

# New materials developed within Contex-t

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## Abstract

Tensile membrane structures were the focus of extensive research during a four year FP6 project **Contex-T**. This project brought together experts from different disciplines to bring the technology for building membrane structures forward. Membrane materials, tension devices, supporting structure, comfort and safety aspects of membrane constructions were studied. This has resulted in a number of successful achievements. This paper will present and discuss a number of these achievements.

*Keywords: membranes, composites, material development, modelling*

## 1 Introduction

**Contex-T** is an EU-funded integrated project for SMEs that brings together a consortium of 29 partners from 10 countries and covers a four year period (August 2006 - August 2010). Each partner has been carefully selected for its expertise and knowledge in the field. This has resulted in a multi-disciplinary group where high-tech SMEs, research institutes and universities integrated their activities to develop a new generation of multifunctional textile materials.

Membrane structures consist of membranes, supporting structures and tensioning devices. The membranes are usually PVC coated polyester fabrics or glass fiber fabrics with a PTFE coating. These membranes are tensioned by steel cables and supported by a structure usually steel, aluminium or wood. Today the membrane provides a passive shelter with limited lifetime. In the project different routes are investigated to develop new concepts and new knowledge for development and manufacturing of active membranes which offer a safe and comfortable shelter. The approach does not only comprise the development of new materials but also addresses the intelligent use of the materials in the applications.

The research conducted in the project focused on the membranes and shells, the supporting structure and architectural and construction aspects. More in particular it aimed at:

- changing the surface properties of membranes in order to increase the ease of cleaning. The main route for achieving this goal was to look for innovative coatings based on silicon elastomer, sol-gel technology and new top coating.
- changing the optical properties in order to reflect heat radiation without imparting on the optical properties in the visual region and to model the comfort properties (including acoustic comfort) of membrane constructions.
- study of the fire safety of membranes and membrane constructions. The fire behavior of standard types of membranes as well as new designed membranes was studied using standardized test methods and new designed large-scale fire experiments. Furthermore attention went to the toxicity of smoke gases during a fire.
- the study of kinetic membrane constructions. The kinetic structures studied employed origami-like foldable construction elements;
- the replacement of the steel construction with cementitious based composites and steel cables with ropes;
- Knowledge management and collaboration tools for multi-sectorial product development;

In order to study the new designed materials, different demonstrator buildings were erected in different places in Europe. These buildings showed the materials which were developed during the project.

More detailed information on the project and the consortium can be found on the project website [1].

## **2 Membranes**

Because they are used outdoors, membranes are exposed to many different challenging environmental and weathering conditions. They quickly collect all types of dirt which is not easily removed. Finding an appropriate top coating which releases the dirt is therefore of paramount importance especially for PVC membranes as these membranes have a low surface tension. The requirements of a new membrane material should combine the good mechanical behavior, flexibility and ductility of polyester yarns combined with the non flammability and UV resistance of the glass fibers. The coating should also be flexible, easy to be welded, should have a good adhesion to the yarns and should have the possibility of different translucency. The surface should be self cleaning even under urban environment and vehicle exhaust. The appearance should be more elegant, more like a cloth, soft and high strength and demonstrating the character of high sophisticated fabric.

Different routes for achieving an easy cleaning surface were studied:

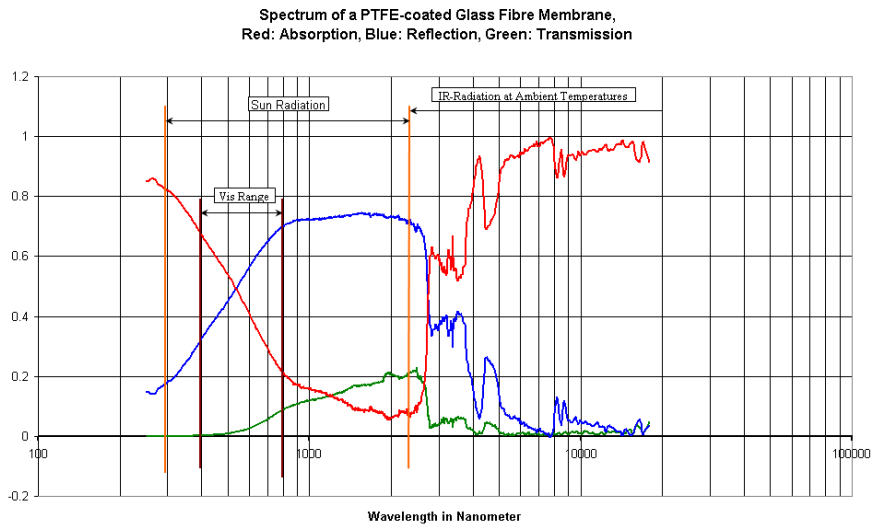
- silicone top-coat on silicone rubber and UV-curing systems
- topcoats based on acrylates, fluorocarbon and other polymeric species)
- New types of fluorinated top-coat
- Sol-gel based coatings

The UV-curable systems which were studied comprised different types of acrylates. Hardness, flexibility, abrasion resistance, adhesion and chemical resistance were criteria used to evaluate the different candidate solutions. Materials were extensively tested for soiling and cleaning behavior using agreed laboratory test methods and outdoor exposure. Reproducibility, thermal and UV resistance and processability were also subject to study. This characterization has permitted to select promising material combinations which were then produced an industrial scale for demonstration.



Figure 1: Soiled and cleaned membrane which is partially treated with the new topcoatings.

Membrane structure are passive optical barriers. In order to create a comfortable membrane it should permit the transmission of visual radiation but shield the enclosed environment from radiation carrying heat. In the following figure the transmission, reflection and absorption spectrum is presented for a PTFE-glass membrane.



Reflection, transmission and absorption of radiation through PTFE-glass membranes

The modification of the optical properties of membranes was studied by PVDF techniques with different metallic and metal oxide layers and by ITO nano-particle top layers on membranes. Different types of ITO nano-particles in combination with a suited lacquer composition and also suited stacking of layers was studied.

### 3 Membranes constructions

Membrane structures are generally supported by steel construction and steel cables. This steel construction unfortunately is prone to corrosion and therefore the consortium looked for alternative solutions for these steel components.

Cementitious composites offer interesting alternatives either for the complete structure or for parts of the structure. Vubonite, which is a room hardening two component system was studied and further developed. Without reinforcement, its properties are similar to concrete or ceramics. However, since it can be reinforced with glass fibers, very thin but strong elements can be produced. Vubonite combines composite materials technology with requirements which are essential for construction purpose. As such it is presently a unique material. Vubonite is an inorganic phosphate cement and is developed by Vrije Universiteit Brussel, partner in the project [2-7]. The material has significant advantages compared to polyester resins. It is water based and does not require solvents. It generates no VOC or odour and produces no chemical waste. It is absolutely incombustible and has high temperature stability. There are however no design rules available for this high fibre content materials and it shows brittle failure which is dangerous for a building material. During the project a new continuous impregnation method was developed which was patented. This technique allowed a more controlled fibre wetting and post-compaction of the laminate with or without moulding. Careful characterization of the plates produced by this technique, showed that the mechanical behavior of the plates were superior to plates produced by hand lay-up techniques.

In this research a suitable scrim structure to reinforce the vubonite structures was studied. Different scrim structures were analysed in order to find satisfying fiber matrix interaction and sufficient fiber/matrix ratio.

The replacement of steel cables by ropes was studied and especially the design of the suitable connectors and terminators for ropes proved to be challenging. The problem was successfully solved and a patent is pending on the design of the connectors.

#### **4 Comfortable and safe membranes buildings**

Comfort and safety are essential in membrane constructions. Acoustical properties and heat transmission properties are essential for achieving high levels of comfort. The project studied these properties extensively.

The comfort of people or the climate conditions which are required because of the use of the space (museums, operation chambers...) prevail on the rational use of energy: the striving towards a low energy use cannot go at the expense of user comfort. It is the aim of the research to determine the quality levels that can be reached with textile membranes. Quality levels are defined in EN 15251:2005; Criteria for the Indoor Environment including thermal, indoor air quality, light and noise. For membrane components, two thermal elements are crucial: thermal transmittance and avoidance of internal surface condensation.

Until recently, the evaluation of the energy efficiency of a building was based only on the thermal insulation quality of the building envelope. In the mid nineties European consensus grew around an energy performance approach. In this approach the thermal insulation quality of the building envelope remains important, but attention is also paid to the energy fluxes caused by solar radiation, internal heat gains, infiltration, ventilation, heating, cooling and (artificial) lighting

The feasibility to integrate photovoltaic cells in membranes was also studied. Flexible solar cells are today on the market but it was unclear if these components could be integrated due to the high tension which was applied to the membranes. These high tensions can not be transferred to the solar cells as this would lead to destruction of the component. A solution was found in the way these solar cells were attached to the membrane. An intermitted layer was used in to prevent the transfer of forces from the membrane to the photovoltaic cell.

When sound insulation is considered, the main advantage is the low bending stiffness of membranes, allowing dispelling the adverse effect of coincidence out of the building acoustical frequency region. A further advantage may be that sufficiently curved membranes do not show any modal behavior, excluding transmissionpeaks at eigen frequencies. Permeable or microperforated membranes may, when used in double or multilayered membrane constructions, lead to higher sound reduction in certain frequency ranges.

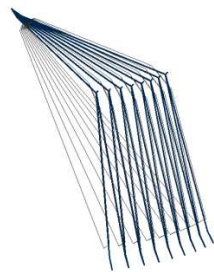
The main disadvantage and impediment of membranes is obviously their low surface mass. However, by carefully designing multilayered constructions, comprising other types of materials, such as poro-elastic or rigid-elastic materials, high sound insulation may be achieved. Membranes have also interesting properties for absorbing sound. Especially permeability gives them an extra way of dissipating

energy by friction effects without having to use a porous material. Also microperforated membranes can be easily designed and tuned to be effective in certain frequency regions. Here as well, the use of double or multi-layered structures, or adding extra damping by porous layers may considerably extend the absorption bandwidth and effectiveness of membrane absorbers.

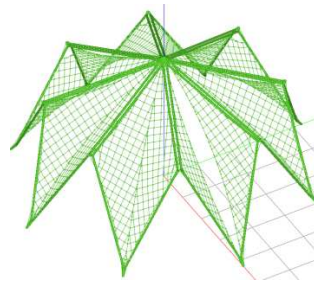
Fire behavior of membranes was studied for a number of standard membranes with small-scale cone calorimeter tests, fire classification test methods prescribed by EN 13501-1, and large-scale fire tests as a reference [7]. The tests were made in order to characterize the products and to relate the test results to the fire behaviour of the membranes in a building. For this a modified room corner test scenario was used according to ISO 13784 and ISO 9705. PVC-PES and Silicone-Glass type membranes were studied and clearly showed a fundamental difference in fire behavior and room conditions during the fire. These differences are due to the fact that PVC-PES membranes break open when exposed to flames while glass fabrics stay intact. This results in higher temperature conditions in the room and in the door. Temperatures up to 350°C are observed for a long period in rooms covered with glass based membranes. It is important to note that all membrane products tested in the large-scale room scenario gave acceptable results when comparing with the same criteria as for normal building products.

## 5 Kinetic membrane constructions

Generally speaking, kinetic structures in architecture consist of a ‘skeleton’ and a ‘skin’ which work together on a functional and structural level to provide shelter. The skeleton, or bar system, acting as a primary load bearing structure, is called kinetic (or kinematic) when movement is introduced in the system by means of a mechanism, aiming at transforming the geometry. For the system to be able to act as a fully fledged architectural shelter, a skin – or membrane - is attached to the primary structure before or after the deployment.



Folded structure



Unfolded structure

## **6 Working together in a large cross-sector consortium**

As described above, the contex-T consortium consists of 29 partners from 10 different countries. It comprises organizations from research and industry, manufacturers and service providers, SME and large companies from several industry sectors. Only through this extreme diversity of the consortium it became possible to target and to finally achieve the wide-spread objectives laid out at the beginning of the project. However, this tremendous potential brought up new challenges in terms of project management and especially the management of knowledge within the project, for which reason a whole project work package has been dedicated to these issues.

To enable collaborative work of partners all across Europe, without having to rely on numerous personal meetings, cutting edge information and communication technologies had been applied. A collaborative web space has been set up for the project which had been accessible for each and every project partner at any time. Besides 'standard' project management features, like a common document repository, a conjoint calendar, the project address base and web links to pages of common interest, the collaborative web space had been extended with dedicated applications explicitly tailored to the needs of the consortium. Already at the beginning, a data base application came to use to gather and to organize information about state-of-the-art material (which could be used as benchmark throughout the project). Furthermore, applications to support the innovation activities within the various working areas have been installed. Amongst them are applications to present current developments to the consortium, to schedule tests for prototypes and samples, or to order materials from other partners. All of these applications have been supplied with appropriate workflow functionalities to assure an appropriate flow of information and material.

Bearing in mind the knowledge-intensive work carried out to create all these new materials, it will not surprise that the key success factor for the project has been the cognizant handling of knowledge. For every piece of newly developed knowledge it had to be checked if it should be made available to the public (e.g. for dissemination activities), if it has to be distributed to consortium partners (e.g. to be used in other innovation activities), or if it should be treated as internal (sensible) knowledge. Accordingly, three so-called knowledge access layers ('Public', 'Consortium', 'Internal') (see also [2]) have been introduced throughout the project and also have been implemented as foundation for all applications on the collaborative web space.

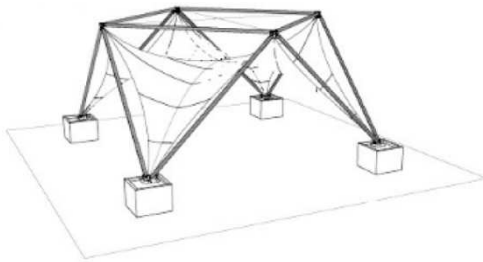
Even though the approach and tools had been new to most project partners, and therefore required time to become acquainted with, the course of the project showed that these concepts, methods and tools have been capable to significantly support the activities of the whole consortium. The documentation of knowledge and materials developed throughout the project has especially been crucial for a successful planning and realization of the demonstration activities presented in the following chapter.

## 7 Demonstrators

In order to study the applicability of different concepts developed in the research phase of the project an number of prototype materials were developed using industrial processes. The aim was to build membrane structures to study the behavior of the materials in near-real conditions. The demonstrators:

- Demonstrator 1: “deployable demonstrator”: a foldable structure for kinetic architecture
- Demonstrator 2: Development of a “cube sail” demonstrator for membranes, cables, and belts
- Demonstrator 3: Development of a “weaving arches” demonstrator for supporting structures,
- Demonstrator 4: Development of a “two story Vubonite” building frame made by vubonite matrix composite members
- Demonstrator 5: Development of thermo-boxes to determine membrane thermal properties
- Demonstrator 6: Development of a demonstrator to determine heat radiation, thermal insulation, and cleaning properties of membranes.
- Demonstrator 7: Integrating photovoltaics and a garden tent

In the following figures two of these demonstrator structures are presented.



Integration of membranes and cables



Two- story vubonite structure

## 8 Acknowledgement

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