FEBRUARY 2021

STATE-OF-THE ART REPORT

context

Smart textiles for building and living (WG4)

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the Horizon 2020 Framework Programme of the European Union

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ABSTRACT

The aim of this document is to provide information on the state-of-the-art related to the topics covered by each working group within the CONTEXT project. It provides information on materials and technologies used to develop smart textiles with targeted performance, general applications of smart textiles in the field, case-studies on the use of smart textiles, opportunities for smart textiles considering the needs of each field, trends on the development of smart textiles in terms of market and technical expectations.

This paper gives an overview of the potential of smart textiles for building and living, ongoing developments, state-of-the-art products and future developments.

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1. INTRODUCTION

Civil engineering and building industry are an integral part of the development of human society as they involve the planning, design, building, operation and maintenance of infrastructures. The venturing of technical textiles or high-performance textiles in this sector has given a great impetus to the quality of construction.

These textiles are used in the construction of buildings, dams, bridges, tunnels and roads and collectively comprise the "Buildtech" sector. They offer mechanical properties such as lightness, strength and resilience as well as resistance to many factors such as creep, degradation by chemicals and pollutants in the air or rain and other construction material as well as the effects of sunlight and acid. These textiles play an important role in the modernization of infrastructure.

Some of the major products covered under this sector are:

- Construction reinforcement
- Insulation for walls
- Hoardings and signages
- Scaffolding nets
- Awnings and canopies
- Tarpaulins
- Architectural membranes
- Roofing materials
- Bridges and roads
- Health public spaces applications
- Home interiors

The **BUILDTECH** sector for textiles includes:

- Textile for building: acoustic & thermal insulation.
- Textile for building: protection against sun, wind, fire, water.
- Textile concrete: protection against UV & electromagnetic radiations.
- Textile integrated LED & other electroluminescent material: energy saving & use of more sunlight.
- Textile reinforced concrete (TRC) composite material: similar to steel reinforced concrete, giving lightweight structures with high durability.
- Textile as an embedded sensor: for structural health monitoring.

Materials used are:

- Glass
- Aramide fibers
- Carbon fibers
- Crosslink with resins
- Natural fibers
- Synthetic fibers

Eco Textiles

Environmental threats on almost every nation in the world today. With this threat gaining its stature day by day, Eco Textiles gain utmost importance as one of the most useful resources that help promote new innovations, in an eco-friendly manner.

OEKOTECH is the term used for technical textiles that are used for environmental protection. It stands for new ideas and interesting concepts in the area of environmental protection, waste disposal (including innovative filtration media) and new recycling technologies. It is opening up new avenues for environmental engineers, safety engineers and personnel in environmental protection agencies.

These eco-friendly textiles provide a range of environmentally responsible alternatives to other resource hungry materials. They tap into both post-consumer and post-industrial waste streams & scrap and reuse them for manufacturing an extremely durable and eco-friendly textile. They not only lead to reduction of waste but also more importantly, save the rapidly depleting natural resources.

Some of the features of these textiles are:

- They utilize ecologically grown fibers.
- They are processed with less damaging inputs.
- The processing units are equipped with good sewage treatment.
- The fabrics are of good quality and long lasting.

A look at some of the products that are manufactured using these textiles:

- Soil seals
- Textile drainage systems
- Erosion prevention systems
- Textiles for protection against hazardous substances
- Mobile containers
- Textile noise barrier systems
- Filter systems (air/water)
- Landfill textiles

2. SMART TEXTILES FOR BUILDING AND LIVING

In the last decade, lots of smart textiles have been developed addressing in particular the construction (or civil engineering) sector, which is representing one of the largest markets for new textile products. We consider smart Fabrics weaved, knitted, coated, bonded or finished used in building and construction: some of these fabrics are visible from the outside or inside; others are integrated into walls, ceilings or flooring.

Smart textiles are intelligent or functionalised textiles with fibres that have new mechanical surface, protection and "intelligence" properties. The textiles take over functions that were previously not used or conceived for textile applications. Smart Textiles react to external influences and they are used in technical applications. New integrations of functions into textile structures are sensory, actuator, communicative, heating/cooling and luminescent.

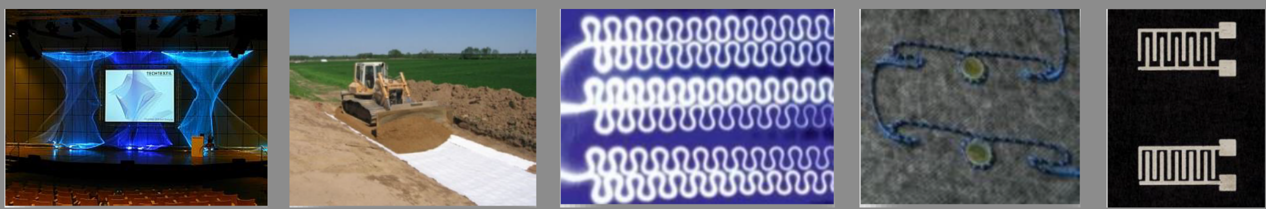

Figure 1 - Examples of functionalised textiles [1]

Textile plays a main role in building infrastructure offering properties like light-weight, strength and also give thermal and acoustic insulation and resistance from sunlight, chemical and pollutants. Textile industry provides now high modulus and high strength fabric to replace steel, wood, concrete.

Smart Textiles used in civil applications include also geotextile. A geotextile is a product of the textile industry characterized by physical, mechanical and hydraulic likely to be used in civil engineering, in contact with the ground.

The functions that geotextiles can carry out are basically:

a) hydraulic functions - Drainage - Filtration
b) mechanical functions - Separation - Reinforcement - Protection

Figure 2 - Geotextile functions [2]

Textiles may also be used in architecture to bring in technological innovation and improve the aesthetics of buildings.

The following are main properties that technical textiles applications can bring to the building sector:

- High tensile strength and high tear strength are the most primary requirements. Ability to withstand snow, rain, strong wind; in case of bridges or walkways weight is a key element for a structure based on textiles.
- High resistance to mechanical wear and low maintenance fabrics like EFTE and glass fibres, which have good buckling properties.

The exterior of fabrics need to be strong enough to hold UV radiations and mechanical wear and tear for a long period of time. Performing in the most extreme temperatures and climates is one quality that need to be considered while using textiles for architecture.

Light absorption, reflection, and transmission are the main factors that need to be assessed to ensure a good illumination and low energy consumption of a structure. For example PFTE fibre glass coated fabrics reflect 70 percent of light while a transparent EFTE may reach 95 percent of transmission rate.

The colours and prints used on such textiles also affect the lighting and thermal properties of spaces they are used in. Hence, a proper combination needs to be considered.

Acoustic insulation and thermal balancing are extremely vital features while selecting a fabric for building textile architecture. Multi-layered structures that have air cavities between them for air circulation are one way of monitoring the thermal energy.

Cleaning and maintenance of fabrics is also necessary. Hence fabrics with anti-soiling and self-cleaning properties are preferable in such constructions.

Examples of advanced textiles for the construction sector comprise fabrics used for the rehabilitation of buildings, geotextiles for railway, roadway embankments or coastal protection, high performance technical textiles for tensile structures and textiles used in advanced roofing systems. These materials can provide both strengthening, stabilization and monitoring functions compared to traditional materials.[3]

Figure 3 - Example of textile structure for earthquake containment [4]

Sun and weather protection as well as light and temperature regulation are the main applications for the new smart fabrics produced in these last years, such as the bituminous membranes used as barriers. Textile layers are used to solve water stagnation and perforation risk for roofs.

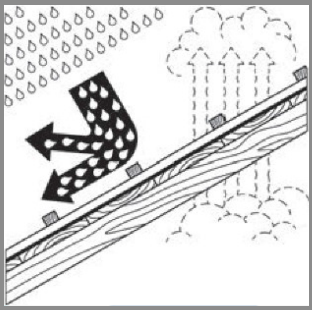

Figure 4 - Protection of roofs [5]

The design, construction, maintenance and repair of civil infrastructure is one of the largest industry in the world representing approximately 10% of world GDP. Technical textiles designed for this market can therefore represent an important turnover. But the construction industry is hardly associated with innovative textiles.

With the need for designs to be more flexible, the pressure on reducing material cost, and the requirement of aesthetically advanced and eco-friendly materials, technical and smart textiles have become ideal options for construction. Fabrics made with aramid carbon and glass fibres combined with the strength of composites give civil engineers and architects a new range of materials to work with, in combination with the less weight they confer when building a structure. A lot is taking place in this respect: for instance, concrete is reinforced with textiles instead of steel. This results in larger spans, for example for bridges. Seamless textile hoses are used to renovate dilapidated canals.

The retrofitting of existing masonry walls and soil structures is particularly important for earthquake protection of historic buildings and protection of earthworks against landslides. Unreinforced masonry structures are highly vulnerable because being originally designed mainly for gravity loads they often cannot withstand the dynamic horizontal loads in case of strong earthquakes.[3]

Figure 5 - Textile structures for earthquake containment and landslides[4]

Soil structures, such as embankments, are subjected to landslides after heavy rainfalls or during earthquakes. Hence the necessity of efficient methods for the retrofitting of existing masonry buildings and earthworks and of related monitoring systems to possibly prevent the structural damage.

Alternative technical textile buildtech materials are developed to perform both thermal and acoustic functions simultaneously. Smart textiles, developed from waste wool and recycled polyester fibers, show a good sound absorption properties (in an overall frequency range 50-5,700 Hz) and good thermal insulation properties in terms of thermal conductivity. These alternative material could contribute to the cost and energy savings.

Lightweight constructions, realized with smart textiles and smart materials in general, represent an economical alternative to traditional buildings, one of whose main drawbacks is the very high energy load needed to keep internal comfort conditions, as they are unable to curb rapid swings of temperature. In the following an example of 3D textiles for inner tube creation for thermal insulation and heat dispersion is shown, where the first smart textile create ventilation ducts parallel to the weft, semi-rigid; the second smart textile is drapable, flexible and ventilated (internal air blow).

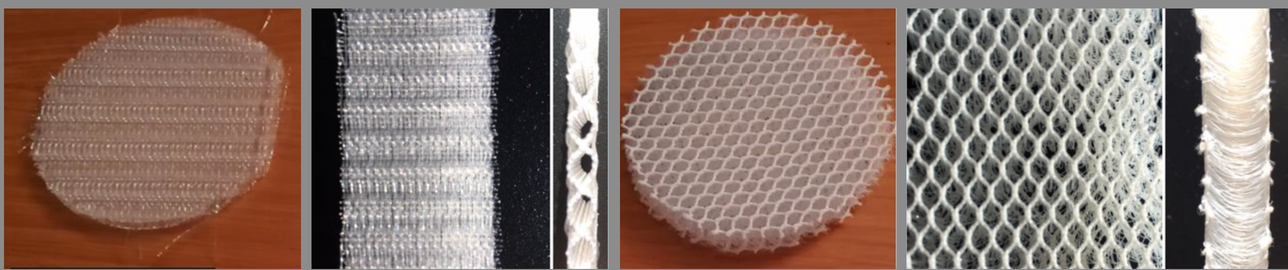

Figure 6 - 3D textiles with inner cavities for thermal insulation and heat dispersion[5]

In buildtech and geotextiles, nanotechnology now plays a vital role. Nano-technology improves existing textile properties and offer additional functional performances by increasing chemical, mechanical, biological and photochemical properties. Nanotechnology also makes possible the arrangement of different functions in the same textile or the generation of completely new properties.

On textile surfaces nanosize particles (such as titanium dioxide -TiO2-, silver -Ag-, Barium titanate -BaTiO3-, alumina, silica, and others) were coated, to create self-cleaning or antibacterial properties; other properties achievable by nanoparticles are: flexible solar panels, enhanced thermal/acoustic insulation, light transmission/reflection, UV and electromagnetic shielding, hydrophilic/ hydrophobia, fire resistance, aesthetic finishing.

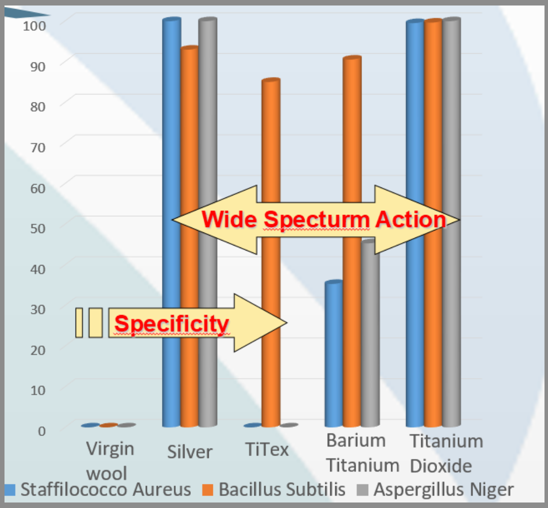

Figure 7 - Bacteria killing properties of different nanosize particles [5]

Finally, nanotechnology allows to embed sensors into textile structures, for advanced applications 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). Despite the demonstrated benefits of sensor embedded textiles for structural health monitoring (SHM) of constructions, many building practitioners are still not so much familiar with the behaviour and the characteristics of these materials, thus limiting their implementation and preventing the achievement of high standards in quality assurance and control for construction projects.

Another such operations of smart textiles is venturing out in the arena of architecture and in the living and interior design. The demand for textiles in architectural construction is growing day by day, while the textiles for the interior is modifying their traditional contribute.

The introduction of new fibres, new polymers, adhesives, and lamination coats brought in new possibilities for textile in creating architecture.

Many smart textiles and technologies have been incorporated in making textiles in architecture more interesting. Chromic materials that change colours like photochromic (in reaction to the intensity of light), thermochromics (in reaction to the intensity of temperature), and piezochromics (in reaction to pressure) are being used. Besides these, phase changing materials (PCM), conductive optical fibres, and even shape memory materials (SMM) are being developed to increase functionality and aesthetics of textiles used in structures.

Figure 8 – ETFE roof Maco Technology[6]

In the traditional vision, textiles for the interior part of the constructions have been considered as a finishing touch rather than a crucial component of the design as a whole. In reality, however, it is impossible to design a room or an interior space without them.

Textiles have been always an important part of the interior of human habitations, as well as human transportation systems such as cars, buses, passenger trains, cruise ships or airplanes. In that respect textile served three basic purposes:

- Decoration (carpets, wall coverings, curtains & drapes, table cloths, etc.)
- Comfort (upholstery, seat covers, mattresses, bed sheets, blankets, carpets etc)
- Safety (safety belts and nets, airbags)

The hometech textile has been always the segment where the innovation goes through slowly. Hometech is a field of technical textiles, which includes products for household, primarily for interior decoration and furniture, carpeting, floor and wall coverings, cushion materials, textile reinforced structures, filters, sun protection products, and many others.

These products can create comfortable, practical, hygienic, and beautiful solutions for modern living. Recent developments in the home furnishings industry include the creation of nonwovens that kill dust mites in bedding, repel dirt, and contain antimicrobial qualities.

While the basic functions remain unchanged, increased user and regulatory requirements for textile interiors have already made such products more complex, multifunctional or even "intelligent". Thanks to innovations like new antimicrobial technologies and integrated moisture barriers, designers no longer have to sacrifice aesthetics for safety.

FUNCTIONALITY	APPLICATION
Stain or water repellence	Table cloth, curtains, furniture, car, bus, train, airplane seats
Flame retardance	All possible textile interior of buildings and transport systems
Anti-static behaviour	Upholstery and seat covers
Anti-bacterial behaviour	Bedding, medical textiles
UV-protection	Roofs, tents, awanings, blinds, curtains
Insect repellance	Tents, nets
Odour absorption	Bedding, furniture, car, bus, train, airplane seats

Other advancements have to do with improved sustainability of finishes. Manufacturers are changing their products to make them more sustainable, with a longer life-cycle, easily maintainable, and away from chemicals and products that are being shown to be harmful to human health.

This marriage of high-performance and sustainability is a recent trend and is being driven by growing market demand. Part of reducing this impact has been the removal of harmful chemicals and elements like antimony, perfluorinated compounds and heavy metals, such as cadmium and hexavalent chromium. But the use of recycled material has also become more common as the availability of 100 percent post-consumer recycled polyester fibers and yarns has increased.

3. SPECIFIC APPLICATIONS OF TEXTILES FOR BUILDING AND LIVING - EXAMPLES

New textile material for building

Solar protection

External and internal blinds: fabric adaptation according to thermal permeability to reduce cost of heating or air conditioning.

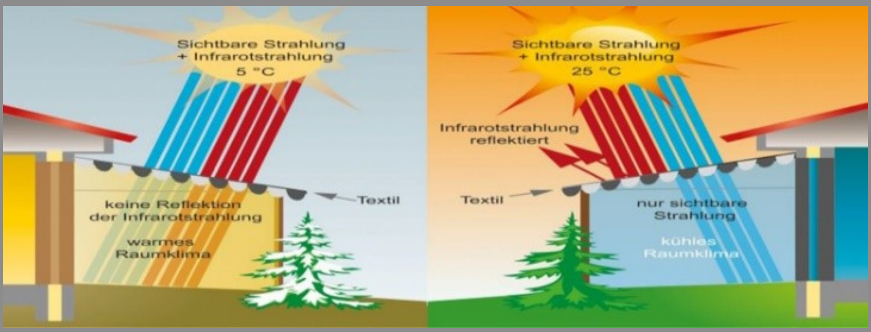

Figure 9 - Solar protective functionalised textiles for external applications[5]

New textile material for building

Textile origami for space habitats

A design team is working on the MoonMars project - architecture plans for smart human habitats and research stations on other planets. They are experimenting origami and high-performance textiles to create habitats that are compact enough to be transported and easy to deploy in extraterrestrial environments.

Figure 10 - The MoonMars prototype entrance tunnel[7]

Figure 11 - Textile origami[7]

The habitats are made of complex forms sculpted by incorporating origami structure into digital weaving processes. The forms are lightweight, can be unfolded into different shapes and are functional in a variety of circumstances. High-performance textiles and origami provide unique and protective architectural advantages in unfriendly environments. For example, the angled facets of origami structures mean that incoming micrometeorites are less likely to hit surfaces at 90 degrees, dissipating the energy of potential impacts and the risks of penetration. Solar panels embedded in shape-shifting textiles can follow the sun to gather more energy through the day.

New textile material for building

Monitoring in buildings - Structural Health Monitoring

Structural Health Monitoring (SHM) is an emerging technology, aiming to afford to the structure a capability for load monitoring and for damage detection. This is done by attaching permanently to the structure a sensor network for example fibre optic sensors), accompanied by data processing system.

Easily integrated into textiles, these sensor-embedded systems have specific potential for the construction industry.

For example moisture in buildings leads to considerable building damage in new and old buildings. A novel rope-shaped textile core-sheath structure was developed, which can directly measure impurities in buildings and is manufactured according to a cost-effective textile technology.

Figure 12 - Textiles with sensing carbon coatings embedded in concrete to detect load changes and prevent damages

There are also smart textile employing carbon fibers conductivity or using a sensing coating with incorporated carbon particles for measuring strains and evolution of damages while monitoring changes of electric resistance under increasing load. Textiles with sensing coatings showed piezoresistive properties under compression and tensile loads, which is a promising result for their use as embedded sensors to increase the safety of buildings.

New textile material for building

Textiles for earthquake-proof construction

Researchers and citizens are constantly finding solutions for building earthquake proof buildings.

Figure 13 - The world's first earthquake resistant building strengthened by carbon fiber[8]

An innovation in earthquake engineering is a curtain of cables anchored to ground to make building earthquake proof: threads made from thermoplastic carbon fibre composite are tied and braided to form a strong flexible rod which is 90% lighter than reinforcement bars and has the same strength. To make earthquake proof buildings these composite rods are tied & secured roof to the ground and installed around the building. Rods are also installed inside the building to strengthen the interior walls.

During an earthquake, the building shifts from one side to another, which results shaking of the building and causes building to collapse.

These composite threads made up of textiles helps in rods to stretch and draw the structure back in opposite direction to prevent the shaking phenomen.

New textile material for building

Fabric banners, signage and displays help guide visitors

Printed textiles are creating new aesthetic possibilities and visitor experiences in museums. Stretch ceiling offers a range of technical and aesthetic qualities and some unique possibilities for interior design, including exhibition displays.

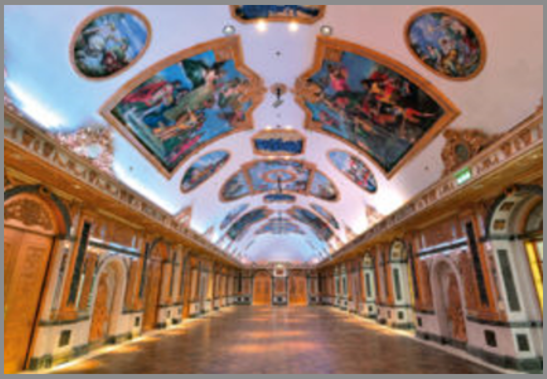

Figure 14 - Barrisol® acoustic printed membrane at Palace of Versailles[9]

Ceiling is nonflammable and acoustic properties can bring additional benefit to spaces where there are large numbers of visitors; the system also offers a soft light when backlit in ceilings or in printed signage.

New textile material for living

Transparent, self-adhesive textile shades windows

Self-adhesive "curtains" allow to see out the window during the day and prevent people from being able to look in. The patented transparent textile feels very natural, yet adheres to windows and other glass surfaces. Unlike plastic window coverings, it is breathable as well as moisture and heat resistant.

This smart textile product keeps the heat out, making it an excellent solution for windows exposed to the sun's glare. It is temperature and pressure-sensitive as well as UV-resistant. The woven fabric is antibacterial and fire-retardant, and features solvent-free acrylic glue that is double layered, making it appropriate for humid conditions.

Figure 15 - Self-adhesive textile shades window[10]

New textile material for building

Breathing sculpture absorbs air pollution

For the Milan Design week a Breathing sculpture was realized with the ability to absorb pollution. It can absorb as much as the emissions of 90,000 cars per year.
The textile panels are made of a unique fabric that employs a simple system using natural airflow, indoors or out, to neutralize pollutants.

Figure 16 - Kengo Kuma Breathing Sculpture[11]

As air passes through the mesh fabric, a nano-molecule activated center traps and disaggregates pollutants. Cleaner, more breathable air then continues in its natural cycle.

New textile material for building

Textile-reinforced concrete

Textile-reinforced concrete is a type of reinforced concrete in which the usual steel reinforcing bars are replaced by textile materials. Instead of using a metal cage inside the concrete, this technique uses a fabric cage. Textile-reinforced concrete is generally thinner than traditional steel-reinforced concrete. As an example, carbon fabrics are used as reinforcement, characterized by light weight (2/3 lighter than steel), high stiffness (2 times stiffer than steel) an high tenacity (5 times stronger than steel).

Fabrics made of flax fibres are also drawing attention for the reinforcement of concrete as a more sustainable alternative to glass or carbon fibres, with additional challenges to consider. Indeed, as well as for glass fibres, plant fibres are weakened by an alkaline environment (such as the once created in cement based matrices) due to the dissolution of their lignin and hemicellulose components, and alkaline hydrolysis of the cellulose molecules, in addition to a mineralisation through the migration of hydration products in the lumens. Therefore, two options can be considered to implement plant fibres as reinforcement of cementitious matrices: either using a less alkaline formulation of cementitious matrix or using an adequate coating to protect the fibres from a conventional cementitious matrix.

New textile material for architecture

Textiles for the creative use of lightweight

Textiles are used in architectural design to take more advantage of the lightweight (for building scopes) and of tricks of the light (for aestethical scopes).

New textile material for building

Thermal insulating materials based on waste textile fibers

In recent decades, a growing concern about protecting the environment is arised and grown exponentially. The area of constructions is one of the most impacting, because they are the largest energy consumer and the largest producer of waste. In this context, new thermal insulation materials are realized based on natural fibers, sheep wool and hemp, which are renewable resources, with increased availability at national level.

Figure 17 -Thermal-acoustic insulation RECYCLETHERM KMO[12]

The composite materials bsed on natural fibres offer thermal insulation properties superior to those existing on the market and consequently increase the energy efficiency of the buildings. The composite materials bsed on natural fibres offer thermal insulation properties superior to those existing on the market and consequently increase the energy efficiency of the buildings.

New textile material for building

Geotextiles for slope stabilisation

Geotextiles are now commonly used to stabilise steep slope soil veneers. Other smart textiles for the erosion control are used on slopes to prevent soil erosion, as well as vegetation or seed wash-out due to rainfall.

New textile material for building

Structure monitoring in geotextiles

Special solutions for distributed measurement of mechanical deformations over extended areas of some houndred metres, detection of chemicals, measuremnt of the structural integrirty and the heath of geotechnical structure are urgently needed.

Distributed fiber optic technology offers the capability to measure strain and deformation at thousands of points along a single fiber up to tens of kilometers. This is of particular interest for monitoring geotechnical structures where the technology allows the detection and localization of ground movements. Fiber optic sensing system offers ability to detect and localize deformation induced by geological assessments, monitoring kilometers with a single instrument and localizing the event with a precision better than 1 meter.

New textile material for building

Structure monitoring in geotextiles

The creation of photovoltaic (PV) effective layers on flexible technical textiles allows to:

- give self-sufficient power supply for vehicles and silo roofs.
- Building-integrated photovoltaics with textile-based solar cells.

New textile material for living

New textiles for aesthetical aspects

Optical fibres in woven fabrics of fine yarns (silk, wool, linen, and optical fibres).

Figure 18 - Applications of optical fibres on textile structures[13]

Fabrics can be dyed with specific pigments: thus, the colour change according to the intensity of light or heat to which they are exposed. Chromic materials change colour due to an external stimulus, which can be light, heat, electricity, pressure, liquid or electron beam. Inks and dyes are used for making chromic prints on textiles or for dyeing embroidery yarns.

New textile material for living

Functionalised textile materials

Photocatalytic textile coverings are 24/7 active in the presence of sunlight or full-spectrum fluorescent lamps and can eliminate more than 95% of viruses, bacteria and mold present in the environment, in the early 90 minutes of use. The functionalisation of textile surfaces allows for dirt-repellency and self-cleaning, bacteria-killing and mildew-proof.

The combination of nanomaterials and functional polymers, without hindering or altering the traditional "feel and flavor" of materials, allows for:

- Self and easy cleaning surfaces;
- Anti-microbial, anti-virus and mite repellency;
- IR and UV reflective materials;
- Biomonitoring systems directly printed onto the materials surface;
- Monitoring of VOC and interior air quality.

Nanosize particles such as titanium, silver, Barium titanate, alumina, silica, and others have been coated on textile surfaces by different technologies and processes:

- Atmospheric and vacuum plasma.
- Polymeric compounds reticulation by Electron Beam, UV microwaves, RF ultrasounds.
- Combination of nanomaterials, gas, polimers.

New textile material for building and living

Textile heating system

A new generation of heating panels is today available on the market, created with thin metall yarns for heating wires (warp yarn) and bus wires (weftyarn), realized with a special warp knitting technology. They can be used, among the others, in matresses.

New textile material for building and living
PCM for buildings, home and comfort

PCMs are thermal storage materials for regulating temperature. Microcapsules filled with paraffin wax are attached to textiles by coating or in the spinning process. When the wax changes its phase from solid to liquid and back, heat is absorbed and released. By cooling and warming the wearer, phase change textiles maintain the microclimate temperature within the comfort zone.

As demand in thermal comfort of buildings rise increasingly, the energy consumption is correspondingly increasing. The integration of PCM in building walls is a way to enhance the storage capacity of building envelops and then to rationalize the use of renewable and non-renewable energies.

New textile material for building and living
Shape memory materials

In response to external stimulus, shape memory materials change shape, and once stimulus is removed, return to their original shape. Thermally responsive SMPs are used in textiles for added temperature regulation and permeability. The shape change takes place at the transition temperature due to kinetic properties of molecular chains.

The integration of SMPs in fabric provides many fascinating and improved properties such as good aesthetic appeal, comfort, textile soft display, smart controlled drug release, fantasy design, wound monitoring, smart wetting properties and protection against extreme variations in environmental conditions.

4. OPPORTUNITIES AND TRENDS

Smart textiles encourage new models for generating creative and new solutions in architectural design and practice. The current trend in the development of materials for architectural applications gives importance to energy and sustainability issues, and this also applies to textiles in architecture. Fabrics applied in architecture need to combine strength and functionality in a lightweight product at competitive prices.

The application of textiles in architecture is in the interior, on the building envelope and in an urban or rural environment, and depending on the conditions of location, function and design characteristics, the required performance varies. There are different ways in which textiles and their properties are used in the construction of buildings. Textile membrane and tensile structures and sun protection systems are most commonly present. Textile membranes and tensile structures are most often present when creating roof structures, canopies, facades, and sun protection systems. The trend is the development of collapsible and non-collapsible structures and opportunities for their application for textile buildings, as second building skin, as facade components and structures between buildings (Figure 19).

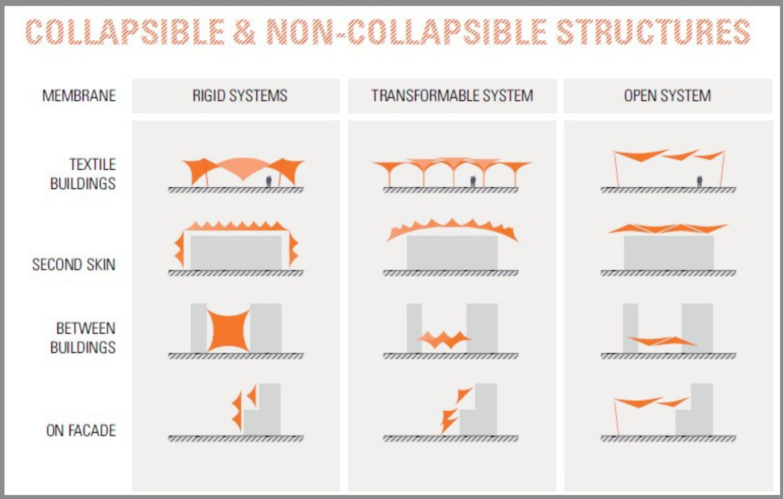

Figure 19 - Collapsible and non- collapsible textile structures and opportunities for their application in the built environment [14]

Regarding the application of textiles in architecture, the challenge is the continuous concept development in terms of adjusting to different conditions and requirements as well as the integration of new smart technologies. The following challenges can be identified that open up different opportunities:

- From a structural point of view, tessellating structures are a current challenge.
- Solar harvesting introduces the integration of PV cells into textile structures, which imposes specific characteristics in terms of form and supporting technologies.
- Requirements for different colour options and lighting effects, both in terms of natural lighting and artificial.
- Application of biomimetic in textile design giving opportunities for new or improved textile materials and textile architectural forms and structures.
- Integration of greenery into textile structures to contribute to environmental protection.

Smart textiles are able to sense different stimuli (signals), to respond and adapt their behaviour to them in an intelligent, or at list logical way.[15] Introduction to smart textiles and their applications. They may be divided into two classes: passive and active. Passive smart textiles have the ability to change their properties according to an environmental stimulation. Active smart textiles are fitted with sensors and actuators to connect internal parameters to the transmitted message. They are able to detect different signals from the environment (temperature, light intensity, pollution, etc.), to decide how to react, and finally to act using various textile based, flexible or miniaturized actuators (textile displays, microvibrating devices, LED, OLED, etc.). It can be noted that the most important requirements for smart textiles include soft and flexible sensors production. The application of such devices is necessary for the connection of architectural textile structures with the human beings, in order to recognize the reactions of users to the achieved comfort and to enable the reaction of textile components and systems in order to create appropriate comfort.

A present trend, regardless of the field of textile application, is that designers need to consider the real need and ease of use in terms of functionality, positioning, compatibility, maintenance and aftercare, and the clarity of the interface between the technology and the user.[16]

Today there is a different approach to textiles; fabrics have to be regarded not only just as a surface, to be interpreted graphically, aesthetically or by touch-sensitive, but as a material to all intents and purposes, with its own intrinsic structure and performances. The market of textile products started to change radically. Standard, traditional productions, mainly addressing the apparel market, are identified with a low innovation and technology level, medium to low quality and complex productions, with the use of state-of-the art process technologies and product research, a strong aesthetic element, as well as certain and high quality levels, quick time-to-market, production flexibility and customer service. Currently, there is a new phase in the textile field in which new materials allow to make dynamic and interactive products, able to offer protection, comfort and performance. The textile materials are therefore becoming the basis for a completely new range of new applications.

The last evolution of textile in smart, intelligent, digital and interactive materials is made growing day by day the interest in textile sector: today, dynamic market segments such digital, health, transportation, civil engineering, energy or security have an important added value that may be captured by textiles as supports.

Actually smart textiles have a wide range of applications:

- Medical applications
- Military applications
- Heat protection
- Comfort wear
- Civil engineering (building and geo applications)
- Interior and living - architecture
- Transportation
- Energy sector

Today we can see, and we can use and apply a few products of potential smart textiles. Many smart textiles are not yet fully developed, especially from the point of view of reliability, and are not actually ready for the market. There are hundreds and hundreds of prototypes that are more or less ready or reliable, in research laboratories, but the scale-up has not yet been done.

For example in the building sector, textile-based smart materials have shown a lot of promises. Smart textiles encourage new models for generating creative and new solutions in civil engineering projcts and in architectural design.

The current trend in the development of these materials gives importance mainly to:

1. Energy and sustainability issues.
2. Stimuli-responsive functional textile.

Stimuli-responsive functional textiles provide potential and enormous current opportunities in the textile industry, building sector and living and furniture segment. Smart textiles with stimuli-responsive can move or change their shapes, achieving different forms in garments, enhancing their functions and aesthetic appeal. Window curtains or screens with SMPs can open and close intelligently under environment stimulation, as seen in the previous parts of this report. The change of fabric configuration or functions can also be used for protection against extreme environments. With the rapid development of stimuli-responsive functional textiles and novel strategies for integrating these intelligent functions into textiles, it is anticipated that the research into smart textiles will grow in multiple dimensions as a result of their promising potential applications. In the future, textiles may perform functions that are much more significant, far beyond what is being achieved at present.

4.1 Energy and sustainability issues

Mainly in Europe, a number of structures, being them historical bridges, churches or palaces and monuments, are hundreds of years old. The structures are exposed to environmental and tectonic influences and therefore require maintenance, inspection and often monitoring.

But not only old building stock demands attention, newly built bold engineering structures designed for a service life of 100 years and more require continuous observation of how special influences damage or at least change the behaviour of the structure.

So the challenging structural health monitoring projects and solutions became fundamental in civil engineering discipline.

Conventional techniques used for SHM are limited to electrical means, i.e., the use of strain gauges for strain measurement, for instance, where a pool of wires carrying a current not only poses a safety threat, but also is tedious to install and is not resource-efficient.

With the advancements in material sciences, the sensor research field is heading towards the implementation of an ultimate "nerves system" that can be utilized to sense various, if not all, physical, chemical and biological aspects not only of living beings but also of natural and/or man-made surroundings. This is evident from current trends towards the "smart city" concept, where the implementation of sensor systems to monitor the physical conditions of the civil structures of a city plays a vital role in addressing the economic benefits and ethical need for safe and sustainable infrastructures. So, the fabrication of novel woven textiles with a fully integrated strain-sensitive yarn for application to the built environment as a structural health monitoring system to monitor and ascertain structural damage in real time are now a field to explore in details in the smart textile sector.

For example, optical fiber-based sensors "embedded" in functionalized carbon structures (FCSs) and textile net structures (TNSs) based on alkaline-resistant glass are at now realized for the purpose of structural health monitoring (SHM) of concrete-based structure.

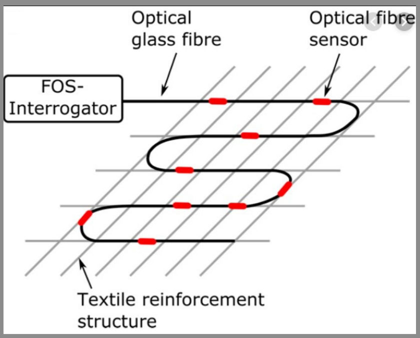

Figure 20 - Optical fiber-based embedded sensors [17]

4.2 Stimuli-responsive functional textile

In the textile world production, the non-woven is the sector with a constant growth trend. The key aspect of this development can be traced back to the universal necessity to reduce production costs, reduce energy consumption, use materials with a lower environmental impact and increase the production flexibility of the plants, all maximizing the quality and functional performance of the finished product. In textile and wood sectors, where materials obviously have a considerable volume of waste, the ability to transform them from wastes into resources is an advantage at all levels.

The building sector has started not from a long time to use textile fibers in the form of non-woven fabrics, basically to operate structure consolidations. Non-wovens are integrated into the construction itself becoming the stressed part of the structures. They are also used as thermal / acoustic insulation and can be constituted by mineral, synthetic and animals fibers (i.e. waste wool). The characteristics of nonwovens for building purposes are:

- High thermal / acoustic insulation properties (insulation of walls, floors, roofs, etc.);
- High mechanical resistance to delamination (structural reinforcements);
- High moisture and vapour permeability;
- Superior tear strength;
- Resistance to weather and to the aggression of mould and bacteria (outdoor or foundations);
- Duration of the performances over time.

Nonwovens in the home furnishing industry instead are evolving from use in traditional applications such as upholstery, floor coverings, underlay and blankets to innovative, smart solutions to improve and protect interiors.

Recent developments in the home furnishings industry include the creation of nonwovens that kill dust mites in bedding, repel dirt, and contain antimicrobial qualities.

Figure 21 - Samples of nonwovens [18]

Starting from the previous assumptions and state of the art, it is possible to point at innovative products realized with the airlay technology. The airlay forming machine uses a ducted air flow, to transport textile fibers and deposit them by layers on a perforated surface, in order to form a mat out of defined thickness and density. The randomized orientation of the fibers gives the veil an isotropic resistance to stress, a fundamental characteristic to use the product in a wide range of applications.

The solution of the transport and the formation of the web through air flows, represents the optimal compromise between simplicity, cost-effectiveness of the process, quality of the product and flexibility of use: the fibers and the other materials can be conveyed in mixes of various nature, length, denier and weight.

Different materials compositions was defined for the realization of many innovative products,
including recycled natural/wood fibers and thermoplastic fibers layers, able also to respond to environmental impact reduction.

The use of recycled fibres in the production of new materials is an important aspect for both environment and economy. Use of recycled fibres from textile wastes is gaining more importance day by day. It is known that recycled fibres exhibit weaker mechanical properties compared to virgin ones, but if appropriate application areas are found, the use of recycled fibres in the formation of new products have huge impact on saving the raw material resources and energy.

Figure 22 - Textile waste recycling process [18]

Airlaid webs formed by thermal bonding have shown good properties for their application in furniture (filler for sofa or chairs) and building sector (insulation panels) without the use of chemicals for the fibers bonding. The non-woven panels combining natural fibers or scraps with thermoplastic polymers by thermal compression showed interesting mechanical properties for furniture sector applications (panels for desk or bookcase) and building (internal wall covering panels). The performance properties of these new materials include functional characteristics such as moisture regain and absorbency or repellence, flame retardant and frictional behaviour.

5. CONCLUSIONS

Textile will be more and more widely used in all industrial sectors: building and living is one the most relevant in terms of possible applications and manufacturing potential-uptake.

Textile industry changes rapidly, the methods of today is not sufficient to meet the problems of tomorrow's technology. The industrial building market is in deep troubles nowadays, and the recent sanitary emergency created further effects on a demand that was already stagnating before. The pandemic is causing anxiety and some major changes in the home construction market. Everything from the touring process, to the building process, to the financing process, to the settlement process has been affected.

The economic picture of building sector gets a bit better when growing countries in Europe are considered, particularly Greece, Germany, Holland, Hungary, England. Lately, the housing market is beginning to show signs of stabilizing and is moving forward from the pandemic. The introduction of innovative products and solutions, with advanced performances and green concepts, can support the re-launch of the sector after the turbulent times of year 2020, giving new oxygen to the building and living economy. Here technical and smart textile can significantly come in, as they are able to bring properties (like the reduction of bacteria or even viruses) that could really make the difference for the future.

Jarod Blaney, Mid-Atlantic division president of PulteGroup (US) recently affirmed: "During this pandemic, I do think people will lean toward newer materials and a known history of the home, driving new demand over similarly priced resales in the short-term". Builders say there are plenty of factors pointing to a strong market in the future: population growth; household formation; historically low interest rates and inventory levels; and continuing growth of the 55 and older buyers. This favourable forecast has to be met by building sector manufacturers: for example, the need to sanitize closed environments can be facilitated by the wider use of textile structures, as well as the need for safer constructions, like in cases of earthquakes or other catastrophes (a tsu-nami for instance).

Construction industry sector members and clients will exponentially evaluate and consider workplace safety and compliance issues. Maintaining an "employment and a place of employment, which are free from recognized hazards that are causing or are likely to cause death or serious physical harm", is required of every employer. The same for public spaces and private homes.

This report is therefore a key tool to trigger possible solutions to all these issues by using technical textiles and smart textile based solutions. Such solutions range from the tenacity and elasticity of the building to its insulation, from the fighting of hazardous materials affecting human health and environment safety to energy saving, from recycling textile waste for performing applications to the monitoring of the structure health.

Emerging technologies such as plasma, nanotechology and microencapsulation finishing provide strong tools for the textile industry to produce a range of value-added technical textiles. The non-woven and the smart textile sectors show a constant growth trend, widening the use of textile products that are, and most likely will be in the near future, a sophisticated combination of (recycled) materials and new technologies, often leading to the replacement of traditional products for building with new performing applications, both for structures and interiors.

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