GEMTEX Laboratory

www.gemtex.fr

Research activities 2008 - 2011

LABORATOIRE DE GÉNIE ET MATÉRIAUX TEXTILES
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1. Strategy of the development

The GEMTEX research laboratory belongs to ENSAIT, French Grande Ecole one of the leading textile schools in Europe which graduates more than one hundred twenty students per year on Ms Level in France. GEMTEX’s research activities are organized around a three of autonomous research groups, each of which is headed by one or more professors or research scientists and dedicated to applied research for Textiles. These groups are focused on following activities:

- Human Centred Design (denoted HCD),
- Multifunctional Textiles and Processes (denoted MTP),
- Mechanics - Textiles Composites (denoted MTC)

In addition, GEMTEX hosts the

- EUGENIE Technology Transfer Unit aiming at development of research activities with industrial partners and
- Collaborative Projects Unit with main activities focused on development and management of collaborative projects on regional, national and European level.

1.1 History

Textile research at ENSAIT began with GEMTEX creation in 1992 with two research groups: Textile chemistry and Textile automation. In the beginning, the laboratory has been focused mainly on academic researches without close relations with industrial companies. Since 1992, GEMTEX laboratory has developed its research activities, collaborations with other laboratories and started to be involved with industrial companies in early 2000s. Since 2000, the laboratory has undertaken many actions in order to comfort its position as an important actor for textile research with a truly global dimension. Industrials collaborations have been strongly amplified in the last years with creation of EUGENIE in 2009 and with a development of activities related to collaborative projects last few years. All activities undertaken by the GEMTEX take also into account the European dimension. The GEMTEX is part of the AUTEX network (Association for Universities of Textiles) which regroups universities offering textile training and research.

As said above, GEMTEX tries to play an important role in textile innovation and publish its results in international Journals with impact factors ranging from 0.5 to 5. Figure 1 exhibits the increasing activity of publishing. From 2005 to date, paper number has increased of a 2.5 factor.

![Figure 1: Publishing activity in GEMTEX (from 2003 to date in Scientific Journals with Impact Factor)](image)
The Table 1 summarizes GEMTEX European integrated projects (Framework Programmes 6 and 7). GEMTEX – ENSAIT is coordinator of INTIMIRE and MAPICC 3D integrated projects and is involved as partner in several other projects.

Table 1. FP 6 and FP 7. Integrated Projects

<table>
<thead>
<tr>
<th>Year</th>
<th>FP 6</th>
<th>FP 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>1 (Intelltex)</td>
<td>1 (Bioagrotex)</td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td>3 (Bioagrotex, IMS, Intimire)</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>4 (Bioagrotex, IMS, Intimire, Mapicc 3D)</td>
</tr>
</tbody>
</table>

Similar to publishing activity, involvement of GEMTEX in European as well as Federal collaborative projects has increased significantly those past few years. To date, GEMTEX leads European projects in the frame of FP7 and built close partnerships with other universities to take part of other research programs (see section: List of Projects 2010 - on progress).

GEMTEX researchers participate also to a number of International Scientific Conferences (more than 50 per year) and their papers are published in conference proceedings. However, in this report only journals articles, chapters in books and patents from 2008 to date have been presented in order to focus on the best published papers.

1.2 Strategy and innovations

GEMTEX laboratory consolidates its image on international level and remains an important research partner in the field of textiles, clothing and advanced materials such as textile composites. The development strategy of GEMTEX is organised on short and long terms and must guarantee its scientific excellence, independence and sustainability. GEMTEX laboratory has to stay the main innovation tool of ENSAIT. The scientific production of the laboratory has to be balanced in terms of quality and quantity and regarding to its structure including 3 research groups. The active participation to scientific networks and clusters including creation of common research group with DTPCIM textile materials laboratory of “Ecole des Mines de Douai” and participation to the research cluster GIS MTA (Research cluster on advanced textile materials) composed of 5 organizations : ENSCL\(^1\) Lille, HEI\(^2\) Lille, ENSAIT, EMD\(^3\) and Institut Pasteur Lille\(^4\), is one of the laboratory’s priorities. DTPCIM laboratory research activities concerning the infusion process and modelling are complementary with the activities of the group Mechanics – Textile composites which is specialized in design and building of multilayer and 3D reinforcements for composite structures. GIS MTA research cluster aims at

\(^1\) ENSCL stands for Ecole Nationale Supérieure de Chimie de Lille, [http://www.ensc-lille.fr](http://www.ensc-lille.fr/)
\(^2\) HEI stands for Hautes Etudes d’Ingénieurs, [http://www.hei.fr](http://www.hei.fr/)
\(^3\) EMD stands for Ecole des Mines de Douai, [http://www.ensm-douai.fr](http://www.ensm-douai.fr/)
\(^4\) [http://www.pasteur-lille.fr/fr/accueil/index.htm](http://www.pasteur-lille.fr/fr/accueil/index.htm)
increasing of critical mass of laboratories dealing with researches in the field of flexible and multifunctional materials in order to improve the efficiency and a success rate concerning national and European call for projects. Moreover, a broad area of cluster members expertise ranging from medical applications (Institut Pasteur of Lille) to chemical and colour sciences (ENSCL and HEI) and textile & composite activities (EMD and ENSAIT) is supposed to bring optimal facilities and answers to industrial problems related to our activities.

The scientific cooperation agreement signed in 2010 between ENSAIT and Ecole des Mines de Douai in 2007 enabled a development of several research actions between the DTPCIM laboratory and GEMTEX. Therefore, 5 large research projects in the field of composite structures, on national and European levels, have been approved and have started recently. These activities initiated a creation of a common research group between two laboratories specialized in the field of textile composites.

2. Laboratory structure and members

GEMTEX laboratory structure is shown in Figure 2. Research activities are organised in 3 research groups with important collaborations among them. The three research components are centered on textile materials and processes and lead by senior Professors. The major strength of GEMTEX Lab. is its deep knowledge of textile structures and its know-how to manufacture them.

Figure 2. GEMTEX organisation

The list of permanent members of the laboratory is given in the Table 1 with their functions and field of expertise. The faculties (28) are presented in the first part of the Table 1, and then Post-Doctoral researchers (3), Research Engineers (4), Technicians (3) and Administrative staffs (9) are presented.
Altogether, there are 47 permanent members. In the Tables 2 and 3 the lists of current PhD students and PhD students that have completed their studies in 2010 are given.

Table 1. GEMTEX permanent members

<table>
<thead>
<tr>
<th>First Name</th>
<th>Last Name</th>
<th>Function</th>
<th>Fields of expertise</th>
<th>Major Research field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauthier</td>
<td>BEDEK</td>
<td>Assistant Professor (HEI)</td>
<td>Functionalized textiles</td>
<td>HCD</td>
</tr>
<tr>
<td>Usha</td>
<td>BEHARY - MASSIKA</td>
<td>Assistant Professor</td>
<td>Bio-textiles</td>
<td>MTP</td>
</tr>
<tr>
<td>François</td>
<td>BOUSSU</td>
<td>Assistant Professor</td>
<td>Textile Composites - ballistics</td>
<td>MTC</td>
</tr>
<tr>
<td>Pascal</td>
<td>BRUNIAUX</td>
<td>Professor</td>
<td>Virtual garment</td>
<td>HCD</td>
</tr>
<tr>
<td>Christine</td>
<td>CAMPAGNE</td>
<td>Professor</td>
<td>Functionalized textiles</td>
<td>MTP</td>
</tr>
<tr>
<td>David</td>
<td>CREPIN</td>
<td>Assistant Professor</td>
<td>Mechanics - Finite Elements</td>
<td>MTC</td>
</tr>
<tr>
<td>Eric</td>
<td>DEVAUX</td>
<td>Professor, Head MTP Group</td>
<td>Nano structures - Polymers</td>
<td>MTP</td>
</tr>
<tr>
<td>Daniel</td>
<td>DUPONT</td>
<td>Professor (HEI)</td>
<td>Colour</td>
<td>HCD</td>
</tr>
<tr>
<td>Pierre</td>
<td>DOUILLET</td>
<td>Assistant Professor</td>
<td>Mathematics</td>
<td>HCD</td>
</tr>
<tr>
<td>Ahmida</td>
<td>EL ACHARI</td>
<td>Associate Professor</td>
<td>Grafting, chemistry</td>
<td>MTP</td>
</tr>
<tr>
<td>Manuela</td>
<td>FERREIRA</td>
<td>Assistant Professor</td>
<td>Materials</td>
<td>MTP</td>
</tr>
<tr>
<td>Xavier</td>
<td>FLAMBARD</td>
<td>Assistant Professor, ENSAIT Director</td>
<td>Knitting</td>
<td>MTC</td>
</tr>
<tr>
<td>Stéphane</td>
<td>GIRAUD</td>
<td>Assistant Professor</td>
<td>Flame retardancy</td>
<td>MTP</td>
</tr>
<tr>
<td>Michel</td>
<td>HAPPIETTE</td>
<td>Assistant Professor</td>
<td>Supply chain management</td>
<td>HCD</td>
</tr>
<tr>
<td>Ludovic</td>
<td>KOEHL</td>
<td>Professor, GEMTEX Deputy Director</td>
<td>Sensory analysis, data processing</td>
<td>HCD</td>
</tr>
<tr>
<td>Vladan</td>
<td>KONCAR</td>
<td>Professor, GEMTEX Director</td>
<td>Smart textiles</td>
<td>HCD</td>
</tr>
<tr>
<td>Julie</td>
<td>LEFEVRE</td>
<td>Researcher (HEI)</td>
<td>Colour</td>
<td>MTP</td>
</tr>
<tr>
<td>Xavier</td>
<td>LEGRAND</td>
<td>Assistant Professor</td>
<td>Textile Composites - structural parts</td>
<td>MTC</td>
</tr>
<tr>
<td>Maryline</td>
<td>LEWANDOWSKI</td>
<td>Assistant Professor</td>
<td>Measuring, testing</td>
<td>MTP</td>
</tr>
<tr>
<td>Anne</td>
<td>PERWUELZ</td>
<td>Professor</td>
<td>Surface treatment, sustainable development</td>
<td>MTP</td>
</tr>
<tr>
<td>Besoa</td>
<td>RABENASOLO</td>
<td>Professor</td>
<td>Sustainable Supply Chain</td>
<td>HCD</td>
</tr>
<tr>
<td>François</td>
<td>RAULT</td>
<td>Assistant Professor</td>
<td>Functional textiles</td>
<td>MTP</td>
</tr>
<tr>
<td>Maryline</td>
<td>ROCHERY</td>
<td>Assistant Professor</td>
<td>Functional textiles</td>
<td>MTP</td>
</tr>
<tr>
<td>Fabien</td>
<td>SALAÜN</td>
<td>Assistant Professor</td>
<td>Micro capsules, comfort</td>
<td>MTP</td>
</tr>
<tr>
<td>Sébastien</td>
<td>THOMASSEY</td>
<td>Assistant Professor</td>
<td>Forecasting, decision algorithms</td>
<td>HCD</td>
</tr>
<tr>
<td>Bernard</td>
<td>VERMEULEN</td>
<td>Assistant Professor</td>
<td>Fibres &amp; yarns</td>
<td>MTP</td>
</tr>
<tr>
<td>Philippe</td>
<td>VIROMAN</td>
<td>Assistant Professor</td>
<td>Non-woven structures</td>
<td>HCD</td>
</tr>
<tr>
<td>Xianyi</td>
<td>ZENG</td>
<td>Professor, Head HCD Group</td>
<td>Sensory analysis, data processing</td>
<td>HCD</td>
</tr>
<tr>
<td>Aurélie</td>
<td>CAYLA</td>
<td>Post Doc</td>
<td>Sensors, nano structures</td>
<td>MTP</td>
</tr>
<tr>
<td>Cédric</td>
<td>COCHRANE</td>
<td>Post Doc</td>
<td>Sensors &amp; actuators</td>
<td>HCD</td>
</tr>
<tr>
<td>Jalloul</td>
<td>ELFEHRI</td>
<td>ATER: temporary Teacher and Researcher</td>
<td>Automation</td>
<td>HCD</td>
</tr>
<tr>
<td>Jallal</td>
<td>ISAD</td>
<td>ATER: temporary Teacher and Researcher</td>
<td>Chemistry</td>
<td>MTP</td>
</tr>
<tr>
<td>Fern</td>
<td>KELLY</td>
<td>Post Doc</td>
<td>Chemistry, flexible displays</td>
<td>HCD</td>
</tr>
<tr>
<td>Xuyuan</td>
<td>TAO</td>
<td>ATER: temporary Teacher and Researcher</td>
<td>Textile electronics</td>
<td>HCD</td>
</tr>
<tr>
<td>PhD #</td>
<td>First Name</td>
<td>Last Name</td>
<td>PhD thesis title</td>
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<td>------</td>
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<td>-------------</td>
<td>----------------------------------------------------------------------------------</td>
<td></td>
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<tr>
<td>PhD 1</td>
<td>Benjamin</td>
<td>ALLART</td>
<td>Integration of tracking filters for tracking a wheelchair from a mobile base</td>
<td></td>
</tr>
<tr>
<td>PhD 2</td>
<td>Claire</td>
<td>GRELAKOWSKI</td>
<td>Textile electronics interfaces</td>
<td></td>
</tr>
<tr>
<td>PhD 3</td>
<td>Stojanka</td>
<td>PETRUSIC</td>
<td>Textile structures for controlled drug delivery systems</td>
<td></td>
</tr>
<tr>
<td>PhD 4</td>
<td>Ayham</td>
<td>ALRUHBAN</td>
<td>Design and characterization of new knitted textile reinforcements for the development of composite material</td>
<td></td>
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<tr>
<td>PhD 5</td>
<td>Chiraz</td>
<td>AMMAR</td>
<td>Control and characterization of colour effects - application to textile-based materials</td>
<td></td>
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<tr>
<td>PhD 6</td>
<td>Ahmed</td>
<td>HAMMOUDA</td>
<td>Development and optimization of a binding machine single sided dried composite textile preforms</td>
<td></td>
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<tr>
<td>PhD 7</td>
<td>Marie</td>
<td>LEFEVRE</td>
<td>New composite structures integrating multilayer fabrics for vehicle armors</td>
<td></td>
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<tr>
<td>PhD 8</td>
<td>Cuong</td>
<td>HA-MINH</td>
<td>Characterization and optimization of new textile structures resistant to ballistic impact</td>
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<tr>
<td>PhD 9</td>
<td>Jan</td>
<td>VAN ROEY</td>
<td>Study of dynamic behaviour of one sided device for linking of composite reinforcements</td>
<td></td>
</tr>
<tr>
<td>PhD 10</td>
<td>Lichuan</td>
<td>WANG</td>
<td>Developing a support system for creation of clothing styles using advanced computing</td>
<td></td>
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<tr>
<td>PhD 11</td>
<td>Awa Soronfe</td>
<td>DOUMBIA</td>
<td>Nanoparticles for the production of materials and biodegradable acid-based PLA</td>
<td></td>
</tr>
<tr>
<td>PhD 12</td>
<td>Marion</td>
<td>AMIOT</td>
<td>MANSART: Textile Materials Architectures structural applications</td>
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<tr>
<td>PhD 13</td>
<td>Senem</td>
<td>KURSUN</td>
<td>Support system for the visually impaired people integrated within clothing - use of conductive fibres</td>
<td></td>
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<tr>
<td>PhD 14</td>
<td>Jérôme</td>
<td>VILFAYEAU</td>
<td>Numerical modelling of the weaving process of fibrous reinforcements for composites</td>
<td></td>
</tr>
<tr>
<td>PhD 15</td>
<td>Munir</td>
<td>ASHRAF</td>
<td>Study and development of treatment of nanotechnology-based textiles: application to self-cleaning fabrics</td>
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<tr>
<td>PhD 16</td>
<td>Nizar</td>
<td>DIDANE</td>
<td>Development of intumescent polyester fibres for manufacturing of textile materials recovery and composite structures</td>
<td></td>
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<tr>
<td>PhD 17</td>
<td>Brahim</td>
<td>LAOUISSSET</td>
<td>Development of an intelligent design support system for production of advanced composite materials</td>
<td></td>
</tr>
<tr>
<td>PhD 18</td>
<td>Walid</td>
<td>NAJVAR</td>
<td>Contribution to numerical simulation of stamping process textile preforms for composite applications</td>
<td></td>
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</table>
Table 3. GEMTEX PhD students who graduated in 2010 and 2011 (14, until the end of May’11)

<table>
<thead>
<tr>
<th>PhD #</th>
<th>First Name</th>
<th>Last Name</th>
<th>PhD thesis title</th>
</tr>
</thead>
<tbody>
<tr>
<td>PhD 1G</td>
<td>Walid</td>
<td>JERBI</td>
<td>Improving the productivity of non-woven production lines. Development of online quality analysis of non-woven products</td>
</tr>
<tr>
<td>PhD 2G</td>
<td>Ahmed</td>
<td>KERKENI</td>
<td>Biofunctionalized PET fibrous structures with molecules of biological origin</td>
</tr>
<tr>
<td>PhD 3G</td>
<td>Radhia</td>
<td>ABD JELIL</td>
<td>Modelling the relationship between process parameters and textile characteristics of the finished product from integration of measured physical and human knowledge</td>
</tr>
<tr>
<td>PhD 4G</td>
<td>Ionut</td>
<td>NEAGU</td>
<td>Three-dimensional modeling and simulation of dynamic behavior of the yarns submitted to strengths from fabric</td>
</tr>
<tr>
<td>PhD 5G</td>
<td>Gauthier</td>
<td>BEDEK</td>
<td>Design of a multilayer auto cooling textile structure</td>
</tr>
<tr>
<td>PhD 6G</td>
<td>Christophe</td>
<td>NOCITO</td>
<td>Photovoltaic textile structures integrated to owning</td>
</tr>
<tr>
<td>PhD 7G</td>
<td>Xuyuan</td>
<td>TAO</td>
<td>Smart textiles structures – fibrous transistors</td>
</tr>
<tr>
<td>PhD 8G</td>
<td>Jalloul</td>
<td>ELFHEKI</td>
<td>Anti-ulcer device – system approach</td>
</tr>
<tr>
<td>PhD 9G</td>
<td>Aurélie</td>
<td>CAYLA</td>
<td>Implementation of multi-filament-based polymer blend with biphasic loaded carbon nanotubes</td>
</tr>
<tr>
<td>PhD 10G</td>
<td>Gwilady</td>
<td>BENISTANT</td>
<td>Anti-viral functionalization of textile structures</td>
</tr>
<tr>
<td>PhD 11G</td>
<td>Yijun</td>
<td>ZHU</td>
<td>Identification and characterization methodology of the criteria of well-being of clothing textiles</td>
</tr>
<tr>
<td>PhD 12G</td>
<td>Gaurav</td>
<td>AGARWAL</td>
<td>The influence of technical parameters of textile products on the sensory effects of softening by instrumental measurements and sensory analysis</td>
</tr>
<tr>
<td>PhD 13G</td>
<td>Saad</td>
<td>NAUMAN</td>
<td>Geometrical Characterization of Warp Interlock Reinforcement Based Composites And Their Online Structural Health Monitoring Using Flexible Textile Sensors</td>
</tr>
<tr>
<td>PhD 14G</td>
<td>Inès</td>
<td>BOUFATEH</td>
<td>Analysis of criteria of social responsibility and environmental assessment of the supply chain for the textile</td>
</tr>
</tbody>
</table>

As a world-class research facility, GEMTEX Lab is a valued partner to the local, regional and national education community. GEMTEX Lab's long-term commitment to science education continues to focus on increasing the number of PhD students with a substantial background in textiles, strengthening the motivation and preparation of all students.
3. Research Groups

This section gives a comprehensive overview of research activities of GEMTEX groups their main achievements and collaborations among them.

The overall importance of scientific research is evident. All the objects, real and virtual, are made as result of research activities. Highly profitable and flourishing industrial sectors are those where the research efforts and investments were the strongest. The situation in the Textile – Retail complex is different. Research activities supposed to bring higher added value to textile based objects and products are not satisfying. Despite of efforts, the number of high quality scientific articles is not significant all over the world and particularly in Europe, comparing to the number of jobs and the annual turnover of our industry. This situation should change. The promotion of research activities in the Textile – Retail complex are the main objectives of the GEMTEX laboratory. This is also done through the organization of International Scientific Conferences and exhibitions involving GEMTEX members as scientific committees’ members or even Conference Chairmen.

The GEMTEX laboratory scientific excellence, together with the relevance to industry or to GEMTEX goals, should be achieved by the important research efforts in the field of textile processes and materials. The purpose of the report on GEMTEX research activities is to outline various scientific activities of research groups.

3.1 Human Centred Design Research Group

3.1.1 Keywords:
Decision support system, modelling and optimization of products, processes and organizational systems, human factors: perception, cognition and man/material/environment interactions, instrumentation and control
3.1.2 Overview

Regrouping the skills of 11 permanent teachers/researchers of GEMTEX Laboratory, this research group aims at developing advanced computational tools and instrumental and human measuring methods for design of advanced materials, such as multifunctional and intelligent materials, as well as personalized garments. Characterization and modelling of human factors, including expert knowledge on products and processes, consumer’s perception (fabric hand, textile appearance, comfort and well-being), fashion styles and body shapes, and control and optimization of man/material/environment interface, constitute the key issues in the proposed design processes for materials and finished products. Modelling with learning from experimental data, human cognition and physical lows is the main computational tool used in this group. In the frame of these activities, 5 PhD students defended their thesis in 2010 and 2011, and 9 PhD students are carrying out their research projects.

The activities of HCD group are realized in strong cooperation with MTP group (Multifunctional Textiles and Processes) and MTC (Mechanics – Textile Composites), in the frame of Sustainable development-based design for materials and processes, sensory design of advanced materials, and design of smart textiles and also in structural health monitoring of composites using flexible fibrous sensors and adapted miniaturized electronic devices. About 50% PhD students working on the topics of HCD are supervised by researchers of these groups.

Our research group is working around the following topics:

1 - Personalized product design using virtual prototyping

This theme aims at developing a new design concept called « man/garment/environment interface», which requires collaborations between different areas. Its main objective is to integrate virtual prototypes, sales elements, fashion styles and wearer’s fitting comfort into the same design process by suitably applying garment CAD software and modelling textile structures and human bodies. According to Figure 3, this virtual technology-based design process include the following steps: a) 3D digitalization of human body using body scanner (Fig. 3-1) ; b) Modelling of consumer’s body surface from data generated from the scanner (Fig. 3-2) using a neural network; c) Creation of a 3D adaptive and parametric model with the concept of man/garment interface , integrating an adaptive or fixed model of human body, a model of ease allowance and a model of garment (Fig. 3-3); d) Creation of a model of ease allowance using fuzzy logic and sensory evaluation of fitting comfort; e) Creation of a garment model using draping techniques (Fig. 3-4) based on the model of ease allowance and the 3D
visualization of the virtual garment, and realization of 2D garment patterns for analyzing fabric deformation and verifying material constraints (Fig. 3-5,6); e) Dynamic visualization of the realized 3D virtual prototype for validating the proposed design (Fig. 3-7), and association of the geometric model of the garment and the mechanical model in which Newton law is applied (Fig. 3-8).

The concept of man/garment/environment interface enables to relate the work of different design offices to sales elements on Internet through a series of adaptive models. This virtual technology-based design process can increase 5 times the potential of design. It has been successfully applied to garment and furniture design.

2 - Sustainable development-based design for materials, processes and supply chain

This theme first aims at developing a number of multi-criteria decision support systems for evaluating textile processes, materials and organizations of the textile supply chain in terms of environment, human health and social impacts. A normalised evaluation procedure will be proposed to acquire relevant data from professional experts and physical measurements. The decisions support systems can be optimised by taking into account not only the specific evaluation and measuring data but also the general professional human knowledge on production systems.

Currently, an evaluation system of multiple criteria decision making has been developed in order to carry out the life cycle assessment of textile products in the whole textile supply chain in terms of environmental impacts. Another risk-based system of multi-criteria decision support system has been developed by integrating more general sustainable criteria (environment protection, recycling capacity, energy saving, human health and safety, and social impact) (See Figure 4). By combining expert knowledge on enterprise strategy and measured criteria using linguistic computation techniques, this method permits to select the most appropriate textile material and its supplier.

![Figure 4. General scheme of the hierarchical evaluation structure](image)

Based on the evaluation results, new organizational solutions are proposed for realizing demand driven production, sourcing and marketing.

In the past decades, manufacturing activities have mainly migrated in countries which provide lower production costs, especially in the textile-apparel sector. In the framework of sustainable development, this new configuration involves numerous logistical and supply chain challenges. Indeed, the increase of lead times combined with the short life cycles of products such as fashion apparel, require advanced information and decision systems. Therefore, demand forecasting is then crucial and
extremely challenging since it is the entry of the supply chain management. The success of the whole supply chain for textiles and garments highly depends on forecasting accuracy.

A number of new forecasting systems have been proposed (see Figure 5) by taking into account the textile-apparel constraints, including:
- horizons related to the supply lead time,
- SKU proliferation
- high-fashioned life cycle of products
- seasonal trends
- many exogenous factors

**Figure 5. Decision support system to classify and predict life curves of SKU in the apparel industry**

**Figure 6. Identification and quantification of the bullwhip effect in a 2 scale supply chain**
Another aim of this theme is to model the textile-apparel supply chain, composed of many actors and a huge number of parameters, to identify and quantify bullwhip effect (due to errors of forecasts and sourcing strategies) on inventories, service levels and profits (see Figure 6).

However, other strategies currently arise as an interesting alternative or a complementary method of the demand forecasting approach. Among them, demand driven models, late stage configuration and postponement methods, have demonstrated their efficiency in some industrial sector. These strategies require high technology systems to share and to deal with many data. The aim of the team is to propose further developments in terms of design product and SCM in order to implement these strategies in the specific textile-apparel market. Demand driven sourcing decreases inventories, makes replenishments possible, makes the use of raw materials and energy more efficient and reduces markdown volumes in retailing. By combining the best practices of global and local sourcing the sustainability and competitiveness will be enhanced. New environmentally acceptable methods of producing textile fibres and source-reduction of the textile chain will be proposed by designing for less material but more consumer value.

3- Computerized design of advanced materials using decision support systems

This theme aims at optimizing multifunctional material design using decision support systems and intelligent techniques (fuzzy logic, neural network, genetic algorithms). In the activities of this theme, there exist strong collaborations with the group MTP (Multifunctional textiles and processes). The problems encountered in computerized design for materials mainly include modelling of processes and textile materials with insufficient data, formalization and analysis of human knowledge on processes and products, searching for optimal design of experiments with few tests.

For modelling textile materials, the research work is focused on

- extract and select relevant structural features of materials using image analysis,
- modelling the relation between structural features of materials and functional properties using neural network and data clustering,
- developing decision support systems for material design with multi-criteria,
- modelling and simulate pore structure of textile materials (yarns and nonwoven) using image analysis and fuzzy techniques,

For modelling of a process, the research work is focused on

- selecting relevant process parameters in order to reduce the complexity of the model and make easy the parameter adjustment,
- modelling the relation between selected process parameters and features of finished products by integrating measured data and expert human knowledge,
- developing a decision support system for nonwoven production by realizing an industrial vision system for measuring uniformity properties, permitting to perform online quality inspection of products and optimize production.

The combination of these two models can be used for predicting quality criteria from design factors of new materials without taking any measures, and determining suitable design factors for new materials from quality requirements (See Figure 8).

![Figure 8. Modelling of relations between design factors and quality criteria](image)

Based on the previous work, we proposed a general design process for multifunctional materials. Inspired by Design for Six Sigma (DFSS), this design process is composed of five stages: Define-Measure-Analyse-Design-Verify.

![Figure 9. General design process for multifunctional materials](image)
Our study is concentrated on the stage “Design”, which is divided into two parts: manufacturing of prototypes and assessment of prototypes. The main idea of this stage is to validate and validate the previous product using expert’s knowledge and to test it through a limited series of prototypes. The material model and process model described previously have been used for studying the relations between the requested properties (specifications) and the design factors (raw materials, product structure, process configuration and parameters etc.). Three sources of information have been exploited: the production database, statistical data extracted from new experimentations, as well as the knowledge of designers and producers. In this context, a software system integrating the developed models, the related database of materials and other data mining procedures has been implemented and successfully applied to design of several series of nonwoven materials. Also, another software system for global evaluation of prototypes has been developed in cooperation with University of Technology, Sydney. It is a hierarchical evaluation structure, taking into account all abstract and concrete design elements (See Figure 10).

Figure 10. General hierarchical structure for global evaluation of prototypes

4 - Sensory design: integration of human perception and cognition into design processes

This theme aims at characterizing consumer’s perception and cognition (sensory quality of textiles) and integrating them into the design process for textile materials and finished products (sensory design). The techniques of sensory and multi-sensory evaluation as well as advanced computing (fuzzy logic, genetic algorithms, data fusion, clustering ...) are used in the developed methods.

For general consumers, an industrial product can be perceived at two levels (See Figure 11): 1) Basic perception, dealing with their primitive sensation and preference on the product using five senses: vision, touch hand, hearing, odour, and taste. The social and cultural background around the product is not considered. The related perceived criteria can be “soft”, “flexible”, “smooth” for touch hand, and “brilliant”, “light colour” for vision. The basic perceived criteria are easily understood by product designers and often considered by them as one part of design factors. 2) Complex perception, dealing with abstract and complex social and cultural concepts around the product. The related concepts include fashion, brand effect, well-being, comfort, health friendly, etc. Each complex perception
concept can be decomposed into a number of simpler evaluation indicators or ambiances. For example, in some specific situation, fashion style can be decomposed into “sportive”, “relaxation”, “professional”, and “luxury”. Each evaluation indicator is usually associated with a series of fashion images describing the corresponding ambiance. Complex perception is generally used by marketing departments for characterizing consumer’s behaviours and evolution of markets. They are not easily mastered by product designers in the development of new materials.

Figure 11. Relationship between design and consumer’s perception

In the frame of basic perception characterization, we have worked on fabric hand, fabric appearance, colour and thermal comfort. The main activities include:

- training sensory panels and organizing sensory evaluation for acquisition of normalized sensory data (descriptors and scores)
- formalizing sensory data provided by experts and consumers using fuzzy logic in order to extract relevant information on perceived quality of products
- measuring relevant physical features related to fabric hand (KES: Kawabata Evaluation System, optical profiler and UST: Universal Surface Tester) and colour (multi-angle colorimeter)
- modelling relations between selected physical features and normalized sensory descriptors for different categories of textile materials and creating the corresponding material library. This step permits to interpret physical features of materials using sensory descriptors.
- modelling relations between process parameters and selected physical features in order to improve sensory quality in the production of new products
- developing optimized design of experiments using dynamic learning techniques in order to reduce evaluation cost while maintaining accuracy of results
- characterizing the relations between different sensory panels, especially between sensory descriptors used by experts and general consumers, and predicting consumer’s preference from sensory descriptors
- evaluation of thermal comfort in a climatic chamber and modelling relations between textile parameters and thermal comfort for developing new comfort-oriented materials
In the frame of complex perception characterization, we have worked on multi-sensory evaluation and modelling in the aspects of general comfort for garments, well-being, human body shapes and fashion styles. The main activities include:

- developing a new consumer evaluation method for acquisition of data on well-being of textile materials by means of a set of fashion images describing the corresponding ambiances (sportive, leisure, relaxation, ...)
- modelling the relations between design factors (material parameters, colour, style) and criteria of well-being
- aggregating sensory data of different aspects (fabric hand, colour, appearance, styles, ...) in order to develop criteria of well-being and comfort and predict behaviour of consumers
- developing searching engines for deducing concrete design elements (cutting, material, colour, ...) from abstract sensory criteria of fashion designers and general public
- interpreting fabric hand from visual information (images, videos, ...) in order to transmit tactile feeling of materials via Internet, and integrate and control sensory criteria in virtual prototypes.

![Diagram showing the relationship between design factors and criteria of well-being](image)

**Figure 13.** Modelling the relations between design factors of materials and criteria of well-being
A software system for characterization and modelling of well-being has been implemented and successfully applied in a garment company for designing new well-being oriented products.

5 - Smart and multifunctional textiles

In this section the concept of intelligent textiles and apparel developed in our laboratory is introduced.

The term ‘intelligent textiles & apparel’ describes a class of textile structures that has active functions, in addition to the traditional properties of clothing. These novel functions, or properties, are obtained by utilizing special textiles or electronic devices, or with a combination of the two. Thus, a sweater that changes colour under the effect of heat could be regarded as intelligent clothing, as could a bracelet that records the heart rate of an athlete while he/she is exercising.

There are three categories in which intelligent clothing can be classified:

- Clothing assistants that have a ‘memory’, store information and carry out complex calculations;
- Clothing monitors that record the behaviour or the health of the person;
- Regulative clothing that adjusts certain parameters, such as temperature or ventilation.

All intelligent clothing can function in manual or automatic mode. In the case of manual functioning, the person who wears the clothing can act on the added intelligent functions. In the automatic mode, the clothing can react autonomously to external environmental parameters, i.e. temperature, humidity, light, etc.

Communicative clothing can be perceived either as an extension, or as the next generation, of intelligent clothing. Although all clothing communicates intrinsically by virtue of its appearance, the type of communication referred to here is that of information coded and transmitted by means of electronic components in clothing. The integration of portable telephones and miniature PCs are just two of many applications being studied and more are yet to be imagined. Communication can be achieved between clothing and the person who wears it, or alternatively between clothing and the external environment and others. In both cases, ‘communicative’ clothing refers to any clothing or textile accessory that receives or emits information out of the structure that it is composed of.

Everyone wears clothing; however, the needs will be different within any given group of people. Let us simply note that the broad, principal topics are:

- Professionals (the need for ‘hands free’ functions, safety, data exchanges);
- Health care (monitoring, training, remote diagnosis);
- Everyday life (telephoning, wellness);
- Sports (training, performance measurement);
- Leisure (aesthetic personalization, network games).

In this section, the latest achievements of the research team dealing with intelligent textiles structures are presented. The original contribution of the GEMTEX laboratory in the area of intelligent and multifunctional textiles concerns following areas.
i. Textile sensors and actuators

Different fibrous sensors have been designed and realized in our laboratory for various applications such as parachute canopy instrumentation (Figure 14) or structural health monitoring of composites for aeronautical and ballistic applications (Figure 15).

Figure 14. Strain gauge coated on parachute canopy nylon 6.6 fabric

Figure 15. Carbon composites equipped with piezoresistive fibrous strain sensors

Our research team developed heating textiles based on coating by conductive composite polymers (Figure 16) as well as photovoltaic composites used for outdoor textiles (Figure 17). Research activities of our team were focused on the development of conductive textile support and lamination process in order to embed flexible solar cells with amorphous silicon to outdoor textiles.
ii. Flexible displays

Concerning flexible displays our research team realized optical fibres fabrics able to display patterns and text (Figure 18-a). Displays based on LEDs (Figure 18-b) deposited on flexible substrate and integrated to textiles have also been designed and made. Currently we work on electro chromic inks in order to conceive flexible high resolution colour displays for technical textiles.
iii. Textile electronics

The design of fully textile organic electronic circuits is the main objective of this research group. Therefore conductive and semi conductive fibrous structures are currently under investigation. The Wire Electrochemical Field Effect Transistor – WEC FET (Figure 19) is the main achievement of those researches. It enables together with fibrous resistances the realization of textile digital and analogue circuits such as NOR gate, follower, amplifier etc. (Figure 20).

Figure 19. Double WEC-FET realized in GEMTEX laboratory

Figure 20. Textile amplifier with connectors to power supply and scope (black threads in green cotton fabrics)
3.1.3 Key academic collaborations

- GRAISyHM (2008-2010) (regional funding – Regional Research Network in Automation): extraction of relevant semantic information from complex systems with LAMIH Laboratory/University of Valenciennes, Ecole des Mines de Douai, Department of Applied Mathematics and Computer Science/Gent University (Belgium), ERPI (Innovative process research group)/ENSGSI – Nancy

- GDR E HAMASYT (2009-) (CNRS funding): European network of excellent for man-machine systems in transport and industry with LAMIH/University of Valenciennes, HEUDIASYC/UTC in Compiègne, Technical University of Berlin

- ARCUS (2006-2010) (funded by French Ministry of Foreign Affairs and Region of Nord-Pas de Calais): scientific collaboration program with Romania and Bulgaria – partner of GEMTEX: University of Technology of Iasi (Romania) – project topic: Creation and design of garments – use of dynamic modelling and simulation of textile structures

- EU project Asia-Link (2004-2008): European research cooperation program in partnership with University of Minho (Portugal), Donghua University (China) and IIT (India) – Development of research partnership network between Europe and Asia by exchanging young teachers and researchers – research topic: design of multifunctional materials, textile comfort, plasma treatment

3.1.4 Key industrial collaborations


- Industrial project with Bureau Veritas CODDE (2007-2010): evaluation of environmental impact of textile products

- COLIVAD, recognized by the Cluster of Commerce Industry (2006 -2008) and conducted by ACTEOS company: optimal control of delivery process for distant sales

- Industrial project with DAMART and recognized by Up-Tex Cluster (2006 – 2010): selection of relevant textile components in terms of comfort and well-being

- Industrial project with Unilever (2007 – 2011): study of relations between textile hand feeling and effects of the softner in order to optimize product quality

- Industrial project with Décathlon (2006 – 2008): sensory evaluation of thermal comfort of textile products in order to optimize the selection of component parameters

- Industrial project with CLARINS (2011): sensory evaluation of velvet fabric and cosmetic products – Project in partnership with Ecole de Biologie Industrielle (EBI), Cergy-Pontoise, France

- Industrial project with CELABOR (2011): characterization of the correlation between instrumental measures and softness of papers


- Industrial project with Capcusto and recognized by Up-Tex Cluster (2008): study of feasibility of the design chain for personalized jeans

- 2008 – 2011 (Clarins, DGA,...)
3.2 Multifunctional Textiles and Processes Research Group

3.2.1 Keywords:
Surface functions, Interfaces, Sensors – Actuators, Smart textiles ...

3.2.2 Overview
The scientific themes developed in the group "Multifunctional Textiles and Processes" have globally for ambition to confer to textile structures (fibres, woven and knitted fabrics, nonwovens) new functional properties, to contribute to the sustainable development of the textile materials, and at last to understand and master the relationships between the manufacturing processes and the properties of materials.

1- Nanostructuration of textile materials
The basic constitutive element of a textile structure remains fundamentally the fibre. With the development of technical textiles and the idea to give to the textile material a strong added value, the strategy consisting in functionalizing the material in order to offer him original properties has gradually emerged. Whether it is of natural, artificial or synthetic origin, the fibre became the object of numerous transformations, either in bulk or on its surface. Moreover, the exploitation of nanotechnologies applied to textile since a dozen years, as well as the development of smart textiles allowed a very important development of this kind of materials and their applications.
With the acquisition of a melt-spinning pilot line in 1999 (cf. Figure 21), the GEMTEX laboratory began during this period to incorporate functional nanofillers in spinnable polymers with the aim of optimizing the fibres properties. It is first of all the improvement of the fire behaviour of textiles that was envisaged. Various commodity polymers (polypropylene, polyamide) were studied after incorporation of diverse nanofillers (modified clays, carbon nanotubes, graphite). Even if the majority of the results obtained with only clays show that this solution is not generally competitive with the classic fireproof loads, we notice however globally an improvement of the thermal stability of the textile fibres (cf. Figure 22).

Figure 22: TGA experiments under air on PP multifilament yarns filled with various nanoparticles

In the particular case of the carbon nanotubes, a first patent was also deposited in 2004 with the Nanocyl company for the incorporation of these nanofillers in spinnable polymers, in particular for fire resistance applications (E. Devaux, S. Belayer, S. Chlebicki, S. Bourbigot, A. Fonseca, J. Al-Asswad, J.-B. Nagy, “Continuous textile fibres and yarns made from a spinnable nanocomposite”, WO/2004/090204A2, PCT/BE2004/000049). These first investigations allowed the laboratory to acquire skills recognized in the spinning of nanostructured polymers, and to detect very interesting potentialities in particular for the use of carbon nanotubes. These nanomaterials indeed possess electrical conductivity properties which can be exploited for the development of smart textiles and flexible sensors. Within the framework of the European project INTELTEX (PCRD 6), we so contributed to the development of flexible textile sensors for chemical, mechanical and thermal detection. The final goal of this work was to integrate in Personal Protective Equipments (PPE) for fire-fighters, a new textile composite based on the use of these innovative nanofillers enabling them to be alerted after a critical elevation of the surrounding temperature. The realisation of this sensor requires the preparation of a biphasic Conductive Polymer Composite (CPC), where the two polymers have farther melting temperatures and one of which corresponds to the wished detection temperature (cf. Figure 23).
The CNT were introduced in the phase which is sensible to the temperature elevation (polycaprolactone) and protected by the second polymer whose melting temperature is higher (polypropylene). For our application, an interpenetration of the two phases (co-continuous morphology) and a selective localization of CNT in the PCL are privileged in order to obtain satisfactory electrical conductivity. Once the development step of the biphasic conductive multifilament reached, the yarn is embedded in an instrumented woven structure, which permits to record the electrical signal. The presence of a Positive Temperature Coefficient (PTC) effect allows the detection at the melting temperature of PCL (58°C). The first prototypes developed under conditions close to reality show the reproducibility of these promising results. The same kind of approach has been used for the realization of chemical sensors. In the presence of volatile solvents indeed, the polymer shows a swelling which promotes the depercolation of the nanotubes incorporated in the fibre, and then a decrease in the electrical conductivity. Different samples have been tested in various environments and show satisfactory responses (cf. Figure 25 for instance).

Within the framework of the European project IMS & CPS (Innovative Materials Synergies & Composite Processing Strategies) (PCRD 7), we have continued our works on the incorporation of carbon nanotubes in spinnable polymers by using thermostable materials for aeronautical applications. The
elaboration of these multifilament yarns is done with high thermal stability polymers (phenoxy, polyethersulfone) which are soluble in a thermoset matrix of epoxy type. This research focuses on the study of the spinnability of these polymers and on the analysis of the dispersion and orientation parameters of the nanotubes in the yarns. The electrical and mechanical properties of the multifilaments are also investigated. These yarns will indeed be incorporated into composite materials for an improvement of their mechanical and electrical properties (protection against lightning and magnetic interferences particularly).

With the rising concern for environmental protection, biodegradable polymers, biopolymers and biocomposites have attracted considerable attention for biomedical engineering. In competition with petroleum-based polymers, polylactic acid (PLA) is one of the most promising candidates for future developments. PLA is currently receiving considerable attention for rather conventional applications such as packaging materials as well as production of textile fibres (cf. Figure 26), but finds also higher added value technical applications when formulated for instance with dispersed nanoparticles. Multifilament PLA nanocomposites filled with environmentally friendly ZnO nanofillers (with or without surface treatments) have been processed by melt spinning, with the objective of special end-use properties such as antibacterial effects (NANOLAC, INTERREG IV program). Surface treatments of ZnO based on the use of silane promote a good dispersion of nanofillers in PLA. Moreover, this contributes to improve thermal and mechanical properties of PLA compared to ZnO without surface treatment. Besides, bringing antibacterial properties to PLA by adding zinc oxide has been established. Excellent antibacterial activity has been observed with only 3 % of nanofillers on gram positive bacteria and relatively good activity on gram negative bacteria.

The spinning of complex formulations of filled polymers also turned to the development of polyester based intumescent fibres for the manufacturing of covering textile materials and of composite structures (INTUMAT national project). The polyester has good mechanical properties and a relatively low cost. However, it shows a weak fire behaviour which prevents its use in certain domains such as the transport or the building applications. In the railroad sector for instance, the fire standards are strengthened and justify the emergence of such projects. The general idea is to finalize original fire-proofing formulations which use synergetic effects between different fillers (POSS and phosphinates in particular), and promote the intumescence of the textile structure during its combustion.

Lotus effect is a combination of nano-level surface structure and hydrophobic materials. This property has been investigated on textile substrates due to their importance for industrial applications (repellent coating, self-cleaning and prevention of biofouling). The process used to develop such surfaces was to create a nano-roughness on substrates and to coat it with hydrophobic thin layers (deposition of ODTMS with chemical vapor deposition methods). The nano-structuration has been generated by the growth of ZnO nanorods at the surface
of PET (cf. Figure 27) and cotton fabric. Nano-seeds of ZnO, prepared by sol-gel process, are firstly deposited on surface. Secondly, hydrothermal process is used to grow nanorods (SPHERE-HEC program). The average water contact angle on PET fabric without nanorods is 128° after the vapor deposition methods with ODTMS, while the average contact angle on PET fabric with nanorods modified by hydrophobic layer by vapor deposition methods is 158°. These results show that nano-roughness has an important impact on the superhydrophobicity of surfaces. Dielectric barrier discharge (DBD) technologies could also create a nano-roughness at a polymer surface. We have obtained chemical and physical nano-structuration of PP surface by creating bumps of oxidized polypropylene with an atmospheric plasma treatment. Various parameters such as treatment speed or electrical power were changed in order to determine the treatment power impact at the polypropylene surface. Polypropylene film surface topography was analyzed by atomic force microscopy (AFM) in order to observe the surface roughness modifications (cf. Figure 28).

2- Surface treatments of textile structures

Technical textiles are more and more extensively used in the field of medical applications. Since 2007, GEMTEX laboratory develops activities concerning the functionalization of textile structures which will be in contact with a living environment (bacteria, proteins,...), either for antibacterial purposes or for the delivery of drugs and medicines.

Biofunctionalization of biocompatible non biodegradable (PET) and/or biodegradable (PLA) textile fibres has been carried using different methods and products for diverse applications such as apparel, medical and food packaging and even as fibrous membrane for bioreactors. Different biopolymers (such as chitosan and alginate), natural curcumin having particular medicinal properties, and natural nisin (natural antimicrobial peptide produced by Lactococcus Lactis) have been used for surface functionalization of textile with or without a surface activation using atmospheric plasma treatment or UV excimer. Alginate and chitosan have particular properties such as antibacterial and hydrogel forming characteristics. Alginate films immobilized at a 3D porous textile structure seem to be an interesting way for immobilizing and releasing bioactive substances (such as nisin). Moreover, surface functionalization of PET with chitosan confer particular surface properties, and particularly cationic surface (cf. Figure 29), which makes the resulting textile a very good candidate as membrane for
biosorption of surfactin (a lipopeptide) produced by Bacillus Subtiliss in bioreactors (ARCIR 3 and ARCIR 4, regional project).

Another approach developed for antibacterial applications is the functionalization of poly (ethylene terephthalate) and polypropylene nonwovens by using quaternary ammonium molecules and functional polymers (NOTIVIR, national project). The surface modification of these structures promotes indeed antibacterial activities. Several active substances were applied by padding, with or without surface pre-activation by atmospheric air plasma treatment. Physical, chemical and biological characterizations were carried out on the treated samples using various techniques such as wettability, zeta potential, air permeability, cell vitality or antibacterial activity. An optimization of the functionalization process leads to a reduced number of washes after the active substances deposition and to a satisfactory antibacterial activity (4-log reduction) with Staphylococcus Aureus. The antibacterial properties mainly depend on the nature of the active substances (Q1, Q2, -Confidential formulations-), but also on the structural parameters of the nonwovens (MB = Melt-blown, SB = Spun bound) (cf. Figure 30).

![Figure 30: Antibacterial activity for nonwoven structures treated by Q1 and Q2 formulations depending on the mode](image)

Hydrogels have become materials used for drug delivery formulations and biomedical implants, due to their biocompatibility, network structure, and molecular stability of the incorporated bioactive agent. These properties are used in a large range of applications going from food additives to pharmaceutical and clinical applications. The development of PLA nonwoven surfaces functionalized with a bioceramic (hydroxyapatite HA)/multilayers biopolymers (chitosan/alginate hydrogel) has also been studied for future medical applications like bone tissue implantation aiming to replace and/or repair bone defects. Thermo-sensitive hydrogels based on interpenetrating polymer networks of poly (N-isopropylacrylamide) and calcium alginate have also been synthesized and characterized. PNIPAAm is a biocompatible polymer which responds to simple changes in temperature by swelling or deswelling. The ultimate aim of these investigations is to develop textiles for transdermal drug delivery using these thermo-sensitive hydrogels. The temperature control is ensured by a heating textile which serves as substrate for the drug-containing hydrogel (ARCUS project).
Among the properties conferring to textiles a high added value, the comfort notion is extremely important. We worked during numerous years on the microencapsulation of phase change materials (PCM), these functional microcapsules being then fixed to a textile surface (F. Salaün, E. Devaux, S. Bourbigot, P. Rumeau, “Material containing microcapsules, in particular phase changing materials” patent US 2009/0291309A1, PCT/FR05/02986). This kind of approach uses the melting endothermy of microencapsulated species and the exothermy of the crystallization in order to regulate the surrounding temperature. More recently, we were interested in the possibility of conceiving refreshing clothes. For this purpose, the preparation and performance of microcapsules interacting with the absorbed water to promote a cooling effect were investigated. The microcapsules containing xylitol were prepared from xylitol and diphenyl methane diisocyanate (MDI) by an interfacial polymerization process. The size and the morphology of the microparticles can be adjusted by selecting different core/shell weight ratio and stirring rate. The encapsulation yield varies according to the stirring rate applied during the emulsion step and the MDI amount introduced. Thus, a low stirring rate and relatively high MDI amount lead to obtain high encapsulation yield. Furthermore, the encapsulation yield values are related to the urea amounts detected by spectroscopy analyses. This confirms that the formation of urea linkages enhances the stability of the polymer shell and reduces the xylitol diffusion and therefore the formation of oligomers soluble in toluene. Furthermore, the thermal stability of the various microparticles is mainly influenced by the urea content and therefore by their mean diameter. The microencapsulated xylitol was characterized by scanning electron microscopy (SEM) to illustrate its porous surface structure and its morphology (cf. Figure 31). The formation of a porous shell observed by SEM allows the water molecule transfers to promote the dissolution of the crystalline xylitol. DSC analyses show that the xylitol crystalline content and crystallization process depend mainly on the drying time at room temperature whereas the washing tests do not influence these measured heats of dissolution, which illustrate the non-diffusion of the liquid xylitol solution through the porous shell. Thus, the combination of a porous shell with moisture-sensitive compound as xylitol would be useful for a material design of new functional microparticles for thermal and moisture management.

Due to the important roles of the anions played in the biological processes, the recognition and sensing of anions has received considerable attention over recent years. In addition, there is interest in finding better and more efficient ways of detecting anions that can be potentially harmful to the environment or human health. One such anion is cyanide, which is lethal to humans at concentrations of 0.5–3.5 mg per kg of body weight. Consequently, the presence of this anion in drinking water (1.9 μM as maximum concentration) can pose a very serious risk to human health. We have developed in our laboratory a new generation of water soluble chemosensors able to detect selectively the cyanide anions in pure water.
The water solubility of this new chemosensor generation was obtained by the incorporation of the biosourced water soluble molecule such carbohydrates and glycerol units on the starting organic chemodosimeters or by the incorporation of the starting chemodosimeters on poly vinyl alcohol as water soluble polymer. Then, the organic developed chemosensors were grafted on natural cellulose fibres (cf. Figure 32) and its optical properties were studied. The immersion of these functionalized textiles in an aqueous solution of cyanide induced a colour change that can be used for the detection of cyanide down to 0.01-0.07 μM.

3- Relationships between processes and textile products properties – Environmental quantification

The functional properties of a textile product are given by the application field. In order to enhance the main property, to get new properties, or to go to multifunctional textiles, the process needs to be fully understood. The main parameters for the design of new products concern the use of new fibres, and the development of structures with different fibres association, multilayered or with different organization. This has been studied in the field of yarn spinning, knitted fabrics and mostly nonwoven fabrics. The different applications of textile structures include structural composites, thermal and acoustical isolation, filtration and separation, liquid management, biological applications and non-structural mechanical properties. From an environmental point of view, improvements may be provided by the use of new raw materials, which in turn will change the process, or by the use of best available technologies, which have to be developed.

Finishing treatments and dyeing processes are one of the most contributors to environmental impacts on the whole life cycle of a textile product. They are related to high water consumption, and therefore energy use, and to water and air pollution because of the emission of chemicals in wastes. We have study some Best Available Technologies (BAT). The quantification and the analysis of the impacts is done through life cycle analysis, LCA.

Microwaves have been added in a continuous dyeing pilot line. The dyeing speeds are enhanced by the addition of microwaves and the requirement for textile auxiliaries is reduced (cf. Figure 33), thus limiting the environmental impact. The use of plasma treatments to get hydrophilic properties or adhesion improvements of finishing is also expected to decrease environmental impacts.

However, there is a need to quantify the influence of process conditions on the environmental footprint of the textile product. The main target is that, changing the process conditions also changes the product quality. This has to be taken into account in LCA when comparing different process. We
have introduced a lifetime indicator based on the abrasion resistance and color fastness tests results (cf. Figure 34). This has been applied to bed sheets manufacturing processes, with LCA. The negative effect of the manufacturing of a more durable product may go against the positive effects of the lifetime. The modification of a treatment process or the substitution of hazardous molecules with bio-based ones has to be studied by taking into account both the quality of the treated fabric and the environmental impact. A methodology is developed to associate these two approaches.

![Figure 33: K/S colour value according to processing time and micro waves power for a contact temperature of 150°C](image)

Natural fibres from different qualities have also been transformed to get yarns or nonwovens. Different studies have shown the interest of esparto fibres (CMCU, BIOCOMPALFA) and other fibres such as linen, sisal. The different quality of natural fibre is responsible for the carding yield. This may be improved by blending with other fibres. Elementarisation of flax fibres, using enzymatic processes and ultrasound, removes pectin and improves the surface properties which enable the carding process. Nonwovens have been manufacturing using pilot line (CENT), their properties are strongly related to the consolidation parameters process: needlepunching, hydroentanglement,...
Biobased composites have been realized for orthopaedic applications in association with PU resins, and we are studying the use of bioresins from jojoba and castor oil. The association of flax/PP needlepunched layers using hydroentanglement process gives new materials with enhanced mechanical properties (cf. Figure 35). Other properties are optimized with these fibres including acoustic absorption. In air filtration, nonwoven materials have been developed in order to get a filter that combines good permeability and high efficiency. Our results show that section shape fibres improves not only filtration properties of the nonwovens but also main of the properties such as for a given fibre diameter, filtration efficiency can be improved by increasing solid volume fraction, and that the basis length (total length of fibre in unit surface of nonwoven) is a useful parameter for defining the filtration properties (cf. Figure 36). The use of binary blends of different fibre diameters also improves overall filtration behaviour, in comparison to nonwoven filters with equivalent unimodal diameter distribution. A theoretical filtration model is used to predict filtration behaviour for different structural characteristics and compared to experimental results. However, this comparison demonstrates the limits of existing models in the case of fibre blends.

The use of ultrafine fibres is optimal for (supermicroniques, submicroniques, nanofibres) special cross liquid retention. Blending fibres in needlepunched nonwovens increases liquid capillary retention without limiting the absorption kinetics.

The other developments in the nonwoven applications are related to non-structural mechanical properties. In the MEMOTI project, multifunctional material properties were targeted to substitute PU foam: compressibility, resilience, sound absorption, recycling ability, no toxicity. This was achieved by the association of special fibres, such as self-crimping fibres.

Multifunctional properties are also expected for composites applications. In the MANSARD and NWCX project, we are developing thick nonwovens and porous composites to get mechanical properties associated with thermal isolation and acoustic absorption. The use of knitted fabrics for such application is also studied. Most of all these properties are related to the fibres organisation in the nonwoven porous structure. Different methodologies have been set up to get a better understanding of the pores structure. Optical measurements give information on the repartition of fibres in the nonwovens. However, this information is not relevant for thick nonwovens. Fluid behaviour is related to this organisation. With Capillary measurements, static and dynamic equivalent pores radius are representative of the pore size distribution. The air permeability is also a major parameter.
The 3D isotropy of the nonwovens and composites has been studied by using Van Wyk’s model on compression test results. The compressive stress $\sigma$, is related to the fibre volume fraction $\phi$: 

$$\sigma = E(K^n - \phi^n)$$

where $E$ is the fibre modulus. The composites made with nonwovens have an exponent value close to 3, revealing 3D isotropic structures (cf. Figure 37).

![Figure 37: Compression curve for nonwoven composite sandwich](image-url)
3.3 Mechanics – Textile composites Research Group

3.3.1 Keywords
Modelling, simulation, structural parts, aeronautics, armour, ballistic

3.3.2 Overview
The MTC research group focuses on two main fields of application of textile composite structures: Ballistics and Composite structural parts. In the first part of this section research activities related to ballistics and weaving of textile structures able to stop projectiles and debris. Second part is dedicated to novel approaches enabling the design and manufacturing of structural composite parts mainly for aeronautics applications.

1 - Ballistics

Based on the development of specific dobby weaving loom (Fig 38) adapted for multi-layer woven fabrics, different 3D warp interlock structures have been defined, optimized and produced to give, first, a better knowledge of the final geometry of multi-layer fabrics and, second, a new solution to protective material against ballistic impacts with different velocities and threats.
The loom was designed to keep the fabric straight, with a low percentage of 13% of fibre damages, checked during the weaving process.

A first part of the research activities is dedicated to the geometrical modelling and optimization of multi-layers woven fabrics (3D warp interlock).

The study of the warp interlock structures has first begun with a research contract on the 3D geometrical modelling of warp interlock fabric and the mechanical in-situ characterization through the use of fibrous sensor [PhD-13G]. The main difference observed (Fig. 39), between the geometrical tool and the real geometry of warp interlock fabrics made with carbon yarns, pushes us to define a more precise geometrical model able to predict crimp percentages, areal weights and volume fractions reasonably accurately (Fig. 40).

The overall results show that an approximation regarding the cross sectional shape of warp and weft tows which corresponds closely to the reality at meso-structural level is necessary in order to understand and predict the geometry of the fabric. Relative fractional cover is a useful technological
parameter to assign suitable warp and weft cross sectional shapes for prior to weaving modelling of orthogonal/layer to layer warp interlocks. Another advantage is the generic nature of the geometrical approach as it can be applied to other classes of warp interlocks as well (Fig 41).

![Figure 41. Description of 1st variant of warp interlock fabric; a) Wisetex modelling geometric view; b) photomicrographs of longitudinal sections; c) 3D tomography view in weft direction](image)

This work has been reinforced by another research contract done by Dr Irina CRISTIAN (funded by AUF and ARCUS) coming from the Iasi University of Iasi in Romania, from September 2008 to February 2011, to provide a complete clustering of warp interlock fabrics and the optimization of their mechanical characteristics through the in-situ measurements.

A specific study has been also done to check the influence of the warp yarns order of insertion inside a 3D warp interlock fabric on its real geometry (Fig 42).

![Figure 42. Order of warp yarns for the same 3D interlock structure: (left) layer by layer insertion; (right) through the thickness insertion](image)

![Figure 43. Real geometries of the produced warp interlock fabrics taking into account the order of warp yarns; (left) layer by layer insertion; (right) through the thickness insertion](image)
Taking into account the insertion order of warp yarns inside the 3D warp interlock structures, a significant difference of fibres compactness can be revealed and lead to increase the volume fraction ratio by using the well suited insertion method (Fig 43).

Collaborative research activity was also performed with Patrick LAPEYRONNIE (Ph-D student at ENSMD). An experimental study has been achieved to put on the fore the influence of all the weaving process operations on the 3D warp interlock fabric and the influence of the resulted geometry leading to different mechanical behaviours.

Collaborative research activity was also performed with Patrick LAPEYRONNIE (Ph-D student at ENSMD). An experimental study has been achieved to put on the fore the influence of all the weaving process operations on the 3D warp interlock fabric and the influence of the resulted geometry leading to different mechanical behaviours.

Fig 44. Tensile test performed in the warp direction of 3D warp interlock fabric; (left) observed rupture mode; (right) modelled rupture mode

Fig 45. Tensile test performed in the weft direction of 3D warp interlock fabric; (left) observed rupture mode; (right) modelled rupture mode

To complete and better understand the exact geometry of warp interlock fabrics, a research project NUMTISS dealing with the modelling and numerical simulation of the weaving process is in progress since September 2010, for three years [PhD-14]. Additionally, during the NUMTISS research project, in-situ measurements of mechanical stresses of 3D warp interlock fabrics using innovative sensors are under investigation [PhD-28].

The actual process to obtain a precise geometrical model for a 3D textile dry structure, to be used into a numerical computation system and predict mechanical behaviours, can be resumed in main four steps (Fig 46). The lack of precision of the geometrical modelling push to first produce a sample real sample of the 3D textile structure. Then, to obtain a more confident numeric model of the textile geometry a 3D scanning process is used to capture the 3D architecture of the 3D fabric through a non-destructive way. An image analysis process in engaged to confirm the best solution of representative unit cell to be replicated and homogenised in all the directions of the 3D textile structure. Then the
adapted geometry of the 3D textile structure is obtained after a long time of computation process and assuming many parameters which can lead to a non-suitable model to predict the real properties of the final material.

Thus, to propose an alternative approach of the modelling of the manufacturing process of a 3D woven structure made of threads composed of multiple continuous filaments, the project will be focused on the suitable multi-scale model (Fig 47). Then, global knowledge is required on the manufacturing process and the main motions, which influence the produced materials. It also implies knowledge of material law behaviour of the fibrous reinforcement in dynamics during its assembly to give the 3D textile structure.

Figure 46. Actual problems concerning the 3D Textile structure Geometric Model
The proposed solution NUMTISS for a safe and precise 3D textile structure geometry. A second part of the research activities is dedicated to Ballistic impact (individual protection and vehicle armouring).

Based on promising results obtained after research activities oriented to lightweight fibrous reinforcement design, used inside a composite material, a final protective solution was designed, coupled with ceramic tiles, to resist to ballistic impact against armour piercing ammunitions. A post mortem analysis of the textile composite solution shows good delamination behaviour between the different layers (Fig 48).

![Image of textile composite structure](image)

**Figure 48.** Transverse view of the textile composite structure made with 3D warp interlock fabric.

Using patented solution, owned by the GEMTEX laboratory, a research contract named REI-SAFE is currently running funded by DGA (French military funds) to develop a textile composite solution adapted to vehicles armouring, from January 2009 until January 2012 [PhD-7]. During this study, the yarn damage has been checked for the each step of the weaving process. A complete summary of the obtained results on yarns is shown and helps to better understand the degradation process on yarn properties (Fig 49).
Fig 49. Comparison of mechanical properties for each step of the study

Thanks to this work, different yarn behaviour damage has been revealed considering different warp interlock structures. Indeed, weft yarns of O/L multilayer fabric exhibit better behaviour for the breaking tenacity compared to other structures, however the warp yarn is submitted to a lot of damages unlike O/T warp yarns. Regarding the breaking elongation; weft yarns for all structures exhibit almost the same behaviour. The O/T warp yarns keep almost the initial breaking elongation and were not influenced by the woven architecture. Finally, the Young modulus for the weft yarns is almost the same for each structure. Contrary to the warp yarns where, the young modulus in O/T structure is lower compared to the O/L structure. We also note that A/T binding induced fewer damages than the other structures.

Additionally, a research contract MAT-IED is also in progress, from February 2010 until February 2013 [PhD-26], dealing with a development of textile composite solutions for vehicles armouring submitted to high speed impact velocity of IEDs (Improvised Explosive Devices). Existing solutions have been tested to examine the delamination behaviour and the resulted parameters measured on the final target (Fig 50).
Collaborative research activities are also in progress with Royal Military Academy of Brussels on optimization of a foam and textile composite hybrid solutions for the IEDs protection, from April 2008 until April 2011 [PhD-9]. Collaborative research named REI-SNCTex is conducted by Dr Bernard VERMEULEN, Dr Manuela FERREIRA (associate professors in GEMTEX laboratory) and Frédérick VEYET (Textile engineer funded by DGA), to develop high resistance yarns made with carbon nano-tubes (CNT) multi-filaments produced by the CRPP laboratory based in Bordeaux, to be used inside woven fabric as an innovative protective solution for body armours. Experimental studies have shown that washed Single Wall Carbon Nano-Tubes (SWCNT) fibres, tensile breaking strength thresholds are close to 400MPa with a tensile modulus between 10 to 20GPa (Fig 51).

Designing a garment in 3D offers manifold scope for researchers, designers and industrialists alike. If this process is automated, as progressive solutions are being developed by the day, the garment development process in 3D shall not only be rapid but precise. Indeed, the main benefit of our strategy is to obtain a customized product in a short time and at low cost. Here we follow a reverse methodology by reverting from the simulated garment phase on the body of the scan to the static
design phase (Fig 52 – a). This process helps us to detail how and at what distance a garment actually orients itself in free space around the body in simulated phase. This information is used for designing a ballistic protection vest in static phase and validating the result. Then we validate the dynamic phase, i.e. drape the product directly on the 3D body, to check its comfort, ease Fig 52 - b. For this, the flatten from the previous step is necessary to validate the final step and check the deformability of the material Fig 52 - c.

Figure. 52. a; b; c Body armour for women

This project has a double aim, the first is to assure the appropriate protection and yet retain the ballistic vest at the lowest weight and the adequate mobility of policewomen. Ballistic tests have been performed on 3D body armour following the NIJ Standard–0101.04, threat class II (Fig 53).

Figure. 53 (left) 3D body armour to be fired with 9mmX19mm FMJ RN bullet (358 m/s); (middle) 7 shoots according the NIJ norm; (right) resulted shots on 3D form plastilina ROMA n°1.

Finally, a collaborative research contract named EPIDARM was done by Jerome MAILLET (Textile Engineer funded by European Defence Agency) to find innovative solutions based on hybridization of textile material solutions for lightweight, low price, soft and hard ballistic resistant protection to 9mm STANAG norm and 7,62 AP NATO ammunition. The following scheme sums up the different trends to follow in order to match with the definition of each of these protection solutions (Fig 54).
Different experiments have been done on multi-material protective solutions to test their resistance against different projectile types as the FSP or the 9mm ammunition. Better performance of the V50 values (Fig 55) versus the areal density (+5.28%) is obtained for a hybrid solution (3D+PW+F) containing 3D warp interlock fabric compared to another hybrid solution only made with plain weave fabric (PW+F).

A difference of the BFS value of 0.2 can’t be considered as significant and thus, the hybrid solution (3D+PW+F), with a areal density near to 5070 g/m², seems to be an efficient solution compared to the reference solution (Fig 56).

Taking into account all the military commander requirements on soft body armour protection for combat suits, new textile material solutions have been found integrating weight, back-face deformation and cost reductions for the same ballistic protection. Ballistic tests have been performed...
on different configurations of textile material solutions using the STANAG 2920 norm. Main parameters have been identified and their potential effects on ballistic performances have been described. Interesting results are obtained when using different textile materials combined together inside the ballistic protection solution. The performance, as regards the V50 and BFS values with the same areal density, of a given structure of 3D warp interlock fabric inside hybrid solutions has been revealed compared to multi-layer stitched plain weave fabrics. Research activities involving numerical modelling of ballistic protective structures in order to optimize their weight and efficiency are also funded by EDA. The objective of our team is to develop an innovative numerical simulation of ballistic impact of a 3D warp interlock fabric, (October 2008 until October 2011) [PhD-8]. The main part of the research work was done to understand the behaviour of the fabric subjected to ballistic impact in order to find the best suited model. Experience results show that during penetration time of the projectile, the response of the fabric is divided in different mechanisms or phases (see Fig 57 a):

- Formation of a pyramid with the top being the head of the projectile
- Motion of a few of principle yarns (the yarns that pass across contact zone with the projectile and perpendicular to free edge) out-of the fabric plan due to non-kept by fixed edges
- Structure of the fabric and yarn burst out of the fabric at the two free edges due to projectile penetration
- Localized yarn damage zone where principle yarns perpendicular to free edge are essentially slipped toward two sides and principle yarns parallel to free edge are essentially failed in tensile mode because of the fixation at the two ends
- Large zone far from contact zone where there is no yarn damage

These phenomena were also found during ballistic impact event in two models of this study (see Figure 57 b and c).

![Global behaviour of the fabric submitted to ballistic test with an iron ball](image)

Figure 57. Global behaviour of the fabric submitted to ballistic test with an iron ball; (a) real test; (b) Macroscopic model; (c) Mesoscopic model

Recent research activities are also based on the development of a sensor yarn to detect high speed tensile stress performed during a ballistic impact [PhD-27].
2 Textile reinforced composites:

The main objective of our research activities is to be able to provide a methodology where the design of materials and implemented production device are adjusted to each other to an achievable optimal textile solution. Working since 1999 in collaboration with Airbus, EADS and other industrial partners, our team proposed several solutions for new composite carbon parts. In 2002, stitching and tufting (PhD, Ms) combined with braiding or weaving lead to stiffeners reinforcements. In 2006, weaving interlocks structures; we study for interlaminated shearing, were a good answer for low speed impact resistance of composite parts. Our research team is also involved in design and conception of novel textile machines and structures as the Corner Fitting (ALCAS 6th FP) which leads to 9 patents in collaboration with Airbus Company.

i. Fibre steering – collaboration with UNSW – Sydney, Australia

Started in 2004, the collaborations with UNSW – Sydney, Australia on fibre steering are still on-going (Fig. 58). The Genetic Algorithms based optimization has been proposed to determine the best path of tows to improve mechanical resistance according to a fit criterion. Since that period, developments have been done on the structural model: a Finite Element multilayer model has been defined to optimize the structure on 2 or more fit criteria. Besides, an automatic device has been designed.

![Figure 58: GA based optimization of tows in composite structures](image)

Algorithms linking optimization results and automatic device able to apply this result while tows are deposited have been developed in our laboratory.

ii. Engineering model of stamping sheets of textile (Defi 2.3.1) – collaboration with AM Paris Tech (Paris and Angers)

To on-going project is based on an idea to propose a basic and less time consuming model and software to help engineer to design textile patterns for stamping. This study is done in collaboration with AM Paris Tech (Paris and Angers). The main idea is to combine beam finite element with shell finite element: BFE model tensile behaviour, SFE model bending and contact behaviours. The results are promising (cf. Figure 59).
Our goal is to propose an efficient solution for designer of stamping process. A second main part of this study is the identification of model parameters. This part of the process must be as simply as fast. Therefore, a specific device of stamping with CCD camera and force sensor in order to measure deformation angles of textile plies vs. stamping forces has been developed by our research team and is currently under testing phase.

**iii. Devices design for innovative textiles structure reinforcing composite (ALCAS, Defi 2.3.4 & 2.3.5, Raid OUTILS, IMS&CPS, Mappic 3D)**

New and innovative textile structures for composite parts applications are currently studied in the framework of different research projects on national and European level. These textile structures are non-common, they are mostly 3D. They could be 3D braiding made, 3D weaving made, assembling in 3D by tufting or stitching etc. In fact, they are mostly combination of textiles technologies. Technological solutions are driven by problem analysis, by mechanical designing...These works lead to 5 patents (fig 60). Indeed, for the ALCAS project, we developed specific device to answer Airbus ask on Corner Fitting part. It is a shell 3D structuring of a triple point geometry.

To be able to propose novel 3D textile structures, we developed our knowledge on tufting/stitching. It leads to M Piana PhD in 2008 (fig. 61), several Final Study Project with Airbus, PhD work of M Hammouda into Defi 2.3.5 Project.
In order to go further, we propose a new technology to structure volume 3D stiffeners. This technology call Raid OUTILS, allows to structure fiber in 3D, like 2D jacquard could do for 2D. So we can braid or weave in 3D or mix of both totally in 3D. Some results are illustrated in figure 62, 63 & 64.

3.3.3 Academic & industrial collaborations

Main academic and industrial partners:
Mines de Douai, AM Paris Tech - LAMPA, UNSW - School of Materials Science & Engineering,
Airbus Nantes & Toulouse, EADS IW, Aircelle, CETIM, Stratiforme, Hutchinson, Volvo, Loire Modelage, Huguet, Saertex, ...
Also, we participate to GdR MIC 3371: the main objective of this GdR (Group of Research) is to bring together different National skills around modeling of composite processes.

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S. GIRAUD, F. SALAÜN, G. BEDEK, I. VROMAN, S. BOURBIGOT,
Influence of chemical shell structure on thermal properties of microcapsules containing flame retardant agent
Polymer Degradation and Stability, 95 (3), pp. 315-319, 2010, IF = 2.32

F. SALAÜN, E.DEVAUX, S. BOURBIGOT, P. RUMEAU
Influence of the solvent on the microencapsulation of an hydrated salt

F. SALAÜN, E. DEVAUX, S. BOURBIGOT, P. RUMEAU
Development of Phase Change Materials in Clothing. Part I: Formulation of Microencapsulated Phase Change Materials
Textile Research, 80(3), pp. 195-205, 2010, IF = 1.096

J. LIU, B. ZUO, X. ZENG, P. VROMAN, B. RABENASOLO
Nonwoven uniformity identification using wavelet texture analysis and LVQ neural network

J. LIU, B. ZUO, P. VROMAN, B. RABENASOLO, X. ZENG, L. BAI
Visual Quality Recognition of Nonwovens using Wavelet Texture Analysis and Robust Bayesian Neural Network
Textile Research Journal, 80(13), 2010, IF = 1.096

S. H. ERYURUK, F. KALAOGLU, M. BASKAK, B. RABENASOLO
Evaluation of globalization strategies: external analysis of the Turkish clothing industry

AGARWAL, L.KOEHL, A.PERWUELZ
The Influence of Constructional Properties of Knitted Fabrics on Cationic Softener Pick up and Deposition Uniformity

J. ISAAD, A PERWUELZ
Simple route to a novel class of pyrazolidine-3, 5-dione based azo dyes

A. KERKENI, D. GUPTA, A.PERWUELZ, N.BEHARY
Chemical Grafting of Curcumin at PET (Polyethylene Terephthalate) woven fabric surface using a prior
surface activation with UV Excimer lamp
Accepted for publication in Journal of Applied Polymer Science, 2010, IF = 1,187
J. ISAAD, A PERWUELZ
New color chemosensors for cyanide based on water soluble azo dyes

X. ZENG, Y. ZHU, L. KOEHL, M. CAMARGO, C. FONTEIX, F. DELMOTTE
A fuzzy multi-criteria evaluation method for designing fashion oriented industrial products

X. DENG, X. ZENG, P. VROMAN, L. KOEHL
Selection of relevant variables for industrial process modelling by combining experimental data
sensitivity and human knowledge
Engineering Applications of Artificial Intelligence, 23 (8), 2010, pp.1368-1379, IF = 1.44

J. LU, J. MA, G. ZHANG, Y. ZHU, X. ZENG, L. KOEHL
Well-being theme based evaluation in new product development using fuzzy hierarchical criteria group
decision method
IEEE Transaction on Industrial Electronics, accepted in April 2010, paper n°: 09-1774-TIE.R1, IF = 5.47

Y. ZHU, X. ZENG, L. KOEHL, T. LAGEAT, A. CHABONNEAU, C. CHAIGNEAU
A general methodology for analyzing fashion oriented textile products using sensory evaluation
Food Quality and Preference, 21 (8), 2010, pp.1068-1076, IF = 1.94

X. DENG, X. ZENG, P. VROMAN, L. KOEHL
An intelligent multi-criteria optimization method for quick and market-oriented textile material design
Journal of Global Optimization, accepted in September 2010, paper n° JOGO-ISKE-03, IF = 1.45

E. BERTAUX, S. DERLER, V. VENTENAT, L. KOEHL, X. ZENG
Textile, physiological and sensorial parameters in sock comfort
Textile Research Journal, 80 (17), 2010, pp. 1803-1910, IF = 1.1

S. KURSUN, F. KALAOGLU, S. THOMASSEY, I. CRISTIAN, V. KONCAR,
A Study on the beam pattern of ultrasonic sensor integrated to textile structure, International
Journal of Clothing Science and Technology, 2010, IF = 0.531.

S. THOMASSEY
Sales forecasts in clothing industry: The key success factor of the supply chain management

L. GARNIER, S. DUQUESNE., M. CASETTA., M. LEWANDOWSKI, S. BOURBIGOT
Melt spinning of silane-water cross-linked polyethylene-octene through a reactive extrusion process
Reactive and Functional Polymers, 70 (10), pp. 775-783, 2010. IF=2.039
C. COCHRANE, M. LEWANDOWSKI V. KONCAR
A flexible strain sensor based on a conductive polymer composite for in situ measurement of parachute canopy deformation
Sensors, 10 (9), pp. 8291-8303, 2010, IF = 1.87

F. RAULT, C. CAMPAGNE, M. ROCHERY, S. GIRAUD, E. DEVAUX
Polypropylene multifilament yarn filled with clay and/or graphite: study of a potential synergy
Journal of Polymer Science Part B: Polymer Physics, 48, pp. 1185-1195, 2010, IF = 1.59

B. MARTEL, Y. EL GHOUl, A. EL ACHARI, C. CAMPAGNE, L. RAZAFIMAHEFA, I. VROMAN
Improved dyeability of polypropylene fabrics finished with a beta-cyclodextrin-citric acid polymer
Polymer Journal, 42 (10), pp. 804-811, 2010, IF = 1.46

S. NAUMAN, P. LAPEYRONNIE, I. CRISTIAN, F. BOUSSU, V. KONCAR
On line measurement of structural deformations in composites

2011

F. SALAUN, G. BEDEK, E. DEVAUX, D. DUPONT
Influence of the washings on the thermal properties of polyurea-urethane microcapsules containing xylitol to provide a cooling effect
Materials Letters, publié le 01/02/2011, 65 (2), pp. 381-384

High performance polyactide/ZnO nanocomposites designed for films and fibers with special end-use properties
Biomacromolecules, publié le 06/04/2011, 12 (5), pp. 1762-1771, IF = 4.502

F. SALAUN, G. BEDEK, E. DEVAUX, D. DUPONT, L. GENGEMBRE
Microencapsulation of a cooling agent by interfacial polymerization: influence of encapsulation parameters on poly (urea-urethane) microparticles characteristics
Journal of Membrane Science, 01/02/2011, 366 (1/2), pp. 23-33, IF = 3.203

J. ISAAD, F. SALAUN
Fonctionalized Poly (vinyl alcohol) polymers as Chemodosomiter material for the colorimetric sensing of cyanide in pure water
Sensors & Actuators: B. Chemical, 21/03/2011, IF = 3.083

J. ISAAD, A. EL ACHARI
A novel glycoconjugated N-acetylamino aldehyde hydrazone azo dye as chromogenic probe for cyanide detection in water
Analytica Chimica Acta, 29/03/2011, IF = 3.757
I. BOUFATEH, A. PERWUELZ, B. RABENASOLO, A.M. JOLLY
Multiple criteria decision-making for environmental impacts optimisation
International Journal of Business Performance and Supply Chain Modelling, 18/04/2011, 3 (1), pp. 28-42

J. ISAAD, A. EL ACHARI
Colorimetric sensing of cyanide anions in aqueous media based on functional surface modification of natural cellulose materials
Tetrahedron, 21/04/2011, IF = 3.219

J. ISAAD, A. EL ACHARI
A novel cyanide chemodosimeter based on trifluoroacetamide benzhydrol-2 as blinding motif: importance of substituent positioning on intra-molecular charge transfer
Tetrahedron, publié le 21/04/2011, IF = 3.219

G. AGARWAL, A. PERWUELZ, L. KOEHL, K.S. LEE
Interaction between the Surface Properties of the Textiles and the Deposition of Cationic Softener
Journal of Surfactants and Detergents, 13/05/2011, 14, IF = 0.795

G. AGARWAL, L. KOEHL, A. PERWUELZ
Simultaneous influence of ageing and softener on mechanical properties of knitted textiles during life cycle of garment
International Journal of Clothing Science and Technology, 23/05/2011, 23, pp. 152-169, IF = 0.491

X. TAO, V. KONCAR AND C. DUFOUR
Novel geometry pattern for the wire organic electrochemical textile transistor
Journal of the electrochemical society, 158, issue 5, pp. H572-h577 (2011) if = 2.483

I. CRISTIAN, S. NAUMAN, F. BOUSSU, V. KONCAR
A study of strength transfer from tow to textile composite using different reinforcement architectures
Applied composite materials - springer, if = 0.94
Manuscript #acma1059, accepted on 02/03/2011

J.LIU, B.ZUO, P.VROMAN, B.RABENASOLO, X.ZENG
Visual Quality Recognition of Nonwovens using Generalized Gaussian Density Model and Robust Bayesian Neural Network
Neurocomputing, accepted in February 2011, IF: 1.44
4.1 Chapters in Books (2008 to date)

2008

F. BOUSSU, C. COCHRANE, M. LEWANDOWSKI & V. KONCAR,
Smart textiles in automotive interiors,

M. CAMARGO, A.M. JOLLY-DESODT & J. RENAUD
L'agrégation complète-les OWA,
Ingénierie de la décision pour la conception, dans la série « La conception industrielle
de produits » (Ed. B. Yannou), Tome 3, Ch. 12 (2008).

A.M. JOLLY-DESODT & B. YANNOU,
Les méthodes de surclassement : l'école française et l'école belge,
Ingénierie de la décision pour la conception, dans la série « La conception industrielle
de produits » (Ed. B. Yannou), Ch. 13, (2008).

J. LU, X. DENG, X. ZENG, P. VROMAN, F. WU & G. ZHANG,
« A fuzzy multi-objective decision support system for nonwoven products experiment design »,
Computational Intelligence in Decision and Control (2008).

2009

H.P. WANG, A. CHAMROO, C. VASSEUR, V. KONCAR, N. CHRISTOV,
Suivi de trajectoire avec retour visuel par l’approche des systèmes à fonctionnement par morceaux
Automatique Avancée et Informatique Appliquée, Editura Academiei Romane, Bucuresti. ISBN:

2010

S. GIRAUD
Microencapsulation d’un diisocyanate et d’un phosphate d’ammonium – Application : elaboration d’un
système polyuréthane monocomposant à propriété retardatrice de flamme pour l’enduction textile

2011

S. NAUMAN, I. CRISTIAN, F. BOUSSU, V. KONCAR
Chapter 20: Intelligent Textiles for Armoured Vehicles
2011, ‘Smart Textiles for protection’, Editor Roger Chapman, WOODHEAD publishing LTD

I. CRISTIAN, S. NAUMAN, C. COCHRANE and V. KONCAR
Electro-Conductive Sensors and Heating Elements Based on Conductive Polymer Composites in Woven Fabric Structures

B.RABENASOLO, X.ZENG

4.2 Patents (2008 to date)

2008

X. LEGRAND, G. TSARVARISHKI, J. CHARLES, P. BLOT, Airbus France SAS,
Trihedral angle folding method for corner fitting, involves marking lines on respective faces of trihedral angle, and shaping another angle by folding along lines such that orthogonal weaving weft of one of angles is not parallel to stops,
FR2907801 (A1), 2008-05-02

X. LEGRAND, M. PIANA, G. TSARVARISHKI, J. CHARLES, P. BLOT PHILIPPE, D. GUITTARD, Airbus France SAS,
Weaving method for aircraft, involves inserting weft thread in warp sheets, after one side is threaded, to obtain continuous thread forming angle around another side that is displaced with respect to plane of sheets,
FR2907800 (A1), 2008-05-02

X. LEGRAND, G. TSARVARISHKI, J. CHARLES, P. BLOT, Airbus France SAS,
Pick insertion device for shuttle loom, has coupling unit to removable couple rapier with spool, and maintaining unit to removably maintain spool, such that spool is maintained by sheath or at end of rapier,
FR2907804 (A1), 2008-05-02

X. LEGRAND, G. TSARVARISHKI, J. CHARLES, P. BLOT, Airbus France SAS,
Shuttle loom for weaving of semi-cubical type continuous trihedral angle, has shed forming system operated by tilting, directly on hooks, receptacle placed between sides and laps to hold reel and reeds flattening pick traversing laps,
FR2907803 (A1), 2008-05-02

X. LEGRAND, G. TSARVARISHKI, J. CHARLES, P. BLOT, Airbus France SAS,
Shed forming system for use in weaving loom, has sorting device with thrust elements that exert pressure on rod to pivot in direction, and rocker deactivating initialization device when elements exert pressure,
FR2907802 (A1), 2008-05-02
X. LEGRAND, M. PIANA, G. TSARVARISHKI, J. CHARLES, P. BLOT PHILIPPE, D. GUISSARD, Airbus France SAS,
Three-dimensional surface weave,
WO2008049877 (A1), 2008-05-02

X. LEGRAND, G. TSARVARISHKI, J. CHARLES, P. BLOT, Airbus France SAS,
System for weaving a continuous angle,
WO2008049883 (A1), 2008-05-02

2009

F. SALAÜN, E. DEVAUX, S. BOURBIGOT, P. RUMEAU
Material Containing Microcapsules, In Particular Phase-Changing Materials

L. MEZZO, F. LUIZI, D. LUSSEY, E. DEVAUX, C. CAMPAGNE, A. CAYLA, M. ROCHERY
Shear Sensor
Patent N°: 10161582.1 – 1236, 2010

2010

C. NOCITO, V. KONCAR, L. RAYMOND
Composite enroulable photovoltaïque et dispositif de protection solaire comportant un tel composite -
A
FR2935541 (A1), 2010-03-05

C. NOCITO, V. KONCAR, L. RAYMOND
Photovoltaic windable composite and solar protective device comprising such a composite
EP2159848 (A1), 2010-03-03

C. NOCITO, V. KONCAR, L. RAYMOND
Composite enroulable photovoltaïque et dispositif de protection solaire comportant un tel composite
b
FR2935540 (A1), 2010-03-05

C. NOCITO, V. KONCAR, L. RAYMOND
Rollable photovoltaic composite and a solar protection device with such a composite
EP2159849 (A2), 2010-03-03

O. MARET, B. TILLMANN, G. BEDEK, F. SALAUN, E. DEVAUX, D. DUPONT, D. DERANTON
Microcapsules for self-refreshing textile
EP2218498, Publication date: 2010-08-18. (Microcapsules pour textile auto-rafaîchissant,
(09-51008 – 05.02.2009 FR)).

BLOT PHILIPPE, CHARLES JULIEN, PIANA MATHIEU, LEGRAND XAVIER, BESNIER JOEL,
5. EUGENIE Technology Transfer Unit

5.1 Overview & perspectives
For a long time, the ENSAIT has perceived the challenges which it should raise. EU-GENIE, the structure of valorization, has been created in January 2009. Its objectives are to support the companies in their human, technological and strategic development.

EUGENIE works with the companies to improve their process or products and also helps them to create new products for new markets.

All the strategy of EUGENIE is based on the competences of the researchers of the GEMTEX and their know-how in textile technologies and applications. The projects carried out cover the markets of transport, individual protection, medical, environment, building, geotextile and industries (Fig. 65).

The different themes of the 3 groups of research of the GEMTEX, such as textile composites, non-woven, agro-resources, sustainable development and design, allow us to transfer our knowledge for developing new industrials applications in close cooperation with our partners.

EUGENIE promotes the connection between university and companies.

Figure 65. Objectives of EUGENIE technology transfer unit
EUGENIE treats all the contractual aspects on BtoB basis (relation Business to Business). When the answer or the need is collective, it is then taken over by the collaborative projects links and reciprocally.

The objective of EUGENIE is to serve the industry according to their requirements while firstly positioning our specific knowledge and competences for market issues. The reflection is divided into three main services: laboratory test, technical assistance or consultancy, and research (private and collaborative). The main axes of development are Research and Technical Assistance. All prestations are directly paid by companies. In some cases, companies are financed by OSEO and can charge its costs on their CIR (Credit Impôt Recherche).

On 2011, we have 6 thesis directly financed by companies; 4 thesis for ballistic composite, 1 for environment, 1 for aeronautic composite. EU-GENIE, by direct contacts or participation on different Trade fairs and exhibitions, has a growing activity and should reach a turnover of about 750 k€ for 2011 against a turnover of 600 k€ in 2010; an evolution of 25%. In April 2011, the turnover has reached 405 k€.

On perspectives, we are waiting for four responses:

- 1 on project call by EPICE (one of 7 technological demonstrative platforms proposed by French government): aeronautical research

- 3 on project call by ASTRID (in French: Accompagnement Spécifique des Travaux de Recherches et d’Innovation Défense);

- LARZAC: New Lightweight ARmour solutions by hybridization of Alumina and textile Composite materials

- OMEGA: Optimisation of multi-layered soft and hard structures under high dynamic loading

- TELEPAC: Electroactive textile for variable and mastered aerodynamics
5.2 List of projects 2010 (on-going)

Table 4. Projects and evolution 2009 - 2011:

<table>
<thead>
<tr>
<th>Category</th>
<th>2009</th>
<th>2010</th>
<th>April-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Privative Research</td>
<td>217 419 €</td>
<td>555 266 €</td>
<td>362 605 €</td>
</tr>
<tr>
<td>Total Technical assistance</td>
<td>8 180 €</td>
<td>30 076 €</td>
<td>25 330 €</td>
</tr>
<tr>
<td>Total Laboratory and other</td>
<td>15 209 €</td>
<td>6 857 €</td>
<td>16 690 €</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2009</th>
<th>2010</th>
<th>April-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Total Privative Research</td>
<td>90,3%</td>
<td>93,8%</td>
</tr>
<tr>
<td>% Total Technical assistance</td>
<td>3,4%</td>
<td>5,1%</td>
</tr>
<tr>
<td>% Total Laboratory and other</td>
<td>6,3%</td>
<td>1,2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2009</th>
<th>2010</th>
<th>April-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Research Group HCD</td>
<td>0,0%</td>
<td>0,7%</td>
</tr>
<tr>
<td>% Research Group MTP</td>
<td>71,3%</td>
<td>31,4%</td>
</tr>
<tr>
<td>% Research Group MTC</td>
<td>28,7%</td>
<td>67,9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>2009</th>
<th>2010</th>
<th>mai-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process and products</td>
<td>14,9%</td>
<td>3,6%</td>
<td>18,7%</td>
</tr>
<tr>
<td>Aeronautic composite</td>
<td>0,0%</td>
<td>19,4%</td>
<td>10,0%</td>
</tr>
<tr>
<td>Environment</td>
<td>10,0%</td>
<td>7,1%</td>
<td>6,1%</td>
</tr>
<tr>
<td>Polysensoriality</td>
<td>0,0%</td>
<td>0,0%</td>
<td>8,3%</td>
</tr>
<tr>
<td>Smart Textile</td>
<td>39,1%</td>
<td>7,5%</td>
<td>4,8%</td>
</tr>
<tr>
<td>Balistic composite</td>
<td>28,7%</td>
<td>48,5%</td>
<td>41,7%</td>
</tr>
</tbody>
</table>

% CA of the category / global CA of year
6. Collaborative Projects Unit

6.1 The missions of the project mentoring committee, goals and strategy

The missions of the project mentoring committee are:

1. incubate collaborative projects of Research and Development in relation to themes studied in each group
2. create consortium including industrial partners and research cells in relation and complementary to the studies led by the GEMTEX laboratory,
3. assemble and manage national and international collaborative projects
4. make the connection between the financing structures such as the European Commission, regional and national authorities
5. support the dissemination of results of the researches involved in collaborative projects
6. inform the lecturers on the opportunities to finance calls for regional, national and international projects
7. coordinate collaborative R&D projects in which ENSAIT plays an active role in the management of these projects
8. manage the activity of GIS MTA in the collaborative projects assembling

The aim of the project mentoring committee, according to the themes and the research progresses (fundamental stage, R&D or transfer) is to advise the lecturers with the most suitable financing solutions. The diversification of calls and financing solutions also enables to provide long-term support to the developments of the laboratory.

For the fundamental research activities, priority is given to ANR projects calls, with or without specific theme. These projects enable the exploration of new theme or on the contrary to go further into a speciality. The national projects such as projects calls launched by the DGCIS (FUI, single inerministrial fund) enable to:

- promote textile industry through development and transfer activities
- investigate textile opportunities in innovative applications
- make the promotion of Gemtex on a national scale towards academic and industrial partners
- approve new concepts developed at laboratory scale, pilot and finally industrial scale.

European projects are financing tools used to reach the laboratory excellence, to create an international network of academic and industrial partners, ensure the development of emerging themes.

Projects with small consortium of partners (2 to 6), the project mentoring committee may rather choose financing solutions such as OSEO, in particular to develop an innovation in a new sector of application.

DGA is also a financing structure for projects of the GEMTEX, mainly for the sector of composites.

6.2 Report on current projects for 2010

Listing of the 2010-2011 current projects, according to their financing source in the tables hereunder.
## 6.2.1 F.U.I (fonds unitaire interministériel, national funding)

Table 5. FUI Projects - partners & keywords :

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full title and objectives</th>
<th>Partners</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAID – OUTILS</td>
<td>Development of a new textile technology to produce multi-dimensional textile stiffeners</td>
<td>ENSAIT, EDM, ESI, Stratiforme, EADS, Dylco, Achille Bayart, IFTM, CETIM,</td>
<td>Composite, modelling, textile</td>
</tr>
<tr>
<td>Application in transports</td>
<td>with O,U,T,I,L,S sections.</td>
<td>Hutchinson, TRP Charvet</td>
<td></td>
</tr>
<tr>
<td>NWC-X</td>
<td>Development of a new technology for versatile non woven, enabling to produce optimized 3D</td>
<td>Sicomijn, IFTH, Subrenat, Achille Bayart, Stratiforme, EDM, ENSAIT</td>
<td>Non woven, composite</td>
</tr>
<tr>
<td>Application in transports</td>
<td>composites sandwich structures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INTUMAT</td>
<td>Development of intumescent polyester fibres, to produce textiles Coating and composite</td>
<td>Alstom, ENSCL, Crepim, OCV, ESI, IFM, PPE, Duflot industrie, vandenhove,</td>
<td>Polyester, fire retardant, intumescent system</td>
</tr>
<tr>
<td>applications in sectors of home furnishing, railways</td>
<td>structures, including intumescent polyester foams</td>
<td>Cogitobio, EDM, ENSAIT</td>
<td></td>
</tr>
<tr>
<td>Intellitex</td>
<td>Flexible technologies for the production of smart textiles and garments</td>
<td>Doublet, IFTH, Ardèje, Francelog, Polymage, Sinaptec, Mediama, Schappes</td>
<td>Smart textiles</td>
</tr>
<tr>
<td>Application sector: Home furnishing, events</td>
<td>technologies, Siliflow, Mariton</td>
<td>technologies, Siliflow, Mariton</td>
<td></td>
</tr>
<tr>
<td>AM4DL</td>
<td>4 D muscle assistant for logistics</td>
<td>Sapelem, ITM, System U, Inficior, ARTS, Université de Rouen, APL, INRS,</td>
<td>Back coating, technical textiles, prehension</td>
</tr>
<tr>
<td>Application sector: logistics</td>
<td>Normandy living LAB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depoltex</td>
<td>Ecodesign and development of depolluting geotextiles for treatment of sediments draping</td>
<td>Idra environnement, Baudelet, EDM, Nordlys, Dylco, Aftex, Umet, IFTHY</td>
<td>Sediment, geotextile, depolluting</td>
</tr>
<tr>
<td>application in geotextiles, sediments in sea ports</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 6. FUI Projects ENSAIT role & results:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Role of ENSAIT</th>
<th>Obtained Results</th>
<th>Impacts on the employment</th>
</tr>
</thead>
</table>
| RAID – OUTILS | Development of a new technology to enable the position of threads in the three dimensions. | - Patent application  
- Handle a new innovative and unique technology  
- Production of 3D preforms | 1 trésis, 1 engineer |
| NWC-X    | Development of method for analysis and modeling by means of advanced techniques of calculations dedicated for the design of complex materials | Improvement of knowledge in non woven and development of a new method | 1 thesis |
| INTUMAT  | Development of flame retardant formulation able to make intumescent shield  
Spinning of intumescent polyester fibres | knowledge improvement in intumescent systems  
Spinning of intumescent polyester fibres | 1 thesis  
1 technician |
| Intellitex | Development of flexible textile screens | Prototype of screen on laboratory scale | 1 thesis  
1 post-doc 24 months |
| AM4DL    | Development of coating for prehensile holding charges | Launching phase | 1 post-doc 18 months |
| Depoltex | Fonctionnalisation of depolluting textiles | Launching phase | |

Clusters for competitiveness in relation with ENSAIT for national projects are:

- TechTera : technical fibres  
- Uptex : advanced textiles  
- EMC^2 : complex metal and composite structures  
- Novolog : logistic pole  
- IAR : renewable resources  
- Itrans : utilisation of textile in land transport applications  
- Pôles fibres : exploitation natural fibres  
- Capdigital : numerisation, modeling  
- Trimatec : confined space materials, new technology for the environment protection.
6.2.2 ANR (national research agency project, national project)

Table 7. ANR Projects partners & keywords:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full title and objectives</th>
<th>Partners</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mansart</td>
<td>Constructed sandwiches materials</td>
<td>ONERA, EADS, ATECA, SMCI, MATEIS, Armines, Airmat, Airbus, Semap</td>
<td>sandwich</td>
</tr>
<tr>
<td>NUMTISS</td>
<td>Numerical modeling of weaving process of fibrous reinforcement for composite materials</td>
<td>INSA Lyon, Armines, SNECMA, TRP Charvet, Groupe Safran</td>
<td>weaving, modeling, composites</td>
</tr>
</tbody>
</table>

Table 8. ANR Projects ENSAIT role & results:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Role of ENSAIT</th>
<th>Results</th>
<th>employment impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mansart</td>
<td>Development of non woven structures for the sandwich core</td>
<td>Combination of non woven and interlock as new structure</td>
<td>1 thesis 1 engineer</td>
</tr>
<tr>
<td>NUMTISS</td>
<td>Integration to characterize weaving method in 3D structures</td>
<td>. construction of complex 3D structures . training for the presented models . tomographic analysis of complex structures</td>
<td>2 thesis</td>
</tr>
</tbody>
</table>

6.2.3 International and European projects

Table 9. EU Projects ENSAIT partners & keywords:

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full title</th>
<th>Partners</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogrotex</td>
<td>Development of new agro textiles from renewable energies and bio degradable – setting up of furan chemical process – extrusion of</td>
<td>Centexbel, Rodenburg, TFC, Devan, Tecnaro, DS Textiles, La Zeloise, Texinov, D’Appolonia, ITCF, WURF</td>
<td>Biodegradation, geotextile, furan chemistry</td>
</tr>
<tr>
<td>Acronym</td>
<td>Role of ENSAIT</td>
<td>Results</td>
<td>Employment impact</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------------------------------------------------------------</td>
<td>----------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Bioagrotex</td>
<td>Development of non woven structures, natural fibres based on binder resin from furan chemistry</td>
<td>Structure based on natural fibres</td>
<td>Permanent job</td>
</tr>
<tr>
<td>IMS-ICP</td>
<td>Development of complex 3D woven structures interlock type</td>
<td>Poste doc 36 months + 12 months</td>
<td></td>
</tr>
<tr>
<td>INTIMIRE</td>
<td>Development of fibre made of intumescent materials with fire retardant and flame resistant properties for sectors of transport and construction</td>
<td>Fire retardant, composite intumescent</td>
<td></td>
</tr>
</tbody>
</table>

Table 10. EU Projects ENSAIT role & results:

*Non started yet, second semester 2011*
6.3 The aims of development for the collaborative projects

The aims of the project mentoring committee:

- Creation of new academic and industrial partnerships for the development of emerging themes and consolidation of fields of research.
- Give textile an image of innovative material with high added-value by the implementation of new applications by means of collaborative projects (for instance: incorporation of fibres in concretes)
- Enlarge the financing sources and the size of the consortium
- Initiate more collaborative projects in relation with sensoriality and perception of textiles materials, e-shopping, environmental impacts of new advanced textiles
- Driving and managing the collaborative projects to increase the recognition of GEMTEX laboratory, enabling a real strategy of skills and be presented as the initiator

6.4 Financial summary of the collaborative projects and various funding

The pie chart hereunder shows the sources funding proportions for period January 2010 to December 2011. The turnover of collaborative projects for 2010 was 1.731 M€.

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<table>
<thead>
<tr>
<th>Funding sources of running collective research projects 2010</th>
<th>Funding sources of running collective research projects 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Research Agency 25%</td>
<td>National Research Agency 32%</td>
</tr>
<tr>
<td>Ministry of Industry 18%</td>
<td>Ministry of Industry 18%</td>
</tr>
<tr>
<td>Region Nord-Pas-de-Calais 15%</td>
<td>FEDER 15%</td>
</tr>
<tr>
<td>FEDER 21%</td>
<td>Region Nord-Pas-de-Calais 15%</td>
</tr>
<tr>
<td>Other 1%</td>
<td>Other 1%</td>
</tr>
</tbody>
</table>

Figure 66. Funding sources of collaborative projects
Figure 6. Funding sources of collaborative projects (balance)
7. Conclusion

Innovation is essential for achieving competitive advantage in today's high-pressure business environment and even more in the textile and apparel sector. Many EU textile SME companies are internally focused, losing sight of key sources for inspiration, customer needs, and changing marketplaces, thus stifling creativity and long-term growth.

The GEMTEX Laboratory is a unique scientific resource to help companies address these issues. Our approximately 4 € million annual operating budget and world-renowned faculty support close to 3 research groups and some 20 projects on National and EU level, ranging from virtual clothing and smart textiles, to 3D reinforcements for composites and flexible sensors and actuators.

The Laboratory's faculty and research staff are joined by more than 30 PhD students (many of whom have already completed other advanced textile degree programmes before coming to the Lab).

The GEMTEX Laboratory works closely with its partners to provide them with a facilitator for both innovative products and thinking. By pursuing a range of research that no single company could match, the GEMTEX Lab provides an abundance of ideas, technologies, and paradigms for the future.

The main missions of GEMTEX are:

- Development of research activities related to textiles in order to generate knowledge and high level expertise in this field;
- Knowledge Transfer, including the transfer of creative ideas for the use of a single new technology, or the convergence of several technologies.
- Brainstorming Technology and Product-Development Sessions. GEMTEX input can assist companies in creating new product concepts, provide critical feedback during various stages of product development, or help to reframe an existing product line. Faculty members and staff are always available for consultation.
- PhD Student Recruitment, one of GEMTEX greatest strengths is the quality of its students and ENSAIT education programme.
- Intellectual Property, GEMTEX generates more than 4 new patents a year.

We believe in the future of EU textile sector. We are also convinced that this future is bright and that research and development activities are necessary and useful for both, the ENSAIT development and reputation and the EU leadership in the field of high added value textiles.