The Emperor's New Coating

new dimensions for the built environment: the nanotechnology revolution

This leaflet is based on a longer report prepared by SPRU for nCRISP with financial support from the Foundation for the Built Environment, the Office of Science and Technology (OST) and the Department of Trade and Industry (DTI). The origins of the leaflet and the report are in earlier work done by the Construction Associate Programme of the OST Foresight Built Environment and Transport Panel. The longer report provides technical details, references and analysis of nanotechnology research activities. It is available as a pdf file from www.crisp-uk.org.uk.

A vision of the future

Let's imagine the built environment in a few year's time…

Buildings are being erected with completely new materials and components. They have lighter, stronger and fatigue resistant materials that perform better and last longer. The buildings show few signs of ageing or deterioration and suffer less time out of service for repairs and maintenance. Because they are more efficient in terms of insulation, waste products and heating, buildings consume less energy and water. They have less impact on the environment.

Building users in 2020 experience an incredibly clean, durable, responsive, and environmentally friendly environment. There are long established functions, such as self-cleaning wash basins and windows [see box: Toto's Surface Coating] [see box: Pilkington's ***Activ™*** Glass]. Tiny sensors placed in the structure and components and materials have the capability to 'communicate' their current status. Equipped with their own 'memory' regarding shape, function and performance, these materials are self-assessing, self-healing and self-repairing.

Construction processes are redesigned to take advantage of these new materials. Designers and engineers are able to specify particular functional attributes to enhance value to users. Manufacturers provide tailor-made components and materials that can easily be integrated into building structures. Constructors will be able to assemble components with greater predictability and minimal waste.

Aims

The vision is based upon exciting developments in physics, materials science and chemistry, known as *nanotechnology*. This review:

- describes the development of nanotechnology applications for the construction industry today and in the future
- considers ways in which construction can become more involved in nanotechnology as a producer and user in order to gain maximum advantage from the perceived benefits
- outlines possible ways to promote knowledge of the potential of nanotechnology applications for design, engineering and construction firms and their materials and components suppliers.

The document is based on interviews with a broad range of experts within the nanotechnology and construction communities, a review of published material and the results of a survey of leading experts in the built environment sector. The latter was designed to explore the current level of knowledge about nanotechnology and its potential applications.

Toto's Surface Coating

Toto, the Japanese sanitary ware manufacturer, uses a thin film of titanium dioxide – called CeFION - to coat the surface of wash basins and toilet bowls. By minimising surface tension, the coating material reduces the possibility of particles adhering. Sanitary ware is easier to keep clean, remains more hygienic and there is also a reduction in the amount of detergent required during cleaning, thereby reducing environmental impact. CeFION can also be used to reduce steaming up of mirrors and tiles by preventing condensation forming droplets on the surface. In sanitary ware, the material is applied during manufacture by a heat process. But for mirrors, Toto have a spray-on product that can be applied to the existing material. CeFION has also been designed for uses in other situations such as in the kitchen, surgical theatres, car wing mirrors and on the external fabric of buildings.

Pilkington's Activ™ Glass

***Activ™** Glass is a product developed by Pilkington that provides better performance in use, particularly in tall buildings. Grime which would ordinarily stick to the glass, giving it a dirty appearance, is broken down by a daylight activated reaction with the surface coating of titanium oxide. In technical terms, the coating creates a photocatalytic process by reacting with ultra-violet rays, breaking down organic dirt. The second part of the process occurs when rain falls on the surface. Because the glass is hydrophilic, the water spreads across it, rather than forming droplets. It then runs off, taking the dirt away with it. The glass became available for use in the UK in the summer of 2002.*

There is nothing particularly new about these phenomena, however, their application and commercialisation are novel and resulted from engineering the glass and its production process using nano-scale techniques.

The material deposition of the coating on the glass has been designed to be the right size and shape to allow the glass to perform its primary function of letting in light and providing transparency for occupants.

The secondary and tertiary functions of breaking down dirt and allowing it to be washed away were designed to work without detracting from the primary function. The result? Glass that is self-cleaning, with better performance and lower cost in use.

In order to achieve this, the production process had to be re-designed. This involved investment in the first commercial use of an Atomic Force Microscope (AFM) in the UK (1996). This is used for controlling quality on the production line. The microscope is used to probe the surface of the glass and check for defects, which are removed before the glass leaves the production line.

This experience suggests that no matter what developments are achieved in the design of materials to enhance their purity, fabrication into usable components will require further testing and therefore the creation of new manufacturing processes. For example, using nanotechnology it is theoretically possible to design very pure materials which will out-perform those available today. However, the production of such materials at commercial quantities requires new instrumentation and new processes.

What is nanotechnology?

Is this vision of a 'leaner and greener' built environment feasible? The technologies that would make it a reality are already available and many more are in the pipeline. They are all based on nanotechnology: a rapidly emerging interdisciplinary field of research and application at the boundary between the physical sciences, engineering and life sciences. Nanotechnology is defined as the control and manipulation of material at the nanometre (nm or 10-9m) scale in the range from 0.1 to 100nm. The diagram opposite depicts a progression of images from 10cm to 1 nanometer, with the dimension of each side of each square reducing by a factor of 100 between each image.

Rather than a specific area of science or engineering, nanotechnology is a generic technology. Like the rapid and widespread adoption of computer technology in the 1980s and 1990s, nanotechnology may have far-reaching effects across many sectors of the economy over the next two or three decades. It refers to a cluster of techniques and processes concerned with new ways of making things by designing and engineering them at the atomic level. This has already created many new products and processes, such as the lab-on-a-chip, surface coatings, nano structured materials, nano-instruments and tools, and sensors. Nanotechnology applications 'promise more for less: smaller, cheaper, lighter and faster devices with greater functionality, using less raw material and consuming less energy' (Smith, et al, 2000).

There are two ways of working at the nanoscale:

- The top-down approach entails reducing the size of the smallest structures towards the nanoscale. This is achieved by ‘machining’ at increasingly smaller dimensions or carving nano structures out of larger objects. An example is nanophotonics – the integration of electronics and optics at the nano scale. Most of the research on nanotechnology has been conducted top down and is closely related to research on larger and more mature micro or macro-scale technologies already being pursued in the UK.

- The bottom-up approach involves manipulating individual atoms and molecules and exploiting the ability of molecules to self-assemble tiny structures. This resembles the processes of biology and chemistry, where atoms and molecules create self-organising new structures such as living cells or crystals.

Because it is not an homogenous discipline and covers a wide area of applications, there are different ways of thinking about nanotechnology. In particular the boundaries between working at the micro and nano scales are blurred. Some researchers are working on problems at the micro-level (10^{-5} to 10^{-7}m, typically 100 – 1000nm), such as stress fractures, using nano-instruments. Others believe that there is a transition down the size spectrum towards nano-scale.

The challenge of nanotechnology

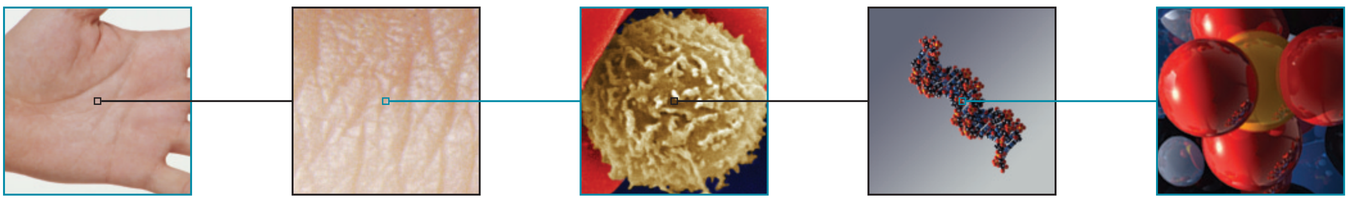
Scientists and engineers in construction and other industries that may adopt nanotechnologies typically work at the macro or microscopic scale. The challenge is to move down from these levels to the nanoscale. Some industries have already made progress in achieving this. For example, mature top-down approaches such as microfabrication techniques used in silicon processing are being taken further in the microelectronics sector and now involve work at the nanoscale.

Failures in many construction materials at the macro or micro-scale are typically the result of tiny micro-cracks. Traditionally, new materials have been developed to overcome such failures by improving macro-engineering properties. But the real source of the problems caused by micro-cracks often occurs much earlier and can only be observed at the nanoscale. Recent improvements in techniques – such as nanoindentation and atomic force microscopy – have made it possible to observe such events at the nanoscale. [see box: University of Paisley’s nanotechnology instrumentation]

Macro, Micro, Nano

How small is a nanometer? Stepping down in size by powers of 100 takes you from the image of the back of a hand at 10cm, to a view of atoms in the building blocks of DNA.

Hand / Skin / White Blood Cell / DNA / Atoms



10 cm / 1 mm / 10 microns / 100 nanometers / 1 nanometer

Moving from the micro to nano scale to construction products: University of Paisley's nanotechnology instrumentation

Since the late 1960s, Professor Peter Bartos and his colleagues at the Advanced Concrete and Masonry (ACM) Centre at the University of Paisley have been involved in researching the characteristics of fractures in brittle matrix composite materials reinforced with bundled fibres. This research was hampered until recently by the absence of adequate instruments for taking measurements at the sub-micro scales. A major breakthrough was achieved when the first generation of nano-testing devices appeared in the early 1990s. This made it possible to observe and measure the properties of materials at the nano scale. A new generation of nano-scale instrumentation, which replaced the original Paisley facility in 2001, includes a specialist laboratory building to house the equipment. The ACM Centre conducts multidisciplinary research on nanotechnology in applications for the construction industry, such as concrete technology (self-compacting concrete), novel production methods (a mixer with no moving parts), and advanced fibre reinforced brittle matrix composites.

Numerical methods and experimental techniques are providing useful descriptions of the processes responsible for the emergence of micro-cracks and other sources of degradation at the nanoscale. The challenge is to move back from nanoscale to the macroscopic level to see how the whole system works together as part of a building. This can be achieved, for example, by creating more reliable and longer lasting components and structures – such as high specific strength and fatigue resistant materials.

As Bob Cather of Arup R&D says … 'we can now see individual atoms, and the potential is to move them around to create 'made to measure' materials'.

While some engineers have been working on micro structures, greater effort is now required to push the technological frontier below the micro to the nanoscale.

From nanotechnology to construction products and processes

There is often a long time lag between upstream scientific breakthrough and downstream commercial applications. Today, nanotechnology can be compared with computing in the early 1970s before the widespread diffusion of this technology. There is a typical pattern associated with the introduction of radically new technology. A long gestation period is followed by a rapid burst of innovative activity, when the new technology begins to have pervasive and far-reaching effects across industries and the economy as a whole. For many years, products developed using nanotechnology were merely a vision of the future. It is only now after more than two decades of basic research, that the emphasis has shifted to the development of commercially viable applications, with successful routes to market (Davies and Saxl, 2000 and 2001).

A disruptive or incremental technology?

While only a few commercial applications are currently available, research in this field is leading to the creation of new classes of products and processes that are expected to become widely available during the latter part of this decade and onwards. Nanotechnology has been called a disruptive technology because it has the potential to displace established technologies and the creative potential to allow radically new generations of products and processes to take their place (Taylor, 2002).

If nanotechnology turns out to be a disruptive technology it implies a 'radical' break with the traditional skills in the sector and the development of new capabilities. Nanotechnology could have some dramatic effects on traditional construction disciplines, such as structural engineering. The advent of new materials will provide an opportunity for engineers to break with their traditional design norms. New design rules will have to be invented to take advantage of lighter, stronger and more flexible structures. Radical product innovations are likely to flow from the visionary idea of developing 'materials by design'. However, it may take 30 years before these new high-tech materials become commercially available.

Alternatively, nanotechnology may develop 'incrementally', as cumulative improvements to existing processes and products over a long period of time. For example, the major manufacturers of concrete are working on a series of product improvements by developing new ad-mixtures that improve the handling of concrete. The fluid and cohesive properties of concrete have been improved by manipulating the surface properties of particles used in the polymers that are added to the material. This makes concrete easier to pour, ensures that the mix fills consistently, improves the overall quality of concrete, and means that concrete is self-compacting.

Opportunity or threat?

There has been significant progress in the adoption of nanotechnology in other systems integration industries, such as electronics, aerospace, motor vehicles and telecommunications. Firms in these sectors are incorporating many new components based on nanotechnology that are cheaper, more efficient and provide greater functionality. There has been less progress in more traditional sectors like construction.

This presents both an opportunity and a threat for the UK construction sector. If we fail to embrace these technological changes and to develop capabilities, traditional firms may face strong competition from new suppliers offering improved materials, components, products and processes incorporating nanotechnology. Those firms that are early to adopt nanotechnology and make the required changes to their organisations, skills and processes may gain an advantage. But for this to happen, current development work on nanotechnology will have to be linked more closely with the needs of suppliers as well as users of the built environment.

Systems integrator firms in construction require a network of suppliers to produce materials and components for them to incorporate in their products and processes. As a potential downstream integrator and 'carrier' of nanotechnology applications, the construction sector can play a pivotal role in the process of commercialising the development and use of this new technology.

As indicated in the table below, some nanotechnology applications leading to new products and processes in construction and the built environment are currently available, while others are close to the marketplace.

Applications leading to new products and processes in construction

Time horizon	Generic applications	Functions
Already available	Nano measurement techniques	Nanoindentation, nanoscratch and nanofabrication methods – used to evaluate weak links in the structure of materials and to test materials for their fracture and bond properties.
	Nanostructured materials, nanoparticles and nanofibres	Used to strengthen and improve the performance of construction materials. Certain types of concrete and cement incorporate superplasticers and stabilisers that are already produced using nano techniques. Nanoparticles provide new improved methods for manufacturing high-quality glass.
	Surface layers and coatings	Used to protect and strengthen materials, as well as provide new functions. Examples include: ultra-thin energy-saving reflecting layers composed of ultra-fine particles that allow only light of a certain wavelength to pass through; adhesion techniques and adhesion processes used as coatings on surfaces; surfaces with catalytic activity; and corrosion-resisting layers.
	Sensors	Such as biosensors, chemosensors, mm-wavesensors, GMR-sensors that are embedded in materials that are used to monitor and control the performance of materials.
Close to market	Cement and plaster (hydraulic binders)	Cheaper, more durable, less cement hydration, self-repairing, etc.
	Surface coatings	On glass (various oxides) - e.g. self-cleaning, water repellent glass, depolluting catalyzers under solar energy, photosensitive applied to other materials (e.g. paints) - improved scratch resistance, UV protection
	Nano-composite materials	Fire protection materials, i.e. increased flame resistance
	Responsive materials	Adapt to the environment and change their appearance: for example, cladding systems that respond to changes in heat or light to maximise comfort and minimise use of energy in buildings.
	General sensors	For environmental, safety or security purposes.

Achieving the vision

In future, the construction sector can be in a position to benefit enormously from developments in nanotechnology. But can UK construction take a more active lead in the commercialisation of this technology? Can design, engineering and construction firms work alongside scientists and engineers responsible for developing new applications? We believe that there are big opportunities for doing this now.

The vision of the future outlined above is unlikely to be realised without a coherent strategy and participation by leading practitioners and researchers. Efforts to date have been largely fragmented: there is a need for a more integrated and coordinated approach. Based on our review, we recommend that the UK construction innovation community – including researchers and firms – must increase its capabilities in nanotechnology by:

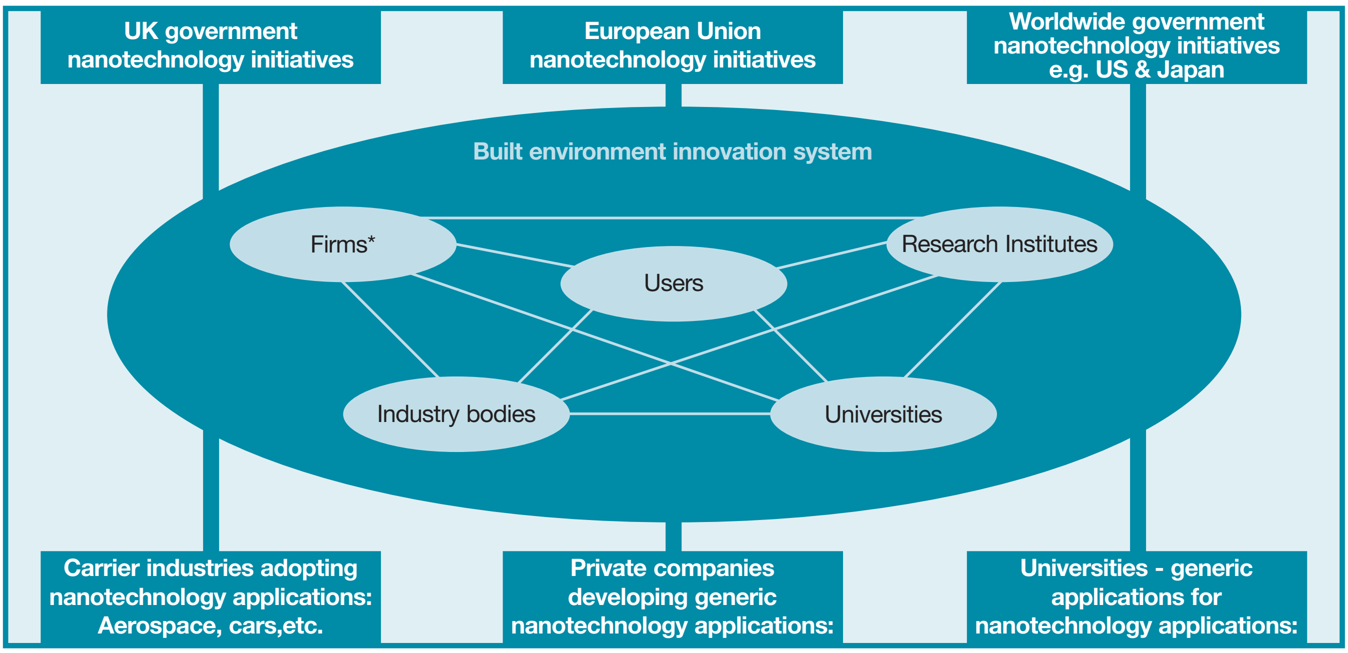
- convincing leading companies and their suppliers of the need to invest in and use nanotechnology to improve their competitive positions
- increasing the number of companies developing and applying nanotechnology and its applications to the built environment
- creating a 'technology watch' so that nanotechnology applications in other carrier industries, such as aerospace or cars, can be tracked and adapted for use in the construction sector
- establishing networks involving leading universities, research institutes and private companies to take ideas from nano research and turn them into commercially viable construction processes and products.

Nanotechnology research – what's going on

The UK is second behind Germany in public expenditures on nanotechnology research within the European Union. In 2002, UK government spending on nanotechnology R&D was about £30m a year. The United States and Japan are leading the world in publicly funded nanotechnology research. The US's federal budget for 2002 includes $604m (£390m) for R&D in nanotechnology. Japan recently announced its commitment to spend 75bn yen (£400m) on developments in this area in 2003.

The built environment sector has an opportunity to benefit from the increasing priority being placed on nanotechnology in the UK and across Europe. The linkages between the built environment innovation system and external developments in nanotechnology are illustrated in the diagram below. It shows the various types of organisations involved in developing nanotechnology applications within the construction sector and depicts the potential and actual interactions between what's going on inside this innovation system and external developments in nanotechnology, such as UK and EC initiatives to promote nanotechnology applications and research.

Nanotechnology inside and outside the built environment innovation system



*includes system integrators, constructors, materials and component manufacturers, consultants, architects, designers, engineers, etc.

Inside the system

Research on nanotechnology with applications for the built environment sector is being undertaken by several research institutes, universities and private companies. While individually there are many important efforts to develop nanotechnology applications by participants in the built environment, these are currently largely dispersed attempts to develop specific applications with little or no overall strategy to coordinate the various parties involved. A number of organisations have been at the forefront of developments in construction specific applications using nanotechnology. Examples of these are given in the long report.

Outside the system

The built environment innovation system in the UK may benefit from a number of external developments in nanotechnology that are speeding up development and commercialisation across industries. Particularly helpful are:

- the UK government's recent decision to ensure that the UK builds on its strengths in nanotechnology and becomes a world class player in developing new applications. In addition, in 2001 the government identified nanotechnology as a priority area in the £41m Basic Technology Programme and introduced a new £25m programme over three years to support business in commercialising these technologies. Nanotechnology is a key research priority in the third round of the Foresight Link Awards, with a budget of £15m. A strategy to turn the UK into a world class player in nanotechnology applications has recently been published by the Department of Trade and Industry (Taylor, 2002).

- the European Union's increased expenditure on nanotechnology research. Out of a total proposed budget of Euro 17.5bn for the 6th Framework Programme, Euro 1.3bn will be allocated to a priority thematic research area on nanotechnology and nanoscience, knowledge-based multifunctional materials, and new products and production processes. The EU has awarded the UK's Institute of Nanotechnology a contract to promote pan-European networking and educational activities in this area.

The UK was among the first to promote university and industrial collaborations in nanotechnology, intensifying efforts to produce downstream commercial applications. Launched in 1988, the LINK Nanotechnology Programme (LNP) provided a framework for collaboration between academia and industry. The LNP projects were carried out between 1989 and 1998, involving 86 participants in 27 projects, including 52 private sector firms and 34 universities or government research laboratories. These activities focused on areas of instrumentation and precision engineering. LNP was closely associated with the National Initiative on Nanotechnology (NION). Supported by the Department of Trade and Industry, NION was set up as an institution based in Scotland to promote awareness and to support collaborative research projects in this area.

With the end of NION and the LINK programme in the 1990s, the UK effort was distributed among the research councils. In a new strategy to build on the UK's strengths, three research councils joined with the DTI and MOD to create two major Interdisciplinary Research Collaborations in Nanotechnology.

The Foresight Materials Panel brought this to the fore with its report "Opportunities for Industry in the Application of Nanotechnology" published by the DTI and the Institute of Nanotechnology February 2002.

What next?

There is a real opportunity for the UK construction community to become involved in the development of nanotechnology, as researchers or potential users. A focal point is needed for this and we recommend the following actions:

- Establish a network of researchers and users through the auspices of nCRISP, to stimulate interest and demand for new types of products and identify research opportunities.
- Commission short reports on the consequences of nanotechnology for:
  - *Design*
  - *Engineering*
  - *Material specification*
  - *Construction work*
  - *Facilities operation and maintenance*
  - *Building performance, including energy costs*
- Develop a website to provide a one-stop shop on information, events, research results and applications

Nanotechnology offers construction professionals the opportunity to design, engineer and build in new ways. It can change the rules of design and engineering, through the auspices of specifying the properties and performance of materials and components in advance. This will challenge existing engineering and design practice, unlocking the potential for architecture, civil, structural, environmental, electrical and mechanical engineering, as well as other professions to break away from their traditional design parameters. A dialogue is needed across the professions to assess and explore how they can become fully involved in future developments, translating technological promise into new benefits for customers and users of the built environment.

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