Nano-enabled Textiles in Construction and Engineering

The construction sector in the EU, with an annual turnover of almost 1000 billion €, accounts for around 30 million jobs, and about 10% of the GDP. Buildings also represent 40% of energy use and 33% of greenhouse gas emissions in Europe. The construction industry is very fragmented, less than 4% of the market is international, and innovation is slow [1,2].

In order to reduce energy consumption and improve performances in the construction sector, an important contribution can be found in technical textiles, which according to their use, are mostly referred to as Construction textiles and as Geotextiles, and will contribute to the transformation of the construction sector into a competitive knowledge-intensive and sustainable activity.

Construction textiles play an important role in the modernization of infrastructures, offering peculiar properties such as lightness, strength and resilience as well as resistance to many factors such as creep, degradation from chemicals, sunlight and pollutants. Their use also provides a marked aesthetic improvement for new and refurbished buildings; so the use is expanding for these new textile materials and innovative techniques for their deployment offer huge potential in the construction of eco-friendly buildings that combine great design freedom with lightness and economy.

Textiles & Construction

Apart from interior applications, textiles are perceived by the construction industry today as mainly for temporary structures. However, with the emergence of new materials and methods they are increasingly considered for more permanent uses. There is, for example, a growing interest in building design and construction to have greener, cleaner, lighter, high performing and sustainable structures[4] and to this end textiles are expected to play, as indicated below, an ever more important role. As mentioned already they are divided in two categories: Construction textiles and Geotextiles. Their features are briefly summarized in the following.

<u>Construction Textiles</u> (also called Buildtech, Buildtex and Architextiles) are a large and increasing number of textiles that are finding their way into architecture, both indoors and outdoors, for surface and hidden applications. Besides tapestry and curtains, textiles are used in roofing, insulation and cladding; in sun, water, wind, fire and noise protection; in floor and concrete reinforcement; in UV and electromagnetic shielding; in diffused lighting using integrated LED and other electroluminescent materials.

High strength, high modulus textile fabrics can be used as a replacement for more traditional materials. The mechanical properties of fabrics made, for example, with aramide or carbon and glass fibres, combined with crosslinking resin systems to form a composite, provide civil engineers with a range of new materials that offer high strength and/or high stiffness with respect to weight; and extreme flexibility in design and use[5]. Textile Reinforced Concrete (TRC) is a composite material with performances comparable to steel reinforced concrete, giving lightweight structures with high durability and high quality surfaces[6].

Innovative membranes made from composites, including textile reinforcement, offer added value in both technical and aesthetic terms. New coatings and fillers, some derived from nanotechnology, are being tested, producing textile membranes combining acoustic and thermal insulation, efficient energy management, controlled light transmission and easy cleaning and decontamination qualities[7]. Other applications include self-healing concrete, localized crack repair, the reinforcement of critical walls, or the wrapping of existing columns, protection against earthquake or hurricanes, explosive incidents, or military/defence purposes.

Also the new trends driven by visionary architects are making room for textiles in construction. For example, an exterior envelope textile façade can be used to add a high profile, visible and dramatic effect, with translucence, resembling glass. Other approaches are directed towards a building "skin" combining visible and performance features, like thermal control, water and dirt repellency, light transmission and acoustical absorption.

Sun and weather protection as well as light and temperature regulation are the main requirements for textiles applications in sport facilities. ETFE fluoropolymer membranes allow 98% light transmission, water repellency, insulating properties controlling interior temperature and humidity of large sport buildings. Around 80% of newly built or refurbished stadiums worldwide have textile roofs and/or claddings.

Another particular application of textiles in architecture is inflatable buildings. High performance inflatable buildings are characterized by a unique design and construction giving them unrivalled portability and speed of deployment combined with the strength and rigidity of a metal framed structure able to withstand wind and snow loads. Each structure is typically comprised of two layers of a fire retardant composite textile connected together. The cavity formed between the layers is pressurized with air producing an extremely rigid structural element which allows large spans to be achieved whilst keeping the overall weight of the structure to a minimum[8]. The replacement of steel cables with textile belts and ropes for tensioning and load transfer will eliminate corrosion problems and facilitate installation.

<u>Geotextiles</u> (also called Geotech and Geotex) form

part of a group of materials known as geosynthetics, together with geogrids, geonets, geomembranes and geocomposites, all being special fabrics made for use in geological situations[9]. Geotextiles, usually in the form of woven, nonwoven and knit fabrics, must respond to specific requirements such as strong mechanical properties, filtration ability and chemical resistance so that they can perform basic functions such as reinforcement, separation, drainage and filtration. They are flexible, extremely robust, easy to install, and generally allow solutions that are less expensive than traditional construction methods. The use of geotextiles can save money by considerably reducing construction times, material and maintenance costs.

Geotextiles are designed for use in civil engineering applications such as erosion control, landslide, soil stabilization, road construction, embankments, dams, and retaining walls. Nonwoven geotextiles are often used as protection layers for geomembranes in containment structures (e.g. landfill, water storage, etc.) where it is required that the geotextile prevents localized stress cracking of the geomembrane by stone projections over the long-term usage of the constructed facility.

The most common fibre polymers used for the manufacture of geotextiles are polypropylene, polyethylene, polyester, and less frequently, polyamide**.** The use of more specialized materials is limited, because geotextiles have to be produced in large quantities and economically.

Nanotechnology adds value

Nanotechnologies have already found application in construction. Nanotechnology plays a role, in fact, in the development of a new concept and understanding of the hydration of cement particles. Nano-size ingredients such as alumina, silica, titania and others have been used to create self-cleaning or antibacterial surfaces, flexible solar panels, self-healing concrete, UV and IR blocking materials, light emitting walls and ceilings.

In the case of construction textiles and geotextiles, nanotechnology can also play a role. It can do so in different ways. On the one hand it can improve existing functional performance by increasing mechanical, chemical, photochemical, and biological properties and on the other hand it can make possible the combination of different functions in the same textile or the introduction of entirely new properties.

In the case of construction textiles the use of nanofibres and nanotubes can, for example, help to make new, lighter and stronger, concrete materials which last longer and are more able to resist strong shocks such as those generated by earthquakes. An example is the seismic wallpaper composite concept, based on a reinforced textile composite system, combining different materials like multiaxial, warpknitted glass and polymer fibres, nanoparticle-enhanced coatings for the textile fabric, nanoparticle-enhanced mortar to bond the textile to the structure, and fibre-optic sensors[10]. The seismic wallpaper is now past the prototype phase taking the first steps towards commercialization [11].

Textiles coated with nanomaterials can provide a variety of attractive features such as: enhanced thermal/acoustic insulation, light transmission/reflection, UV and electromagnetic shielding, hydrophilic/hydrophobic, fire resistance, self-cleaning characteristics and aesthetic finishing for building exteriors.

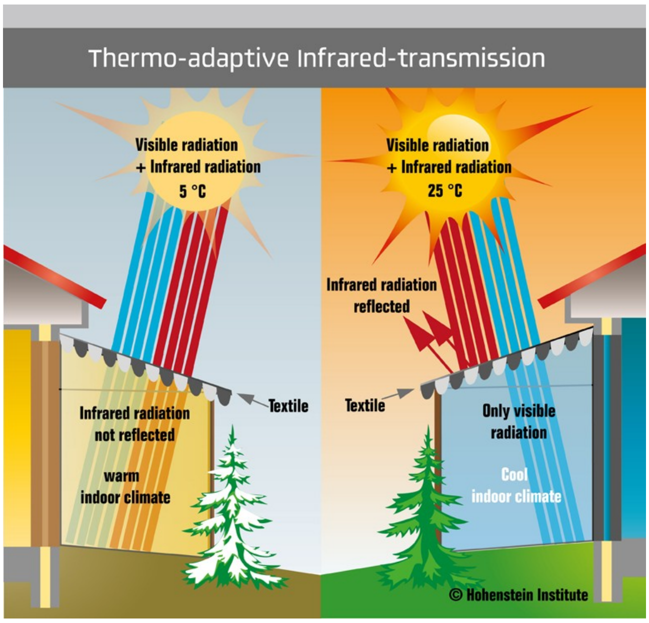


Figure 1: Intelligent textiles which are not only translucent but also able to adapt their thermal permeability to suit the ambient temperature, have the potential of significantly cutting the cost of heating and/or air conditioning. – Source : Hohenstein Institute

Emerging nanofibre technology also plays a useful role in nanocomposite reinforced geotextiles, utilized, for example, in environmental applications, such as for gas collection layers in landfill cover systems,

Nanoclay formulations have been used in geoenvironmental applications to manufacture polyester-based geotextiles with improved effectiveness for the removal of toxic and organic components of leachate solutions.

Tensile structures and fabric roofing also take advantage of an innovative nanoporous insulating material, called an aerogel, which although being a very thin layer, helps boost the insulating R value. It is the lightest known solid material, made up of 97% of air and 3% silica, and has the appearance of frozen smoke[13]. Its application in textile roofing in sport stadiums and the like, prevent heat loss and solar heat gain, while still allowing daylight transmission.

Information Box

Reduction of the fibre diameter to the nanoscale leads to an enormous increase in surface area (1000 m^2/g is possible). Reinforcement of concrete using carbon nanofibres (CNF) and carbon nanotubes (CNT) allows for new high performance nanocomposite materials to be obtained, with excellent properties in fracture prevention, by controlling the matrix cracks at the nanoscale level, enhancing tensile strength and Young's modulus, and also improving the early age strain capacity of the cementitious matrix [12].

Finally, smart textiles, created using nanotechnology–related sensors embedded into textile structures, find application in the monitoring of buildings, to sense a material damage or stress, or the effect of temperature changes, and in geotechnical applications, to monitor distributed strain in slopes with stability problems.

Impacts Economy/Industry

The current global market for technical textiles is around US $127 billion, (23.77 million tonnes) with Asia leading the world in terms of consumption with 8.5 million tonnes followed by USA and Europe with 5.8 and 4.8 million tonnes, respectively. In Germany, which battles the USA for being the world's leading producer, technical textiles amount to about 52% of total textiles sales.

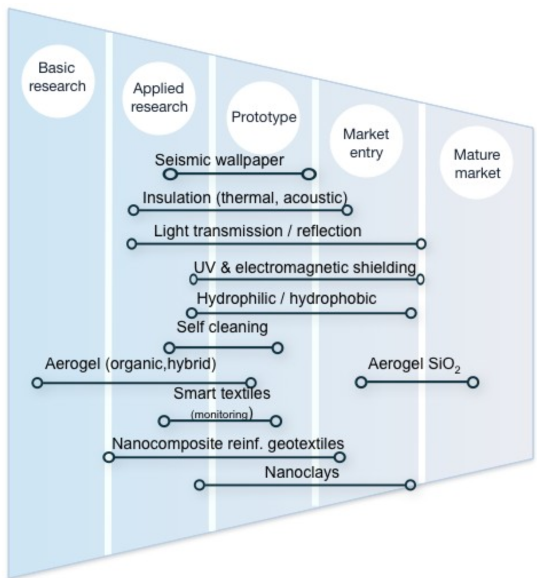
According to general industry consensus, the Buildtech (construction textiles) and the Geotech (for geotechnical applications) segments are among the smaller technical textiles markets, but with higher growth rates. The Buildtech segment amounts to about 10% of the market, corresponding to about US $12.7 billion, with a historical growth rate (2005-2010) of about 5% per year, and an estimated future growth rate of at least 5% per year. The geotech segment is a lot smaller (about 1% of the global market) but has been growing slightly above 5% historically. Global demand for geosynthetics however is projected to increase 8.3% annually, driven by increasing use of geosynthetics and the large-scale construction plans in many developing countries. China will surpass the US as the world's largest geosynthetics market by 2015[14].

The recent global financial crisis is slowing growth, reducing the number of manufacturers, and developing a more focused market approach. However, this situation, true for USA and Europe, is not valid for the Asia-Pacific region, where nine of the top ten most business and consumer confident nations are located [5]. Already, dozens of building materials incorporate nanotechnology, from self-cleaning windows to flexible solar panels to wi-fi blocking paint. From the analysis performed in the recently published "Textiles in Architecture"[5] it appears that most companies studied are using conventional coatings, while only a few seem to have invested in large-scale nanotechnology. As the mass market is under price-pressure, and due to the economic crisis, the investment into fairly new technologies tends to be delayed. As a consequence, only the very high-end companies are using nanotechnology to some extent [15].

Another source sees a problematic diffusion of nanotechnologies in construction, given the cost and the relatively small number of practical applications on the market (which delays the prospect for such an approach) and for the tendency of the construction sector to be a fragmented, low research orientated and conservative endeavour[16]. A current opinion is that in special cases nanotechnology-related products will enable unique solutions to complicated problems that cause them to be cost effective, while in other cases traditional methods for treating the problem may still be best[17]. A similar opinion is reported by S. Nair[18] "some suppliers will be able to overcome the above factors and establish significant markets for nano-related textiles in construction applications, while other products are expected to remain only niche market curiosities".

This opinion is also reiterated by industry sources[19] who estimate the current use of nano enabled textiles in construction and geo-textiles at about 1%. Indeed, in the case of geotextiles the sales concern large quantities (m^2), low prices and rather low margins. In such an environment the additional cost of a nano enabled property (estimated at about 10%) will not readily be accepted, except in such situations where they solve complex problems in a unique way. In the case of construction textiles, where the margins are generally greater, the potential of nano-enabled textiles to impact not only the design of the building but also the "greenness", the comfort level and (depending on the case, often) the cost of the building; will make their added value more readily visible and market acceptance easier, economic conditions permitting. For instance, the market segment for aerogels in the building sector in Europe is currently projected to grow at double-digit numbers pushed by European building codes for energy efficiency[20].

Technology Readiness Levels*



*Dr. P. Roshan, Principal Investigator, Textile Technologies Division, LEITAT Technological Center (Spain), has provided valuable inputs concerning the state-of-the-art of nanotechnology in technical textiles

Challenges

Nanotechnology-related products are slowly making their entrance into the construction sector and various challenges have been envisaged for the introduction in this sector of such innovative technologies that could contribute to the abatement of energy consumption in building construction and maintenance or, with geotextiles, in soil management.

Some bigger companies are now in the process of mapping the textile properties that can be enabled by nanotechnology, and of identifying the (niche) markets from where products can gain wider acceptance (through cost reduction by economies of scale)[19]. Serious R&D efforts, however, can only be undertaken by the bigger players, as the majority of the companies in the technical textile sector are SMEs with a very operational, short-term focus, as opposed to a long-term perspective.

The conservative and fragmented nature of the construction sector is certainly one of the factors slowing nano-enabled construction textiles' widespread application but other big obstacles are also their high cost and until now small production scale of the nanomaterial components. Another general challenge is overcoming public concern related to nanotechnology's possible negative impact on health, safety and the environment. Most companies do not promote products as being "nano" because they do not know how the public will respond to it being applied to everyday life materials. An effort to develop less costly products and assure their safety would likely increase nanotechnology's use. Demand for nanotechnology will likely never be strong until convincing documentation is produced about its functionalities and long-term effects.

Societal/Impact on European Citizen

Energy consumption and emissions reduction.

The construction industry contributes significantly to CO_2 emissions, with buildings responsible for 40% of total European energy consumption and 33% of CO_2 emissions. An "energy efficient" building, according to the US Green Building Council, must save 70% on electricity, 50 to 60% on water and 36% on gas, compared to the standard. To help address climate change concerns, the European Commission has set specific targets to be achieved by 2020, known as the 2020 targets: 20% reduction in energy consumption and in CO_2 emission, and 20% of renewable energy introduction. Nano-enabled technical textiles can provide a valuable contribution to energy consumption reduction, and consequent CO_2 emission reduction in the construction sector. This could be achieved through improved thermal management utilizing such things as nano-related efficient insulating systems.

Health & environment.

The use of nanotextiles can have beneficial effects both for health and the environment. Construction textiles can, in fact, contribute to reducing toxic/harmful substances in the air and increase comfort and thus improve safety and well-being inside the building. Geotextiles, on the other hand, can have beneficial effects on the environment in such areas as improvement in soil stabilization maintenance and effectiveness, erosion control, road and railroad construction or landfill management.

Societal.

There is a shared opinion that the diffusion of nano-related textiles in the construction sector will contribute to people's well-being and environmental management, with improved building performance, economy, user good health and environmental quality[10]. In the mean time, however, there is a concern about the potential risks for health and the environment deriving from the use on nanotechnology-related products, in particular nanoparticles. This concern must be taken seriously and research in this field should be a primary issue[21], although rules and standards should be based on an objective evaluation of the true risks raised by nanomaterials in normal use, avoiding extreme and unrealistic situations.

EU Competitive position

Europe is a world leader with 30% of the overall construction market, but this market is a conservative, mainly local and very fragmented business as less than 4% of it is international[2]. In the field of technical textiles technology, Europe is leading the world, together with the USA and Japan. In Europe, the most developed country in terms of technical textile development is Germany. The development of the nano-enabled textile industry, by the promotion of a cutting-edge R&D can strengthen the EU competitive position also in the construction compartment.

In order to reach the ambitious 2020 targets and to achieve energy neutral buildings by 2050, the European Construction Technology Platform has set up the Energy Efficient Building European Initiative (E2B EI). The latter is a €1 billion programme in which the European Commission and industry will support research on sustainable technologies for the EU construction sector, finalized to develop energy-efficient materials and systems for new and refurbished buildings with radically reduced energy consumption and CO_2 emissions[1,22].

The production on a large scale and at affordable price of nano-related technical textiles for construction applications can provide a valuable contribution towards the 2020 targets and consolidate the EU leadership in this basic sector.

Summary

- Technical textiles are already used in construction and civil engineering applications where they combine design freedom with improved material performances and innovative and often more effective solutions.
- Nanotechnology can improve the functional performances of the technical textiles by increasing their mechanical, chemical, photochemical and biological properties, and by making it possible to combine different properties in the same textile and by introducing entirely new properties.
- Historical growth rates of about 5% per year for Buildtech and Geotech textiles are projected to increase, driven by increased use of these textiles, by large-scale construction plans in many developing countries and by the trend towards more "greenness" in developed countries.
- A very low percentage of the currently marketed construction and geotextiles are nano-enabled.
- Barriers to use of nanotechnology are the serious R&D efforts required, which the majority of enterprises cannot assume (being small SMEs), and the high cost of nano-related textiles.

TEXTILES: nano-enabled textiles in construction & engineering

- The demand side will be reluctant to introduce nanotechnological materials until convincing documentation about functionalities and long-term effects (especially concerning health) is produced.
- The EU is in a leading position in the technical textile sector, and nanotechnology will help to sustain this competitive edge.
- In Germany, which along with the USA is the world's leading producer, technical textiles sales amount to about 52% of total textiles.

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