ObservatoryNano

Economical Assessment / Construction sector

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Table of content

Construction sector

1.1 Executive Summary

This report provides information on the existing applications of nanotechnology in construction and the relevant existing products on the market. Being an enabling tool nanotechnology finds applications in many areas of construction. In the first year of ObservatoryNANO project this study has focused on construction ceramics, cement, glass, insulation systems and paints.

Construction is one of the most strategic industries for Europe providing building and infrastructure on which all sectors of the economy depend. Construction sector is a settled, cost driven and a traditional sector. However, both economical and environmental considerations have been reshaping this sector and this industry has been adopting new technologies. Nanotechnology has a significant impact in the construction sector. Several applications have been developed for this specific sector to improve the durability and enhanced performance of construction components, energy efficiency and safety of the buildings, facilitating the ease of maintenance and to provide increased living comfort.

Main drivers to uptake new technologies and new materials in the construction sector are the regulations to enhance sustainability in all members of the value chain. Also longer service life, easier maintenance and reduced maintenance expenditures, easier handling of construction materials, cleaner processing technologies and increase safety are important factors that drive innovations in this sector. Even if there are important reasons to uptake nanotechnologies there have been critical barriers to be overcome to increase the market penetration of these new products and technologies. The biggest barrier is the cost of new processing technologies and new materials. Apart from the cost, consumer scepticism, lack of large-volume availability of new materials with reliable properties and also lack of awareness of the stakeholders of the industry about novelties are some of the barriers ahead of the spread of nanoenhanced products for construction in the market.

As previously mentioned nanotechnology has found applications in different areas of construction and already there are products on the market. However, penetration of these products is almost negligible. Today approximately 1% of the construction related products on the market have nanoenhanced feature(s). Since the present economic crisis has heavily affected the construction industry, demand and respective sales for all construction related products have declined enormously. Last years' trends for constructing new buildings have changed in favour of renovating buildings.

The sub-segments where nanotechnology has impacts and relevant products that exist on the market are briefly summarized as follows.

Construction ceramics

Nanoenhanced construction ceramics which include floor and wall tiles, countertop ceramics and sanitaryware products have found place on the market with self-cleaning, anti-bacterial, hygienic and scratch resistant features. These nanoenhanced products are usually 20 to 50 percent more expensive then their traditional counterparts. Currently market penetration of these nanoenhanced products are less than 0.5 percent. German company Nanogate AG is the main supplier of coatings that are used to bring new functionalities to construction ceramics.

In Europe some of the companies that have such products are Duravit, Roca, Erlus, Villeroy and Boch and etc.

Cement

Nanotechnology affects cement and concrete in different ways including their processing conditions, released CO_2 emissions, service life and functionalities. Addition of nanoparticles will lead to stronger, more durable, self-healing, air purifying, fire resistant, easy to clean and quick compacting concrete. Some of the nanoparticles that could be used for these features are nano silica (silica fume), nanostructured metals, carbon nanotubes (CNTs) and carbon nanofibers (CNFs). Concrete structures also make profit from nano-enhanced coatings that prevent graffiti and other unwanted stains to adhere on to it.

Nanoenhanced cement has already found use in construction sector, especially the ones which exhibit photocatalytic features. However, their application is, so far, limited to construction of buildings like churches, sensational bridges, etc. as some examples can be found in this report. Prices are still too high for it to become a common material between constructors. In Europe Italcementi, Heidelberg Cement, Lafarge, Clariant, Nanogate AG and BASF have either nanoenhanced cement or nanoadditives for cement / concrete products.

Windows - Glass

Nanotechnology will also have a considerable impact on glass and therefore on windows. For marketing purposes, these windows are commonly called smart windows which implies that they are multifunctional through their energy saving, easy cleaning, UV controlling and photovoltaic features. Another feature that nanotechnology brings to glasses is fire resistance via addition of fumed silica nanoparticles.

Pilkington and Saint Gobain are the leading producers of multifunctional advanced glasses both for construction and for automotive industries. Even the market penetration of these nanoenhanced glasses have been increasing slowly, still they are very expensive, approximately 30 to 80%, with respect to the traditional float glass.

Insulation materials

Nanotechnology can facilitate developing high performance insulation materials / systems. Different forms of insulation solutions, like coatings, vacuum insulation glazing, and nanofoams can be realized.

BASF, Aspen Aerogels and Cabot Corporation are the well-known companies that have products on the market.

Paint

Rheology, settling, surface energy, corrosion resistance and mechanical properties of paint can be improved via addition of nanoparticles into paint. By addition of this nanoparticles paint gets scratchproof, easy cleaning, air purifying, UV resistant, water repellence, flame retardancy and anti-bacterial feature.

Penetration rate of nanoenhanced paints is relatively high compared to the other products mentioned here. These paints are sold on DIY stores which might have an effect on penetration rate. Jotun, Bioni CS GMBH, Yaşar Paint and Chemicals and Akzo Nobel are the leading paint companies in Europe with nanoenhanced paints on the market.

1.2 Definitions and Methodology

1.2.1 What's nanotechnology?

Nanotechnology is a very general term. Currently, there is no definition of the term "nanotechnology" that is generally accepted. This makes it quite challenging to predict "the world market" for products produced by nanotechnology or products with functional components in the nanometre range or products working with a precision in the nanometre range.

However, if the geometry size in at least one dimension is reduced to a critical value below 100 nanometres, most fundamental physical properties, depending on the material, change. Each property has a critical length scale, and with a nanoscale building block being made smaller than the critical length scale, it is possible to control the property's internal and surface chemistry, their atomic structure and their assembly. It is further possible to engineer properties and functionalities in completely new ways. Fine adjustment is possible by altering the sizes of those nano building blocks.

Therefore, in the following the term nanotechnology product refers to this definition:

Products with a functional component with controlled geometry size below 100 nanometres in at least one dimension, and innovative characteristics caused by this critical dimension.

Equipment for analytical or manipulatory purposes that allows controlled fabrication, movement or measurement resolution with a precision below 100 nanometres.

Obviously, only in few cases does such a product consist of nanoscale building blocks alone, without any macroscopic element. Since the value of the nanotechnology contribution to such a product is difficult to estimate, it is only possible to consider the market price value of the end product. This clearly has implications for the determination of the overall market size.

Therefore, we define the smallest unit that can be commercially sold in the marketplace as a "nanotechnology product". Consequently, the market figures in this study are based on the market price of the smallest commercially available units with functional nanotechnology components.

1.2.2 Methodology for preparing the report

To prepare the report a comprehensive approach was followed whose outcome has been included in the report. Initially a desk research was done to know more about the sector, important applications and where nanotechnology has / could have an influence and also to determine the companies which have activities in the field. On having prepared the draft report based on this initial desk research, phone interviews with different experts were carried out. During these interviews our aim was to learn about their experiences and opinions regarding, state of the art and future markets, drivers and barriers that have been faced adopting new technologies, etc. Later on, based on these interviews, the views of participating experts were translated to the report to transmit the opinions of those who have been working in this field.

1.2.3 Methodology for market quantitative assessment

Publicly available annual reports from companies, expert statements and when available, present market prices of products to give an idea about the market state of the products for different applications were used. Due to the present global economic situation, especially since construction sector has been seriously affected, it can be misleading to estimate future market situation for the products mentioned in this report.

1.3 General sector description

The construction sector is strategically important for Europe, providing building and infrastructure on which all sectors of the economy depend. With 11.8 million operatives directly employed in the sector, it is Europe's largest industrial employer accounting for 7% of total employment and 28% of industrial employment in the EU-15. It is estimated that 26 million workers in the EU-15 depend directly or indirectly on the construction sector. In 2007 the whole construction sector in 19 European countries was quantified as more than 1,600 billion Euros.

The last year of expansion in the construction sector since 1999 was 2007. As of September 2008, the negative effect of the global economic crisis is widely seen in the sector. According to a recent report of EuroStat, construction industry was very unstable in 2008 and there was an increase in overall construction costs. Figure 1 shows gross domestic production and construction output, from 2005 with a forecast into 2012. The slowdown of the house sales both in EU and the US lead to a drastic change in the construction related industries' market figures, from construction chemicals, cement / concrete to insulating materials and floor / wall tiles, etc. The European countries where construction industry has been most dramatically affected by the crisis are Spain, Ireland and Greece. **[1,2]**

As a result of the crisis construction of new buildings especially residential buildings have declined enormously leading to an increase in renovation of existing buildings.

Main stakeholders of construction sector are raw materials producers, contractors-developers, architects, engineers, internal designers and finally the end-users be it residents, municipalities, companies, state, or otherwise. Contractors depend upon raw materials to ensure the high quality, cost effectiveness, sustainability and reliability of their projects. All of these stakeholders need to become aware of new technologies and materials, and, accordingly their use and impact in design, maintenance, sustainability and quality of construction.

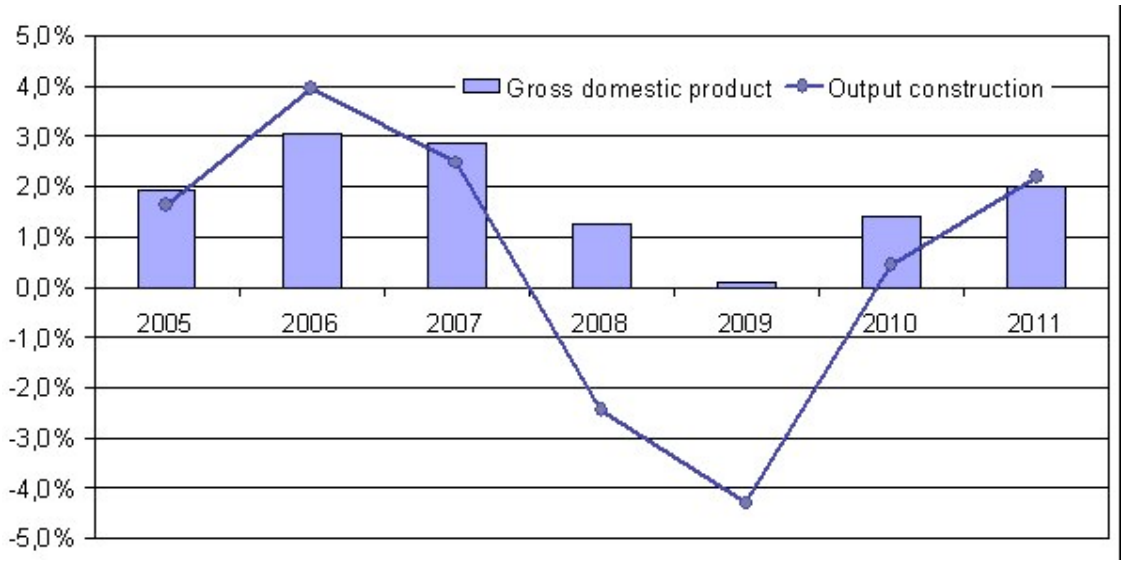

Figure 1. Gross domestic production and construction output (Source: www.euroconstruct.org)

Apart from economical considerations, environmental concerns like global warming are also re-shaping the construction sector. Construction industry contributes to global warming in various ways: first and foremost, the consumption of resources in heating and cooling systems followed by the manufacture of the construction materials like cement and steel. As a result, more and more energy efficient buildings and related research in innovation activities are gaining importance in the sector. **[3]**

As mentioned above, there has been also an increasing trend for renovation which would lead to an increase in the consumption of basic materials like construction chemicals, e.g. ceramic tiles, windows, new insulation materials, heating / cooling systems, coatings and etc.

Construction sector is a settled, cost driven and a traditional sector. It is not a technology driven sector. For example, in the technology driven sectors like information and computing technologies, energy, medicine and etc. sectors have to quickly adopt innovations both to be able to compete with other companies and also to respond to the needs of the consumers. However, this is not the case in construction sector. Uptaking innovations do not lead to drastic and vital changes in the final products which would increase the consumer demand considerably. R&D investments are very low in construction industry, in average 2% of the turnover. And in most of the cases this R&D effort is not really translated into products and also penetration of these new products stay very limited.

At its present state applications of nanotechnology in the construction sector highly depend on chemical industry, therefore on chemicals. Chemicals sector is one of the basic and pioneering industries where the most fundamental and applied research is done. So if there is an innovation in a chemical product which is used for construction, there is an indirect application of nanotechnology (mostly nanomaterials) in the construction sector.

To give an example, BASF is one of the largest suppliers of chemicals for the construction industry. They invested about €180 million in nanotechnology R&D out of €920 million invested in whole R&D activities between 2006 and 2008 [BASF 2008 annual report, www.basf.de].

As previously mentioned, the recent financial crisis heavily affected the construction sector making any assessment of economic impact of nanotechnology in the sector very unreliable.

For example, most of the chemical companies who provide advanced products to the industry could not reflect the increase in chemicals and raw materials costs to the industry.

In addition to the chemical industry, glass industry and basic raw materials industries' like cementitious materials are highly determining in the shape up of construction industry.

1.3.1 Nanotechnology impact in construction sector

Nanotechnology has a significant impact in the construction sector. Several applications have been developed for this specific sector to improve the durability and enhanced performance of construction components, energy efficiency and safety of the buildings, facilitating the ease of maintenance and to provide increased living comfort.

Though self-cleaning feature has been possible to attain using micron sized coatings and surface treatments e.g. Teflon™, polysilazane based coatings, etc. now this feature has become a marketing tool / motto for nanotechnology applications, especially for consumer markets like construction, textile, etc.

Nanoparticles of **TiO_2**, **Al_2O_3** or **ZnO** are applied as a final coating on construction ceramics to bring this characteristic to the surfaces. TiO_2 is being used for its ability to break down dirt or pollution when exposed to UV light and then allow it to be washed off by rainwater on surfaces like tiles, glass and sanitaryware. ZnO is used to have UV resistance in both coatings and paints. Nanosized Al_2O_3 particles are used to make surfaces scratch resistant. These surfaces also prevent / decelerate formation of bad smells, fungus and mould.

Basic construction materials cement, concrete and steel will also benefit from nanotechnology. Addition of nanoparticles will lead to stronger, more durable, self-healing, air purifying, fire resistant, easy to clean and quick compacting concrete. Some of the nanoparticles that could be used for these features are nano silica (silica fume), nanostructured metals, carbon nanotubes (CNTs) and carbon nanofibers (CNFs). Current pressure to reduce CO_2 emissions from the manufacture of cement is guiding research to use nanotechnology to alter the processing conditions of cement, therefore reducing these emissions. Concrete structures also make profit from nano-enhanced coatings that prevent graffiti and other unwanted stains to adhere on to it. In addition to these materials, new lightweight, flame-retardant, self-healing and resilient construction materials, e.g. new nanocomposites, are expected to be helped in their development by nanotechnology.

Nanotechnology will also have a considerable impact on glass and therefore on windows. For marketing purposes, these windows are commonly called smart windows which implies that they are multifunctional through their energy saving, easy cleaning, UV controlling and photovoltaic features.

Nanotechnology could allow the development of materials with better insulation properties, intelligent structures capable of optimizing the use of energy. New insulating materials have been developed with the help of advances in nanotechnologies. These insulating materials are: nanofoams, nanostructured aerogels and vacuum insulated panels (VIPs).

In the future, smart living spaces will be made possible via embedded sensing systems that would enable buildings sense and act according to environment and also to the users' needs. **[4]**

Application of nanomaterials and benefits of nanotechnology in many fields of the construction sector seem endless in principle. However, it is crucial to what extent these novelties would find place in the markets.

In the following sections detailed information on each application, the relevant products on the market, important companies and findings of our economic assessment are provided.

1.3.2 Drivers and Barriers to Innovation in the Construction Sector

The construction sector is one of the most traditional and cost oriented industries which make uptake of innovation and therefore making investments for novelties very difficult. As long as there are not clear / distinct benefits of new materials at a reasonable cost stakeholders of construction industry are reluctant to change the materials and the way they are working. Even though they do bring new features to the products at the present use of nanoenhanced materials do not lead to a significant change in the constructions for constructors to uptake these new materials. Accordingly, penetration of nanotechnology applications to construction sector has been very small. However, construction sector has to adopt technological novelties and accordingly meet the needs of changing lifestyles, environment and socio-economic needs like global warming, energy resources' scarcity and increased cost, ageing population, migration, increase in population density, change in working habits, demand for more functional and comfortable living spaces, etc. **[5]**

Below are the most common drivers and barriers to adopt innovations in construction sector.

Drivers:

Emphasizing the need on innovation in the construction sector, the European Commission is taking measures to change the present focus of constructors from 'cost' to sustainability. Accordingly, the main objective of the different measures / regulations implemented by the EC is towards development of sustainable construction sector. As mentioned above, construction industry contributes to global warming in two ways; heating and cooling of buildings and through the manufacture of materials used for construction. Sustainability in the construction sector is mainly focused on the reduction of emissions, construction of energy efficient houses, etc. which could result in an increase in the use of nanotechnology driven innovations in this sector. Due to traditional and cost driven character, legislations would play the most important role for quicker uptake of innovative technologies and novel materials in the construction sector. Also changing economical situation and changing habits of society would be the key for shaping the market.

In the case of cement, since benefits of most of the functionalities are related to environmental issues, legislations would play an important role in increasing the penetration of new cement products, especially the ones with air-purifying and self-cleaning properties, to the market. For example, under normal conditions motorways, pavements, etc. are made out of concrete ad asphalt and they are not renewed often. If legislation is imposed for building roads to decrease air pollution constructors would have to go for such products and accordingly their market would increase.

Unavoidable consumption of cement in the constructions makes this sector one of the most polluting industries. The cement industry accounts for 5% of CO_2 emissions. Kyoto commitments, which are accepted by most of the developed countries, pressure cement producers to cut their CO_2 emissions limiting their production volumes. Therefore, this is another driver for the cement producers look for ways of innovative processing methods and replace or reduce the consumption of existing polluting materials with new materials.

Another important driver is to decrease the weight of construction materials so as to handle them easily at the construction site. Apart from easy handling, this would also ease the transportation of materials and lead to reduced consumption of energy resources and

accordingly lead to reduced carbon footprint. So in time lighter materials will be preferred instead of their heavier counterparts.

As previously mentioned to be able to increase the service time of construction materials is another incentive for construction materials producers to invest in research and development. This would also decrease the cost related to maintenance and change of deteriorated construction components which could be quite tedious and expensive in some construction components e.g. wall tiles, concrete blocks.

Due to today's changing life styles (some people have started to spend longer time at home than usual and started to work at home (home offices) while some other people hardly spend time at home due to trips, etc. making them look for more comfort at the limited time they are at home) residents look for more comfort and functionality at their homes. Looking for new ways to provide comfort and functional living spaces is another innovation driver for the construction sector where nanotechnology would bring new innovative solutions to the market.

To summarize, the main drivers for innovation in construction sector are:

- Regulations.
- Sustainability.
- Cleaner processing technologies.
- Longer service life and reduced maintenance expenditure.
- Use of less type and amount of material for the same functionality.
- Ease of maintenance of construction components and therefore constructions.
- Easier handling of construction materials at the construction site due to lightening of materials.
- Easier transportation of construction materials leading to less consumption of resources and therefore, final cost.
- Replacement of existing materials with new materials.
- Changing life styles.
- Multi-functionality.
- Having more reliable and sensitive testing tools which would help engineers detect the failures of construction components earlier and predict the lifetime of structures more precisely is an important driver for investing in nanotechnology to ensure the safety of construction components.

Barriers:

In construction sector one of the main inconveniences for the implementation of technological novelties including nanotechnology applications is **cost**. Construction is a cost driven sector and despite the long-term benefits that could be obtained from the use of products including nanotechnology, the initial investment (higher than it is at the moment) remains a major issue for constructors. In some cases big construction companies could afford the high prices for investments, however this is not the case for small companies which are reluctant to change the way they are used to work.

Another important barrier, for now, is the lack of availability of good quality nanomaterials in large volumes. Moreover, uncertainty about long-term reliability of new nano enhanced functionalities and properties of these new construction materials, is a barrier discouraging investment.

There is an endless potential for use of nanoenhanced products in construction related applications. However, for now most of the processing technologies are not convenient for large-scale production which makes the existing products quite expensive. Like for every new product as long as there is not enough demand product conserves its 'niche' character and does not push the industry for automation.

Apart from abovementioned barriers, scepticism of consumers / end-users about benefits of nanotechnology and also safety issues are other factors which slow down the adoption of nanomaterials in the sector. Surveys conducted have shown that end-users have concerns about safety issues and real benefits of "nano" products". To overcome this scepticism large companies supplying materials for the construction sector (cement, glass, paint, etc.) are carrying marketing campaigns promoting the use of these "new" materials with improved properties.

In addition to end-user scepticism, lack of awareness of architects about new materials is another barrier to overcome for widespread use of new materials in the construction sector.

This study also showed that fragmentation of the construction industry and the corresponding slow pace of the information flow continues to be a big barrier for market entry of all new products and technologies.

1.3.3 Relevant product segments and applications

The construction sector could be divided into two main sub-sectors, buildings and civil engineering. Each of this sub sectors include different categories. Buildings include residential and non-residential buildings while civil engineering covers roads, bridges, rails and other infrastructure.

In order to facilitate the market assessment covered in this report, focus is on construction components rather than in final products. The main construction components analyzed in this report are as follows:

- Cement / concrete
- Construction ceramics (Floor/wall tiles and sanitary ware)
- Windows
- Insulation materials / systems
- Paint

1.4 Application: Construction ceramics (Tiles & sanitary ware)

1.4.1 Short application description

Ceramic products used in the construction industry are floor / roof / wall and countertop tiles, sanitary ware and bricks. Ceramic products are manufactured from clays, non-metallic inorganic materials and metallic oxides.

Ceramic tiles are thin slabs, generally used as coverings for floors, walls and kitchen and bathroom countertops. Tiles typically are shaped through extrusion or dust pressing at ambient temperature, then dried and fired to maintain their form permanently.

Ceramic products used for sanitary purposes (e.g. lavatory bowls, wash basins, cisterns, and drinking fountains) are collectively referred to as sanitary ware and are mainly manufactured from vitreous china (semi-porcelain) or earthenware. The typical production levels for ceramic manufacturing facilities vary from 10 to 50 tons/day for fine ceramics and 450 to 500 tons/day for ceramic tiles.

The European ceramics industry records total sales of around €26 billion, and employs 222,000 people. The European industry is estimated to provide a third of total world production, and has been able to maintain a positive trade balance with third countries. While the EU single market has stimulated further concentration in the industry, small and medium-sized companies tend to predominate **[6]**. Even though the EU is the worldwide leader in ceramic tile and sanitary ware production for now; future projections show that within less than a decade this trend will change in favour of the Asian competitors. To avoid this and stay a leader on the market, European players in the field have to be innovative and improve their products with new features. [**7**]

1.4.1.1 Nanotechnology impact

Easy-to clean surfaces have become possible by means of novel improved coatings and special treatments. These products, with easy to clean features, are preferred by the consumers for hygiene, easy cleaning and reduced costs of maintenance.

New coatings, which enhance the so-called easy-cleaning (or self-cleaning) feature, are mainly formed of nanoparticles, e.g. titanium dioxide (TiO_2), silver (Ag). When TiO_2 coatings are applied to enhance the easy-cleaning feature on a surface, the photocatalytic process takes place on the surface. Organic dirt, like bacteria, algae, mould and other germs, on the surface is broken down as a result of the so-called photocatalytic effect minimising bad odours and ensuring a pleasant clean atmosphere and surface. **[8]** (For details of the photocatalytic effect, please have a look at the Construction S&T report)

Another way to create easy to clean tiles and sanitary ware ceramic is creating hydrophobic surface through plasma treatment by changing the surface properties (surface contact energy). Hydrophobic surface means that when water or any other liquid is spread over the surface it would not spread over the surface but would form droplets. And, dirt can be washed down by the water and could be removed easily reducing expenses of maintenance work and cleaning aids.

Using a coating, which incorporates nanoparticles of Al_2O_3 as a final layer on construction ceramics, it is possible to obtain highly **scratch resistant** surfaces.

Additionally, nanoparticles of silver and zirconium are used in coatings especially on sanitary ware products to have **anti-bacterial** feature on these products. In this case nanoparticles of silver and zirconium are added to glaze composition and fired on the construction ceramic.

Apart from coatings, there are ceramic tiles with micro-pores which absorb water molecules present in the environment and forms a nano-sized film of water on the surface. When dirt is present on this surface, it is easily washed away. These special tiles are also claimed to help control humidity in the environment. **[9]**

Remark: There is another way of engineering self-cleaning ceramic tile/sanitary ware surfaces. If the ceramic products are double-glazed, the surface tension changes and the surface becomes smoother. As a result, water is repelled by the surface and the dirt is washed away.

1.4.2 Functional requirements

The construction ceramics sector in Europe need to be able to compete with industries from other regions of the world where labour and raw materials are cheaper. For this reason, they should make use of the technological innovation, know-how and infrastructure by bringing new functionalities to their products. This seems to be the only way to ensure the future market share of the construction ceramics.

Functional requirements of construction ceramics can be listed as follows:

Ease of maintenance: Initial installation and replacement of broken tiles is a tedious, laborious and expensive process. For this reason, self-healing and scratch resistant, non-permeable ceramic tiles are asked for by consumers. Easy cleaning is another important feature for energy saving in addition to its comfort.

Hygiene: Construction ceramics, especially sanitary ware products and ceramic tiles, are used in places like hospitals, sanitary-medical rooms, kitchens and public swimming pools/bathrooms, where sterilization is crucial. Accordingly, it is important to have easy to clean, anti-mould, anti-bacterial and moisture resistant coatings.

Resistance to harsh environments: Due to the changes in construction trends and environments, nowadays construction ceramics may need to face harsh environmental conditions. Durability, scratch resistance, fire retardancy are therefore important.

Safety: If construction ceramics, especially ceramic tiles that are used at wet areas like swimming pools, showers, and bathrooms, are slippery people may slide and as a consequence get injured. Surfaces of construction ceramics should have anti-skid feature to prevent such incidents.

It is important that a product could fulfil all these functional requirements. Furthermore a product should not lose its existing properties when a new functionality is brought to it. For example, when self-cleaning coatings are applied on construction ceramics the surfaces lose their scratchproof property considerably and become more resistant to physical impacts. **[10]**

1.4.3 Boundary conditions

As said before, most of the new functionalities of construction ceramics are brought by coatings that are applied onto surfaces as a last step after glazing. This is usually done through plasma spraying or thermal spraying.

One of the main issues conditioning the use of nanotechnology in the ceramic sector is the cost. In the case of coatings, cost driver is not the nanomaterial used in the solution; it is

the running cost of the tools used to apply these coatings. Increased cost of energy is also an important barrier for the industry. For feasible production of construction ceramics with new features processing technologies should be suitable both for up scaling and for less energy consumption, accordingly for cost optimization and sustainability.

In the market for tiles and sanitary ware, one of the limitations is the probable consumer resistance due to the increasing awareness of the society towards the toxicity of nanomaterials.

1.4.4 Product examples

In Europe most of the leading ceramic tiles and sanitary ware manufacturers have already products on the market with self-cleaning features. Some of these companies are Duravit, Villeroy & Boch, Roca, Vitra. These companies have self-cleaning floor tiles/sanitary ware on the market as follows:

Wondergliss, is a coating developed by **Duravit** together with Nanogate Ag. This coating, which is commercially known as WonderGliss, has been used on sanitary ware ceramics e.g. at washbasins, toilets, bidets and urinals. WonderGliss deprives dirt of a suitable surface to attack - dirt and lime are unable to establish and hold on the smooth surface. Residues simply run off with the water droplets. **[10]**

Hydrotect, developed by **AgroBuchtal.** It is mainly used on ceramic floor tiles with its long-term guarantee. Surface of Hydrotect tiles contains a coating of titanium dioxide ($Ti0_2$) this is baked onto the tiles at high temperatures ensuring the bonding of the materials with the tile surface. When light is captured by each tile the titanium dioxide activates oxygen from the atmosphere, the organic dirt on the surfaces is broken down as mentioned before due to the photocatalytic process. **[11]**

Roca produces sanitary ware products with an easy to clean surface. Roca uses solutions from Nanogate to implement this feature on its products.

ERLUS Lotus is the first self-cleaning clay roof in the world. The burned-in surface finish of Erlus clay roof tile destroys dirt particles, grease deposits, soot, moss and algae with the aid of UV light. **[12]**

Villeroy Boch has a series of easy cleaning products under the name of **ceramicplus**. Ceramicplus provides an easy to clean and dirt repellent surface. This feature is obtained through a special finishing treatment. **[13]**

1.4.5 Economic information for present products

Market penetration of nano-enhanced construction ceramics is less than 0.5%. So far, it has not been possible to reach to a common conclusion related to the sales of these products. Companies who have floor / wall tiles on the market with self-cleaning feature claim that these nano-enhanced products are in average €1/m^2 more expensive than their traditional counterparts. Sanitaryware products with these enhanced features are in average €100 more expensive. **[14,15]**

Under the present economic conditions, where especially residential construction industry is highly affected from the crisis, construction ceramics companies directed their focus to selling innovative products with new features to hospitals, nurseries and other places where hygiene is very important.

Even in these areas there is an unavoidable decrease in sales. The stakeholders of this industry believe that there will be an increase in the sales of their new products and the whole sector will start to recover by the end of 2010.

The main functionality nanotechnology has brought to construction ceramics is self-cleaning and anti-bacterial surfaces. These features can be essential for the applications where hygiene is vital. So, there could be demand for these products for hospitals, etc. as talked above. However, this is not an essential feature that can be demanded from all residential buildings, etc. In residential buildings these self-cleaning products may find more demand for their applications in humid environments to prevent mould related problems. Especially in new buildings (max. 15 years old) bathrooms and kitchens are usually equipped with electronic ventilation systems which prevent the undesirable humidity in the environment. Therefore, the choice of the consumer would be playing an important role in penetration of these products to the market. Since self-cleaning construction ceramics have not been on the market long enough to be sure about their functionalities' long lasting, consumers might prefer traditional ventilation systems. **[16]**

For residential buildings, main demand can come for exterior façade applications where cleaning and maintenance is tedious and expensive. In this case main competitors of these products would be nano-enhanced paint (please find details for paint in the relevant section).

1.4.6 Profiles of selected key companies

Nanogate AG is a German company, which was founded in 1999. Nanogate is an enabling company in the field of chemical nanotechnology. Nanogate bridges the gap between the producers of the basic materials and their industrial implementation into products. Hence Nanogate forms the crucial interface for the commercialization of nanotechnology and focuses on the most attractive segment within the value added chain. Nanogate provides solutions to various industries e.g. automotive, ceramic tiles/sanitaryware, printing, energy, etc. See www.nanogate.de for details.

Duravit is a leading supplier of sanitary ceramic, bathroom furniture, accessories, bathtub furniture and wellness ideas. Having it's headquarter in Germany, Duravit has 19 affiliated companies worldwide. See www.duravit.com for details about Duravit.

AgroBuchtal company of Deutsche Steinzeug Cremer & Breuer AG. It is at the forefront among the world's leading ceramics producers. It concentrates all its strengths on its core business, the production of ceramic covering materials. See www.agrob-buchtal.de for details.

Erlus AG is one of the largest producers of roof tiles and chimney systems in Germany. See www.erlus.com for details.

Roca is a Spanish company set up by Roca family in 1917 as Compañia Roca Radiadores to make cast iron radiators. Today Roca is producing sanitary-ware products, tapware and ceramic tiles. Roca is the market leader in most of the countries where their products are sold. Roca gives big importance to sustainability both in production stage and in final products. More information is available at www.roca.com

Villeroy Boch is a German company which manufactures and markets high-quality ceramic products. Their have two product types, one of them is for Bathroom and Wellness while the other one is for Tableware. Please visit http://www.villeroy-boch.com/en/us/home to get detailed information about this company.

VitrA is a Turkish company which has manufacturing facilities in Turkey, Ireland and Germany. The company produces floor, wall tiles and various sanitary ware products. www.vitra.com.tr

1.5 Application: Cement

1.5.1 Short application description

Cement and, of course its final construction material, concrete are the most important, indispensable materials for the construction industry. Structural strength, durability, quality and sustainable development of constructions be it buildings, bridges, roads, etc depends on the properties of these materials.

Cement is the basic material of concrete, which is the indispensable and traditional building material since the Stone Age. Cement is made by crushing and grinding calcium carbonate (limestone) and other materials containing silicon, aluminium and iron oxides. The blended material is heated at extremely high temperatures (1400 - 1500°C) in a kiln where the compounds react. Products leave the kiln in the form of a nodular material which is called clinker. Later on, clinker is cooled and ground with small portions of gypsum, fly ash, aggregates and other additives to produce cement. To be used for construction applications cement is combined with sand, gravel and water to form concrete.

Concrete is a very versatile material which can be adapted to meet different needs like durability, enhanced ductility, improved thermal and acoustic insulation. It is made from natural raw materials with impurities and variability in the materials size ranging from nanometers to cantimeters. Concrete is reinforced with metal bars, glass fiber, etc to increase its strength. **[17]**

Worldwide annual production of cement is nearly 2 billion tonnes. 25% of this production takes place in Europe. This corresponds to around 750 million m^3 of concrete which is roughly equivalent to an annual consumption of approximately 1.7 m^3 concrete per capita. 4 out of 5 main cement companies are based in Europe. China is the leading consumer of cement with 1.2 billion tons. **[18,7]**

1.5.1.1 Nanotechnology impact

Incorporation of new technologies and investing heavily in research and development for the continuous development of these traditional materials is indispensable for the cement sector in Europe to be competitive.

Research in cement focuses on understanding the behaviour of cementitious materials in nanoscale / microscales and accordingly improving its mechanical properties and service life. It is also important to reduce the CO_2 emission throughout the evolution of concrete which starts during the production of cement. For this reason, many key cement producers have focused their research activities towards reducing CO_2 emissions in addition to having enhanced properties.

Since the interactions in nanoscale or microscale have a drastic impact in the final mechanical properties of the concrete, it is important to understand and therefore, characterize the basic structure and formation mechanism of concrete. In this case, nanotechnology plays an important role with the new characterization tools it brings for understanding the concrete structure and underlying mechanism.

Durability depends on the density of porosity in the concrete structure. Rheology should be controlled. New mathematical tools, modelling tools can be used for this purpose. Strength of the concrete is related to ultrafine particles. Therefore, having better control of

structure would enhance strength and durability of concrete. Understanding behaviour of cement hydrates would be possible by controlling the behaviour in nanoscale.

Improving compacting rate of the concrete via use of nanoparticles, especially nano silicates is another area where the effect of nanotechnology in the concrete industry is seen. In the construction industry there is an increasing trend towards the use of quick compacting / self-setting concrete for the applications where concrete needs to achieve the required strength in a short time e.g. four hours in airport construction jobs, etc. This could be achieved by having proper ingredients, proper design and thermal treatments. One way to achieve required strength in a shorter time is use of nano-silicates.

Nano-additives increase the durability of concrete by increasing the mechanical strength; accordingly, this would have a positive impact on the renovation and repair related expenditures of the existing structures. **[19,20,21]**

Concrete and cement industry is one of the most polluting industries in the world in terms of CO_2 emissions totalling 5% of the world's CO_2 emissions. Production of 1 ton cement releases 0.8 ton CO_2 into the atmosphere from the processing of limestone into clinker. **[3]** Therefore, any improvement which might lead to decreased emissions would have a considerable impact on the economics and improvement. The intention of cement players is to be able to either replace clinker with other additives (e.g. fly ash, limestone, pozzolan, etc), where nanoparticles may play a role, or decreasing its proportion. One of the most important considerations of the cement industry where nanotechnology would bring solutions is reducing CO_2 emissions.

Currently cement manufacturers are concentrating their efforts in recycling construction materials and decreasing the kiln temperatures via use of nano additives. During the production of cement, limestone undergoes a fixed chemical reaction known as calcinations or decarbonation, releasing CO_2 into atmosphere. Additionally, the use of fossil fuels during the essentially thermal process adds extra CO_2 into the air **[22]**. One of the solutions cement manufacturers have brought to this problem is effectively replacing clinker in the production process and reducing the clinker ratio by increasingly introducing new supplementary cementing materials where nanomaterials take part in the scene. The amount of clinker could be reduced /optimized by use of nanoparticles to act as catalyst to driver the reactivity decreasing the Gibbs free energy. Accordingly, this would facilitate also reactions at lower temperatures leading to less fossil fuel consumption.

As it is the case in ceramic tiles / sanitary wares, photocatalytic easy-cleaning feature is incorporated into concrete via use of nano TiO_2 particles. In the case of its use in concrete apart from bringing self-cleaning feature it also plays a role in cleaning the surfaces, especially motorways, from nitrogen oxide particles which are emitted from exhaust gases. This process is simply by conversion of harmful nitrogen oxide (NO_x) to harmless nitrate (NO_3) with the photocatalytic reaction taking place on the surface. Nanotechnology enhanced concrete also finds application on the motorways for reducing NO_x emission due to traffic. For this effect concrete pavements need to include nano TiO_2 particles. As explained for construction ceramics, in the presence of UV and nano particles of TiO_2, photocatalysis takes place helping capture and breakdown of organic and inorganic air polluting particles. This self-cleaning feature on concrete also serves as an anti-graffiti coating. **[23]**

Another area where research efforts in concrete science have focused on is preventing failures or healing of concrete e.g. controlled release of corrosion inhibitors. Unsatisfactory understanding and diagnosis of concrete deterioration, incorrect repair specifications and

the wrong choice of repair products / techniques have lead to dissatisfaction from building owners and the creation of a new European norm, EN 1504.

Also availability of concrete with high performance would make possible construction of structures without need for steel. This would ease the construction in regions where availability of steel is limited and very expensive.

Superplasticizers are nanopolymers added into concrete to improve its strength and workability, these can change the surface tension of pore water and change the charge and the density of the cement grain surface.

1.5.2 Functional requirements

Durability: Concrete structures should have long service life because they are the essential backbones of the constructions and accordingly their maintenance is more tedious and costly with respect to the other components. It is important to have new measuring and characterization tool to help cement producers understand the underlying mechanism that could help them develop longer lasting cement and therefore concrete.

Ease of maintenance: As said before maintenance of concrete structures is very tedious. So it is important that factors that age concrete should be minimized as much as possible. Defects in the concrete should be detected as early as possible and if possible self-healing mechanisms should be incorporated into concrete that would minimize both the failures and decrease the maintenance costs. In that sense it would also be useful to have self-cleaning features that would prevent formation of moulds which deteriorate the concrete and help keep the concrete aesthetically in good condition without dirt and anti-graffiti.

Improved mechanical performance: During its use concrete needs to have improved mechanical strength to ensure the safety of the buildings in the case of natural disasters and to respond to the societies changing needs. To explain this better, since population density is increasing in some regions where land is scarce there is an increasing trend in building skyscrapers where the building is exposed to harsh atmospheric condition, etc. to provide longer lifetime.

Enhanced thermal insulation: Thermal insulation of buildings has gained more importance due to the increased concerns related to global warming. In addition to use of additional insulating materials, it is important to increase the insulating performance of concrete.

Reduced CO_2 emissions: Cement processing methods should be changed to cut the CO_2 gases released during its production. The most polluting component of cement is clinker. Therefore, it should be either totally replaced with new materials or its proportion should be decreased via improving its performance through use of new nanoadditives.

Fast compacting concrete: One of the most time consuming part of the work is to wait for concrete to set. Quick compacting of concrete is really an important property for constructors.

Concrete should be **fire resistant.**

1.5.3 Boundary conditions

The use of new additives, new replacement materials and changes in the processing method should not bring an unfeasible added cost to the producer. The manufacture of cement requires a lot of energy and produces considerably high levels of CO_2 and other emissions to the atmosphere. Therefore, and to comply with current legislative trends in the Euro-zone,

all the innovations in the sector should be aimed at a reduce energy consumption and atmospheric emissions of pollutants.

1.5.4 Product examples

TX Active™ is a quality label developed in collaboration of Heidelberg Cement and Italcementi which shows the durability of the photocatalytic functionality of the finished product. This is a self-cleaning cement due to its special formula which is efficient in destroying atmospheric pollutants. In Milan a commercial building's surface, 3000 m^2, is coated with TX Active™ cement from Italcementi. Iglesia Dives (Church) in Misericordia, IT is a well-known building where TX Active cement was used. In addition to its self-cleaning property, TX Active® plays role in reducing pollution.

Another example where recently TX Active was used for construction is the two white concrete gateway elements of the new I-35W Bridge over the Mississippi River in Minneapolis, US. **[24]**

TiOCem® is the commercial name of the cement with TX Active technology from Heidelberg Cement. **[25]**

EMACO® Nanocrete from **BASF** is a concrete-repair concrete with exceptional properties, improved bond strength, improved densities and impermeability, reduced shrinkage, improved tensile strengths and reduced cracking tendency. It also provides improved compatibility with concrete. This product has found applications in the renovation of office building in Brussels, in a wastewater plant in France, in the renovation of bridge structure in Spain, in a cooling tower, etc. **[26]**

Chronolia™ by Lafarge, quick-setting ready-mix concrete made possible by nanotechnology and the understanding of crystalline growth. **[19]**

Agilia™ by Lafarge, the world's first self-compacting, self-levelling concrete. It generated 2.4% of sales volumes and 12% of COI of Lafarge's concrete business in 2006. 1 million m^3 of Agilia concrete was sold in 2006. In 2006, Agilia sales rose by 33%. **[19]**

Ductal™ by Lafarge is one of the first commercial concrete where steel bars are not used. It exhibits high mechanical strength, durability and self-healing properties. **[19]**

tutoPROM® is an (organo)-polysilazane based anti-graffiti coating developed for concrete and also transport vehicles by Clariant. **[27]**

Nanoguard® StoneProtect is a coating from Nanogate AG which is applied to concrete parts of Europe's longest city tunnel Södra Lanken in Stockholm. **[28]**

1.5.5 Economic information for present products

Quantification of the impact of nanotechnology in the cement market, especially in the field where the effect of nanotechnology is seen in the cement production process related CO_2 emissions reduction is challenging. We need to consider the effect of CO_2 reductions in the production volume. Points to be considered are: use of less fossil fuels due to lowered Gibbs free energy, CO_2 emission quota related cement production allowances, etc. It was reported in the Global Cement Report that global cement consumption rose from 2.2 bn tonnes in 2004 to 2.6 bn tonnes in 2006. China is the biggest cement consuming country with an amount of 1200 m tonnes followed by India (153 m tonnes) and United States (127.6 m tonnes). In Europe the biggest consumer is Spain (55.5 m tonnes) followed by Italy (45.3 m

tonnes). It is foreseen that production volume of cement can reach to 6.5–7 bn tonnes in 2050. However, it is essential to remember that these figures have drastically changed within last year due to the global financial crisis, which would affect future estimates as well.

Worldwide cement industry is lead by few cement and building materials groups. These six international groups are rooted in Europe. These companies are Holcim, Lafarge, Cemex, Heidelberg Cement, Italcementi and Buzzi Unicem. **[18]**

Nanoenhanced cement has already found use in construction sector, especially the ones which exhibit photocatalytic features. However, their application is, so far, limited to construction of buildings like churches, sensational bridges, etc. as some examples can be found in this report. Prices are still too high for it to become a common material between constructors.

Cement companies mostly make benefit of nanotechnology to be able to understand the behaviour of cementitious particles at the nanometric scale. CNTs and CNFs are used for basic R&D. Experts interviewed for this project stated that with their existing production volumes and cost it is not yet realistic to use these materials in products. However, they expressed the biggest breakthrough obtained especially in mechanical properties when these materials are incorporated into cement.

Since benefits of most of the functionalities are related to environmental issues, legislations would play an important role in increasing the penetration of new cement products, especially the ones with air-purifying and self-cleaning properties, to the market. For example, under normal conditions motorways, pavements, etc. are made out of concrete ad asphalt and they are not renewed often. If legislation is imposed for building roads to decrease air pollution constructors would have to go for such products and accordingly their market would increase.

1.5.6 Profiles of selected key companies

Holcim is a global company with production sites in over 70 countries. Holcim is the biggest cement production company. Cement sales of Holcim reached to 160 million tonnes in 2008 while they sold 165 million tonnes of aggregate and about 50 million tonnes of ready-mix concrete. See www.holcim.com for details.

Lafarge is one of the major producers of building materials. Lafarge has one of the world's largest and biggest materials research facility, which employs about 500 people. See www.lafarge.com for details.

Italcementi Group is the fifth largest cement producer with 70 million tonnes of annual cement production. In 2008 cement sales of the company accounted for about €6 billion. Italcementi has been active in 22 countries with 63 cement plants. See www.italcementigroup.com for details.

Heidelberg Cement is the global market leader in aggregates and a prominent market player in cement and concrete. In 2008 its turnover was about € 14 billion. The company carries out its research and development activities through Heidelberg Cement Technology Center. See www.heidelbergcement.com for details.

BASF is the world's leading chemical company which provides solutions for various industries including construction. BASF's Construction Chemicals division supplies its products to ready-mix, precast and concrete producers. It also supplies concrete repair and protection

materials. BASF has more than 130 plants all around the world. Their sales accounted €2.163 million in 2008. For details see www.construction-chemicals.basf.com.

Clariant is a chemical company serving to different markets one of which is construction. Group's sales accounted to €8.1 billion in 2008. See www.clariant.com for details.

1.6 Application: Windows - Glass

1.6.1 Short application description

In buildings, windows provide sound and heat insulation when they are closed, in addition to their prime task of providing passage of light. Windows are usually made out of float glass or different polymer derivatives. In buildings mostly glass windows are used. According to the requirements and preferences of people and geographical conditions, glass windows are glazed with different coatings. Glazing windows is important for both aesthetic and energy saving purposes. **[29]**

In most of the residential constructions, ordinary, monolithic glass is preferred. However, value-added innovative glasses have started to be chosen within the last couple of years which could help to reduce CO_2 emissions. Most common of these glasses is known as low-emissivity (low-E) glasses which suppresses the heat flow. Regulations, climate conditions and of course heating and cooling costs are determining factors for the choice of consumers. These so-called low-E glasses are glazed with a thin layer of metal or metal oxide which plays a role in reducing the heat flow through the glass window. **[30]**

Tinted windows that block the sun's rays have been available for years. Since these glasses also block the light, they are not preferred. Today glasses which block the heat whilst letting the entire light pass through exist thanks to new nano-coatings. Now, thin nano-coatings of vanadium dioxide mixed with just 1.9 % tungsten metal can be applied to windows and act as heat-reflectors, whilst still letting all visible light through. The thickness and amounts of the components of the coating can be altered to adjust the exact temperature at which heat is reflected. This provides helping interior of buildings remain cool without the excessive use of air-conditioning, dramatically reducing both financial and environmental costs. **[31]**

Glass is classified according to its sound transmission class (STC) that reflects the amount of noise reduced when sound wave passes through the window. The further the sound wave needs to travel, the more the intensity of sound wave reaches to interior space decreases. To provide noise insulation either glass thickness is increased or double glass is used. In double glasses the larger the gap between two glasses the better is the insulation. In some double glasses the gap between two glasses can be filled with other gases instead of air to further improve the noise insulation performance. **[32]**

These glasses are classified as insulated glasses. Since detailed information about these glasses are provided in this section of the report, no more information is given related to them in the insulation part.

1.6.1.1 Nanotechnology impact

In the glass sector nanotechnology brings again its features through final coatings applied to the glass surface. As in the case of construction ceramics nano TiO_2 particle incorporating coatings are applied to have self-cleaning, anti-houling effect.

Another feature that nanotechnology brings to glasses is fire resistance via addition of fumed silica nanoparticles. When heated, a transparent thin layer formed of fumed silica nanoparticles turn into an opaque fire shield.

For glasses which could control heat and light transmittance nanoparticles of different materials are added to the raw materials of glass at the melting ingot.

Nanotechnology would enable windows with air purifying, heat radiation and UV rays' transmittance control and also better sound and thermal insulation properties.

Electrochromic windows, publicly known as smart windows, will soon be on the market as a result of advances in nanotechnology. These windows are designed to respond and adapt to their environment. Electrochromic windows have a glass coated with a thin film of semiconducting nanocrystalline metal oxides which are activated by applying voltage. The particles' colours change from dark to clear colours and vice versa under the effect of an electric charge. Accordingly, windows look transparent or opaque controlling the transmittance of UV light. **[33,34]**

One such example is a glass coating which will block any excessive heat; especially useful in the hot regions and during warm summer months when air-conditioning costs can be expensive and resource consuming.

Usually glass is coated during glass manufacturing process via chemical vapour deposition (CVD) process to have energy control features. Another coating method is magnetron sputtering vacuum deposition as known as sputtering. Coating produced by sputtering is not as long lasting as CVD.

Solar heat gain coefficient (SHGC) of glass is the determining factor to indicate the ability of glass to transmit solar radiation. SHGC changes between 0 and 1.0 indicates that glass does not transmit any solar heat whilst 1 denotes that all solar heat is transferred through the glass. **[35]**

PPG glass has a patented distinct processing method for self-cleaning glass where nano TiO_2 particles including coating is applied to hot glass during the forming process to create a long-lasting strong bond which makes the coating an integral part of the outer glass surface. This coating has both photocatalytic and hydrophilic properties. **[36]**

1.6.2 Functional requirements

Functional requirements of windows vary from region to region according to climate conditions and to the type of buildings (residential, non-residential). Accordingly, requirements could be:

Energy efficiency via heat reflection, heat radiation, transparency / transmittance of sunlight. According to the climate conditions, windows are preferred to decrease the transmittance of solar heat i.e. in warm climates, or to allow passage of solar heat in cold climate zones.

Clear visibility: When coated to reduce its solar heat gain coefficient glass should not lose its visibility via becoming opaque or changing its colour.

Noise reduction: In buildings glass should help to keep outdoor noise as much as possible out of the interior spaces. The higher the STC the better the sound insulation performance is.

Ease of maintenance: In addition to its traditional use in buildings, today glass is preferred more and more for façade coatings especially at non-residential coatings. Therefore, easy to clean glass surfaces with scratchproof feature is more and more asked for.

Fire protection: Glass needs to be fire resistant to ensure the safety.

All these features should last as long as the service life of the glass. Also glass needs to fulfil all of these requirements.

1.6.3 Boundary conditions

As it is the case for all products use of new technologies and materials should not bring an unfeasible added cost to the producer. Most of the novelties come through coatings applied to glass. These value added coatings should not slow down the manufacturing process and also processing technologies should be suitable to be applied to large surfaces. Cost of glass manufacturing tools, coating equipments and energy are also important cost factors for glass industry.

1.6.4 Product examples

Pilkington Active is the world's first self-cleaning glass which has been on the market for a long time. Other varieties of Pilkington Active offer additional features like solar control and low-emissivity energy-saving glass.

Pilkington Optilam is a high security glass which remains in place even when broken. Different varieties of Optilam is produced for different applications i.e. noise control, solar control, UV screening, bullet and blast resistance or privacy.

K-glass is a low-emissivity glass from Pilkington. **[37]**

SunClean® is a long-lasting multi functional self-cleaning glass from PPG Industries with a coating which includes nanoparticles of TiO_2. In addition to its easy cleaning feature, it also reduces the transmittance of UV and increases the solar heat gain coefficient 0.05 point. **[36]**

SunGate® is a low-E glass from PPG Industries aimed for the consumers in cold climate zones. SunGate transmits the sun's visible light and directs solar shortwave infrared energy into the home. It also reflects the heat energy (infrared wave) that comes from a building's heating system back to the building. Low-E coating present on SunGate glass is transparent and reduces the transmittance of UV light. **[36]**

Solarban is another low-E glass especially developed for hot climate regions by PPG Industries. The thin low-E coating blocks solar energy. It is said to let 64% less heat from the sun enter through window compared to an ordinary glass window.

Beneq provides different coatings and coating systems for glass industry under the registered names of **nCOLOR®**, **nCLEAN®** and **nHALO®**. They have anti-reflective coatings, energy control coatings, easy to clean coatings and anti-bacterial coatings.**[38]**

BIOCLEAN Self-cleaning glass is a product of Saint Gobain Glass which was specially designed to remain cleaner for longer than conventional glass. **[39]**

COOL-LITE is a solar control glass produced by Saint Gobain Glass. It is manufactured by depositing a coating of metallic oxides by magnetically enhanced cathodic sputtering under vacuum conditions onto clear or body tinted glass. **[40]**

There are many products on the market especially on DIY stores which claim to have nanoparticles and are usually sold in the form of pressurized solutions for glass surface treatment. Most of these products bring self-cleaning, anti-mist features to both construction and automotive glasses. Some example products / producers are:

Nanosafeguard, Percenta, UV Chemicals, ShineOn from SCF Technologies, etc. Brief information about some of those products can be found below:

ShineOn is a thin coating developed by SCF Technologies using nanotechnology. It is applied to existing windows with a cloth, giving them the self-cleaning properties that previously could only be applied during the glass manufacturing process. **[41]**

Percenta Nano Window Sealant SR is an alcohol-based system, which protects outer glass and synthetic surfaces from tarnishing. The applied sealant develops a thin, invisible, hydrophilic film on the surface, which due to a photocatalytic process reacts with daylight / UV radiation. This reaction breaks down muck on the glass, with no need for detergent. It can be used for greenhouses, solar panels and conservatories. When water hits it, a hydrophilic effect is created, so water and dirt slide off, the so-called 'self-cleaning effect'. **[42]**

1.6.5 Economic information for present products

Construction industry is the major consumer of flat glass with a consumption volume of approximately 40 million tonnes. According to the 2008 annual report of Pilkington Glass the global market for flat glass was about 50 million tonnes in 2007.

Four companies are dominating the glass market all around the world. After China, Europe accounts as the biggest flat glass consumer with a 10 millions tonnes of market volume. In Europe key glass manufacturers are Saint Gobain, NSG (which owns Pilkington), Guardian and Sisecam. Total glass production capacity in Europe is 11 million tonnes. PPG Industries', which is the main producer in the US, 2008 sales accounted to $16 billion. Group's glass sales form 12% of their sales.

In 2007 China was the leading flat glass manufacturer with about 23 million tonnes of glass production.

Due to the strict regulations in Europe double-glazing even triple glazing has been enforced in some countries. Also regulations have been an important driver for the increased demand for low-E glasses. Low-E glass has become a standard in many countries like Germany and UK. **[43]**

Electrochromic glasses are still very expensive for their applications in construction though it would be the main industry to adopt this application in the future. Smart glasses are initially marketed to industries like helmets, automotive windows where glasses with small surfaces are used with the aim of increasing the awareness of the product with its benefits. Market for electrochromic glasses is expected to reach to $1.9 billion in 2013 where construction would form the second largest user market after transportation generating $218.3 million in 2013. **[33,44,45]**

To give a more specific example, nanoenhanced glasses of Pilkington are approximately 30 to 80% more expensive than conventional glasses. Penetration of these advanced glasses into the market is low as only big construction companies and experts like architects and designers ask for them, everybody else just either doesn't know about them of simply asks for conventional glass.

1.6.6 Profiles of selected key companies

Pilkington is one of the biggest glass and glazing products manufacturer of the world that belongs to NSG UK Enterprises Limited. They produce glass and glazing products for both

automotive and construction industry. Pilkington is the first producer of self-cleaning glass Pilkington Active. Please see www.pilkington.com for more details about the company.

Saint Gobain Glass is the float glass manufacturing company of Saint Gobain Group. It specializes in float glass production and magnetron coated glass. Please see http://uk.saint-gobain-glass.com/ for more information about the company and its glass products.

PPG Industries is a company which is based in the US with manufacturing facilities all around the world. It is the leading glass production for residential buildings in the US. They have a variety of energy control and self-cleaning glass products. Please see http://corporateportal.ppg.com/NA/IdeaScapes/productInfo/glass/ for more information about the company and its glass products.

Asahi Glass is Japanese glass manufacturing company which is one of the largest flat glass manufacturers in the world. In addition to construction sector, company provides glass to different sectors including electronics, energy, automobile, etc. Please see http://www.agc.co.jp/english/index.html for more information about the company and its glass products.

BENEQ is a Finnish company which supplies equipment and technology to glass industry especially for functional coatings. Please see www.beneq.com for more information about the company and its services for glass industry.

ChromoGenics AB is a Swedish company founded by Professor Claes-Goran Granqvist and his research group at Uppsala University in Sweden. This is a leading company in development and manufacturing of products based on electrochromism. Please visit http://www.chromogenics.se/index_eng.htm for detailed information about ChromoGenics.

1.7 Application: Insulation materials

1.7.1 Short application description

Preventable heat losses in buildings is a major reason for heating / cooling related energy consumption and consequently increased living costs. Insulation reduces unwanted heat losses or heat gains and hence can decrease the energy demands of heating and cooling systems. In addition to thermal insulation, acoustic insulation, fire insulation and impact insulation are also important.

Thermal resistivity coefficient of an insulating material, known as R-value, is a determining factor for effective thermal insulation at the buildings. The higher the R-value of the insulating material the better is the insulation.

Most common insulation materials are fibreglass, mineral wool and foams of polymer derivatives. Mineral wool and glass are usually used in the form of blankets while polymer derivatives are in the form of rigid sheets. Vacuum insulated panels (VIPs) are also a novel and more innovative insulation system.

Insulation needs change according to climate, building design, position of the building, budget and personal preferences. Awareness of society and especially regulations play a critical role for implementation of insulation systems and use of insulating materials in buildings. Although sanctions could be imposed through regulations for widespread use of insulation systems, implementation speed of regulations could be very slow in some countries impeding utilization of insulating materials. It can be said that awareness of individuals is usually more important.

The leading companies in the field are Knauf Insulation and Kingspan Insulation. Others are Rockwool, Celotex, Superglass, Instafoam and etc.

1.7.1.1 Nanotechnology impact

Nanotechnology can facilitate developing high performance insulation materials / systems. Different forms of insulation solutions, like coatings, vacuum insulation glazing, and nanofoams can be realized.

Foams are very typical insulation materials used in buildings. Thermal resistivity of open porous insulating materials like foams increases when its effective pore size decreases. This well established principle creates the opportunity for nanoporous materials to be used as the core material for extremely effective vacuum insulating panels. In nanoporous materials, thermal conduction through the solid portion has weak temperature dependence and is in some cases hindered by the small size of the connections between the particles making up the conduction path. Thermal conduction by liquids or gases inside the solid is possible, although conduction sizes are only the sizes of the mean-free path for molecular collisions. When the pore's size is comparable to or smaller than the mean free path of the liquid or gas, the molecules of the latter collide more often with the molecules forming the solid part than among them. In fact, the liquid or gas molecules will tend to stick to the molecules of the solid part, virtually eliminating the thermal conductivity through the liquid or gas inside the material. This is known as Knudsen effect. **[46]**

Actual insulation obtained through traditional insulating materials is usually 50 % of the theoretical value. Since nanofoams' pore sizes are about 100 nm, they provide improved insulation by limiting the diffusion of gas molecules.

Aerogel is a form of nanofoam, an engineered material designed for high strength to weight ratio. Aerogel is also known as liquid smoke which is an open cell polymer with pores smaller than 50 nanometers in diameter. Aerogels have the highest internal surface area per gram of material of any known materials because of its complicated, cross-linked internal structure. They also exhibit the best electrical, thermal and solid insulation properties of any known solid.

Silica aerogels are the lightest weight solid material known (less than 0,05 g / cm^3) with excellent thermal insulating properties, high temperature stability, very low dielectric constant and high surface area. Since aerogels have very low sound velocity through structures they perform very well as sound insulators. With their good shock absorbance property aerogels serve as excellent impact insulators. **[47,48,49]**

Vacuum insulation panel (VIP) is an advanced insulation system which provides an insulative value of three to seven times higher than other insulation materials with the same thickness. Vacuum insulation panel encloses a core insulating material enveloped in an air-tight casing to which vacuum is applied. Typical core materials are polystyrene, polyurethane and silica. Today it is possible to replace these core materials with nanoporous materials. Combined use of nanoporous materials with VIPs provide very good insulation with an increased R value. Micro and nanoporous aerogels are very good candidates for being core materials in vacuum insulation panels but they are quite sensitive to moisture. Airtight wrapping is good to prevent moisture intake. **[50]**

Other means of providing insulation in buildings is through thin films deposited on glass surfaces, windows by increasing the R-value by suppressing radiative heat flow. To do so, coating materials which have low emissivity are used on windows. These so-called low-E materials lower the total heat flow through windows. These coatings are transparent to visible light and opaque to infrared radiation.

In another case for hot climate zones to decrease the use of air-conditioning- solar heat gain could be controlled via use of solar control coatings.

There are also paint like coatings which provide insulation on roofs, walls and etc.

1.7.2 Functional requirements

Performance: Insulating materials / systems need to have very low conductivity values (high R-value) to act as good insulators.

Hydrophobicity: Water vapour or water degrades the insulation performance. For this reason, insulating materials should be hydrophobic and vacuum insulation panels should not retain water in the structure so that it does not retain moisture, because it would effect its insulating performance badly.

Long service life: Insulating materials and VIPs should retain their properties as long as possible.

Easy and economically feasible installation is an important requirement for insulation materials' and systems' use in buildings.

Impact resistant: VIPs should be resistant to mechanical impacts so that their casing is not damaged during installation and in use.

1.7.3 Boundary conditions

Traditional insulation materials / systems promote corrosion (this phenomena is known as corrosion under insulation, CUI - http://www.industrial-nanotech.com/corrosion_under_insulation.htm] because they also trap the humidity. For this reason, it is essential that used insulation materials do not impede the permeability of the building material they are applied to. They should also not bring additional processing / integrating costs to the constructor.

Like many other nanomaterials cost effective, high quality and large volume production of nanoporous insulating materials is important for their widespread applications.

1.7.4 Product examples

Nansulate® HomeProtect Clear Coat is a coating developed by Industrial Nanotech Inc. that can be applied like paint to provide insulation as well as anti-bacterial feature. It can be applied to exterior and interior surfaces i.e. ceilings, walls and floor boards.**[51]**

PCI Nanosilent® is a polymeric isolation mortar material developed by BASF. This material is a mixture of special polymers and rubber granules which replaces mortar in concrete. In addition to giving flexibility to concrete, it also provides improved sound insulation. 15kg of Nanolight replace 25kg of flexible mortar. **[52]**

RELIUS Roof Acryl Nano Tech® from BASF is formulated with special pigments which are able to create a heat protection shield providing both heat and cold-resistant roofs. Besides its insulating function, it has an easy to clean feature.

ASPEN Aerogels have hydrophobic nanoporous aerogel insulation products on the market (Silica based products are used for transparent insulation) **[47]**

ThermalWrap™ is a thin nanogel blanket from **Cabot Corporation.** It is a good thermal and acoustic insulator which could be easily used for insulating roof, walls and facades of a building. **Nanogel®** is the silica aerogel from Cabot Corporation. **Nanogel®** is one of the main competitors of Aspen Aerogel.

1.7.5 Economic information for present products

As it is the case in all sectors of construction, demand and correspondent sales of insulation materials decreased considerably leading to changes in the market estimates due to the global financial crisis. Insulation market experienced good growth until mid 2007 but after the first signs of credit crunch in the US this trend changed. Most noticeable slowdown was seen in the insulation of new buildings for residential purpose. The state of the market is considerably better in the case of insulation materials used for renovation purpose. According to reportlinker global demand for insulation materials is expected to increase 4.6% annually to $36.6 billion by 2012. Also Freedonia research predicts a similar, 5.3% increase for insulation materials in 2012. **[53,54]**

Corroborating to the market estimates one of the leading players in the insulation market, Rockwool Insulation foresee a sales decline of 14% in 2009.

Another important player in the insulation market with its insulation panels, Kingspan Insulation stated in its 2008 Annual Report that their panels' sale decreased 7% with respect to 2007. **[55]**

New developed nanoenhanced insulation materials are still very expensive for their use to become a common practice.

Contrary to the general slowdown trend seen in the market, Cabot Corporation's sales increased in Aerogel Business from €3 millions in 2007 to €10 millions in 2008 according to the 2008 Annual Report. **[56]**

It has not been possible to find market related data of the other existing products from BASF and Aspen Aerogels.

Vacuum insulation panels are said to be expensive for their use in construction application.

1.7.6 Profiles of selected key companies

Cabot Corporation is an American specialty chemicals and performance materials company. Cabot has silica aerogels on the market with the tradename Nanogel®. It is the first company to produce aerogels in large volumes at its manufacturing site in Germany. Please visit www-cabot-corp.com to learn more about this company.

Aspen Aerogel is another American company specialized in the production of silica aerogels for different industries including construction. Please visit www.aerogel.com to have detailed information about this company.

Industrial Nanotech Inc. is an American company which provides energy saving coatings for residential and non-residential buildings. For more details please visit http://www.industrial-nanotech.com/

1.8 Application: Paint

1.8.1 Short application description

Paint is a pigmented chemical liquid which is applied to a substrate, in case of construction to interior and exterior walls / roofs and pipes, simply to protect the surface and also to give a colour to the surface it is applied. In today's constructions, paint is also used for energy preservation by modifying light reflection or heat radiation of a surface. Paint is also used on metal surfaces to impede corrosion.

Paint is composed of pigments, adhesives, binder, solvent and other additives.

The **binder** is the most crucial component of paint which forms the actual film. However, with the new technological developments today it is possible to find also binder-free paints. The binder imparts adhesion, binds the pigments together and influences durability, flexibility, toughness and gloss potential of the paint. Binders include synthetic or natural resins i.e. acrylics, polyurethanes, melamine resins, epoxy or oils. So-called water based paints include a water based dispersion of sub-micrometer sized polymer particles.

Pigments are granular solids added into the paint to provide basically colour and toughness. Some paints may also contain dyes in combination with pigments. In addition to giving colour to paints, pigments are also used to colour the glass. Natural pigments include clays, calcium carbonate, mica, silicas and talks while synthetic pigments are usually engineered molecules.

Solvents are used to control the thickness of the paint (to decrease the viscosity of the paint so that it can be easily brushed) and also to facilitate drying of the paint. Solvent evaporates during the course of drying releasing volatile volatile organic compounds (VOCs). Solvents are classified into two groups as hydrocarbon solvents and oxygenated solvents. Hydrocarbon solvents include hexane, toluene, xylene and etc. which are known as toxic chemicals that can be dangerous to health. Oxygenated solvents include acetone, methol, ethanol and etc. Their use is not very common because they are more expensive. In the world there is an increasing trend towards decreasing the amount of solvents used in paints to cut down VOCs released to living environment.

Paint additives improve the paint and also bring new properties like anti-scratch, heat insulation, etc. **[57,58]**

Some of the important players of paint industry are Akzo Nobel Group, PPG, Rohm and Haas, Jotun Group, Nippon and etc.

1.8.1.1 Nanotechnology impact

Various additives could be added to paint to have significant impacts on the paint. Additives can modify surface tension, improve flow properties and the finished appearance, increase wet edge, etc. Nanomaterials are used as additives like fillers, pigments and etc. Usually nano additives / nanoparticles are embedded and fixed in organic polymer.

Nanometals or nanoceamic particles are added to the paint composition to change the final properties of the paint. Most common nanoparticles used are: TiO_2, ZnO, Al_2O_3, fumed silica and ZrO_2.

Rheology, settling, surface energy, corrosion resistance and mechanical properties of paint can be improved via addition of nanoparticles into paint. By addition of this nanoparticles paint gets scratch-proof, easy cleaning, air purifying, UV resistant, water repellance, flame retardancy and anti-bacterial feature. Also nanoenhanced paints dry faster than their normal counterparts without releasing any volatile organic compounds (VOCs) that impose health risks.

There are also nanoenhanced paints that improves the thermal insulation of buildings when applied to roofs, walls and floors.

1.8.2 Functional requirements

Anti-settling during storage: Paint should not become viscous and the particles dispersed in the paint should not settle in storage.

Flame retardancy: When exposed to fire paint surface should prevent spread of flame over the surface and also it should suppress the smoke.

Ease of maintenance: Paints should be easy to clean and stains of harsh chemicals should be removed easily. Also paints should be hygienic, anti-bacterial, anti-odour and anti-microbial.

Short drying time: Paints should dry (cure) as fast as possible without releasing any chemicals to the environment.

Scratch resistant: Scratches (cracks) are unwanted on the paint surface. Therefore any mechanical impact, thermal change and humidity change in the environment should not lead to cracks.

Barrier properties: When exposed to rain and during its use at humid environments paint should not absorb water vapour which would lead to creep and degradation in insulating properties.

Resistance to thermal changes: Since interior and exterior spaces encounter temperature changes i.e. day to night and seasonal temperature changes, it is important that components of paint should be stable to prevent crack formation.

UV resistance: As mentioned before paints are used on internal walls and external walls for decorative purposes in addition to the other functionalities. Since it is exposed to sunlight after a while the colour of the paint starts to fade. So as to keep its colour as it is applied on the first day paint should be resistant to UV.

Increased reflectivity: Applications of paint on roof surfaces it is important that paint reflects the UV light and prevents over heating of the buildings.

Long service life with enhanced performances: As it is the case in all products paint should be durable while preserving its performance.

1.8.3 Boundary conditions

Nanoenhanced paints are produced the same way as normal paints. Since nanoparticles are handled at the production site, more powerful ventilation systems need to be installed to ensure health and safety of workers. Dispersion of nanoparticles in paint is one of the problem.

One of the major drawbacks is the uncertainty of long-term performance of these novel products.

1.8.4 Product examples

Evonik – non-drip paints Evonik has fumed silica based product which is sold under the name of AEROSIL® to control rheological features and also to improve corrosion resistance of paints.

COL.9® is a nanobinder from BASF which is applied onto paints. It protects paints against dirt and weather. **Herbol® Symbiotec®** is an exterior wall paint developed by Akzo Nobel using **COL.9®**. This paint has dirt-repellent feature due to this nanobinder which creates a hydrophilic surface in its composition. It does not let build up of any dirt, bacteria, mould and algae on the surface. This product is also effective in maintaining insulating properties of wall and insulation systems through a good moisture management system.

Nanoguard® is a technology developed by Behr Paints. Using this technology coatings, including paints have enhanced functionalities eg. better adhesion, dirt repellent, moisture resistant and UV resistant. BEHR Basement & Masonry Waterproofing Paint and BEHR Premium Plus Ultra are some of the products that are developed using Nanoguard Technology.

Nano Ipek Matt, Nanomatt and Nanotex are nanoenhanced paints from Yasar Paint Group (DYO) with self-cleaning, anti-scratch and anti-bacterial features. Nanomatt and Nano Ipek Matt are for interior applications while Nanotex is for exterior spaces.

Nanosön is flame-retardant water based paint from Yasar Paint Group.

MAXIT Airfresh Plaster – is a plaster which can be applied on ceilings and walls. Making use of nano sized TiO_2 particles it includes in its formula and the so-called photocatalytic effect it eliminates unwanted odors, air pollutants and organic volatile compounds.

Bioni Comfort interior to improve the room climate (?)

Bioni Nature is a nano-enhanced paint that has anti-bacterial and air purifying functionalities.

Bioni Hygienic is another interior paint especially aimed for high hygiene required spaces with its anti-microbial property.

Bioni Perform is an external paint with moisture regulating and anti-mould properties.

Bioni Roof is special multi purpose paint / coating for roofs which are made up of clay, concrete, artificial slate tiles and corrugated iron. It is resistant to UV light, to harsh cold / hot weather conditions. It prevents growth of moss and also reduces the build up of heat in the building.

1.8.5 Economic information for present products

Nanoenhanced paints have already penetrated into the market. These paints are available on DIY stores and usually preferred by residents. Constructors do not tend to invest in paint and use high quality innovative paints especially for residential buildings because residents rather re-paint their homes according to their needs and taste.

As other construction related industries paint sector has been affected from the present global economic situation. In paint industry raw materials prices shape up the sector.

The market for nanodispersions as binders for coatings is likely to reach about Euro 50 million in the next ten years. **[59]**

Regulations like EU VOC directive would increase the market penetration of nanoenhanced paint strengthening their position in the paint market. **[60]**

1.8.6 Profiles of selected key companies

Bioni CS GMBH is a German paint company whose core business is the development, production and marketing of coatings to construction industry. The company has wide range of paints with various functionalities. Bioni's nanoenhanced paints were developed as a result of R&D collaboration with Fraunhofer ICT. Please visit www.bioni.de to learn more about Bioni.

Yaşar Paint and Chemicals is one of the main business branches of Turkish company Yaşar Group. Yaşar Paint and Chemicals supplies products to different industries e.g. construction, automotive, marine and etc. with paints and coatings. Construction paints are sold on the market with different commercial names DYO, Evim and Dewilux. Company is one of the pioneers in nanoenhanced paints holding various patents. To have more information about the company please visit www.yasar.com.tr/English.

Behr Paints is one of the major construction paint suppliers in the North American market. Please visit www.behr.com for detailed information.

Jotun is a Norwegian global paint supplier. The company's product spectrum covers decorative paints, marine coatings, protective coatings and powder coatings. The company added nano enhanced paint which will be on the market in autumn 2009 into their products. Please visit www.jotun.com to have more information about Jotun.

Akzo Nobel is a Dutch company which provides paints, coatings and specialty chemicals to various industries. Please visit www.akzonobel.com to learn more about their activities.

References

[1] EUROSTAT

[2] Euroconstruct Press Info, December 2008.

[3] World Business Council for Sustainable Development www.wbcsd.org

[4] Nanotechnology in Construction, Nanoforum 2006.

[5] '*Accelerating the Development of the Sustainable Construction Market in Europe*',Report of the taskforce on Sustainable Construction, European Comission, 2007.

[6] http://www.cerameunie.eu/industry.html.

[7] European Construction Technology Platform Vision 2030, 2005.

[8] ObservatoryNANO Scientific and Technological Trends on Construction.

[9] *Ceramic Tiles: Above and beyond traditional applications*, Arnaldo Moreno Berto, Journal of the European Ceramic Society 27, 1607 – 1613 (2007).

[10] Duravit – Wondergliss Products User Manual.

[11] www.agrobbuchtal.de

[12] www.erlus.com

[13] http://www.villeroy-boch.com/en

[14] Expert views

[15] Information was obtained through a shelf research at DIY stores and online stores

[16] Expert views

[17] www.cembureau.eu

[18] Global Cement Report

[19] Concretes for the 21st Century, Lafarge www.lafarge.com/lafarge/CONTENT_SHEET/20070612/06122007-press_themabook-extensia_chronolia-uk.pdf

[20] www.nanocem.org

[21] Report of the workshop on nanotechnology for cement and concrete, P. Taylor *et al.* September 2007.

[22] International Cement Review, August 2008.

[23] www.nature.com

[24] http://www.italcementigroup.com/ENG/Media+and+Communication/News/Corporate+events/20060228.htm

[25] www.heidelbergcement.com/NR/rdonlyres/28528B72-3125-4370-B657-616609415500/0/6TioCem_Broschuere_englisch.pdf

[26] www.emaco-nanocrete.com

[27] www.clariant.com

[28] Smalltimes.com/articles July 21, 2008

[29] www.glassonline.com

[30] http://en.wikipedia.org/wiki/Low-emissivity

[31] http://www.nanoforum.org/educationtree/energy/energy-coatingsforglazing.htm

[32] http://www.stegbar.com.au/products/windows_and_doors/glass_and_glazing/acoustic.php

[33] Presentation on '*Smart windows: A new nanotechnology for energy savings in buildings*' at Northern Nanotechnology Confeence in 2008 by Dr. C.G. Granqvist, The Angstrom Laboratory and Chromogenics AB.

[34] Presentation on '*Thin films and functional glass coatings*' at Northern Nanotechnology Conference in 2008 by Dr. Joe Pimenoff, Beneq

[35] www.arkema-inc.com

[36] http://corporateportal.ppg.com/NA/Glass/ResidentialGlass/Homeowners/ProductInformation/SunClean/

[37] www.pilkingtonselfcleaningglass.co.uk

[38] www.beneq.com

[39] www.selfcleaningglass.com

[40] http://in.saint-gobain-glass.com/b2c/default.asp?nav1=pr&nav2=single%20pane&id=2088

[41] www.scf-technologies.com

[42] http://www.nanovip.com/node/4663

[43] Pilkington Glass Financial Report (2008 fiscal year)

[44] Freedonia Advanced Glass Market, June 2008

[45] http://www.bccresearch.com/report/AVM065A.html

[46] Nanoroadmap on Materials, FP6

[47] www.aerogel.com

[48] http://www.azonano.com/News.asp?NewsID=6982

[49] www.cabot-corp.com

[50] http://www.toolbase.org/building-systems/interior-partitions-ceilings/vacuum-insulation-panel

[51] http://www.nansulate.com/nansulate_homeprotect_clearcoat.htm

[52] http://www.basf.com/group/corporate/en/innovations/research-verbund/research-projects/products/nanosilent

[53] 'Thermal Insulation In Europe', *Reportlinker* December 2007.

[54] 'World Insulation To 2012', *Freedonia Market Report*, February 2009.

[55] Kingspan 2008 Annual Report.

[56] Cabot Corp. 2008 Annual Report.

[57] http://en.wikipedia.org/wiki/Paint

[58] http://www.nipponpaint.com/paint_elibrary/paint_insights.html

[59] http://www.azobuild.com/News.asp?NewsID=5276

[60] http://www.thefreelibrary.com/Paint+and+coatings:+what+will+be+coloring+the+market+in+2007%3F(Market...-a0171582229

Annex: Expert engagement

This report has been partially based on the interview done with following experts:

Dr. Alexander Sieber, Clariant International Ltd.

Dr. Paul Acker, Lafarge Research Center

Dr. Javier Gravalos Moreno, Acciona Infrastructures

Dr. Roger de Block, Saint Gobain / European Construction Technology Platform

Dr. Gülsen Çeliker, Yaşar Paint & Chemicals Turkey

Dr. Jordi Balcells, ROCA Sanitario

Mr. Victor Draper, ROCA Vitreous China

Dr. Maria Lopez Tendero, AIDICO Spain

Dr. Margarita Lecha Taitot, AIDICO Spain

Dr. Arnaldo Moreno Berto, ITC Spain

Dr. Vicente Sanz Solana, ITC Spain

Following experts have contributed to the content of this report via discussions held at ObservatoryNANO 1st Annual Symposia in Düsseldorf:

Prof. Dr. Antonio Porro, LABEIN Technalia Spain

Dr. Pavel Trtik, EMPA Dübendorf Switzerland

Prof. Dr. Michael Schmidt, University of Kassel Germany