Effect". The first self-cleaning house was of course Fujishima's own house.

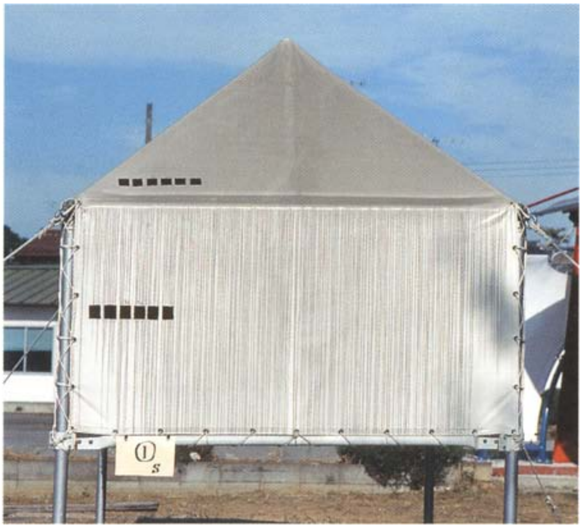
Together with the University of Tokyo, the Japanese tile producer Toto Ltd. developed photocatalytic tiles that were launched on the market in 1994 and continue to be successfully marketed today, in Japan as well as under licence in various other countries. At the RCAST University in Tokyo, Kazuhito Hashimoto and Toshiyo Watanabe have researched photocatalysis in more detail, including its process in visible light.

In addition to the catalyst, the UV component of light, with a wavelength of less than 390 nm is considered essential for the reaction to occur, and its intensity plays an important role. As such, photocatalytic self-cleaning surfaces are generally speaking more effective outdoors than indoors. The method is predestined, for example, for use on building façades.

The hydrophilic properties of TiO_2 were discovered much later. Due to its increased surface energy such 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. Photocatalytic surface coatings are often applied to façade panels made of glass or ceramics or to membranes. As the self-cleaning effect does not function without water, eaves should be designed so that they do not prevent rainwater or dew from reaching the façade. It is also necessary in glazing to abstain from the use of silicon-based seals and sealants – the oils they contain transfer to the glass and are incompatible with the surface coating, rendering it par-

TiO_2 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.

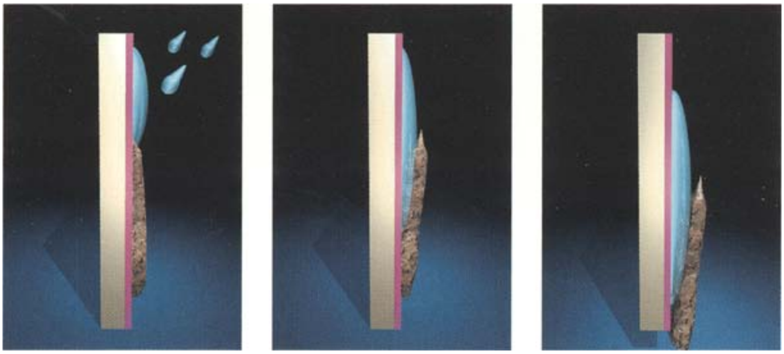
tially hydrophobic and resulting in unsightly streaking. In combination with photocatalytic coatings silicon-free sealants have to be used. Similarly, contact with any kind of film-forming detergents (e.g. high-gloss coatings) must also be abandoned.
In production, it is only economical for mass-produced glass as the coating is usually applied in the factory using chemical vapour deposition (CVD), a vacuum coating technique in which an ultra-thin coating is applied in vapour form. Such coatings cannot be retrofitted. However, this does not limit its application exclusively to large buildings; it can be equally appropriate for example for conservatories and winter gardens. In road building the transparent coating can also be used, for example for noise barriers. Tiles with baked-on durable coatings are available for use both indoors and outdoors. Likewise, concrete, another common building material for façades, can also be equipped with a self-cleaning surface.
Photocatalytic glass can be combined with other typical functions such as solar-protection glass. The market for self-cleaning coatings is expanding most rapidly in Japan, where it has become common practice in many cases for new glazed façades. The variety of photocatalytic applications already available on the market is quite varied and ranges from windows to vacuum



Water washes off the dirt.

cleaners to fridge-freezer deodorising units. In addition to the self-cleaning properties, photocatalysis can also be used to achieve air-purifying, water-purifying as well as antimicrobial properties.

An interesting application, which has already been implemented in experimental prototype form, is the exploitation of the cooling effect of evaporating water. The canvas and steel roofing as well as the windows of a trade fair pavilion in Japan (Expo 2005, Aichi, Nagakute area) were equipped with a photocatalytic TiO_2 coating and subjected to a constant stream of water. Due to the hydrophilic property of the surface, the water immediately formed a thin film, which evaporates quickly, absorbing in the process ambient warmth and thereby reducing the indoor temperature noticeably. Initial estimates suggest a potential energy reduction of between 10 and 20% in comparison to conventional air conditioning. In Japan, this effect is traditionally achieved by sprinkling water on the ground – in this case nanotechnology represents a perfect symbiosis of tradition and high-tech.



These roof tiles, which have been on the market for some time, have self-cleaning properties thanks to photocatalysis.

Muhammad Ali Center MAC

Louisville, Kentucky, USA

Architecture	Beyer Blinder Belle Architects & Planners LLP, in cooperation with Lee H. Skolnick Architecture + Design Partnership, New York, NY, USA
Façade design	2×4 Inc., Glen Cummings, New York, NY, USA
Client	Lonnie and Muhammad Ali, Founders Ina Brown Bond
Product	Hydrotect, photocatalytic self-cleaning ceramic tiles
Manufacturer	Agrob Buchtal architectural ceramics, Deutsche Steinzeug America
Completion	2005
Area	approx. 9,000 m²
Façade	approx. 1,500 m²

In the home town of the boxing legend Muhammad Ali, "The Greatest", his life's dream has become built reality: the MAC is an international cultural centre that promotes individual talent and respectful understanding of one another. It is therefore more than a Muhammad Ali Museum, and caters for seminars, lectures, films, exhibitions, symposia and so on. Prominently positioned on the banks of the River Ohio, the building has a striking appearance, in particular due to its façade. Ceramic tiles with different colour glazing are arranged on a 30 × 60 cm grid according to a particular pattern. From a distance it appears as an oversized mosaic depicting typical boxer stances and a likeness to Muhammad Ali. From close-up the figurative depiction gives way to an abstract pattern. To maintain a consistently good appearance and to keep down the cost of cleaning, the 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. Investigations have shown that 1,000 m² of photocatalytic façade has the equivalent effect of 70 medium-sized deciduous trees.

Hyatt Regency Garden Chapel

Osaka, Japan

Architecture	Obayashi Corporation, Japan
Client	Hyatt Regency Osaka
Product	Sky Clear Coat fabric/TiO_2 photocatalytic self-cleaning membrane
Manufacturer	Taiyo Kogyo Corporation
Completion	2001
Area	50 m^2

A small covered chapel sits atop the expansive roof garden of this hotel, and is used for Christian wedding ceremonies. By day, its pure white membrane covering in combination with the green of the well-kept lawns creates a fresh contrast; at night it becomes a bright glowing sculpture. In its function as a wedding chapel it is essential that it always appears clean and neat as the classic colour of Christian weddings is white. 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.

Narita International Airport of Tokyo, Terminal 1

Chiba, Japan

Architecture	Nikken Sekkei Ltd., Japan
Client	Narita International Airport Corporation
Product	Ever Fine Coat/TiO_2 photocatalytic self-cleaning membrane
Manufacturer	Taiyo Kogyo Corporation
Completion	2006
Area	6,250 m^2

In 2006, the Narita International Airport in Tokyo underwent comprehensive renovation. In the process large sections were covered with textile roofing. 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. In central areas of Tokyo, the use of self-cleaning awnings has been common practice for several years and they have proven to remain much cleaner than their conventional counterparts. Although conventional surface coatings, glass, PTFE or ETFE materials are also self-cleaning, they are not able to stop dirt deposits from accumulating.

AKT – Am Kaiser's Turm

Heilbronn, Germany

Architecture	müller.architekten, Matthias Müller, Heilbronn, Germany
Client	Tengelmann Warenhandelsgesellschaft
Product	Pilkington Activ, photocatalytic self-cleaning glass
Manufacturer	Pilkington Deutschland AG/Pilkington Group
Completion	2006
Total area	approx. 13,000 m^2

A listed industrial monument overlooking the River Neckar was renovated and extended to three times its original area. The 30 m high silo tower capped with neon advertising is a landmark building in Heilbronn's industrial area. A glass cube containing a bar and lounge has been placed atop the rectangular Bauhaus-inspired architecture of the brick tower. The fully glazed windows afford a fantastic view over the city and the vineyards on the surrounding hills. 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.

east Hotel

St. Pauli, Hamburg, Germany

Architecture	Jordan Mozer & Associates Ltd., Chicago, IL, USA
Client	east Hotel und Restaurant GmbH
Product	Pilkington Activ, photocatalytic self-cleaning glass
Manufacturer	Pilkington Deutschland AG/Pilkington Group
Completion	2005

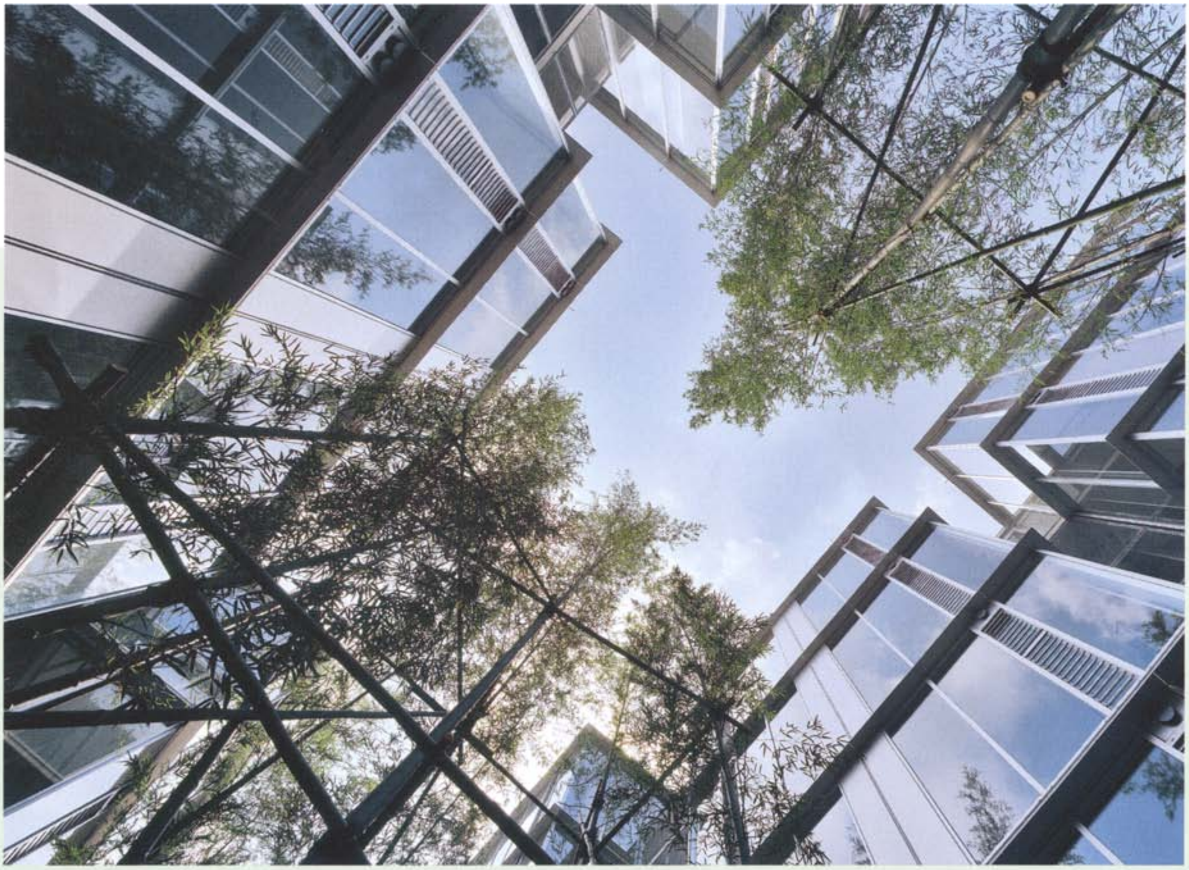
A well-kept appearance is always vitally important for a hotel, and even more so when it is a prize-winning design hotel. The self-cleaning function of the glass is therefore especially useful for hard-to-reach locations such as overhead glazing or glazed external walkways. It is these areas that usually appear most unsightly in other hotels, for example when walking under them or breakfasting in the conservatory. A glazed roof covered in dirt and bird droppings is not the perfect accompaniment to a fresh croissant.

G-Flat

Tokyo, Japan

Architecture	Koh Kitayama + architecture Workshop, Tokyo, Japan
Product	Sagan Coat, photocatalytic self-cleaning coating
Manufacturer	SYK Corporation Inc.
Completion	2006
Area	2,636 m^2

Each of the buildings in this housing scheme is fully glazed, with wall slabs serving to divide and structure the scheme. Fittings in each flat allow the degree of privacy and indoor climate to be regulated individually despite full height glazing. Such buildings must be kept scrupulously clean to maintain their transparency. A photocatalytic self-cleaning glass coating helps the glass stay clean and is transparent due to its nano-scalar qualities.



Kurakuen private residence

Nishinomya City, Hyogo, Japan

Architecture	Casa Akira Sakamoto Architect & Associates, Osaka, Japan
Client	Private
Product	Hydrotect, photocatalytic self-cleaning paint
Manufacturer	Toto Ltd.
Completion	2005

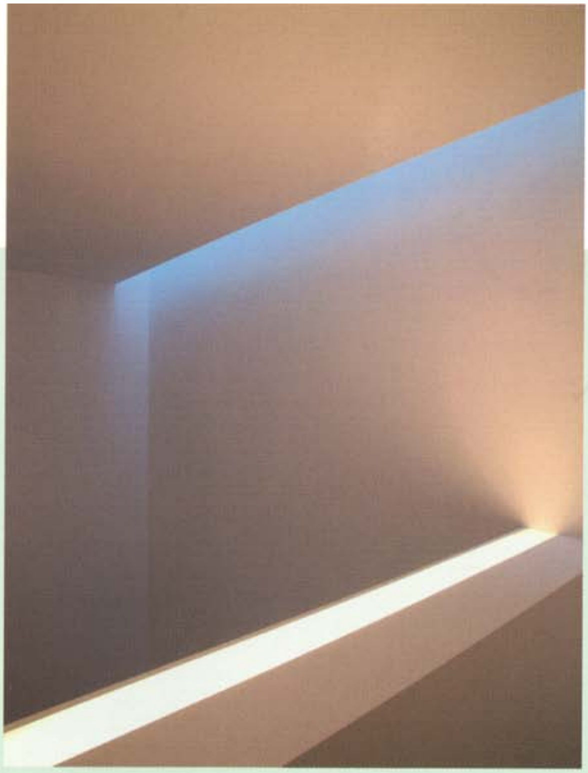
The architectural office responsible for both these houses has specified self-cleaning photocatalytic colour coatings for most of its projects since 2002. Both projects have a minimalist formal language, with clear volumes and plain pure white surfaces. Openings between indoors and outdoors create views and changing light situations that subtly bathe the walls in different atmospheres: the sun shining through a gap in the clouds, the wind blowing the clouds, a bird crossing the sky... For such pure aesthetics, perfect surfaces un-

Senri New Town private residence

Osaka, Japan

Architecture	Casa Akira Sakamoto Architect & Associates, Osaka, Japan
Client	Private
Product	Hydrotect, photocatalytic self-cleaning paint
Manufacturer	Toto Ltd.
Completion	2006

blemished by dirt are essential. In these projects the photocatalytic self-cleaning outdoor coating is more than simply practical; it helps preserve the buildings' aesthetics.

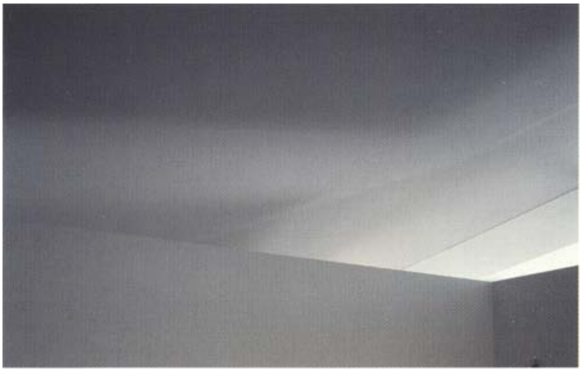


House in Creek

Hiroshima, Japan

Architecture	Keisuke Maeda/UID Architect & Associates, Hiroshima, Japan
Client	Private
Product	Hydrotect coat, photocatalytic self-cleaning coating
Manufacturer	Toto Ltd.
Completion	2006
Area	111 m²

A young Japanese architect designed this low-cost house for a family with three children. Using a reduced palette of materials, the design is characterised by a powerful dialogue between concrete, steel and wood and the surroundings. A functional façade coating was used on the external walls of the building to counteract the build-up of dirt and grime. 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.



Disabled-access housing for elderly people

Frick, Switzerland

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

The elderly people's home, the winning project of an architectural competition, was chosen for its optimal floor plan arrangement and its economical use of the site. The building contains 28 flats and adjoins a park. All the access corridors are fully glazed, offering a transparent and expansive view out over the park. The glazing consists of 81 prefabricated elements, a metal and timber construction with a large pane of fixed glazing and a smaller section that can be opened as required. Around half of these are electronically driven to ensure sufficient natural ventilation. The inner panes of the glazing are made of laminated safety glass; the outer panes integrate the dual functions of solar protection and self-cleaning using photocatalysis. The façade 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.

MSV Arena soccer stadium

Duisburg, Germany

Architecture	ar.te.plan, Burkhard Grimm, Michael Stehle, Dortmund, Germany
Client	MSV Duisburg
Product	Pilkington Activ, photocatalytic self-cleaning glass
Manufacturer	Pilkington Deutschland AG/Pilkington Group
Completion	2004
Area	18,000 m² traffic area

Over a period of just over a year, a new soccer stadium was built in the centre of the Ruhr conurbation to house 30,000 fans of the MSV, the Duisburg soccer club. More than 15,000 m³ of concrete were used, 3500 tonnes of steel reinforcement, around 30 steel pylons and last but not least almost 7,500 m² of turf (heated from beneath) were laid and an almost 40 m² large screen was erected.

1,500 m² of glass were needed for the impressive 120 m wide glass and aluminium façade. 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.

Children's playground in the Mannou National Government Park

Kagawa, Japan

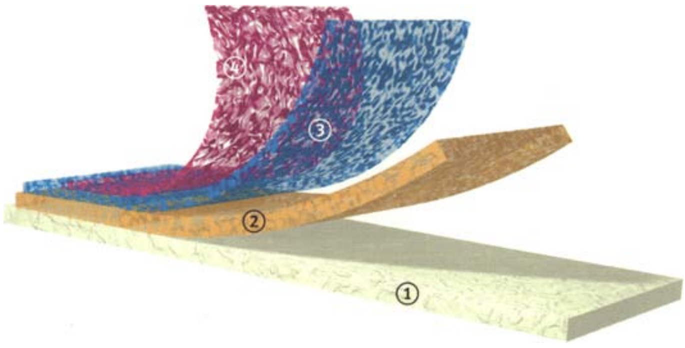
Architecture	Urban Design Consultant Inc., Japan
Client	Ministry of Land, Infrastructure and Transport
Product	Ever Fine Coat, photocatalytic self-cleaning membrane
Manufacturer	Taiyo Kogyo Corporation
Completion	2004
Area	700 m²

Located in the centre of a park, a new children's playground was built, part of which is covered to protect against the sun. The circular tensile membrane follows the circular shape beneath and forms a roofed-over indoor-like space. The membrane not only shades the play area beneath, it also offers protection against UV light, which is harmful for young children's particularly sensitive skin. 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)

Easy-to-clean Smooth surfaces with reduced surface attraction.
Surface repellence without using the Lotus-Effect.

So-called easy-to-clean (ETC) surfaces are water-repellent and accordingly are often confused with other self-cleaning functions such as the Lotus-Effect. However, unlike the latter, easy-to-clean 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. Easy-to-clean surfaces are therefore hydrophobic, i.e. water-repellent and often also oleophobic, i.e. oil-repellent, making them well suited for use in bathrooms.
The easy-to-clean function of surfaces is also often confused with other photocatalytic self-cleaning functions. The primary difference here is that easy-to-clean surface coatings do not require UV light to function and their hydrophobic surface properties – as opposed to hydrophilic – cause water to run off in droplets rather than forming a thin film of water. Sometimes surfaces that are simply particularly smooth are incorrectly labelled "easy to clean" surfaces. Similarly, ETC surfaces should not be confused with Teflon coatings: Teflon (PTFE) exhibits multi-directional non-stick properties, and its graphite fill material gives PTFE its characteristic dark colouring, which is anything but transparent.
Water that runs off inclined ETC surfaces forms droplets, washing away surface grime in the process. This function is used for coating ceramic sanitary installations and shower cubicle glazing. Wood, metal, masonry, concrete, leather as well as textiles are likewise candidates for hydrophobic coatings. Generally speaking, easy-to-clean surfaces are less susceptible to dirt accumulation ("dirt-repellent"). The benefit: stress-free



"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

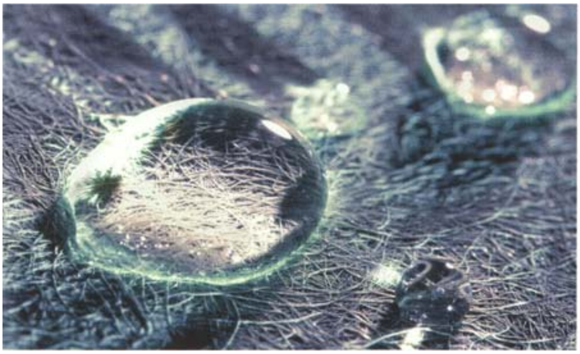
2 coloured ceramic material is applied

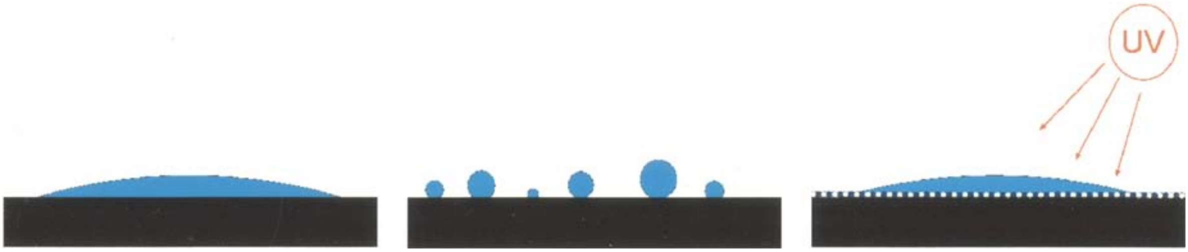
3 optional printing

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.





A comparison of surfaces with different wetting properties.

A water droplet on a conventional surface.

Droplets on a hydrophobic ETC or Lotus-Effect surface form spherical shapes.

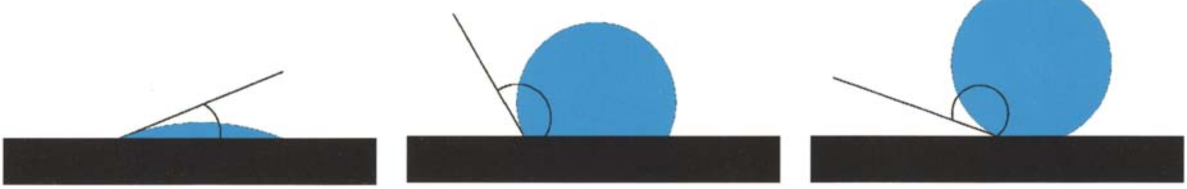
A hydrophilic photocatalytic surface activated by UV light.

and easy cleaning saves time and costs. What may seem simply an added convenience for home consumers pays for itself at the larger scale of facility management where cleaning costs represent a high proportion of maintenance costs.

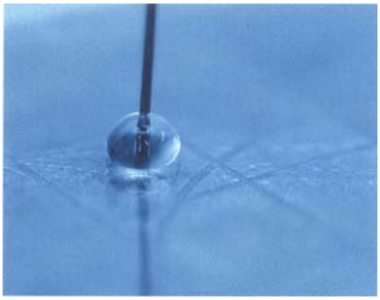
Water droplets are not always beneficial and can have disadvantageous effects: the spherical form of water droplets has the smallest surface area to volume ratio of all volumes. The drying time is correspondingly longer and this should be taken into consideration for particular areas of application. A disadvantage is that droplets dry individually, leaving behind dirt residues – although these are easy to remove. When only a small amount of water is involved, droplets of run-off water can form runways. 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.

Abrasive detergents and brute force application by cleaning personnel – in the worst case both together – are not uncommon and with time will damage ETC surface coatings, unless they are scratch-resistant.

The angle of contact determines the hydrophobic degree of a surface. The contact angle describes the degree of wetting, and is a function of the relative surface tensions of the solid, water and air.



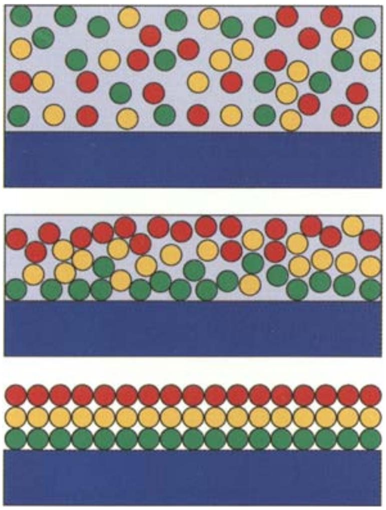
Ultra-clean white surfaces of poolside armchairs and the interior of a yacht, achieved using water-repellent surface coatings.



Ideally, one should select products that have proven their resilience in reliable testing procedures. Likewise, where small print in product details recommends gentle cleaning and the avoidance of abrasive cleaning agents, this should not be ignored, in order to ensure the longevity of the product.

The retrospective coating of surfaces generally lasts only a few months, though this is not necessarily a problem if one is aware of it and can plan for it. However, this does not represent a truly durable solution (unless the coating is constantly renewed), particularly in the building sector where durability and sustainability are important.

Superhydrophobic materials and coatings are therefore most beneficial where dirt accumulation needs to be kept to a minimum and water repellence ensured. As such, ETC surfaces are most commonly found in interiors, but can also be employed outdoors for better weather protection.



Measuring the contact angle of a droplet.

The functional layers of an ETC coating:

Different particles in a sol-gel solution …

arrange themselves in a process of "self-organisation" as the solution dries out …

the lower layer adheres to the substrate, the central layer bonds both layers, the upper layer provides the water-repellent property.

ETC surface coatings are not only suitable for ceramic sanitary fittings but can also be used on enamel surfaces.

Science to Business Center Nanotronics & Bio

Marl, Germany

Architecture	Henn Architekten, Munich, Germany
Client	Degussa, Creavis
Product	ccflex, nanoceramic wall covering
Manufacturer	At the time of construction Degussa, today Evonik
Completion	2005

The research centre was conceived and built for Degussa, Creavis. With its transparent façade, clear forms and material and colour concept, the architecture embodies the company philosophy: the transfer of know-how from science to business.

Degussa benefits from being able to use their in-house products: various parts of the interior feature a particularly robust nanoceramic wall covering. It is flexible, impact-resistant and is vapour 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 water-repellent surface, together with a water-repellent adhesive to protect the joins, means that this product can be used in all manner of wet areas. In this respect it compares favourably with wall tiles. Thanks to a slightly mottled colouring the joins are practically invisible, giving the impression of a homogeneous uninterrupted surface.

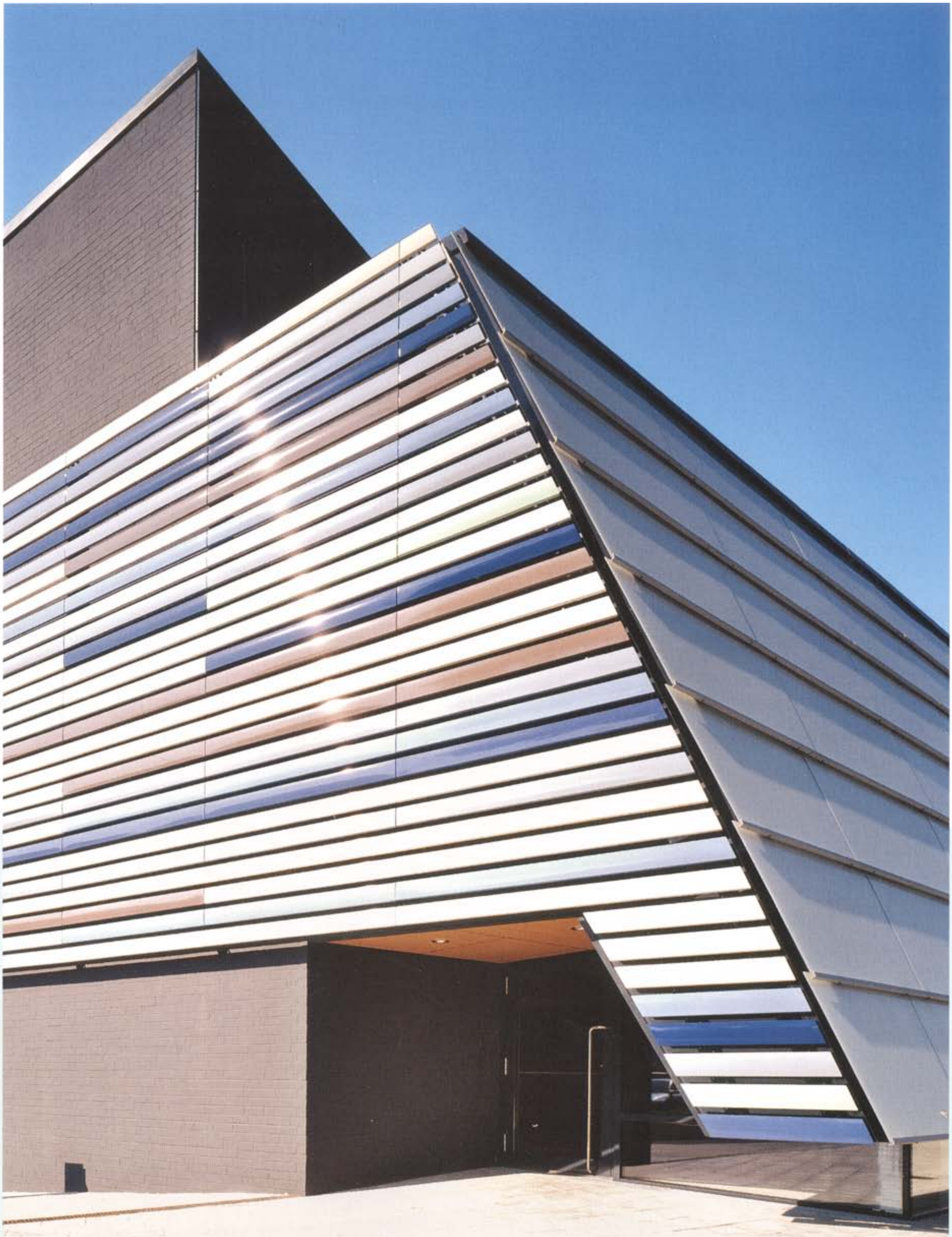
Kaldewei Kompetenz-Center (KKC)

Ahlen, Germany

Architecture	Bolles + Wilson, Münster, Germany
Client	Franz Kaldewei GmbH
Product	Kaldewei steel-enamel with self-cleaning "Perl-Effekt", easy-to-clean surface
Manufacturer	Kaldewei
Completion	2005

Kaldewei is unique among bath manufacturers in that it has its own in-house enamel development and production facilities. By wrapping its building in a veil-like façade of coloured steel-enamel panel elements, behind which the existing melting facilities can be seen, the company expresses its brand through architecture.

The enamelled façade 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.



Private residence

Erlenbach, Switzerland

Architecture	burkhalter sumi architekten, Zurich, Switzerland
Client	Private
Product	Samicolor NanoBois nature, hydrophobic wood treatment
Manufacturer	Kälin & Co. AG
Completion	2005
Area	415 m² net floor area

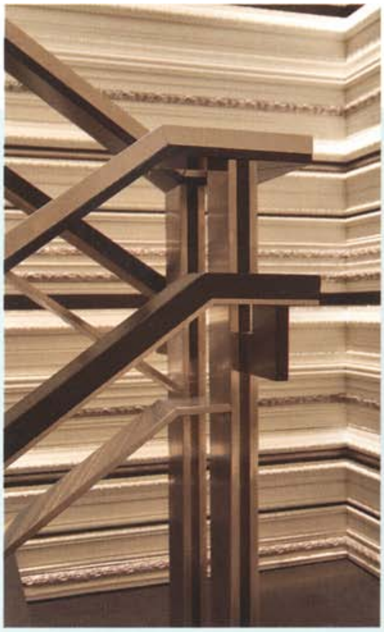
The house is located on a site overlooking Lake Zurich and with a view over to the Alps. The sculptural and minimalist character of the house is emphasised by the enclosure of the shell in a delicate envelope of vertically slatted larch wood. The slender slats show particularly well around the perimeter of the loggias. 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.

Modern Classicism

Shanghai, China

Architecture	MoHen Design International, Shanghai, China
Client	MoHen Design International
Product	Sp-II, Energy Conservation Paint
Manufacturer	Shanghai Pujin Macromolecule Material Science and Technology Development Ltd. Co., Apex Group
Product	Nano-stone panels with hydrophobic treatment
Manufacturer	Sunny Win Light Ray Nano Technology Co. Ltd. in cooperation with the Industrial Technology Research Institute (ITRI)
Completion	2006
Area	498 m^2

This Chinese office interior combines classical and contemporary design elements such as specially designed chandeliers made of acrylic glass and floral wall panels made of a white acrylic material. Stainless steel sliding doors conceal everyday work equipment and form the rear wall of the office space. The colour scheme is a combination of primarily black, white and steel with the dominant lines playfully governing the design. Most elements have a decorative character, and are augmented in their function with the help of nanotechnology: 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.



Urban lounge / Light bubbles

St. Gallen, Switzerland

Architecture	Carlos Martinez Architekten, Widnau SG, Switzerland
Light design	Vogt & Partner, Winterthur, Switzerland
Art	Pipilotti Rist, Zurich, Switzerland
Client	Raiffeisenbank St. Gallen
Product	Nano-Vitro
Manufacturer	NanoSys
Completion	2005

In spring 2005, the carefully designed urban ensemble of the Raiffeisenbank was completed in the centre of St. Gallen. The outdoor spaces are designed as an "urban lounge", the winning project from an earlier ideas competition. The project is as novel as it is radical, covering the jagged urban space of the neighbourhood in carpet – a tongue-in-cheek public living room for lounging around in. "Lightbubbles" that appear to float in the lounge provide diffuse light. With a diameter of 3 m and a mother-of-pearl-like fibreglass covering made of Scobalit, the lights both function as illumination and create an atmospheric mood through coloured light. 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.

Air-purifying

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

Though not able to completely purify air, the use of nanomaterials makes it possible to improve the quality of air. It enables unpleasant odours and pollutants to be eradicated. Healthy air is a fundamental and ever more important resource that at the same time is becoming ever more precious. Legislation was initially introduced to reduce the level of outdoor air pollution; the need to improve indoor air quality followed later. The air-purifying properties of nanomaterials are beneficial in both cases and play an important role both for indoor as well as increasingly for outdoor environments.

Indoors

The indoor air quality is particularly important in industrialised nations where people spend a large amount of time indoors and unpleasant smells or even pollutants are commonly associated problems. Although our sense of smell greatly influences our general feeling of well-being, it is all too often neglected. Together with hazardous substances, unpleasant smells have a significant effect on how we feel. Even the most beautiful space will not feel comfortable if the indoor air quality is disagreeable.

We usually deal with this problem by more or less eliminating any unpleasant smells indoors, either by airing the room, by masking it with another perfume or with the help of resorptive materials, though these have a limited capacity. Nanotechnology, on the other hand, 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. Various products are already available on the market, with or without antibacterial combination.

This approach can also be used to counteract the sick building syndrome (SBS). 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, however photocatalytic processes, which can also be used for air-purifying purposes, require daylight. As such the use of photocatalytic systems indoors must be planned carefully. A further advantage is that the catalytic effect and therefore the purifying function of nanomaterials does not wear off.

The same principle applies for pollutants such as nicotine or formaldehyde. Their molecules can also be cracked and filtered out of the indoor air. In contrast to other well-known pollutants such as asbestos, formaldehyde is not always pre-existent in a building but can be introduced as part of new installations. The ability to reduce indoor air pollutants is therefore equally relevant for new as well as for existing buildings to avoid the occurrence of sick building syndrome. Nicotine is a further substance that can be broken down using nanomaterials, and can in some cases obviate the need for separate smoking and non-smoking areas. Ammonia, benzene and fish odours are among further contaminants that can be removed with the help of nanomaterials, and the palette is expanding constantly as research into the decomposition of further substances continues.

Air purification technology is increasingly being used for textiles and paints. It should be noted that although it is possible to improve the quality of air, this does not necessarily make it "good". Other factors such as oxygen content and relative humidity also contribute to the air quality and should not be neglected when using air-purifying products. It would be wrong to assume that an air-purifying carpet means one no longer needs to open the window – it cannot replace regular ventilation. Insufficient ventilation leads to an inevitable build-up

Air-purifying curtains across the width of this dance and work-out room help maintain a better indoor air quality.

Air-purifying interior plaster.

In the call centre of "die fabrik" in Cottbus, Germany, the surfaces are both air-purifying and sound insulating.

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

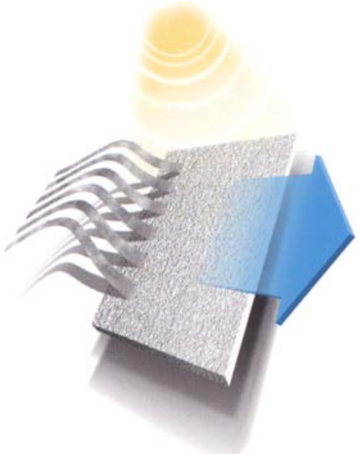
Air-purifying materials such as plasterboard or acoustic panels.

of relative humidity and eventually results in mould formation and further associated problems. The oxygen content of air is a further contributory factor for indoor air quality. Lastly, a third good reason to ventilate sufficiently is to allow the CO_2 that is generated to escape. Our sense of smell also serves as a warning and by eradicating the smell of something, for instance urine, we trick it but without removing the cause. The same applies for apparently nicotine-free spaces – other pollutants from cigarette smoke are still present in the air. Rather than just dealing with the symptoms, spaces should be properly cared for. It is always better to remove the cause than to tackle the bad air. However, where this is difficult, or impossible to influence, air-purifying surfaces can help improve the indoor air quality and with it the comfort of the users. It is not an all-encompassing solution for dealing with indoor pollutants.

Outdoors

Environmental pollution and the quality of air outdoors has long been a topic of public discussion in Europe, particularly as public education and awareness of ecological aspects and sustainable development increases. More and more companies are demonstratively highlighting their commitment to sustainability and the eco-movement has emancipated itself from its previous niche existence to a marketing and lifestyle factor. The air-purifying capacity of photocatalytic concrete for example provides a possible means of combating existing pollutants. Recently, building façades, road surfaces and the like, equipped with appropriate coatings, are being implemented in test installations to counteract the effect of industrial and vehicle exhausts. It transpires that photocatalytic self-cleaning concrete (see p. 117) for example also has an additional air-purifying effect. This added effect was discovered only later and new developments are regularly making press headlines. Applications are air-purifying paving stones, road surfaces and paints. At present these materials are still expensive, but a start has been made.
Noteworthy in this respect is the "Picada" research project – Photocatalytic Innovative Coverings Applications for Depollution Assessment – funded by the EU from 1996 to 2003. As part of the project, test installations and pilot projects were undertaken to demonstrate the



Photocatalytic pavement surfacing.

Concrete paving panels with photocatalytic properties used as a design element in a car park.

efficiency of photocatalytic air-purifying surfaces. 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.

As with indoor air environments, outdoor air purification applications are only a supporting measure for tackling symptoms and are an adequate means of reducing existing pollution. They do not eradicate the cause of pollution but can be used to reduce smog and improve the outdoor air quality. The question is whether a noticeable difference to the quality of air can be made with the use of air-purifying surfaces, and how significant this effect actually is.

With regard to reducing air pollutants, greater attention should be given to avoiding their emission in the first place. However, it will take a while before environmental protection aims are fully realised. Until then, once their effectiveness has been demonstrated, air-purifying surfaces may offer a possible interim solution. It remains to be seen wheter one day the extensive use of such surfaces will become standard practice in urban conurbations.

Atelier and villa for a calligrapher

Ymanashi, Japan

Architecture	Kazuyasu Kochi, Kochi Architect's Studio, Tokyo, Japan
Product	Moiss, air-purifying building board
Manufacturer	Mitsubishi
Completion	2004
Area	62 m^2

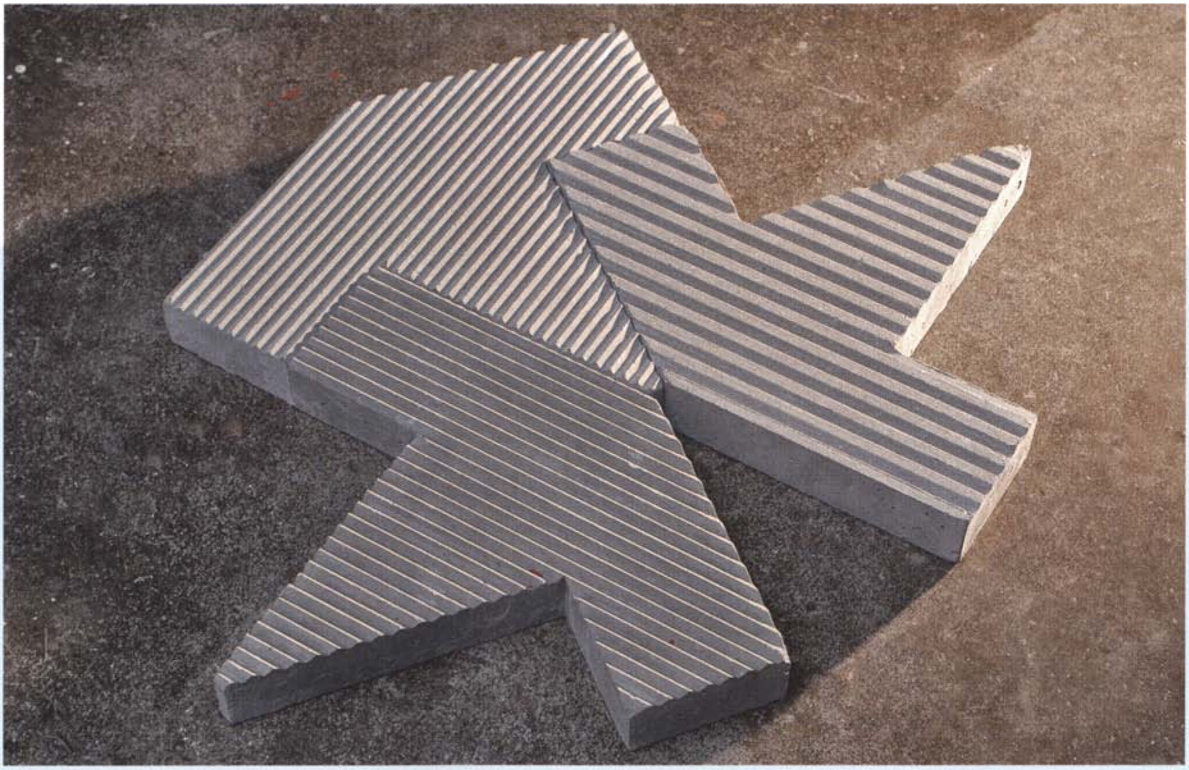
This unusual weekend house and calligraphy atelier has two stories and a roof terrace. Although located in the countryside with fresh air all around, the indoor air atmosphere is less than ideal due to its sporadic use as a weekend house, as it is aired only irregularly. By using unvarnished wood and air-purifying building boards that eliminate airborne contaminants, the architect was able to reduce the problem of poor air. The building boards are vapour permeable, absorbing and releasing moisture from and back into the air, in the process cleaning pollutants and odours from the air by breaking them down into their constituent parts. In addition, the building boards can be safely disposed of after the end of their useful lifetime.

Paving for Leien Boulevard

Antwerp, Belgium

Architecture	51N4E Space Producers, Antwerp, Belgium
Client	City of Antwerp
Product	Air-purifying paving tiles
Manufacturer	With integrated technology from Mitsubishi
Area	48,000 m^2

A decorative paving tile was developed for central Antwerp with a multiangular form whose shape is derived from Moorish patterns. 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. In this way, large areas of the urban realm have the potential to be used to reduce pollution levels in inner cities. As such the paving tiles represent an exemplary combination of decoration and function.



Jubilee Church, La Chiesa del Dio Padre Misericordioso

Rome, Italy

Architecture	Richard Meier & Partners, New York, NY, USA
Client	Vicariato di Roma
Product	TX Millenium, TX Active, photocatalytic cement
Manufacturer	Italcementi
Completion	2003

Three giant sails reaching up to 36 m into the sky give this church and community centre its unmistakable appearance. Made of prefabricated high-density concrete, their white colour is achieved by adding Carrara marble and titanium dioxide to the mixture. The photocatalytic self-cleaning additive enables the architect to achieve his trademark white colouring in an urban environment that is heavily polluted by car exhaust gases. The building not only remains clean, the large surface area of the sails also helps combat pollution by reducing the amount of volatile organic compounds (VOCs) and nitrogen oxide in the air considerably.

Anti-fogging

ANTI-FOGGING Clarity for steamed-up surfaces.

As soon as moisture condenses or settles on surfaces it forms many small droplets that combine to cloud a surface. Condensation on a mirror, for example, stops it from being usable. One way to maintain a clear view is to heat the mirror continually so that moisture evaporates, but a permanently clear mirror of this kind also requires constant energy input.

Due to nanotechnology a permanently clear view is now possible without the use of electricity. The solution is an ultra-thin coating of nanoscalar titanium dioxide, which exhibits a high surface energy and therefore greater moisture attraction. On hydrophilic surfaces moisture forms an ultra-thin film instead of water droplets. It still settles on the surface but remains invisible. The film is transparent, creating a fog-free clear appearance. Bathroom mirrors are obvious candidates for such coatings, as are glass surfaces in air-conditioned rooms in the tropics, which tend to cloud as soon as outdoor air streams into a room. Anti-fogging coatings can also be applied to plastics.

Another method has been discovered by researchers at the Massachusetts Institute of Technology (MIT) in 2005, and a similar coating has also been devised at the University of Queensland in Australia: a glass-like nanoporous surface coating made of several layers containing minute holes made by nanoparticles. The surface appears flat to the naked eye but is in fact super-hydrophilic. Moisture is drawn into the tiny pores

Mirrors with anti-fogging coating do not steam up.

thereby stopping water droplets from forming. A thin invisible layer of water forms and the surface remains clear.

Anti-fogging sprays are effective as a temporary means of making surfaces appear clear but the effect does not last long. Further application areas for anti-fogging surfaces are currently being developed but are not yet ready for the market place.

Two aspects are common to all anti-fogging variants: condensation itself is not stopped. Instead, and more importantly, it remains transparent and therefore appears invisible. A clear view is possible at all times, simply and effortlessly, without the need for heating, wiping down or a hairdryer.

Fragrance capsules

Fragrance capsules Sophisticated fragrances from microcapsules.

Our sense of smell is highly sensitive, affecting our subjective perception and with it our emotional response. Among the many conventional means of influencing our sense of smell, a recent innovation in this field uses minute fragrant capsules. Fragrances are enclosed in a microcapsule and only released in a controlled manner. Microcapsules of only a few micrometres in size enclose the fragrance with an ultra-thin and more or less impermeable membrane. The aroma function is initiated according to a "release-on-demand" principle, i.e. the capsules burst on mechanical contact, for instance when under pressure or when rubbed, releasing the fragrance contained within. This can be triggered, for example, by sitting on a padded bench or by walking on a carpet. The fragrance, whether flowery or exotic, is released and can unfold. It is released only when the tissue containing millions of capsules is put under pressure. As such, the microcapsules are of little use in wall panelling or curtains. Textiles, whether in upholstery, carpets or even leather, are more suitable for being equipped with this function.

Fragrance capsules complement the current wellness trend and knowledge of the positive effect of aromas for the body and spirit (e.g. aromatherapy) ideally. A further area is "design for the senses", in which aromas are often employed. Interior designers can make specific use of fragrances, for example lending wellness rooms in a hotel a pleasant smell of flowers or designing trade fair stands to be an experience for the senses. In all of these there is a certain amount of manipulation, both positive and negative.

An interesting application area is leather, which due to changed production processes has lost its typical smell. Today the smell is reintroduced using a solution that

produces the smell of leather when rubbed. This way the material fulfils the expectations of the consumer and underlines the high quality of the material – even though the smell is actually unnecessary. In this case the consumer probably is not averse to the manipulation that takes place.
The use of fragrances, whether natural or synthetic, should be regarded critically in the context of the rising incidence of allergies. Allergies in response to fragrances are increasing and it is becoming ever more difficult to avoid exposure to fragrances, especially when they are not declared. Because our sense of smell is so sensitive, aromatic overkill is neither desirable nor necessary, especially when people are exposed to fragrances and their potential consequences against their will.
Microcapsules exist in different forms with regard to their fillings, which can be gaseous, solid or fluid, and the greater or lesser permeability of the container. Common to all methods is that the fillings are released when the container is placed under pressure. The basic principle is well known from carbon paper. Whether intelligent textiles or cosmetics, which can transport active agents using this approach, they all contain innovative microcapsules. Similarly, microcapsules are also used to carefully target the controlled release of active substances in medications.

Thermal insulation: Vacuum insulation panels (VIPs)

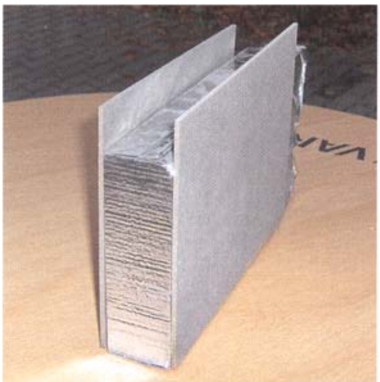
VIPs Maximum thermal insulation, minimal insulation thickness.

Vacuum insulation panels (VIPs) are ideally suited for providing very good thermal insulation with a much thinner insulation thickness than usual. In comparison to conventional insulation materials such as polystyrene, the thermal conductivity is up to ten times lower. This results either in much higher levels of thermal resistance at the same insulation thickness or means that thinner insulation layers are required to achieve the same level of insulation. In other words, maximum thermal resistance can be achieved with minimum insulation thickness. At only 0.005 W/mK, the thermal conductivity of VIPs is extremely low.

The historical precursor to vacuum insulators is the thermos flask, which functions according to the same basic principle: low thermal conductivity is achieved not, as usual, by enclosing pockets of air but by evacuating the air entirely, i.e. the creation of a vacuum. In thermos flasks the air between a twin-walled glass vessel is evacuated, whilst 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.

Vacuum insulation panels can be used both for new building constructions as well as in conversion and renovation work and can be applied to walls as well as floors.

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.
There are several aspects that should be taken into account in planning practice. In particular, wherever possible standard dimensions should be used; non-standard sizes are possible but more expensive due to the complex production techniques. For the panels to function correctly, it is imperative that the vacuum-enclosing skin is not pierced. This means that the panels cannot be cut to size or worked in any other way. For openings and items that penetrate the insulating layer, one should employ a combination of panel sizes or use panels that are factory-made with predefined openings. Likewise, the panels must be handled with care, both on site and during transport, to avoid damaging the panel's relatively sensitive skin. A loose skin indicates that the VIP has been damaged. It is advisable to instruct the site supervisor to pay special attention to the correct handling and working of VIPs. Special products are available that protect the actual VIP with foam layers to prevent damage of the sensitive skin.
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. The cold bridge results from the much



Vacuum insulation panels with a protective encasement.

Different sized vacuum insulation panels in storage.

VIP insulation must be made to measure and fitted precisely on site.

higher thermal transmittance of the gap. Likewise penetrations of the insulating layer are similar candidates for cold bridges. Heat loss through conduction around the edges of VIPs can also occur, especially when aluminium coated foil is used instead of plastic foils. This is often the case for lower-cost panels. In general the gap between VIPs should be treated with care.

The efficiency of the insulating effect, regardless of the thermal conductivity coefficient stated, is not only a factor of its installation but also the size of the panels. Large format panels are more advantageous.

VIPs are more expensive than conventional insulation materials and today are not necessarily conceived as a general replacement for conventional insulation. The use of VIPs is most suited to application areas where thin layers are desirable and where space is limited and conventional solutions cannot be implemented, for instance where thick constructions would result in uneven transitions. Also the greater floor area, and therefore higher property value, achievable by the use of thinner insulation layers may be sufficient to justify the increased cost of the VIPs. The thin construction and high insulating performance of VIPs also makes them attractive for the renovation of existing buildings. In all cases, vacuum insulation panels offer great potential in the general context of improving energy efficiency through better insulation and accordingly contribute to reducing the amount of CO_2 emissions.

VIPs have existed since the 1950s, but were previously far too expensive for economic use in construction. In recent years, intensive research has been undertaken to reduce the production costs and time significantly with the help of new materials (such as Aerogel as a fill material). In future, improvements in the production of VIPs can be expected, facilitating a more widespread application of highly efficient insulation materials. In the context of the ongoing debate on global warming, their worldwide potential is vast.

The lifetime of modern panels is generally estimated at between 30 and 50 years, with some products exceeding 50 years. A number of factors contribute to this, including the integrity of the skin, the degree of vacuum within, the seal and last but not least the correct installation of the product. Humid environments reduce the overall lifetime of the product. After the end of their useful lifetime, the panels can be recycled.

Vacuum insulation products are applied successfully not only in building but also to insulate pipelines, in electronics and for insulating packages, for example for the cool chain transport of medications.

Sonnenschiff centre

Freiburg, Germany

Architecture	Rolf Disch, Freiburg, Germany
Art	Erich Wiesner, Herbert Dreiseitl
Client	Solarsiedlung GmbH
Product	Vacuum insulation panel (VIP) and phase change material (PCM)
Completion	2006
Area	6,500 m² residential and commercial floor area

The mixed-use residential and commercial centre is situated next door to a solar housing estate and provides new amenities that were previously not locally available. The Sonnenschiff's forward-looking concept combines an economic and efficient use of energy with the use of regenerative energy sources, to the extent that the building produces more energy than it consumes. Solar and wind energy as well as geothermal warmth are utilised and natural, regenerative and recyclable building materials are employed. Vacuum insulation panels (VIPs) have been used for insulation and phase change material (PCM) latent heat storage systems for regulating indoor temperatures – both highly energy efficient systems. The VIPs constitute the insulation of the external walls and window parapets as well as the ventilation flaps on the main façade. Compared with other insulation materials of the same thickness, they offer ten times better insulation. PCMs in the walls and roof construction store ambient heat as they change material state. As such they help keep rooms cool and passively regulate the indoor air temperature. The concept is rounded off by an ingenious light, ventilation and heating concept. The implementation of a colourful artistic concept gives the building an eye-catching appearance.

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 seven-storey mixed-use residential and commercial building in Munich is the first building of a substantial size to be fully clad with vacuum insulation panels (VIPs). Despite adverse factors, the freestanding building fulfils ultra-low energy standards.

The compact rectangular form of the white building is punctured by large windows that wrap around its corners. At between eight and ten times greater efficiency than conventional insulation materials, the ultra-slim VIPs are extremely good insulators. Their potential lies not only in reducing energy consumption but also in maximising the available area as a result of thinner wall constructions. The use of VIPs resulted in a floor area gain of 10% of the overall floor area.

VIPs were also used in the roof terrace and window constructions. This inner-city building illustrates how the use of VIPs leads to energy savings as well as increased economic returns.

Thermal insulation: Aerogel

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

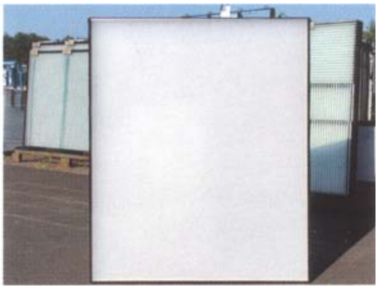
In comparison to the relatively well-known self-cleaning properties of nano-based surfaces, nanotechnology-infused thermal insulation represents a new development. A product known as Nanogel, a form of aerogel, not only provides high performance thermal insulation but also effective sound insulation.
Aerogel currently holds the record as the lightest known solid material and was developed back in 1931. The current variant used in construction has been produced by the Canadian Cabot Corporation in Frankfurt am Main for several years. The patent originally belonged to the German chemical concern Hoechst, but as Hoechst became Aventis, Cabot took over the aerogel activities and subsequently the patent for "Nanogel". The gel is a globular granulate and appears milky, translucent and somewhat cloudy. When held in the hand, the pure material has an extraordinary, fascinating and otherworldly feel to it that eludes comparison with most other haptic experiences. It is almost as if it derives from another star, or at least fresh from the NASA laboratories. The latter is not so far from the truth, as this is where aerogels were first developed for various applications designed for outer space.
In reality, aerogel is relatively banal: it is simply an ultra-light 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 glass-like 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 ex-

Aerogels in combination with glass

Opaque nanogel pearls.

Translucent nanogel granulate.

Heaps of aerogel.



cellent thermal insulation properties. The extremely high thermal resistance is expressed in a very low coefficient of thermal conductivity of just 0.018 W/mK. Aside from reducing heat loss, in cool regions the "cold wall" effect is also less pronounced, whilst in hot climates heat transfer from outside is reduced. Consequently, aerogels can help reduce heating and cooling costs significantly. It is used as an insulating fill material in various kinds of cavities – between glass panes, U-profile glass or acrylic glass multi-wall panels – and is therefore well suited for use in the external envelopes of buildings.

Because it is translucent, aerogel exhibits good light transmission, spreading light evenly and pleasantly. Direct sunshine is transformed into a glare-free soft light, making blinds or louvres unnecessary and mostly obviating the need for artificial daytime lighting. The evenness of the light distribution means that on grey days it can appear lighter indoors than outside – subjectively, as this cannot physically be the case. UV light does not cause colouration of the material. Due to the hydrophobic property of the material, moisture and mould are not an issue.

In addition to its thermal insulating properties, aerogel also acts as a sound insulator according to the same basic principle. The air molecules immovably trapped in the nanopores of the aerogel stop sound waves from passing through the material. As such Nanogel-filled glass panels are suitable not only for use in façades but also for interiors, for instance as enclosures around

A close-up of aerogel granulate.

Glazing elements filled with aerogel.

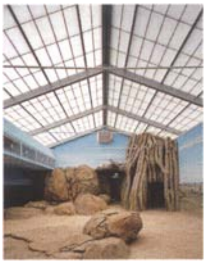
Glass sample with black edging and aerogel-filled glazing cavity.

conference areas in offices. For indoor use, laminated safety glass should be specified so that the aerogel filling does not spill should the glass break.

Aerogel with its above-average thermal and sound insulation properties contributes towards energy efficiency, which is its primary functional property. It is an extraordinarily high performance insulator and a comparatively new product on the market. A further advantage is its good light transmission and daylight transmittance. From an aesthetic point of view, its light weight makes homogeneous and slender façade constructions possible – all in all a whole catalogue of advantages with great potential. At present, only a handful of companies offer this innovative product on the international market.

County Zoo

Milwaukee, WI, USA



Architecture	Zimmerman Design Group, USA
Product	Kalwall+ Nanogel glazing
Manufacturer	Kalwall Corporation
Completion	2005
Area	Approx. 840 m^2 glazing

Daylight is important not only for people. The Florence Mila Borchert Big Cat Country building, constructed mostly of stone and concrete, was beginning to show its age. Better natural lighting was needed to improve conditions for the big cats. A key problem in this respect was the fulfilment of thermal performance and energy efficiency legislation. This was solved through the installation of aerogel-filled glass panels, which provide glare-free natural daylight whilst ensuring greater energy efficiency. The lions should benefit measurably – daylight is supposed to have a positive effect on the reproductive cycle of the animals.

School extension

London, England

Architecture	Jacobs UK Ltd., Glasgow, Scotland
Client	Buckinghamshire County Council
Product	Kalwall+ Nanogel glazing
Manufacturer	Stoakes Systems Ltd.

An extension to an existing school building makes the most of daylighting. The south elevation, behind which classrooms, the assembly hall, an internet café and a dance studio are located, is clad entirely in translucent 70 mm thick aerogel-filled panels. The panels soften daylight, providing a pleasant and light atmosphere indoors whilst obscuring the view outwards. Its excellent thermal insulation properties (U-value 0.28 W/m²K) result in energy savings, reducing the school's running costs and offsetting the initial investment necessary to finance such large translucent surfaces.

Sports hall

Carquefou, ZAC du Souchais, France

Architecture	Agence MA, Murail Architectures, Nantes, France
Client	City of Carquefou
Product	Multi-wall panels with Nanogel filling
Manufacturer	Cabot Corporation
Completion	2006
Area of sports halls	3,360 m²
Façade surface	1,450 m²

All elevations of this sports complex have been clad with aerogel-filled multi-wall polycarbonate panels. With this construction the architects voluntarily comply with the guidelines set down by the French "green" environmental initiative Haute Qualité Environnementale (HQE). Additional solar protection is unnecessary, allowing a clean and unified appearance uninterrupted by brise-soleils or louvres. Natural daylight provides an even and glare-free illumination of the indoor space, and additional indoor lighting is not necessary during the day. There are no cast shadows that could be distracting for certain sports. The thermal insulating effect of the aerogel panels also reduces the heat demand: a 25 mm thick panel has a U-value of 0.89 W/m²K and is available in 1.05 m wide panels of up to 6 m in length.

Factory

Zaisertshofen, Germany

Client	Ruf Maschinenbau GmbH & Co KG
Product	Aerogel-filled multi-wall polycarbonate panels
Manufacturer	E.M.B. Products AG Licht- und Lufttechnik GmbH

A factory in Bavaria needed glare-free light in its workshops. 16 mm thick translucent aerogel-filled multi-wall polycarbonate panels were installed in the skylights to provide uniform glare-free natural illumination in the workspace beneath. With a U-value of 1.31 W/m^2K, this is a practical and relatively straightforward application of an aerogel-based product.

Temperature regulation: Phase change materials (PCMs)

PCMs	Passive temperature regulation.
	Reduced heating and cooling demand.

Regulating the temperature of buildings consumes vast quantities of energy for both heating and cooling, in the process producing CO_2 emissions. With the help of nanotechnology, the energy consumption can be significantly reduced. Latent heat storage, also known as phase change material (PCM), can be used as an effective means of regulating indoor room temperatures. The good thermal retention of PCM can be used both in new and existing buildings as a passive means of evening out temperature fluctuations and reducing peak temperatures. It can be used both for heating as well as cooling (e.g. to protect against overheating).

A good example that illustrates the high thermal capacity of latent heat stores is an ice cube that begins to change to its liquid state at 0°C. The liquid state also begins at 0°C but the energy required for this change of state is equivalent to that required to heat liquid water from 0°C to 80°C. This "hidden" thermal buffer, or the latent thermal storage, is correspondingly large, and this principle can be used for the insulation of buildings using PCM. The word "latent" can be regarded as meaning "hidden" – it exists but is not evident.

The use of phase change materials is not new. In ancient Baghdad, rooms were kept cool with the help of a natural PCM: ice. Research into PCMs has been undertaken for many years. In the 1940s, first attempts were made to use PCM in buildings in the USA, and in 1953 the first microcapsule was patented, also in the USA. The widespread application of the material has only become feasible since the production of microcapsules (more precisely micro-encapsulated phase change material, MPCM), which represented a milestone in the development of PCMs. In the 1980s the NASA undertook basic research and development into PCMs, enter-

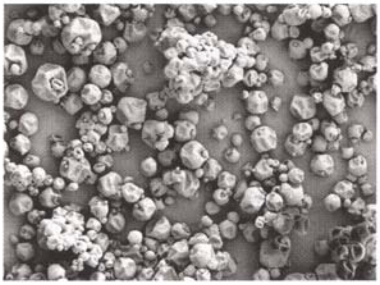
Close-up of a phase change material embedded in glazing.

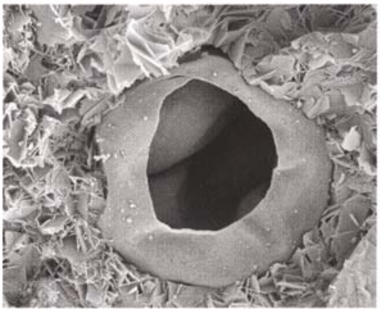
Crystallisation of a salt phase change material.

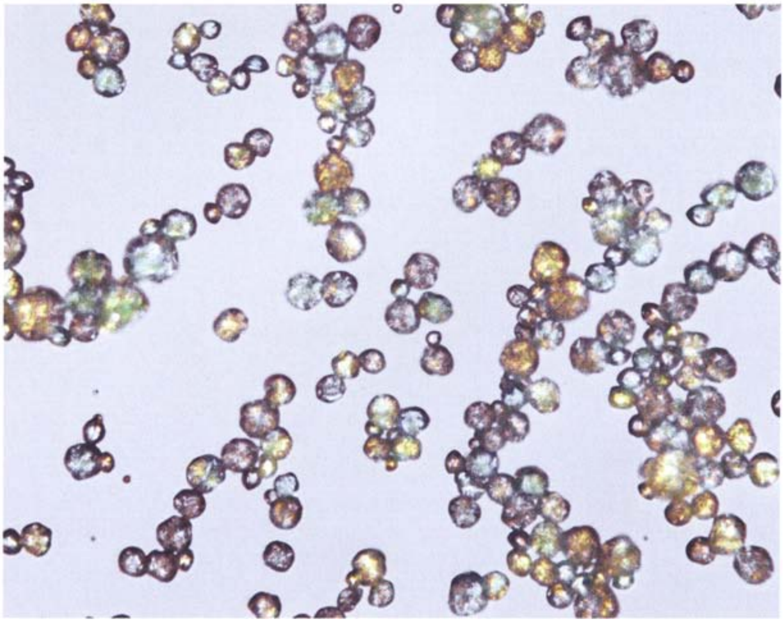
Wax droplets with an acrylic glass sheathing that is practically indestructible, even by sawing or drilling.

An image of an opened microcapsule embedded in a concrete carrier matrix, taken using scanning electron microscopy.

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.







ing into partnership with industry from 1988 onwards. Thermally adaptable spacesuits and gloves for astronauts were developed that enabled the wearer to withstand the extreme temperatures of outer space. Important patents followed in the early 1990s. In the context of building and construction, the main application area is for conserving energy.

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, whereby around 3 million such capsules fit in a single square centimetre.

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 amount of energy that is taken up or released is considerable so that even a comparatively small mass has a large thermal retention capacity, with which temperatures inside buildings can be regulated. During a phase change, the warmth is retained latently for as long as is required to change from one physical state to another. During this process, the PCM absorbs a particular amount of heat, the specific latent heat, equivalent to the amount of energy required to melt the paraffin. Instead of rising, the temperature of the PCM remains constant. The process functions according to the same principle in the opposite direction – during a phase change PCMs are able to store warmth as well as cold (known as the "free-cooling principle").

Energy is therefore stored latently when the material changes from one physical state to another, whether from solid to liquid or from liquid to gaseous. The latent warmth or cold, which effectively fulfils a buffer function, can be used for temperature regulation.

The predefined, so-called switching temperature, in which the phase change from one physical state to another occurs in latent heat storing materials designed for construction, is defined as 25°C, as above this temperature the indoor air temperature is generally regarded as being unpleasantly warm (as given in the German regulations for workplaces). Depending upon the PCM used, to regulate a 5°C increase in temperature only 1 mm of phase change material is required in comparison to 10-40 mm of concrete. The PCM has a far greater thermal capacity: a concrete wall warms

PCM plaster applied on interior walls provides thermal insulation.

up much more quickly whilst the temperature of a PCM remains unchanged. PCMs are available with different switching temperatures for different application areas. In areas other than construction, switching temperatures can vary considerably, ranging from minus degrees to 100°C.
In the meantime, PCMs have become available in the form of additives that can be integrated into conventional building materials such as plasters, plasterboards or aerated concrete blocks with specific retention properties. The first two materials can be used to add a temperature regulatory function to an interior, the latter to equip a building with latent heat storage properties from the outset. Most importantly, the materials need to be exposed to warmth. For example, it would not make sense to internally insulate an aerated concrete block PCM wall, as it would hinder the effectiveness of the PCM. From a fire safety perspective, it is important to note that paraffin, as used in PCMs, is flammable and PCM products are not therefore classified as flame-resistant.
In contact with other building materials, paraffin-based latent heat storage products do not cause any (undesirable) chemical reactions, such as corrosion.
An added advantage, particularly on-site, is that due to their small size, the globular PCM contained in materials are practically resistant to damage. As such mater-

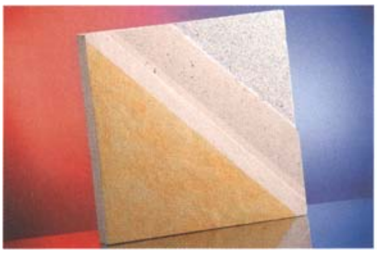
Layer composition of a decorative PCM gypsum plaster applied to a masonry substrate.

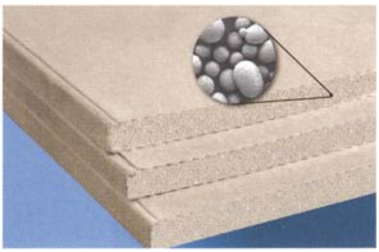
Although only 15 mm thick, this plasterboard panel contains 3 kg of micro-encapsulated latent heat storage material per square metre.

ials can be mechanically worked without damaging the temperature regulation function.

During the phase change, a change in volume occurs, which needs to be considered when materials are used in enclosed containers. Materials containing PCM should have a good thermal conductivity to ensure rapid transfer to and from the PCM. Paraffin has a relatively low thermal conductivity, but is compensated for by a higher reactivity resulting from the large surface area of the minute particles. To benefit from a continually functional PCM, the thermal capacity of the PCM should not change over its lifetime.

In addition to conserving energy by reducing the energy demand for heating and cooling, PCMs are also recyclable and biologically degradable. As with other innovative insulation materials, there is a large market for the use of PCMs in the construction industry, as they improve indoor climates, reducing costs and in some cases even obviating the need for air conditioning. With regard to the need to reduce CO_2 emissions, PCMs offer a further nanotechnology-based opportunity to achieve this aim. Latent heat storage systems are already successfully used in transport containers for sensitive materials, in outdoor clothing, as a base component for creams as well as for food wrappers. Their use could become widespread in the construction industry.





"Sur Falveng" housing for elderly people

Domat/Ems, Switzerland

Architecture	Dietrich Schwarz, GlassX AG, Zurich, Switzerland
Client	Jürgen Schwarz
Product	Latent heat storing glass, phase change material (PCM), GLASSXcrystal
Manufacturer	GlassX
Area	148 m² GlassXcrystal glazing

An experienced architect, who is also a scientist, developed a latent heat storing glass, which was followed soon after by the founding of a start-up company under the name GlassX AG. Among the projects realised using this glass is a building with 20 disabled-access sheltered flats in the Swiss Alps. All flats have large expanses of south-facing glazing and, depending on the season, the flats are heated actively or from passive solar gain. 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. The material's change of state is therefore immediately reflected in the building's appearance – function and aesthetics are inseparably connected. The buffer function of the latent heat store enables the indoor temperature to be regulated mostly passively, resulting in significant energy savings for heating (and cooling).

UV protection

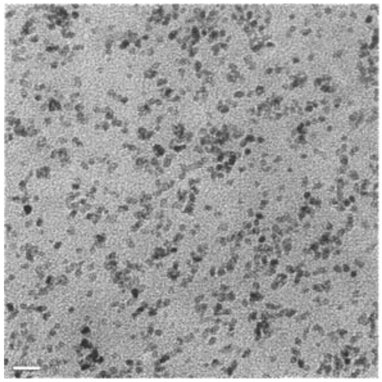
UV PROTECTION Lasting and highly transparent protection.

UV protection, or protection against harmful UV sunrays, is in demand in architecture. Woods as well as coloured surfaces change colour significantly when exposed to UV light as it destroys the colour pigments and colourings. The material itself is also affected. The degenerative effects impact not only on the appearance but possibly also on the stability of materials. Lasting protection against the damaging ultraviolet spectrum of light is therefore desirable.

There are two kinds of UV protection, both of which are organic and employ additives. Both are typically used in combination: one variant involves the use of UV absorbers that filter out the harmful rays in sunlight before they come into contact with the material itself. As such they need to be on an upper layer and are typically applied in the form of a protective lacquer. The second approach uses so-called free-radical scavengers, which in contrast to the first approach take effect at a later stage. They prevent the continued degeneration of an already damaged material, by reacting with the free radicals that form and converting them to inert compounds. This type of additive is typically impregnated in the material itself.

A disadvantage of both approaches is that neither is able to offer absolute protection – they simply lessen the effect of UV light and delay its impact. Additionally, both substances are organic compounds and are therefore themselves subject to a degree of degeneration through UV light. This means that the protective effect decreases over time. In other words, the material degeneration advances ever more rapidly – first discolouration, then embrittling and finally chalking (the formation of a light, fine powdery crust on the surface). For this reason, conventional means of UV protection cannot provide durable and lasting protection and degeneration as a result of UV light is inevitable in the long run.

Electron microscope image of UV-absorbent zink oxide particles contained within a clear varnish. In order for the material to remain transparent, the particles must be sufficiently small and not clump together. The even distribution can be seen clearly.



A new means of UV protection using inorganic substances represents an innovation. Their primary advantage is that they do not themselves degenerate and therefore provide a lasting protective effect.

Three compounds, titanium dioxide (TiO_2), zinc oxide (ZnO) and Ceroxide (CeO) are particularly well suited for this purpose. TiO_2 mainly absorbs the energy-rich UV-B rays, leaving the UV-A spectral region unaffected. ZnO provides protection against UV-B and UV-A rays, which are closest to visible light; it therefore covers the largest spectral region. CeO absorbs not only UV rays but also a small amount of visible light, resulting in a slightly yellowish colouring, which limits its possible application areas.

A prerequisite of protective coatings is that they are transparent so that the colouring and structure of the material beneath is preserved. To achieve this, the individual inorganic UV-absorbing particles in the formulation must be smaller than 15 nm in size. Below this size they no longer scatter visible light and become effectively invisible. Larger particles or the agglomeration of smaller particles to large aggregates – or as one might say clumping together – lead to a noticeable cloudiness in the formulation, for example a lacquer coating, even in low concentrations.

Agglomeration-free particles are gradually coming on to the market in the form of lacquer additives. In the near future we can expect to see lacquers and varnishes that are able to provide lasting UV protection, for example for high-grade woods. Using these inorganic compounds in the form of lacquers, it is possible to provide lasting protection against harmful UV rays that does not wear off with time.

Solar protection

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

Solar protection against heat gain from solar radiation is offered by two kinds of self-darkening glass. Electrochromatic switchable glazing was previously available on the market, but has since largely disappeared due to two main disadvantages: a constant electric current was necessary to maintain a darkened state and larger glass surfaces often exhibited optical irregularities.
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, i.e. one switch to change from transparent to darkened, and a second switch to change back. Different levels of light transmission with various darkening effects are also possible, either as a smooth gradient or clearly differentiated. The electrical energy required to colour the ultra-thin nanocoating is minimal. The switching process itself takes a few minutes, which can appear quite slow. The range of panel sizes currently available is relatively limited as the products have only recently come onto the market – the maximum size at present is 120 × 200 cm. Further panel sizes and improved switching speeds can be expected in the future.
The integration of electrochromatic glazing in a building's technical services affords greater control, although

Electrochromatic glass with an ultra-thin nanocoating needs only be switched once to change state, gradually changing to a darkened yet transparent state. At present the maximum dimension of glazing panels is limited.

it is still advisable to allow users the ability to control glass panels individually. It is generally possible to combine the electrochromatic function with other glazing properties such as laminated safety glass or thermal or noise insulating glazing. In future coloured glazing should also be available, expanding the design possibilities greatly.

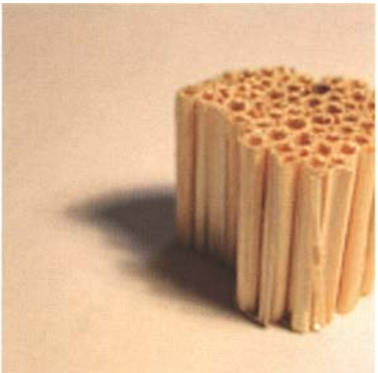
Photochromatic glass is another solution for darkening glass panels. Here the sunlight itself causes the glass to darken automatically without any switching.

In both cases blinds or curtains may no longer be necessary. Glare-free light and shading is particularly important for office interiors with computer workstations. Both variants also provide partial shading rather than complete closure so that a degree of visual contact to the world outside always remains. Nanotechnology has made it possible to provide an energy-efficient means of solar protection that can also be combined with other glass functions.

Fire-proof

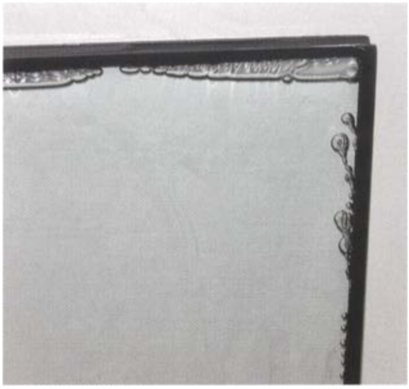
FIRE-PROOF Highly efficient fire protection.
Light and transparent.

In the nano-scene, a relatively small company from Switzerland, Interver Special Glass Ltd., has made headlines with its fire safety glass. 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 product was developed in cooperation with the German chemical concern Degussa, which has produced particles of "between 4 and 20 millimicrometres" under the name Aerosil for over half a century and is a major producer in the field. The raw material Aerosil, a pyrogenic silicic acid, is produced by Degussa and used for a number of purposes including in the paint industry. 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. Standard products are generally between 90 and 380 m^2 per gram!
The main advantages are the comparatively light weight of the glass, the slender construction and accompanying optical appearance as well as the long duration of fire-resistance. These provide benefits for building construction, installation, transport, aesthetics and last but not least the security of the users and the fire service. In the event of fire, the fire-resistant layer expands in the form of foam preventing the fire from spreading



The gel fill material in the glazing cavity (here faulty but clearly visible) foams when exposed to fire for an extended period.

A robust sandwich panel made of straw and hemp with a glassy coating that serves as a bonding agent and is also fire-resistant. When exposed to fire the product smoulders and extinguishes.



and keeping escape routes accessible for users and firemen alike. The additional layer does not exhibit any clouding, streaking or fractures and is practically invisible. An additional side effect is improved noise insulation. The ambitious product fulfils international testing criteria, norms and regulations and is certified for use around the world – currently it is installed in Dubai's newly constructed Dubai International Airport.
Aerosil is also used for other applications such as in the pharmaceuticals industry, the cosmetics branch, for high-temperature insulation material and the production of anti-drip paint.
Since the beginning of the 1990s, the company Vetrotech Saint-Gobain International has conducted research into foaming silicate fire-resistant materials in fire safety glazing using a patented nanotechnological method. This approach improves on the previous energy-intensive manufacturing process significantly, requiring less energy and being more environmentally friendly. Together with the producer of the nanosilicate raw material, the company optimised the complex production processes, in which nanoparticles of less than 70 nm are used, resulting in a slender, stable and highly transparent fire safety glass. The fire-resistant mass is not affected by UV light and even thin layers offer fire retarding properties in excess of 120 minutes.

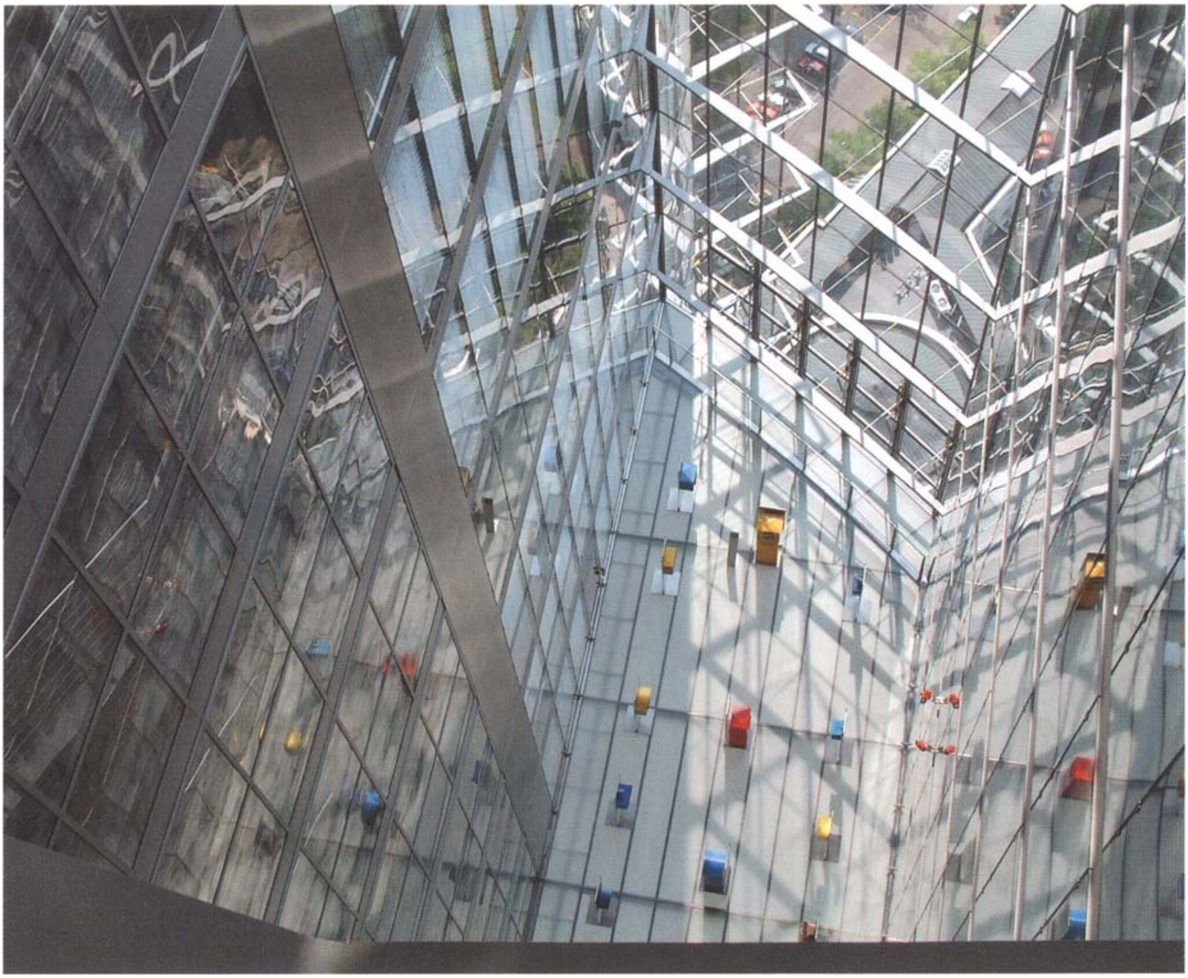
In the event of a fire the nanosilicate forms an opaque protective layer against the fire, which also protects against heat radiation. In terms of design, the first ever curved fire safety glazing is of interest. In addition "flush glazing" is also possible, with individual panes directly abutting without the need for vertical mullions.
These products are also used in other application areas, such as for glazing in cruise ships and tankers.
Flame-resistant lightweight building boards, sandwich constructions made of straw and hemp, are a further interesting application. Originally developed for rapid construction in developing countries with special climatic needs, these panels can also be used for interiors and exhibition stands. By coating the product in a transparent covering of glass-like particles, it is possible to render it weatherproof and flame-resistant, despite the fact that it is made of natural, inherently easily flammable materials. The glass-like coating also serves as the adhesive and further flame-retardant additives are not required. This technology is of particular interest for corridors, foyers and meeting areas, i.e. wherever fire safety is of particular importance. In the event of fire, the panels do not burn but char. Despite the glass-like coating, the panel is vapour permeable and can be shredded at the end of its useful lifetime.

Deutsche Post headquarters

Bonn, Germany

Architecture	Murphy/Jahn, Chicago, IL, USA
Client	Deutsche Post Bauen
Product	SGG Contraflam fire safety glass
Manufacturer	Vetrotech SaintGobain
Completion	2005
Area	90,000 m² gross floor area

The landmark 160 m high office tower in Bonn, the former capital city of Germany on the River Rhine, accommodates more than 2000 members of staff. The oval tower's façade is clad in high-tech transparent glazing and transparent materials are also used throughout its interiors: glazed partitions, glazed staircases and glazed connecting bridges are central elements of the interior design concept. A fire safety glass with a particularly slender profile was selected for the project. Space, form, construction and materials are carefully coordinated, resulting in a harmonious overall concept.

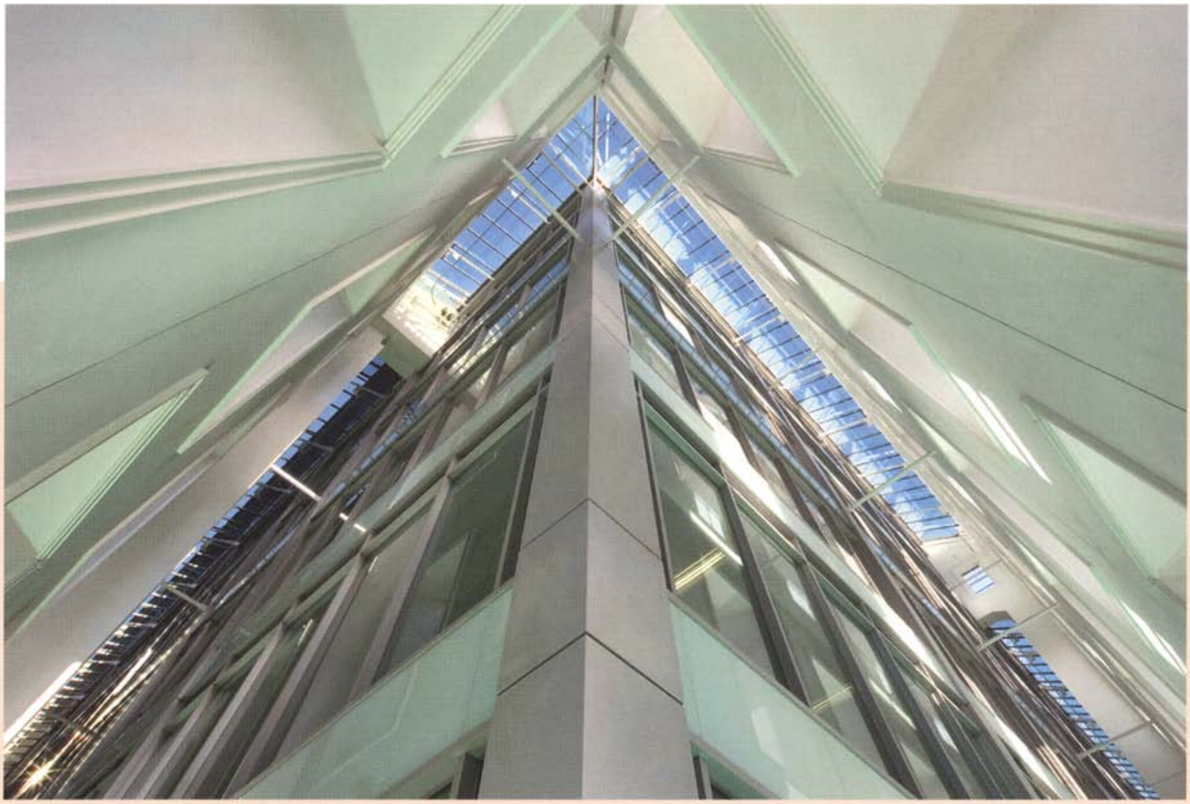


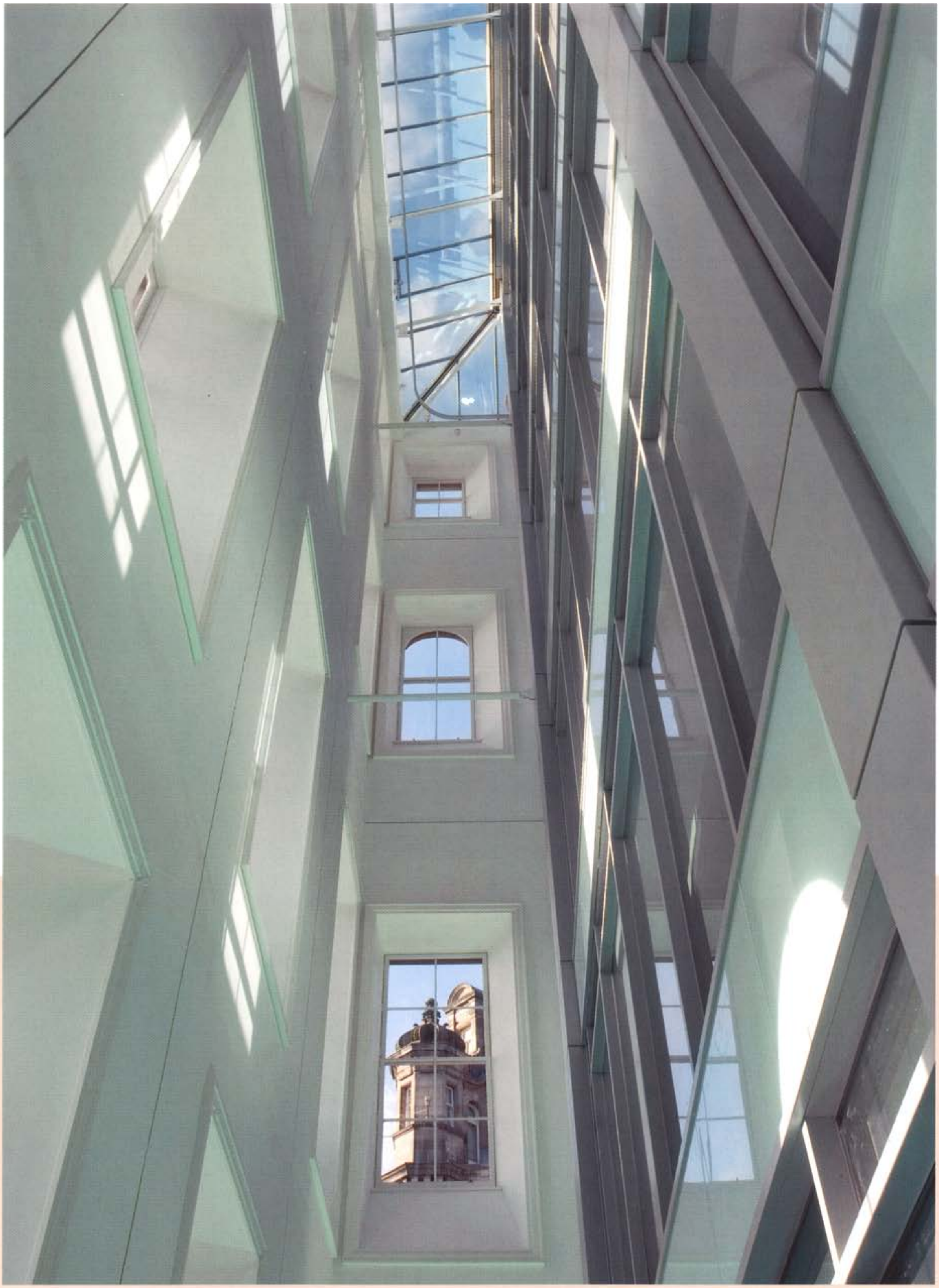
Waverley Gate

Edinburgh, Scotland

Architecture	SMC Hugh Martin Architects, Edinburgh, Scotland
Client	Castlemore, Development Company
Product	SGG Contraflam fire safety glass
Manufacturer	Vetrotech SaintGobain
Completion	2005
Area	20,000 m²

Waverley Gate is a complex in Edinburgh's central commercial and business district offering state-of-the-art premium office space with all the necessary facilities. Not only does it offer the largest contiguous office space in the city, it also has low running costs thanks to energy-efficient planning. The roof of the building has an unusual rooftop garden and an atrium provides additional daylight for the interiors, lending it a spacious and airy atmosphere. 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

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

Anti-graffiti coatings, which are applied to surfaces to reduce the adhesion of graffiti, have been on the market for a while but have two major disadvantages: the protective coating cannot be removed and the material it is applied to is sealed and therefore forfeits its permeability.

An anti-graffiti function is intended as a preventative measure to avoid unsightly graffiti to buildings or constructions such as noise barriers, walls and bridge piers. Numerous application areas are conceivable for both new constructions as well as in building conservation. Coating manufacturers and sprayers are entrenched in an ongoing battle, on the one hand to develop graffiti-resistant surfaces and on the other to develop sprays that stick more effectively. The sprays are therefore typically chemically aggressive.

A new means in the battle to protect existing building fabric is offered by anti-graffiti coatings that make use of nanotechnology. 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. As the material remains permeable potential damage resulting from dampness is avoided. The ultra-thin nanocoating lines the capillary pores without closing them. More dense

Historic monuments such as the Brandenburg Gate in Berlin are protected with an anti-graffiti coating.

materials such as compressed concrete in general require less coating material.
In addition, the coating also reduces dirt accumulation significantly, making the coating applicable for use on floor surfaces too. Chewing gum can be removed more easily and normal surface water, e.g. rain, has a certain rinsing, self-cleaning effect. It is nevertheless necessary to check in advance how durable the coating is, particularly for floor surfaces exposed to continual wear and tear.
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. This layer is not reversible, i.e. once applied at least within the pores it cannot be removed. In contrast to sacrificial coating systems, the nano-based anti-graffiti coating is permanent, remaining in place even after graffiti has had to be removed repeatedly. Some coatings have to be renewed every few times graffiti is removed. The initial application is sprayed (special protective measures are necessary in the USA and Australia) or

Noise barriers are ideal candidates for the use of anti-graffiti coatings.

The UEFA headquarters in Nyon, Switzerland, is fitted with flooring that makes it easier to remove chewing gum.

painted on, and a test application is advisable. The appearance of the underlying surface remains unchanged, but variants with added colour pigments are also possible if desired.

Such systems are also used in other application areas, for instance in road building and transport – the BAST (Federal Highway Agency) in Germany already lists nanocoatings as a permanent anti-graffiti system.

New Centre Ulm

Ulm, Germany

Architecture	Stephan Braunfels Architekten, Berlin, Germany
Client	Sparkasse Ulm
	August Inhofer Wohnbau, Senden
Product	Faceal Oleo HD, anti-graffiti and dirt-repellent coating
Manufacturer	PSS Interservice
Completion	2006
Area	6700 m² total gross floor area

Ever since the destruction caused during the Second World War, the urban state of the Neue Straße in Ulm has remained unresolved. On one side it borders on the Ulm Minster and Richard Meier's Stadthaus building, on the other side the medieval city hall and Gottfried Böhm's city library building. The insertion of two new infill buildings, a Sparkasse bank building and the Münstertor department store, provides better definition of the surrounding urban space. The Sparkasse consists of two intersecting volumes that meet to form a glazed slot opposite the city hall. The tapering form of the department store relates to the medieval scale of the surroundings.

Both buildings have exposed concrete façades 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.


ZONE

Hofjäger 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

Four prestigious buildings arranged around a park in the heart of Berlin offer modern and luxurious living. The spaciousness of the outdoor areas reflects the generous planning and quality of fittings in the interiors. An appropriate and modern security concept is a vital part of the complex. 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.

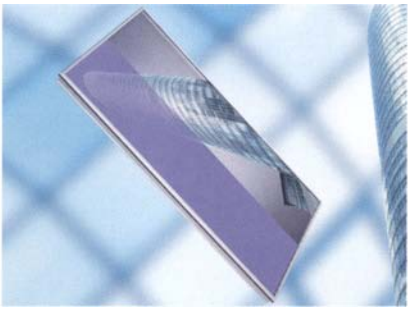
Anti-reflective

Anti-reflective Improving solar transmission.

The transmission of light through transparent materials such as glass or plastic, which reflect some of the incident light, is reduced by the reflection of light rays. Glass allows a maximum of 90% of incident light to pass through it. This phenomenon is caused by a change in the refractive index as light passes through two different media (e.g. glass and air). The decisive aspect is therefore the refractive index.

The use of anti-reflective glass to solve the problem of reflection is in itself nothing new. In interior architecture, such glass is used in exhibition design for glass cabinets for example. Its complicated manufacture, which involves applying several layers, means that it is expensive. The adhesion on plastic is also not as good as on glass. A further disadvantage is that such multilayer interference systems only work in the spectrum of visible light with a wavelength of between 380 nm and 780 nm, with increased reflections in other parts of the spectrum. Unfortunately, the gains made in the spectrum of visible light do not outweigh the losses in the infrared area and as such they are not useful for improving the effectiveness of solar collectors.

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 30–50 nm large silicon-dioxide (SiO_2) 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 150 nm is regarded as ideal. The ratio of reflected light reduces from 8% to less than 1%. Another cost-



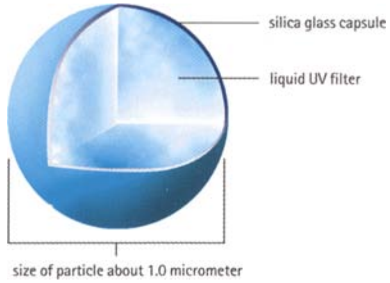
A photovoltaic module with and without anti-reflective (AR) solar glass coating.

Silica glass capsules are used in nanoporous anti-reflective coatings with a thickness of 150 nm that are also able to reflect the invisible spectrum of light.

effective means of producing anti-reflective surfaces is the moth-eye effect. The cornea of moths, which are active mostly at night, exhibit a structure that reduces reflections. The Fraunhofer Institute in Germany has developed a similar structure that can be impressed or injection-moulded onto glass. Using hot-process embossing, the visual transmission of glass can be increased to over 98%, and of plastics such as acrylic glass to over 99%. In addition to its anti-reflective function, dirt-repellent and antistatic properties can also be integrated.

The disadvantage of conventional anti-reflective technology, such as the limited spectral region and the complex production process, are eradicated using nanotechnology. Anti-reflective glass can now be used in large quantities in construction in order to benefit from the increased solar transmission resulting from broadband spectral dereflection. Of particular interest is the increased efficiency of photovoltaic systems as the entire spectrum of solar energy from 400 to 2500 nm is now transmitted. The degree of transmission at low angles of incidence is also much better than before, making such systems less dependent upon the angle of the sun. By reducing the amount of under-utilised and therefore lost solar energy, the energy gain and efficiency of the photovoltaic systems is improved, resulting in an overall performance gain of up to 15%.

The nanocoating has a long lifespan and is no more susceptible to dirt than normal glass. In comparison to conventional anti-reflective glass it has a higher abrasion resistance, making it all in all well suited for everyday use.



Antibacterial

ANTIBACTERIAL

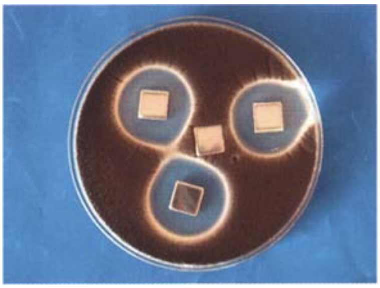
Bacteria are targeted and destroyed.

The use of disinfectants can be reduced.

Supports hygiene methods – especially in health care environments.

Photocatalytic surfaces, which are described in more detail elsewhere in this book (see p. 72), also have an antibacterial side effect due to their ability to break down organic substances in dirt. 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. Various products are already commercially available and the product palette ranges from floor coverings to panel products and paints to textiles with an innovative finish that renders them germ-free. In Japan, where hygiene is accorded special importance, such materials are particularly popular and are under constant development.

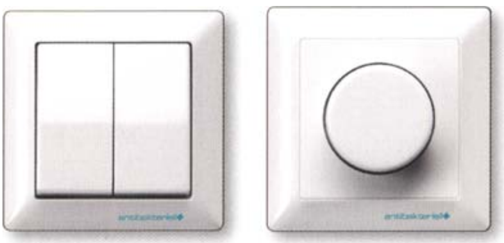
Bacteria are omnipresent and a part of everyday life, although not always desirable. The increased level of hygiene in private households has led to a veritable antibacteria mania that is more detrimental than it is useful. However, there are areas where bacteria can indeed be damaging. In hospitals, for example, harmful bacteria abound on the one hand and weaken patients on the other. The deployment of disinfectants has now changed, becoming more directed, as opposed to the "blanket approach" previously used. Like hospitals, doctor's practices also fight an ongoing battle against germs, with a multi-pronged approach involving disinfectants, antibiotics and building up resistance. The question is how best to protect against germs and bacteria without using the traditional indiscriminate blanket approach.



Fungicidal coatings on stainless steel plates reduce the formation of the mould *Aspergillus niger*. The inhibition zone that has formed is clearly evident when compared with that of the reference plate in the middle.

Sanitary, care and medical facilities are areas particularly susceptible to germ transmission. This can be counteracted through the use of antibacterial surface coatings that react against many of the more important pathogens. The antibacterial agent is a constituent part of the material itself.

Medicinal equipment, when coated accordingly, remains germ-free. For example, hearing aids that reduce inflammations have proved most successful. In interior architecture all surfaces are suitable candidates for antibacterial surface coatings, whether enclosing surfaces such as floors, walls and ceilings or furnishing such as textiles, sanitary installations, shelves and worktops, and in particular knobs, buttons and switches that are in constant use by patients and staff.
The antibacterial effect is achieved through the use of silver nanoparticles only a few nanometres in size. The antimicrobial properties of silver have been known for more than 3000 years, and are in essence nothing new. The use of silver tableware and cutlery is a case in point. Physicians have also used silver as a disinfectant since the end of the 19th century. The primary difference between the current use of silver and that of the past is one of scale – previously silver was used in its classic form as a metal alloy and was comparatively coarse in structure.
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.



Curtains with antibacterial properties.

Contact surfaces such as light switches, door grips and handles are typical germ accumulators. An antibacterial material, such as that used for this light switch, can prevent germs spreading.

Nanoscalar silver particles contained in the glaze applied to ceramic sanitary installations lend it antibacterial properties.

An antibacterial wood coating, also containing nanosilver, is applied to the surface of a chair. Wood has a natural antibacterial effect that is lost when coated with conventional varnishes or paints.

Antibacterial coatings are typically used on the surfaces of furniture, for example in material coatings, upholstery and paints and varnishes.

In addition, it is also advisable to equip surfaces with an anti-stick function to prevent the build-up of a biofilm of dead bacteria from which new bacteria could eventually grow.

Silver nanoparticles not only reduce the need for chemical disinfectants but also reduce the amount of cleaning time necessary. As the use of disinfectants in health care cannot yet be avoided, it is important that coatings and materials are proven to be able to withstand standard disinfectants. Antibacterial surfaces based on silver nanoparticles represent an effective and unobtrusive bacterial killer, which when employed sensibly can offer significant benefits.

Housing estate

Duisburg, Germany

Architecture	Joachim Osterland, Essen, Germany
Client	Deutsche Annington Immobilien
Product	Bioni Perform, antibacterial façade paint
Manufacturer	Bioni CS
Completion	2004

The mould on the façades of this housing estate in Duisburg proved hard to eradicate. In the past a combination of insulation and fungicidal silicon resin-based paint was used to resolve the problem, however the remedy lasted only two years. Microbe infestation became visible again and mould and mildew formation followed soon after, necessitating a second renovation of the elevations. This time a solution developed by the renowned Fraunhofer Institute for Chemical Technology in collaboration with a paint manufacturer was chosen. 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.

The same façade coating has been used for the very large and world-famous "The Palm" complex in Dubai (40,000 m² of roof surface). Antibacterial wall paints have also been used in the interiors of the Al Wasl Hospital, also in Dubai. In hospitals in particular, where hygiene is a central aspect, biocide-free antibacterial paints offer major advantages.

Operating theatre

Goslar, Germany

Architecture	Schweitzer + Partner, Braunschweig, Germany
Client	Harzkliniken, Goslar
Product	"Hydrotect" tiles, photocatalytic surface with antibacterial effect
Manufacturer	Agrob Buchtal Architectural Ceramics, Deutsche Steinzeug AG
Completion	2005

In both operating theatres, the floors and walls have been clad in photocatalytic tiles. Hygiene is of primary importance in operating theatres and antibacterial tiling contributes to lessening the risk of infection. In the Klinikum im Friedrichshain, the architects have gone one step further and minimised the amount of tile joints, lessening weak points where bacteria can settle and lending the room a calmer appearance. Large-format 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.

Operating theatre

Berlin, Germany

Architecture	Höhne Architekten, Berlin, Germany
Client	Klinikum im Friedrichshain
Product	"Hydrotect" tiles, photocatalytic surface with antibacterial effect
Manufacturer	Agrob Buchtal Architectural Ceramics, Deutsche Steinzeug AG
Completion	2003

Patient's hospital room prototype

Berlin, Germany

ARCHITECTURE	100% interior Sylvia Leydecker, Cologne, Germany
CLIENT	succidia Verlag
PRODUCT	Capasan, air-purifying wall paint
MANUFACTURER	Caparol
PRODUCT	Drapilux air, air-purifying textiles
MANUFACTURER	Drapilux
PRODUCT	Accent Wood, antibacterial floor covering
MANUFACTURER	Tarkett
PRODUCT	antibak, antibacterial wood varnish
MANUFACTURER	Clou
PRODUCT	Microcare, antibacterial and dirt-repellent upholstery fabrics
MANUFACTURER	Microcare
PRODUCT	AS 500 antibacterial, antibacterial light switches
MANUFACTURER	Jung
PRODUCT	ccflex, water-repellent, scratch-resistant and vapour permeable ceramic wallcovering
MANUFACTURER	Degussa, Evonik
PRODUCT	Jasba Centino with Hydrotect treatment, self-cleaning floor tiles
MANUFACTURER	Jasba, Deutsche Steinzeug
PRODUCT	Subway with Ceramicplus treatment, easy-to-clean WC
MANUFACTURER	Villeroy & Boch
COMPLETION	2006

The "Private Patient's Hospital Room of the Future" is a concept for an exemplary prototype of a possible future hospital room. Its purpose was not to envision things that are not yet possible but to develop concrete practical proposals for designs, paying particular attention to the demands of private patients. The concept is based on five main pillars: functionality, comfort, design orientation, corporate design and an atmosphere of well-being. The overall concept, which includes proposals for the room layout (bed, bathroom, lounge), material, form, colour, light and so on, integrates numerous different nanosurfaces. Although not a declared aim of the project, many such materials proved to make practical sense in the course of developing the concept. For example, 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. The poor air quality often found in hospitals is improved by using air-purifying textiles and wall paints. Easy-to-clean surfaces are perfect for sanitary installations. Last but not least, wall tiles in the bathroom, with their unhygienic joints, are replaced by a water-repellent yet vapour-permeable ceramic wall covering.

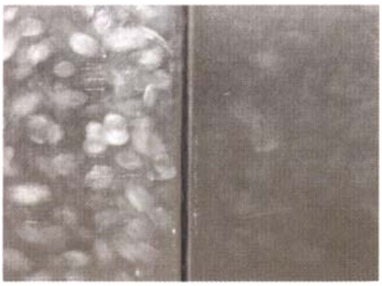
Anti-fingerprint

ANTI-FINGERPRINT No more visible fingerprints.

Steel and glass are popular materials in architecture but when used in interiors they have a disadvantage – fingerprints show very clearly. Materials that are within easy reach are often touched, mostly because they have a related function, but sometimes just because they are there. This affects almost all interiors and as such this area benefits most from anti-fingerprint and touch-proof coatings.

Steel and satin-finish glass surfaces are particularly affected by repeated touching. The appearance of cleanliness, whether desirable for aesthetic or hygienic reasons, vanishes when surfaces are covered in fingerprints. An anti-fingerprint coating can offer a suitable solution for this problem and in some cases makes it possible to employ such materials in the first place. With the help of these coatings fingerprint marks are made practically invisible. The fingerprints are actually still there but thanks to the nanocoating they are almost imperceptible. The coating alters the refraction of the light in the same way the fingerprint itself does so that new fingerprints have little effect – one can think of the coating as a kind of enlarged fingerprint. 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. On careful examination it is possible to see traces of fingerprints, but the improvement in comparison to normal uncoated surfaces is striking.

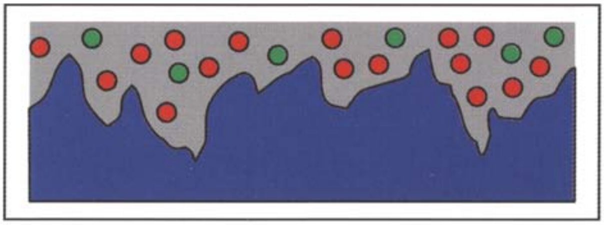
The coating itself is ultra-thin and steel that has been coated can be bent into shape without the coating breaking or fracturing. This can be especially useful for the production of particular architectonic details, and

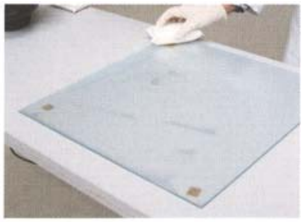


The effect of the anti-fingerprint coating on this sheet of stainless steel is clearly evident.

The functional principle of a coloured protective coating retrofitted to a glass surface:

1. The coating material is applied with a slight excess to the glass (shown in blue). Colour pigments (red) and stabilisers (green) are contained within the matrix of the coating (shown in grey).
2. Removal of excess material by hand or machine.
3. Fully hardened protective coating.





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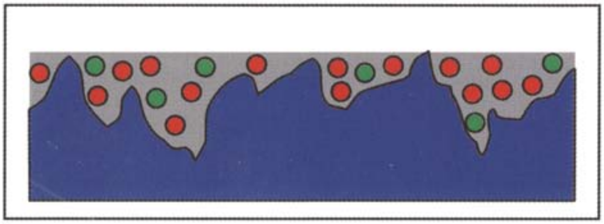

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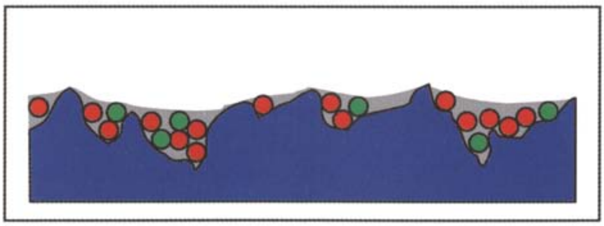

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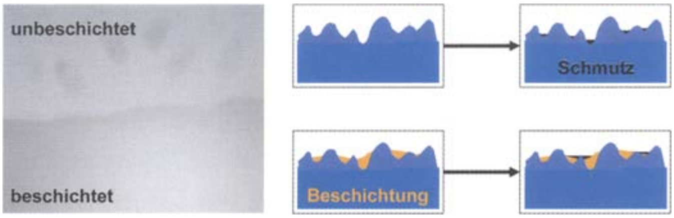


Functional principle of an anti-fingerprint coating (below) vs. an uncoated surface (above).

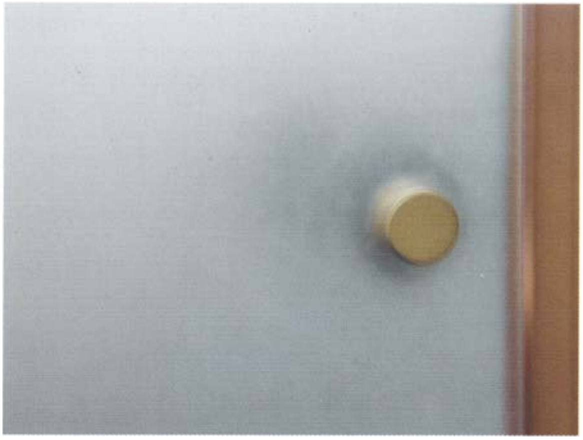
the coating is used mainly for applications such as lifts, cladding and furniture.

Over the last decade, sandblasted glass has become a popular material in interior design. Translucence is particularly attractive as a design feature of doors, partition screens and furniture. However, the sandblasted side of the glass is very susceptible to fingerprints. Where protection is necessary, a silicon coating is usually applied to the surface. Unfortunately, when cleaned such surfaces acquire a typical cloudy appearance. An anti-fingerprint coating can avoid the disadvantages of the silicon coating – the nanocoating ensures the lasting optical appearance of the glass. The coating not only reduces the impact of fingerprints but also of dust, which on smooth surfaces can be wiped away but becomes more ingrained and harder to remove from sandblasted surfaces. At present the coating is not entirely transparent and as such cannot yet be used on clear glass.

Facility management benefits from this as well as other nanocoatings as they lead to a reduction in cleaning costs. The coating is effective also for smaller surfaces where cleaning can be especially time-consuming. Typical trouble spots, such as surfaces around doorknobs and grips, remain clean and look as good as when first installed.

A more recent innovation is a touch-proof coating that can also be used for colouring matt glass. Coloured matt glass is usually achieved using coloured glass, silk screen printing or coloured foils in combination with laminated safety glass and is comparatively expensive. A cheaper option is to apply coloured self-adhesive foil to existing glass but the end result is not of a high quality. A new cost-effective option is the use of

The critical area around doorknobs.



a coloured touch-proof nanocoating on etched or sandblasted glass. The intensity of the colour depends on the roughness of the glass and the angle you look at it. The colour palette is currently limited to pastel colours and it is not yet possible to specify exact colours. The colours remain colourfast when exposed to UV light and do not fade.
An important aspect here, as with other nanocoatings, is scratch-resistance, which should be assessed carefully depending on where the product is to be used.
Anti-fingerprint coatings are useful for stainless steel and sandblasted glass wherever one can expect people to touch them, i.e. where they are in easy reach. Nanocoatings enable glass and steel to be used for interiors without being impaired by visible finger- and handprints and obviate the need for regular cleaning; in short, to achieve a clean appearance.

Scratchproof and abrasion-resistant

SCRATCHPROOF AND ABRASION-RESISTANT	Improvement of scratch and abrasion resistance.
	Transparent coating.
	Creating a basis for durability.

Nanotechnology makes it possible to improve scratch-resistance whilst maintaining transparency. Scratch-resistance is a desirable property for many materials and coatings can be applied to materials of different kinds such as wood, metal and ceramics. There is no ideal coating, rather two basic principles apply: self-healing layers, which are less susceptible to scratching, or glass-like hard scratch-resistant layers, for which different companies offer specific products. The manufacture requires great care to achieve the desired level of transparency, which excludes the use of coarse additives.

Materials are generally subject to wear and tear by abrasion, e.g. from being walked on, from scrubbing and cleaning or similar. The science of how materials behave under friction and wear is known as tribology (from the Greek *tribos*, meaning friction). Nanotechnology has made so-called tribological coatings possible, which offer abrasion-resistance or low friction and are therefore resistant against wear and tear and also corrosion. These are already well established in mechanical engineering and have replaced conventional toxic lubricants.

Such layers must firstly adhere to the surface they are coating and secondly be resistant against wear and abrasion. This is assessed using abrasion tests.

The hard variant of the scratch-resistant function is achieved through a glass-like coating. This layer can also protect other functional layers to prolong their durability. Glass-like nanocoatings made of silicon dioxide form a hard and resistant surface. For example, Easy-to-clean (ETC) coatings in a washbasin last con-

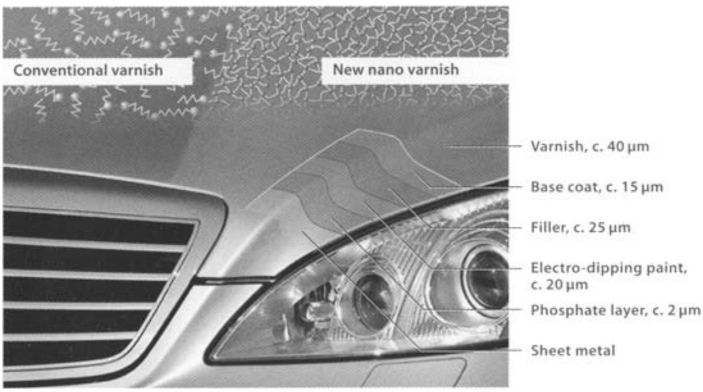
Scratchproof varnishes are not able to withstand major damage, for instance scratches from a key, but they can protect a car from scratching resulting from a car wash or from dirt and dust in transit. Layers of a protective varnish.

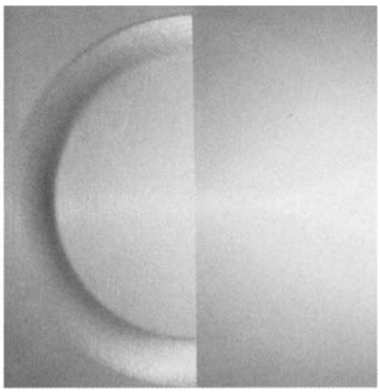
Abrasion tests indicate a surface's resilience against abrasion and wear and tear.

siderably longer when combined with a scratchproof function. It is important to be aware that scratch resistance does not mean protection from major mechanical impact, such as scratches caused by keys.

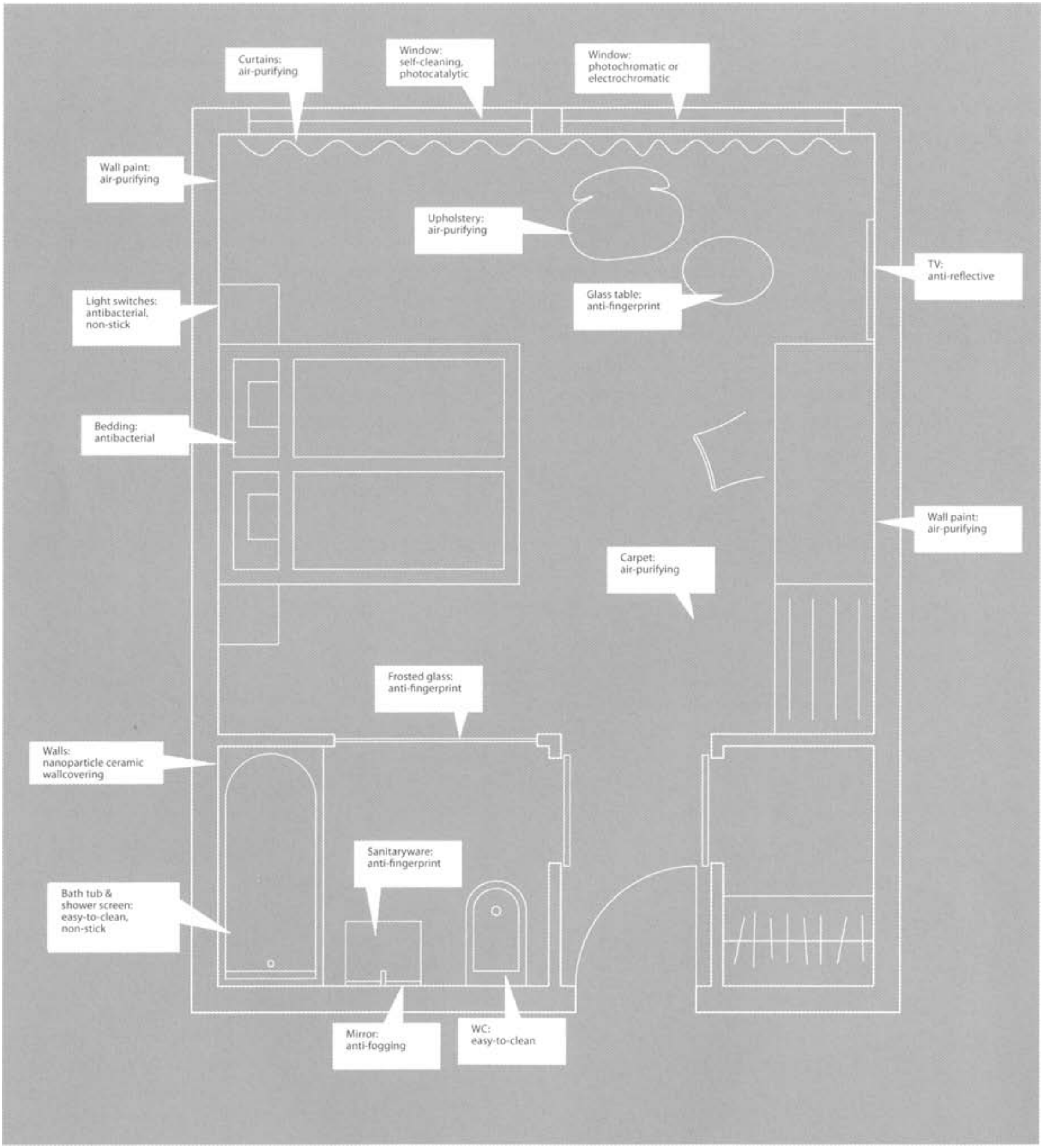
For architectural applications, recently developed scratch-resistant stainless steel coatings are of particular interest and are available in transparent or coloured form. Scratchproof lacquers are a standard feature of certain car models. The protective layer preserves the gloss of a vehicle's paint, avoiding damage from quartz dust hitting a car while driving or scratching in the car wash. The German drivers license also has a scratchproof coating and wearers of spectacles benefit from similar coatings.

In the architectural context, scratchproof paints and varnishes are desirable, for instance to protect the varnished surfaces of parquet flooring or the surfaces of other gloss lacquered surfaces. Consumers who associate patina with negative connotations such as a "lack of care" and "old and worn" will value a durable gloss that maintains its original appearance. Not everyone shares the love that many architects have for authentic patina. Scratch-resistant surfaces in combination with UV protection and easy-to-clean properties seem to be a particularly attractive combination for many users, in order to reduce traces of use. Likewise cleanly designed surfaces maintain their appearance better through the use of scratchproof and abrasion-resistant surfaces.

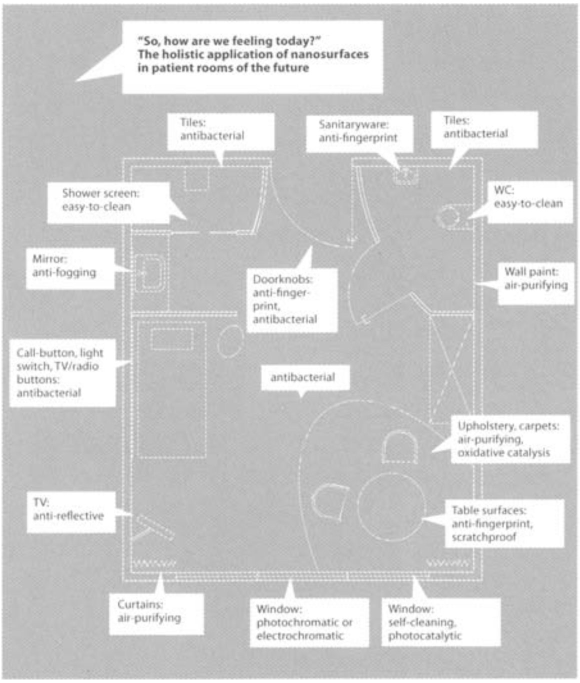


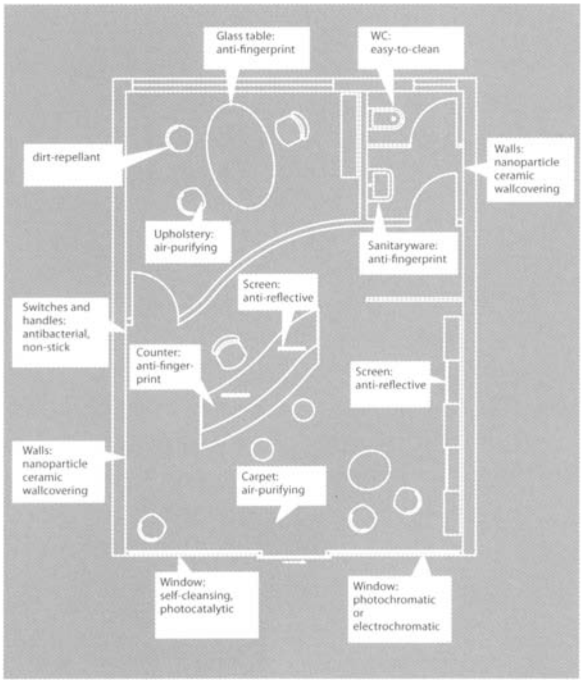


The holistic application of nanosurfaces in interiors



Nano functions have been employed in interior design only occasionally if at all, and more or less by chance. The schematic plans for a hotel room, a patient's room in a clinic or hospital and a bank branch demonstrate concepts for a general strategic approach to using nano functions in interior design. The overall concept varies depending on the respective needs of the different uses. The spaces are optimised through the strategic use of nanosurfaces with regard to aesthetic, economical and ecological concerns. Improved comfort and cost-effectiveness go hand in hand. Cost assessments should take account not only of the initial expenditure but also the follow-on costs, which are reduced considerably. Despite the fact that these are visionary concepts, they could already be realised today in this or a similar form.





Acknowledgements

There are so many people I would like to thank that it is quite impossible to list them all here. This in part due to the numerous contacts made at trade fairs, symposia, lectures and other meetings in the lively "Nano Scene", an active community without whom I would never have been able to gather so much useful information. There are many with whom I have shared informative discussions, who have given pointers, supplied official information and offered personal opinions or even inside stories, among them scientists, company employees and their directors and not least several architects – all have provided background information and contributed in some way to this book. I would like to thank all those who gave so generously of their time.

In particular I would like to thank Harry Kroto (The Florida State University) and Professor Michael Veith (Leibniz Institute for New Materials) for their willingness to contribute forewords to this book. Likewise I am grateful to my two guest authors, Dr. Marius Kölbel (MaterialInnovation) and Dr. Sascha Peters (Bremen Design Centre), for their elaborations on their respective areas of expertise (product design and dangers and risks). I would also like to thank Dr. Matthias Koch (Merck KGaA) for his helpful "checks" behind the scenes.

I also would like to extend my thanks to all those involved in making this book for their support and cooperation: my editor Andreas Müller, who put forward the idea for this book, managed the entire project and calmly oversaw its development, and the graphic designer Miriam Bussmann, for giving the project an appropriate graphic form. Thanks also go to my colleagues at 100% Interior in Cologne, the interior designer-combo Melanie Keil and Stephanie Kammer for their commitment and support.

... and as writing a book can sometimes be quite stressful, last but not least my special thanks to my family Christian, Eileen and Tessa.

People

No history would be complete without its "stars" of the scene. Certain names from the nano community, among them several Nobel Prize winners, crop up repeatedly in the media and some have attained near cult status. The following list, in no particular order, is intended to help the reader identify people mentioned in the context of nano discussion – a personal "Nano Walk of Fame******" without ranking and by no means exhaustive.

Richard Philipp Feynmann _ gave a pioneering speech "There's Plenty of Room at the Bottom" in 1959 at the Caltech California Institute of Technology, Pasadena, USA, awarded the Nobel Prize for Physics in 1965

Norio Taniguchi _ coined the term "nanotechnology" in 1974, Tokyo University of Science (formerly Science University of Tokyo) "Rikadai/Ridai", Tokyo, Japan

Kazuhito Hashimoto _ leading researcher into photocatalysis, RCAST (Research Center for Advanced Science and Technology), The University of Tokyo, Tokyo, Japan

Toshiyo Watanabe _ leading researcher into photocatalysis, RCAST (Research Center for Advanced Science and Technology), The University of Tokyo, Tokyo, Japan

Akira Fujishima _ discovered TiO_2 photocatalysis as a student, "Honda-Fujishima Effect", 1967, RCAST, The University of Tokyo, Tokyo, Japan

Gerd Binnig _ inventor of the scanning tunnelling microscope (STM), a milestone in the development of nanosciences, IBM Research Center, Zurich, Switzerland, awarded Nobel Prize for Physics in 1986

Heinrich Rohrer _ inventor of the scanning tunnelling microscope (STM), IBM Research Center, Zurich, Switzerland, awarded Nobel Prize for Physics in 1986

Ernst Ruska _ development of electro microscopy, Fritz Haber Institute of the Max Planck Society, Berlin, Germany, awarded Nobel Prize for Physics in 1986

Richard E. "Rick" Smalley _ discoverer of the C_{60} carbon molecule / fullerenes or buckyballs in 1985, Rice University, Houston, Texas, USA, awarded Nobel Prize for Chemistry in 1996

Harold W. "Harry" Kroto _ discoverer of the C_{60} carbon molecule / fullerenes or buckyballs in 1985, Florida State University (FSU), Tallahassee, Florida, USA (prior to 2004 he worked for 37 years at the University of Sussex, Brighton, UK), awarded Nobel Prize for Chemistry in 1996

Robert F. "Bob" Curl Jr. _ discoverer of the C_{60} carbon molecule / fullerenes or buckyballs in 1985, Rice University, Houston, Texas, USA, awarded Nobel Prize for Chemistry in 1996

Wolfgang Krätschmer _ Max Planck Institute for Nuclear Physics, Heidelberg, Germany, in 1990 he co-developed a process for the manufacture of macroscopic amounts of buckyballs

Don Huffman _ University of Arizona, Tucson, Arizona, USA, in 1990 he co-developed a process for the manufacture of macroscopic amounts of buckyballs

Sumio Iijima _ AIST/Research Center for Advanced Carbon Materials, Meijo University, Nagoya, and NEC Corporation, Japan, discoverer of carbon nanotubes in 1991

Bill Joy _ computer expert and Silicon Valley icon, founder of Sun Microsystems, his article "Why the Future Doesn't Need Us" in *Wired* magazine in 2000 marks the beginning of the nano debate

Michael Crichton _ author and film director, his science-fiction novel *Prey* about a swarm of nano-robots was published in 2002

Kim Eric Drexler _ founder of the pro-nano Foresight Institute, Palo Alto, USA in 1986 (since 2005 Foresight Nanotech Institute) together with his now ex-wife Christine Peterson, in 2002 he left the Foresight Institute; author of the science-fiction novel *Engines of Creation*, in which he describes "assemblers" and the nightmarish so-called "grey goo" scenario

Pat Roy Mooney _ nano critic, head of the Canadian NGO environmental protection group ETC (Action Group on Erosion, Technology and Concentration, Winnipeg, Canada), awarded the Right Livelihood Award (the "Alternative Nobel Prize") in 1985

Wilhelm Barthlott _ botanist, researcher and owner of the trade mark for the "Lotus-Effect", Nees Institute for Plant Biodiversity at the University of Bonn, Germany, awarded German Award for the Environment in 1999

Werner Nachtigall _ leading figure in Bionics

George M. Whitesides _ chemist, notable nano pioneer and intellectual, has been awarded numerous prizes, Harvard University, Cambridge, Masachusetts, USA

Charles Philip Arthur George Mountbatten-Windsor, Prince of Wales _ London, UK, prominent critic of nanotechnology

Wolfgang Heckl _ nano pioneer, biophysicist, director of the German Museum in Munich, Ludwig-Maximilians-Universität, winner of the Descartes Prize for Science Communication

Fuchs, Harald _ nanophysicist, Westfälische Wilhelms-Universität in Münster, Germany, director of the Institute for Nanotechnology, Karlsruhe, Germany, co-founder and scientific director of the Centre for Nanosciences (CenTech), Münster, Germany

Günter Oberdörster _ toxicologist and nano pioneer in this field, University of Rochester, Rochester, New York, USA

Eva Oberdörster _ environmental toxicologist, research into ultra-fine particles, Southern Methodist University, Texas, Dallas, USA

Don Eigler _ physicist and nano researcher, in 1989 his rendition of the IBM logo using 35 atoms is regarded as a milestone in nanotechnology, IBM Centre Zurich Rüschlikon, Switzerland, now at the IBM Research Center Almaden, San Jose, California, USA

Richard Buckminster Fuller _ visionary architect, famous for his "geodesic domes" (e.g., American Pavilion at the Expo 1967) which served as inspiration for the name buckyballs

Raymond "Ray" Kurzweil _ scientist and nano prophet, author of *The Age of Intelligent Machines* (1990) and *The Age of Spiritual Machines* (1999)

Michael Veith _ chemist and scientific director of the world-renowned Leibniz Institute for New Materials (INM) which conducts chemical research into nanotechnology, research department for chemical vapour deposition (CVD) technologies, Saarbrücken, Germany

Trade fairs, conferences and events

Trade fairs are often accompanied by a conference, and conferences and congresses often incorporate a poster exhibition. The following list represents a subjective selection of international nano-relevant conferences and events. Dedicated "nano trade fairs" are at present limited in size, however many trade fairs, such as the Hannover Messe with "Schauplatz Nano", incorporate an extra platform for nanotechnology. Several nano-websites provide calendars of current events, for example the overview of national and international nano-events on www.nanotech-now.com.

nano tech, International Nanotechnology Exhibition & Conference, the worldwide largest trade fair for nanotechnology; Tokyo International Exhibition Center Tokyo Big Sight, Tokyo, Japan

Nanofair, International Nanotechnology Symposium; a cooperation between the cities of Strasbourg in France and Karlsruhe, Dresden and the VDI (The Association of German Engineers), Germany

NanoEurope, St. Gallen Trade Fair, Switzerland, from 2009 in alternation with the Messe Düsseldorf, Germany

nanotech + materialweek frankfurt, NanoSolutions and MaterialVision, Messe Frankfurt, Frankfurt am Main, Germany

Schauplatz Nano (Showcase Nano) at the Hannover Technology – Innovation – Automation Exhibition; Hannover Messe, Germany

Materialica, International Trade Fair for Material Applications, Surfaces and Product Engineering; Munich International Trade Fairs, Germany

EuroNanoForum, Messe Düsseldorf, Germany

MiNaT, International Trade Fair for Precision Mechanics and Ultra-Precision, Micro and Nano Technologies; Messe Stuttgart, Germany

European Coatings Show, NürnbergMesse, Nuremberg, Germany

NanoSMat, International Conference on Surfaces, Coatings and Nanostructured Materials; Algarve, Portugal

Nanotech Expo, São Paulo, Brazil

NSTI Nanotech Expo, The Nanotechnology Conference and Trade Show; changing venues, Santa Clara 2007, USA

JAPAN NANO, International Symposium on Nanotechnology; Tokyo Big Sight, Tokyo, Japan

Nano Tech Taiwan, Taiwan International Nano Tech Exhibition; Taipei World Trade Center (TWTC), Taipei, Taiwan

Taiwan Nano Exhibition, NTU Sports Center, Taipei City, Taiwan

ChinaNANO, International Conference on Nanoscience and Technology; Beijing International Convention Center (BICC), Beijing, China.

Conference on Composites/Nano Engineering (ICCE), Haikou, Hainan Island, China

Swiss NanoConvention, Berne, Switzerland

NanoToxicity Conference, Paris, France

MEIINEC, Middle East International Inventions & Nanotechnology Exhibition & Conference; Dubai, UAE

nanoTX, Dallas Convention Center; Dallas, USA

Nanotech Northern Europe, The Helsinki Fair Centre, Helsinki, Finland

Surfacts, International Trade Fair for Surface Treatment; Karlsruhe Trade Fair, Karlsruhe, Germany

nanoDE, BMBF Federal Ministry of Education and Research Nanotechnology Days; bcc Berliner Congress Center, Berlin, Germany

International Conference on Nanostructured Materials, international changing venues, 2008 in Brazil

Events of particular relevance to the building sector

International Symposium on Nanotechnology in Construction, The Centre for Nanomaterials Applications in Construction (NANOC), LABEIN TECNALIA; changing venues, for example Bilbao, Spain, and Scotland

CC-NanoChem, Saarbrücken, Germany – annual one-day seminar on “Innovation through Nanotechnology: New Surfaces in Architecture, Furniture and Design”

VDI The Association of German Engineers, “Nanotecture – Nanotechnology in Architecture and Construction”, one-day seminar

Sources and further information

Useful links

www.nanoforum.org (European Nanotechnology Gateway)
www.cordis.europa.eu/nanotechnology (European Commission Nanotechnology Website)
www.bmbf.de (BMBF German Federal Ministry of Education and Research)
www.nanotruck.de (Nanotruck, BMBF)
www.bmbf.de/en/nanotechnologie.php
www.nano.gov (National Nanotechnology Initiative, USA)
www.nsf.gov (National Science Foundation, USA)
www.nset.gov (The Nanoscale Science, Engineering and Technology NSET, Subcommittee of the US National Science and Technology Council NSTC, White House, coordinates the National Nanotechnology Initiative NNI)
www.ectp.org (National Technology Platforms NTP, European Construction Technology Platform)
www.vdi.de (The Association of German Engineers)
www.fraunhofer.de (Fraunhofer Society)
www.nano.fraunhofer.de/
www.nasa.gov (National Aeronautics and Space Administration, NASA, USA)
www.idw-online.de (German Science Information Service)
www.innovations-report.de
www.techportal.de
www.nanotech-now.com ("your gateway to everything nano")
www.nanovip.com (international business directory)
www.nanowerk.com
www.etcgroup.org (Action Group on Erosion, Technology and Concentration)
www.foresight.org (Foresight Nanotech Institute)
www.e-drexler.com (K. Eric Drexler)
www.nanofactory.org.uk
www.nanonet.go.jp
www.nanochina.cn
www.nano.org.uk (Institute of Nanotechnology, Scotland)
www.nano.ivcon.net
www.kompetenznetze.de
www.zae-bayern.de
www.ccnanochem.de
www.inm-gmbh.de (Leibniz Institute for New Materials)
www.nanomat.de
www.ejipac.de (European-Japanese Initiative on Photocatalytic Applications and Commercialisation)
www.picada-project.de (EU photocatalysis project)
www.lotuseffect.de
www.nanoproducts.de (German-language site with daily news about new products)
www.nanosafe.org
www.nanopartikel.info (NanoCare project)

www.luxresearchinc.com (business consultancy for emerging technologies)
www.cientifica.com
www.basicfeynman.com (clear website about the life and work of Richard Feynman)

Last but not least, Feynman to colour in yourself:

www.physicscentral.com/coloringbook/feynman.pdf

Films

www.vega.org.uk The Vega Science Trust (science site with interesting lectures, interviews etc.)
www.nanoreisen.de ("Nano-journeys – adventures beyond the decimal")
www.powersof10.com (Charles und Ray Eames – cinematic journey through the dimensions)
www.youtube.com (keyword "nanotech")

Brochures

"Nanobiotechnology – A Fundamental Technology of the 21st Century": www.nanobionet.de
Nano-Initiative – Action Plan 2010: www.bmbf.de/pub/nano_initiative_action_plan_2010.pdf
"Nanotechnologie, Innovationen für die Welt von morgen", 3rd edition: www.bmbf.de/pub/nanotechnologie_inno_fuer_die_welt_v_morgen.pdf
"Nanotechnology Conquers Markets, German Innovation Initiative for Technology": www.bmbf.de/pub/nanotechnology_conquers_markets.pdf
www.bmbf.de/pub/nano_nachhaltigkeit_ioew_endbericht.pdf
"Nanotechnologie in Architektur und Bauwesen. Innovationsbegleitung Nanotechnologie": VDI Technology Centre, via www.vdi.de
Fraunhofer Magazin, published by the Fraunhofer Society, Germany: www.fraunhofer.de
Hessen Nanotech, various brochures including "Nanotechnologie und Bauwesen": www.hessen-nanotech.de
"Nanotechnology – Small matter, many unknowns": www.swissre.com
nanonow magazine: www.nano.org.uk

Many of the above sites and organisations also publish regular newsletters.

Finally, faithful to the motto "there's plenty of room at the bottom", take your time to enjoy and explore the World Wide Web and the ever more interesting nano discoveries that are to be made in its unplumbed depths…

Books

Broderick, Damien, *The Spike. How our lives are being transformed by rapidly advancing technologies*, 2001, Forge Books

Bullinger, Hans-Jörg (ed.), *Trendbarometer Technik*, 2003, Hanser Verlag

Boeing, Niels, *Nano?! Die Technik des 21. Jahrhunderts*, 2004, rowohlt

Feynman, Richard P., *The Pleasure of Finding Things out*, 1999, Helix Books

Jopp, Klaus, *Nanotechnologie – Aufbruch in's Reich der Zwerge*, 2003, 2nd updated edition 2006, Gabler

Ilfrich, Thomas, Ivcon.net Corp., *Nano A–Z*, glossary of nanotechnology, 2005, and *Nano + Mikrotech I, II, III, IV*, available annually since 2003, Books on Demand

Nachtigall, Werner and Blüchel, Kurt G., *Das große Buch der Bionik*, 2000, DVA

Oesterreicher, Marianne, *Highlights aus der Nanowelt*, 2006, Herder Spektrum

Rubahn, Horst-Günther, *Nanophysik und Nanotechnologie*, 2002, Teubner

Sutherland, John D., *The Future of Nanotechnology and Robotics*, authorHOUSE

Uldrich, Jack, *The next big thing is really small*, Random House, Business Books

For those whose interest in nano literature has not yet been stilled, the following science-fiction literature makes good holiday reading (don't forget to pack the nano sun cream)

Anderson, Kevin and Beason, Doug, *Assemblers of Infinity*, 1993

Crichton, Michael, *Prey*, 2002

Drexler, K. Eric, *Engines of Creation: The coming Era of Nanotechnology*, 1986

Stephenson, Neal, *Diamond Age*, 1995

Publications and lectures by the author on nanotechnology and architecture

Moderator for the Nanoforum Bau, "nanotech + materialweek frankfurt", Messe Frankfurt, 2007

"Nanobeschichtungen für Innenraumgestaltung und Architektur", Bremen Design Centre, 2007

"Lover's Club: Innenarchitektur und Nanooberflächen", Bau, Messe München, 2007

CC-NanoChem at MaterialConneXion, Cologne, 2007

"Nanosurfaces in the patient's room of the future", *consulting.world*, 02/2007

Colloquia at various Chamber of Architects training sessions, 2004–2007

CC-NanoChem at MaterialConneXion, Cologne, 2006

Euromold, Messe Frankfurt, 2006

"Das Privatpatientenzimmer der Zukunft", project, 2006

"Die Zukunft hat schon begonnen – Nano-Oberflächen könnten in Hotelzimmern zu mehr Komfort und Wirtschaftlichkeit beitragen", *hotel objekte* 2–3/2006

"Wie geht es uns denn heute? – Das Gesundheitszimmer der Zukunft", *Mensch Architektur & Design* 01/2006

"Selbstreinigende Hotelzimmer", *hotel objekte* 05/2006

"Bankshops oberflächlich betrachtet – Oberflächender Zukunft aus der Nanotechnologie", *POS-Ladenbau*, 2006

CC-NanoChem, Saarbrücken, 2005

A series on nanosurfaces in *medAmbiente*, 02, 03 & 04/ 2005 as well as *Architektur special edition* 01/2005

"Maßgeschneidert – Nanotechnologisch veredelte Oberflächen", *designreport*, 7+8/04

"Innenräume und Oberflächen: Innovationen und Trends", interzum, Koelnmesse, 2003

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p. 82, Müller Architekten / photo: Dietmar Strauß
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