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## Nano in the Construction Industry

### Summary

In the construction industry and in architecture, nanotechnology and nanomaterials provide new opportunities. "Nano-products" for construction purposes are currently found in four main sectors: cement-bound construction materials, noise reduction and thermal insulation or temperature regulation, surface coatings to improve the functionalities of various materials, and fire protection. At the present time, nanomaterials – and therefore "nano-products" – remain considerably more expensive than conventional alternatives due to the required production technology, and the technical performance of many products remains to be demonstrated. Both industry workers as well as end users can come into contact with nanomaterials when using a "nano-construction material" and need to be protected from potential health hazards. Information on which nanomaterial is found in which form and concentration in a product is often unavailable, particularly to end users. Once a nanomaterial is solidly embedded in a matrix, for example in concrete or in insulation material, then the probability of exposure is very low or non-existent according to current knowledge, as long as the product is not destructively worked or processed. When workers spray a nano-surface layer or mix mortar at a construction site, for example, they are subject to a potential health hazard by inhaling the dust or tiny droplets of liquid (aerosols). As "nano-construction products" currently play a subordinate role on the market, the current environmental threat due to nanomaterials appears to be low. Nonetheless, virtually no data are available on exposure, so that no comprehensive risk assessment can currently be undertaken for any nanomaterial.

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### Introduction

Nanotechnology and nanomaterials offer interesting new opportunities in the construction industry and architecture, for example through the development of very durable, long-lived and at the same time extremely lightweight construction materials. Novel insulation materials with very good insulation values are already available on the market, enable a thermal rehabilitation of buildings in which conventional insulation is not possible, and can help to improve energy efficiency. A wide range of methods for the treatment of surfaces is also available, including glass, masonry, wood or metal; the goal is to improve functionalities as well as extend the lifetime of the materials. Such surface coatings also promise to conserve resources, for example water, energy and cleaning agents.

Although the research sector has been reporting intensively about new nanotechnological developments, the reality shows that "nano-products" in the construction industry continue to play a subordinate role and currently merely occupy niche markets. The construction business is considered to be conservative, and innovations often have a difficult time breaking into the market<sup>1</sup>. One of the main reasons for this is the continued high prices. Currently, nanomaterials – and therefore "nano-products" – are still considerably more expensive than the conventional alternatives due to the required production technology<sup>2</sup>. Construction materials are generally used in large amounts: small price differences can enormously increase overall costs when considering the total volume of a building or other structure. Moreover, the technical performance of new products must first be demonstrated<sup>2</sup>. In buildings, the calculated time spans are in the range of 20 to 30 years, making it difficult for example to apply a coating with a durability of only 1 to 3 years<sup>1</sup>. Longer-term, practical experience with many nano-products is still lacking, and we simply know too little about their

product life. Accordingly, the construction industry for the time being prefers to rely on proven, conventional products.

Our state of knowledge about nanotechnological applications and products, their availability and their performance in the construction industry is currently very limited. A survey conducted in 2009 in the European construction sector showed that most respondents ( $\approx 75\%$ ) were unaware of whether they were working with "nano-products" or not<sup>2</sup>. This is also partly because there is no mandatory labeling of nanomaterials in building materials: the prefix "nano" – like in many other branches – is used in advertising a product only if the manufacturers have justified hopes of improved sales. Often, it is not evident to users whether a nano-product actually contains nanomaterials, what nanomaterials might be involved and in what amounts they may be present. Not all products that feature the term "nano" actually contain nanomaterials. Often, the term "nano" merely refers to structures in the nano size range, for example the pore size of a particular material, or to the size of structures that form when a mortar hardens. The use of the designation "nano" in product claims and advertising has again been declining in recent years. This is because information about potential environmental or health risks of nanomaterials, in particular via the media, has led to more cautious buying patterns.

The present dossier provides an overview of nanotechnological applications and products in the construction industry and focuses on the question of potential environmental and health risks that these products may entail.

## Fields of Application and Products

“Nano-products” in the construction industry are currently concentrated in four sectors: (1) cement-bound construction materials, (2) noise reduction and thermal insulation or temperature regulation, (3) surface coatings to improve the functionality of various materials, as well as (4) fire protection. Based on manufacturer’s specifications, the German Trade Association for the Construction Industry (deutsche Berufsgenossenschaft der Bauwirtschaft; BG Bau) has compiled a list of construction and cleaning products that advertise under the heading “nano” or that use nanotechnological effects. The list also contains information about whether the properties of the product can be attributed to the addition of nanoparticles or nanostructures. Based on the cut-off date 19.1.2012, the list contains 63 products from the sector cement-bound construction materials (mortar, cement, roofing tiles), paints, varnishes and other products designed to coat surfaces<sup>3</sup>.

### 1. Cement-bound construction materials

#### a. Ultra High Performance Concrete (UHPC)

Concrete is a type of artificial stone made of cement, aggregate materials (sand, gravel, grit) and water. More than ten billion tons of concrete are produced annually all over the world every year, making it, volume-wise, the world’s largest human-produced commodity and by far the most important construction material in the construction industry<sup>4</sup>. The strength of concrete can be attributed to the minute crystal needles (calcium silicate hydrates), that solidly interlink with each other during the hardening process. Electron microscopes can be used to depict and study the structures down to the nanoscale, including analyzing the correlation between the nanostructure of a construction material and its properties. This enables a target-oriented optimization of construction materials for a particular application<sup>5</sup>. Over the last few years, this has led to new developments and material improvements. Nanoscale binders can give concrete, as the conventional construction material, new prop-

erties with regard to workability, strength and durability. Adding silicon dioxide nanoparticles fills the pores in the concrete, making it denser and harder. Ultra high performance/high-strength concrete also contains steel fibers, which improve tensile strength. These types of concrete attain a steel-like compressive strength of over 200 N/mm<sup>2</sup>. Polymer additives (for example artificial resins) help liquefy and stabilize the cement suspension, which is used to develop self-compacting concretes<sup>4</sup>. The high strength and density of UHPC enables especially lightweight and delicate constructions such as bridges. The Gärtnerplatzbrücke<sup>6</sup>, a bridge inaugurated in 2007 over the Fulda River in Kassel (Germany), was the first larger bridge in Germany to use ultra high performance concrete for the prefabricated elements (Fig. 1). In addition, the concrete elements were joined with a novel bonding technique<sup>7</sup>.

Another example is the Wild-Brücke<sup>8</sup> in Völkermarkt (Carinthia, Austria), a bridge inaugurated in October 2010 and worldwide the first medium-sized road bridge whose main support structure was made of UHPC<sup>9</sup>.

#### b. Repair mortar for concrete repair work

External influences, for example salty, moist air, frost, wind and rain, along with aging and heavy loads, damage concrete structures by creating cracks as well as chipping and flaking-off at the surface. These burden the construction industry with high costs. Novel repair mortars, which according to the manufacturer’s specifications are based on nanotechnology, are characterized by improved technical properties such as greater



Figure 1: The Gärtnerplatzbrücke across the Fulda in Kassel River, made of ultra high performance concrete (Source: [www.gaertnerplatzbruecke.de](http://www.gaertnerplatzbruecke.de))

density, tensile bending- and compressive strength as well as frost resistance. They are also said to help minimize damage to concrete. Moreover, the low weight and the simple workability promise additional advantages for the user. The manufacturers of such repair mortars emphasize that the improved properties of their products are not the result of added nanoparticles but rather that a detailed understanding of cement hydration<sup>10</sup> represents the basis for the improved quality and density of the nanostructures in the cement paste<sup>11</sup>.

#### c. Photocatalytically active concrete products and coatings

Under the influence of (UV)-light and water (humidity), nanoscale titanium dioxide accelerates chemical reactions. This produces oxygen radicals that break down and decom-



Figure 2: The “Jubilee Church” in Rome, built with photocatalytically active, “self-cleaning” concrete made by the company Italcementi. (Source: [quartier-magazin.com/quartier08/der-weise-riese](http://quartier-magazin.com/quartier08/der-weise-riese))

pose organic material. This process, known as photocatalysis, is applied in the construction industry and architecture to create “self-cleaning” building materials and to break down air pollutants. When worked into cement or applied in a layer on concrete, the photocatalytic activity of nano-TiO<sub>2</sub> helps decompose dirt composed of organic matter, which is then washed off when it rains<sup>12</sup>. Externally, the buildings maintain their original appearance for a longer period. An example is the “Jubilee Church” in Rome, which was constructed in 2003 (Fig. 2) and whose white concrete shows no signs of soiling even years later<sup>13</sup>.

Air purification is a further area of application of photocatalytically active concrete products. In metropolitan areas, the high levels of nitrogen oxides from vehicular traffic represent a major problem. Concrete products such as roof and paving stones with photocatalytic TiO<sub>2</sub> are designed to improve air quality by converting nitrogen oxides from the surrounding air into nitrate<sup>14</sup>. A further potential application lies in noise-reducing walls or road surfaces. In the PICADA project (Photocatalytic Innovative Coverings Applications for Depollution Assessment)<sup>15</sup>, funded by the EU, the effectiveness of photocatalytically active cement mortar was investigated with an experimental setup. Here, a 40-80% reduction in nitrogen oxide was recorded<sup>16</sup>. Under real-life conditions, the effectiveness of noise-protection walls with a photocatalytic coating was studied in The Netherlands between 2005 and 2009 along autobahn test stretches<sup>17</sup>. No improvement in air quality through reduced nitrogen oxides could be demonstrated. A potential explanation for this result could be, among others, the too short contact between the air and the photocatalytically active coating. In the framework of the EU research project “PhotoPAQ”, running until 2013, the effectiveness of such coatings will be studied on a stretch of a road tunnel in Brussels<sup>18</sup>. Published results are not yet available. Currently, the special cement with nano-TiO<sub>2</sub> is still considerably more expensive than conventional cement. A careful consideration of costs and benefits is therefore required, as are additional studies on the potentially hazardous byproducts of the photocatalytic degradation process<sup>19</sup>. Based on the currently available data, the prevention of pollutant emissions at the source would be more effective than expensive photocatalytic concrete products or coatings.

**d. Ground stabilization in road construction**

In order to protect a road from frost damage, the roadbed must be properly prepared. Novel polymer dispersions<sup>20</sup> with nanoscale silicon dioxide, which is mixed into the cement, are designed to extend the durability of roads while at the same time promising improved workability<sup>21</sup>. Like in ultra high performance concrete, the SiO<sub>2</sub>-nanoparticles fill out the interspaces of the concrete particles, yielding a particularly uniform and dense concrete matrix. Moreover, the polymers in the dispersion are also water repellent. This decreases the water absorption capacity of the road foundation and improves frost resistance. These novel additives promise additional advantages: locally available materials (sand, clay or excavated earth) can be used to produce the roadbed, whereby less material needs to be transported. The setting process of binding agents (for example cement) and the polymer additive can take place using either freshwater and salt-water, and processing is possible even at temperatures below -10° C. According to the manufacturer, these nanopolymer dispersions are also suitable for sealing- and base-layers in hydraulic engineering projects and sewer canal construction, as well as in dam and landfill site construction.

**2. Thermal insulation and noise reduction, temperature regulation**

One of the greatest challenges in the construction sector is the thermal renovation of existing residential and industrial buildings. Here, applying novel insulation materials based on nanotechnology could make an important contribution<sup>4</sup>. In the past, energy consumption has increased steadily. In Austria the value in 2009 was almost 80 % higher than that in 1970. In private households, about 30 % of the energy is used for space heating<sup>22</sup>. This points to a great potential for energy savings here. The Austrian Energy efficiency Action Plan<sup>23</sup> to implement the EU-Energy Efficiency and Energy Services Directive specifies that 9 % of the annual average energy consumption should be cut by 17.5. 2018 at the latest. The measures to achieve this target include boosting the renovation rate in residential buildings and the thermal renovation of all post-war buildings (1950-1980) as well as promoting low-energy and passive house standards.

Innovations attributable to nanotechnology also enable thermally insulating buildings in which a conventional, approximately 20-cm-



**Figure 3: Nanogel®**  
(Source: [www.guenstiger-daemmen.de/daemmstoffe/aerogel-p400-wls-0021](http://www.guenstiger-daemmen.de/daemmstoffe/aerogel-p400-wls-0021))

thick exterior insulation is not possible (for example in older buildings with structured facade) and thereby achieve very good insulation values:

**a. Aerogel**

Aerogel is an especially lightweight material that can for example be produced from silica. The gel is dried in a special process, yielding a type of solid foam that consists of more than 95 % air. Such silica aerogels were first produced back in the 1930s<sup>24</sup>. The pores of this material measure only a few nanometers, explaining the brand name Nanogel®. The thermal conductivity of a material with pores on the nano-scale is minimal because only a few gas molecules have space in the pores, thus reducing the heat transfer from one gas particle to another. Aerogel holds 15 entries in the Guinness Book of records, among others as the “best insulator” and “lightest solid”. Combining Aerogel and stone wool yields so-called Aerowolle®, which is incorporated into thin plasterboard for interior insulation<sup>25</sup>. Aerogel can also be filled in between two window glass panes<sup>26</sup>. Such glazing successfully blocks infrared radiation as well as noise. Nonetheless, Aerogel is not transparent, yielding a “translucent glass” effect. An insulating plaster with Aerogel<sup>27</sup> is currently under development and is expected to be on the market in 2013.

**b. Vacuum Insulation Panels (VIP)**

The core of these special insulation panels consists of nanoscale silica, graphite or silicon carbide in a vacuum and is surrounded by a particularly dense and stable laminated sheet made of synthetic material and aluminum<sup>24</sup>. By removing the heat-conducting air, these only 2-4-cm-thick panels attain especially high insulation values that are comparable with conventional insulation materials such as approx. 20-cm-thick polystyrene panels. Such VIPs can be used both indoors and outdoors, for example for walls, roofing

and terraces, but also in cooling units<sup>28</sup>. VIPs, however, are relatively sensitive because mechanical damage can destroy the vacuum. This makes cutting to size impossible. Moreover, the costs are currently still high.

**c. Latent heat storage**  
 (“Phase Change Materials”, PCM)  
 – Temperature regulation

In summer, very high temperatures can be reached in loft conversions or in buildings that were erected using lightweight technology. This can be countered with plastering, bricks, concrete or clay panels with incorporated PCM that are produced based on paraffin waxes. In this approach, paraffin spherules with diameters in the micro- or nanometer scale are enclosed in a stable coating of plastic or acrylic glass. When the wax melts at higher temperatures, it extracts heat energy from the surroundings through the phase shift from solid to liquid. When the temperature drops again, for example at night, the wax becomes solid again and releases this heat energy. Construction materials with PCM are suitable for temperature regulation in interiors and, optimally, can even entirely replace the need for air conditioning<sup>29</sup>.

**d. Electrochromic windows**  
 with nano-coatings

Electrochromic windows consist of two glass panes (sandwich pane) with an electrically conductive, transparent coating. The interspace contains a sol-gel-layer<sup>30</sup> of tungsten trioxide. Applying a small electric current (up to 3 V) turns this nano-structured coating blue and reduces the passage of sunlight through the laminated pane<sup>31</sup>. The light and heat input into a room can be individually controlled with such electrochromic panes. The switching time depends on the size of the windows and can be between three and five minutes, which might be considered a disadvantage. As opposed to conventional electrochromic window panes, no permanent power supply is required.

**3. Surface coatings**

In the construction sector, a wealth of nanotechnology-based products that can functionalize various surfaces are already on the market. The focus is on dirt- and water-repellent along with “self-cleaning” coatings. These include facade paints, window panes, roof tiles, surface protection for construction materials against water penetration, mosses, algae or mold, and “anti-graffiti” or “anti-fingerprint” coatings. These applications were already treated in a separate [NanoTrust Dossier \(Nr. 020en\)](#).

**4. Fire protection**

Special fire-resistant glass consists of two glass panes with an only 3-mm-thin filling of nanoscale SiO<sub>2</sub>, which foams in the event of a fire. Such panes can withstand a continuous fire of more than 1000 °C for up to 120 minutes; they have the additional advantage of being very light and thin. The coating itself is hardly visible. Beyond applications in buildings, these panes are also used for ship windows and portholes. Using nano-SiO<sub>2</sub>, lightweight sandwich panels of straw and hemp, such as those used in trade fair construction, can be coated and made fire resistant. Despite the glass-like coating, the panels are diffusible and, at the end of their useful life, can be normally shredded and disposed of<sup>1</sup>.

Nano-structured silicate particles (so-called “nano-clay”) can be incorporated in plastics to optimize their flame-retardant properties and their heat resistance. Such nanocomposite materials are for example applied in producing cable insulation or covers (e.g. fuse boxes, sockets) in interior finishings<sup>4</sup>.

**5. Applications currently under development**

Based on their special properties<sup>32</sup>, carbon nanotubes (CNTs) are of special interest in the development of reinforced concrete. Adding only 1% by weight of CNTs can improve the mechanical properties. In particular, multi-walled CNTs (MWCNTs) can increase the compressive and tensile strength. Technical challenges still remain to be met in the uniform incorporation of CNTs into the concrete matrix (clumping of CNTs, poor binding of CNTs with the matrix). Up until now, these problems, along with the ongoing high production costs and currently unpredictable health risks of CNTs have hindered the introduction of a concrete product with CNTs. Sensors that are based on nanotechnology (nano-electromechanical devices, NEMS) are also under research and development. These can be implanted in concrete and can serve in quality control and help monitor durability. In the future, such sensors will help measure the density and viscosity of the concrete along with parameters that influence durability (e.g. temperature, moisture, pH, vibrations)<sup>33</sup>.

**Health aspects**

In principle, there are two exposure pathways of end users to nanomaterials from a “nano-construction product”<sup>2</sup>:

1. When applying a ready-to-use product (for example a facade paint) or a product that is admixed to another material on site (e.g. an additive for concrete);
2. During the destructive treatment of a “nano-product”, for example drilling, sanding or milling.

Both workers as well as private end users can come into contact with nanomaterials when using a “nano-construction product” and must therefore be protected against potential health hazards. This is guaranteed in the employee protection sector by legal regulations and corresponding risk management measures in businesses or companies<sup>34</sup>. Especially in the case of end users, however, information on which nanomaterial is present in which form and concentration in a product is often missing. According to the EU-Directive on the Classification, Labeling and Packaging of Substances and Mixtures (CLP-Directive<sup>35</sup>), manufacturers are not obliged to inform their customers that their product contains nanomaterials. One possibility would be a Material Safety Data Sheet (MSDS), but in the case of products that come with an MSDS, it is up to the manufacturer to decide whether such health and safety information about an incorporated nanomaterial is included<sup>2</sup>. Accordingly, the information transmission along the entire value chain – from the manufacturer of a product containing nanomaterials to the end user – is generally not given.

According to our present state of knowledge, if a nanomaterial is permanently bound in a matrix, such as in concrete or in an insulation material, then the probability of an exposure to that nanomaterial is very low or non-existent, as long as the product is not destructively treated. Even in the latter case, however, studies show that working nanocomposite materials with sandpaper does not lead to a release of nanoparticulate components<sup>36</sup>. One study showed that drilling through concrete with a nano-additive resulted in higher nanoparticle concentrations in the ambient air than in the case of conventional concrete. Unfortunately, the currently available particle size measurement instruments can only determine the number of particles per unit volume of air: no characterization of the particles is possible, and therefore the composition and source of the measured particle concentrations cannot be determined. The authors of the study suspect

that the motor of the drill emits more nanoparticles when penetrating the denser and harder nano-concrete due to the higher drilling intensity<sup>37</sup>. At any rate, the operation of electric appliances and heating units, as well as combustion processes, probably release a higher concentration of nanoparticles.

When a nano-coating is sprayed or mortar mixed at a construction site, workers are exposed to a potential health threat by inhaling dust or minute liquid droplets (aerosols). The above-mentioned study also examined workplace exposure when handling dusty and liquid materials. Mixing mortar led to short-term peak nanoparticle concentrations in the air. These values, however, were dependent on the weather conditions: considerably lower concentrations were measured under strong winds. A somewhat higher nanoparticle concentration was recorded when spraying a coating containing nano-TiO<sub>2</sub>, although this could potentially also be attributed to the emissions of the motor of the spraying machine. The result of the above workplace studies lead to the conclusion that the contribution of the machines used (mixing machines, drills, diesel engines, etc.) – as well as cigarette smoke – contribute more to the nanoparticle concentration in the ambient air than the used “nano-construction products”. In the Netherlands, so-called “nano-reference values” were introduced in a precautionary approach due to the lack of exposure limits for nanomaterials at the workplace. In the above study, these reference values were not exceeded at any of the investigated workplace situations. Accordingly, no additional nano-specific safety measures were deemed necessary<sup>37</sup>.

To avoid a potential health threat to employees through nanomaterials, European manufacturers of nanomaterials, in a precautionary approach, have for some time been pursuing a preventive policy. One example is special codes of conduct<sup>38</sup>. Since particularly the inhalation of nanoparticles represents a potential health hazard<sup>39</sup>, measures were

set to prevent this. Thus, most nanomaterials are produced in liquid form as suspensions or solutions, or in a sealed environment in order to minimize the exposure risk. Moreover, most nanoparticulate additives are also marketed by the product manufacturers in liquid form. If this is not possible for technical reasons, such as in the case of silica dust for ultra high performance concrete, then other solutions are sought. One example is the use of water-soluble packaging materials that do not impact the product properties of the concrete<sup>2</sup>. Certain branches, such as the paint and varnish industry, have also compiled special operational guides on the safe use of nanomaterials<sup>40</sup>.

## Environmental advantages and threats

The potential environmental advantages of “nano-products” along with the potential environmental threats through nanomaterials have already been treated in two [Nano Trust Dossiers \(Nr. 026en und 027en\)](#), so this issue will be treated here only in brief.

Environmental advantages of construction products containing nanomaterials or of products based on nanotechnology are expected especially in the sectors energy savings and conservation of resources. Novel insulation materials can help to reduce the energy demand for heating and cooling of residential buildings and office space and can also be applied in cases where conventional insulation is not possible. Special nano-coatings can increase the lifespan of materials or, as in the case of “self-cleaning” coatings, can help reduce the cleaning effort and therefore reduce the demand for energy, water and cleaning agents. For most “nano-construction products”, however, no comprehensive life cycle analyses or comparative ecobalance evaluations (versus con-

ventional building material) are available, so that the actual environmental advantages cannot be quantified.

As “nano-construction products” currently play only a subordinate role on the market, the present environmental threat through nanomaterials appears to be low. Nonetheless, virtually no data are available on exposure, so that no comprehensive risk assessment can currently be made for any nanomaterial. Wastes and wastewater represent the main potential sources of input into the environment. In the case of “nano-construction products”, this would be the dumping of building rubble with nanomaterials or an improper disposal of paints or varnishes via the sewer system. Studies have shown that nanoparticulate TiO<sub>2</sub> from facade paints can leach out and enter the environment. To date, no specific regulations govern the disposal or the recycling of construction products containing nanomaterials. For certain nanomaterials, for example nano-TiO<sub>2</sub> or nanosilver, laboratory studies have shown toxicological effects in the environment. Nonetheless, the actual input of these materials into the environment and their behavior in natural ecosystems remains largely unknown.

## Notes and References

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- <sup>3</sup> [www.bgbau.de/d/pages/praev/fachinformationen/gefahrstoffe/nano/index.html](http://www.bgbau.de/d/pages/praev/fachinformationen/gefahrstoffe/nano/index.html).
- <sup>4</sup> Luther, Wolfgang, 2008, *Einsatz von Nanotechnologien in Architektur und Bauwesen*, commissioned by: Hessisches Ministerium für Wirtschaft Verkehr und Landesentwicklung, Nr. Band 7 der Schrifreihe der Aktionlinie Hessen Nanotech: HA Hessen Agentur [www.hessen-nanotech.de/mm/NanoBau\\_final\\_Internet.pdf](http://www.hessen-nanotech.de/mm/NanoBau_final_Internet.pdf).
- <sup>5</sup> Flatz, Christian, 2009, *Nanostruktur am Bau, zukunft forschung – Magazin für Wissenschaft und Forschung der Universität Innsbruck*, 01/09, 18 [www.uibk.ac.at/forschung/magazin/2/lackner\\_troi.pdf](http://www.uibk.ac.at/forschung/magazin/2/lackner_troi.pdf).
- <sup>6</sup> [www.gaertnerplatzbruecke.de](http://www.gaertnerplatzbruecke.de).
- <sup>7</sup> Juschkus, Ute, 2010, *Nanotechnologie und Ultra Performance Concrete (UHPC)*, *RKW-Fachinfo – Nanotechnologie am Bau (1)*, 4-6 [www.rkw-kompetenzzentrum.de/uploads/media/2010\\_MA\\_Nano-am-Bau.pdf](http://www.rkw-kompetenzzentrum.de/uploads/media/2010_MA_Nano-am-Bau.pdf).

## Conclusions

In the research and development sectors, great efforts are being undertaken to improve material properties and introduce new nanotechnology-based products that could be of interest to the construction industry. This stands in contrast to the conventional behavior of the construction industry so that, in reality, “nano-construction products” still play a very subordinate role in this business. Greater acceptance can only be expected when such products become available at competitive process and their technical behavior is sufficiently substantiated. Determining the environmental and health threats of construction products with nanomaterials will require additional studies under realistic conditions. Equally important is the development and adaptation of measuring instruments to analyze the workplace and environmental exposure.

- <sup>8</sup> [www.wild.raum.at](http://www.wild.raum.at).
- <sup>9</sup> WILD-Brücke – UHCP in der Praxis als Ergebnis der Forschung. TU Graz. [www.zement.at/Service/literatur/fileupl/koll08\\_09freytag.pdf](http://www.zement.at/Service/literatur/fileupl/koll08_09freytag.pdf).
- <sup>10</sup> Cement hydration is the chemical process behind the hardening of cement after mixing with water, involving the formation of hydrated calcilcates, aluminates and ferrites in connection with hydrated gel masses, whereby the developing crystals penetrate each other and are fused by the gel masses. (source: Lexikon/Glossar Gebäudetechnik [www.gbt.ch/Lexikon/Z/Zementhydratation.html](http://www.gbt.ch/Lexikon/Z/Zementhydratation.html)).
- <sup>11</sup> Product example: [www.emaco-nanocrete.com/german/produkte.html](http://www.emaco-nanocrete.com/german/produkte.html).
- <sup>12</sup> See also NanoTrust Dossier 020en.
- <sup>13</sup> Building small: Nanotechnology makes inroads in the construction industry. Chemical & Engineering News, June 2011 [greenharmonyhome.com/wordpress/?p=2936](http://greenharmonyhome.com/wordpress/?p=2936).
- <sup>14</sup> For additional information and products see for example. [www.heidelbergcement.com/de/de/country/zement/lieferprogramm/spezialzemente/tiocem.htm](http://www.heidelbergcement.com/de/de/country/zement/lieferprogramm/spezialzemente/tiocem.htm); [www.italcementigroup.com/ENG/Research+and+Innovation/Innovative+Products/TX+Active/](http://www.italcementigroup.com/ENG/Research+and+Innovation/Innovative+Products/TX+Active/).
- <sup>15</sup> PICADA Project (Photocatalytic Innovative Coverings Applications for Depollution Assessment. [www.picada-project.com/domino/SitePicada/Picada.nsf?OpenDataBase](http://www.picada-project.com/domino/SitePicada/Picada.nsf?OpenDataBase).
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- <sup>17</sup> Dutch Air Quality Innovation Programme; [www.ipl-airquality.nl](http://www.ipl-airquality.nl).
- <sup>18</sup> Bessere Luft durch neue Oberflächen? Troposphärenforscher untersuchen Spezialbeschichtungen. Informationsdienst Wissenschaft. 139.174.2.142/de/news439662. Project PhotoPAQ (Demonstration of Photocatalytic Remediation Processes on Air Quality). [photopaq.ircelyon.univ-lyon1.fr](http://photopaq.ircelyon.univ-lyon1.fr).
- <sup>19</sup> Juschkus, Ute, 2010, Superzweg TiO<sub>2</sub> – Umweltschutz mit Nanotechnologie, *RKW-Fachinfo – Nanotechnologie am Bau (1)*, 9-10 [www.rkw-kompetenzzentrum.de/uploads/media/2010\\_MA\\_Nano-am-Bau.pdf](http://www.rkw-kompetenzzentrum.de/uploads/media/2010_MA_Nano-am-Bau.pdf).
- <sup>20</sup> Polymer dispersions are a mixture of plastic particles in water.
- <sup>21</sup> For further information see: [www.nanosky.com/de/nanosky\\_nts.html](http://www.nanosky.com/de/nanosky_nts.html).
- <sup>22</sup> [e-control.at/de/konsumenten/energie-sparen/thema-energieverbrauch](http://e-control.at/de/konsumenten/energie-sparen/thema-energieverbrauch).
- <sup>23</sup> Bundesministerium für Wirtschaft und Arbeit, 2007, 1. *Energieeffizienzaktionsplan der Republik Österreich gemäß EU-Richtlinie 2006/32/EG* [ec.europa.eu/energy/demand/legislation/doc/neeap/austria\\_neeap\\_de.pdf](http://ec.europa.eu/energy/demand/legislation/doc/neeap/austria_neeap_de.pdf).
- <sup>24</sup> Juschkus, Ute, 2010, Zwergenträume – Nanoschäume. Energieeffizientes Bauen mit Nanotechnologie, *RKW-Fachinfo – Nanotechnologie am Bau (1)*, 7-9 [www.rkw-kompetenzzentrum.de/uploads/media/2010\\_MA\\_Nano-am-Bau.pdf](http://www.rkw-kompetenzzentrum.de/uploads/media/2010_MA_Nano-am-Bau.pdf).
- <sup>25</sup> Aerowolle® of the company Rockwool: [www.aerowolle.de](http://www.aerowolle.de).
- <sup>26</sup> See for example Okagel® produced by the company Okalux. [www.okalux.de/produkte/marken/okagel.html](http://www.okalux.de/produkte/marken/okagel.html).
- <sup>27</sup> Aerogel-Dämmputz isoliert historische Bauten einfach und wirksam. EMPA. [www.empa.ch/plugin/template/empa/3/101225/—/l=1](http://www.empa.ch/plugin/template/empa/3/101225/—/l=1).
- <sup>28</sup> For product examples see the companies Vaku-Isotherm: [www.vaku-isotherm.de/ebene2.html](http://www.vaku-isotherm.de/ebene2.html) or Porextherm: [www.porextherm.com/produkte.html](http://www.porextherm.com/produkte.html).
- <sup>29</sup> For a product example of a micro-encapsulated PCM, see: Micronal®, BASF; [www.micronal.de/portal/basf/ide/dt.jsp?setCursor=1\\_286688](http://www.micronal.de/portal/basf/ide/dt.jsp?setCursor=1_286688).
- <sup>30</sup> See NanoTrust Dossier 006en.
- <sup>31</sup> See: Blau und grau färbende Sol-Gel elektrochrome Fenster. Nanoinfo, INM Leibniz-Institut für Neue Materialien. [www.inm-gmbh.de/wp-content/uploads/2011/04/handout\\_Elektrochrom\\_de\\_2011.pdf](http://www.inm-gmbh.de/wp-content/uploads/2011/04/handout_Elektrochrom_de_2011.pdf). For a product example see the company Infraselect: [www.flachglas.de/uploads/X\\_PDFs/Broschueren/INFRASELECT\\_4\\_08.pdf](http://www.flachglas.de/uploads/X_PDFs/Broschueren/INFRASELECT_4_08.pdf).
- <sup>32</sup> See NanoTrust Dossier 022en.
- <sup>33</sup> Mann, Surinder (Institute of Nanotechnology), 2006, *Nanotechnology and Construction*, November 2006: Nanoforum [www.nanoforum.org/dateien/temp/Nanotech%20and%20Construction%20Nanoforum%20report.pdf?09052012123958](http://www.nanoforum.org/dateien/temp/Nanotech%20and%20Construction%20Nanoforum%20report.pdf?09052012123958).
- <sup>34</sup> For an overview on the aspects of employee protection see NanoTrust-Dossier 029en.
- <sup>35</sup> Directive (EG) Nr. 1272/2008 of the European Parliament and the Council of 16.12.2008 on the Classification, Labelling and Packaging of Materials and Mixtures, amending and repealing Directives 67/548/EWG and 1999/45/EG and amending Directive (EG) Nr. 1907/2006. [eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:353:0001:1355:DE:PDF](http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:353:0001:1355:DE:PDF).
- <sup>36</sup> Wohlleben, Wendel, et al., 2011, On the Lifecycle of Nanocomposites: Comparing Released Fragments and their In-Vivo Hazards from Three Release Mechanisms and Four Nanocomposites, *small (16)*, 2384-2395.
- <sup>37</sup> Van Broekhuizen, Pieter, et al., 2011, Use of nanomaterials in the European construction industry and some occupational health aspects thereof, *Journal of Nanoparticle Research 13(2)*, 447-462 [www.nanoservices.nl/include/Van\\_Broekhuizen\\_et\\_al\\_2011\\_Use\\_of\\_nanomaterials\\_in\\_the\\_European\\_construction\\_industry1.pdf](http://www.nanoservices.nl/include/Van_Broekhuizen_et_al_2011_Use_of_nanomaterials_in_the_European_construction_industry1.pdf).
- <sup>38</sup> See also NanoTrust-Dossier 016en.
- <sup>39</sup> See also NanoTrust-Dossier 003en.
- <sup>40</sup> Hermann, Andreas, et al., 2009, *Sichere Verwendung von Nanomaterialien in der Lack- und Farbenbranche – Ein Betriebsleitfaden*, commissioned by: Verkehr und Landentwicklung Hessisches Ministerium für Wirtschaft, Nr. Band 11 der Schriftenreihe der Aktionslinie Hessen-Nanotech, September 2009: HA Hessen Agentur GmbH [www.hessen-nanotech.de/mm/Betriebsleitfaden\\_NanoFarbeLacke\\_Vorab.pdf](http://www.hessen-nanotech.de/mm/Betriebsleitfaden_NanoFarbeLacke_Vorab.pdf).

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