1. Introduction

In the range of every day fashionable clothing the design is a mean of achieving a positive reaction of an observer and potential customer. It is in human nature to respond on visual experience of an object, meaning the surroundings objects as well as clothing and other product for personal everyday use. This visual experience and psychophysical reaction that arises from that visual impulse have a crucial impact on drawing the decisions about accepting or rejecting certain product. Aesthetic design can affect the success or failure of a clothing system through the way it makes the user feel, allows for personal expression, and generally enables the physiological functions of clothing.

The importance of human reaction on positive visual impulses and aesthetics should be considered as an important factor also in the field of highly specified, protective textiles and clothing in professional and personal wear. The evidence is growing that fashionability also affects the way protective clothing is perceived. [1] But when it comes to a protective clothing the design cannot be perceived only as the mean of fashionability than as an complex process covering an extremely wide range of circumstances, as indicated by the breadth of activities and diverse contexts. The process of designing specific protective clothes includes the entire design activity for the development of new products with high technological content from the initial idea and first project concept, to the feasibility analysis, considering new materials and different types of research during the steps of designing, prototyping and final manufacturing.

The development of effective protective clothing products and systems is essential for the safe conduct of specifically identified activities spanning, for example: conventional and extreme sports, police and military operations, chemical, agricultural and industrial working, medical and surgical procedures, fire fighting and space exploration. Textiles and clothing systems designed to protect from physiological discomfort have a long history, for example, from clothing designed to protect early motorists and pilots exposed in open vehicles and planes. But in a recent decades, the importance of protective properties of textiles and clothing in ones professional but also personal every day life, arised from growing health and safety awareness together with the period of change and innovation in the science,
design and art of textiles. The late 20th century saw an unprecedented increase in emphasis on protection of the human from occupational, recreational and basic everyday-life hazards. The range of hazards and the means of combating them continue to grow and become ever more complex. A consequence of this is the development and exploitation of new textile fibers, structures, and clothing systems whose purpose is to provide improved protection, whilst maintaining comfort, efficiency and well-being, but also must includes the right balance of fashion, trends, cultural aspects and aesthetics. Rapid progress in textile development now offers enhanced functionality and responsiveness to changes in environmental conditions, and the recent development of `smart' and `intelligent' textiles is accelerating.

In following chapters the role of a design process in protective clothing production will be explain, considering the product development design process appropriate for protective clothing, the increasing synergy between fashion considerations and functional design and the reconciliation of factors which must be taken into account. It also illustrates some current examples of developments in protective clothing.

2. Design Process in Protective Product Development

The specific requirements on protective properties of a personal professional or everyday clothing differs significantly regarding the category of hazards that the wearer will be exposed and knowing the needs of a customer is one of the first factors to be determined when responding to a design request. Protection may be required for various conditions from extremes of hot and cold weather, dirt, chemical spillages, fire, bullets, cuts, impact and abrasion, together with safety considerations including visibility and personal protection. Successfully designed protective suit must have all specific functional requirements and all components optimized in their mutual system in use, to enable the activity to be successfully carried out whilst maximizing protection and eliminating or minimizing the risk.

So in order to be acceptable to the user, the clothing must balance functional elements with both structural design and aesthetic considerations, including the important subjective element of comfort.

So, designer who is working in a field of protective clothing is not working only in a field of artistic expression based on a subjective sense of harmony and beauty. The scientific approach is necessary to explore all the possibilities in finding the solution to a specific problem. Designing special protective clothes requires numerous researches and acquiring knowledge form the field of different technologies, nanotechnology, engineering, smart textile and textile with special properties production, etc.

Successful design in the case of protective clothing must respect strictly defined functional requirements and conform to regulatory standards for the specific industry, meaning the following properties:
consider functional requirements
consider is the designed idea appropriate for specific task acquiring satisfactory aesthetic
is it fit for purpose, durable and does it performs to or exceeds required standards
is acceptable to the user respecting the culture, traditions, specification, manufacturing and costs

These are only the basic requirements on design when it comes to protective clothing. Additionally, a good, successful design must provides an innovative approach resulting in innovative concepts that simplifies existing products, extends norms or breaks new ground in materials, manufacturing or design concept, adds value by exceeding specifications in functionality, ergonomics, ease of use or other aspect. But yet, basic fashion considerations must be taking into account such as:

- self-perception and identity
- cultural identification with recognizable social groups, fashion currency; awareness of relevant fashion and lifestyle trends
- feelings and emotions including comfort and wellbeing
- appropriate form, style, materials and color
- cut, style and proportion

Recently, the increased use of technical fibers developed for specific protective needs, is noticeable in casual clothing like sportswear. So the fashion works along with personal protection and special acquirements.

For example it is often the case that military or fire-fighters and police wear modern branded sportswear for off-duty activities, which they find to be comfortable, practical and fashionable, and are now demanding similar styling together with functionality for their work-based clothing, to improve flexibility and maneuverability whilst performing tasks. Professional soldier also began to have demands on their current clothing from the point of view of comfort, but also from the point of appearance. So, designing protective clothing means balancing between design requirements and function, performance, protection and comfort.

As it has been said earlier, designing the new product in a field of protective clothing is actually major research and development project which includes all sorts of testing, evaluation, and particular official standards and procedures knowing. The usual practice in such projects is that the testing and evaluations during the product development is carried out in laboratory environment where the real conditions cannot be achieved completely. That is why the product development process does not end with first realization of a prototype but requires constant continuations and improvement based on a studies performed with actual users. For example, during development of sportswear and outdoor wear some of the prominent sportsmen and women within the activities themselves became consultants in the research and development process and helped to refine existing designs and develop new products for protective and performance clothing. These have developed into some of the most successful sportswear and outdoor brands such as Helly Hansen and O'Neill. Also the development of highly sophisticated
Responsive manikins for use in thermal comfort, fire, pressure, and crash testing has provided enhanced data in areas which are difficult to test safely with humans.

Regarding the sportswear with special properties and performances, the involvement of sports champions in innovation and new material development processes is not the inheritance of a couple of latest decades. Way back in the first half of the 20th century, in the late 20-es, a true innovator from the world of sports, René Lacoste revolutionized the tennis men’s sportswear. The traditional tennis court wear for men was a long sleeved starched shirt made of the classical woven fabric. René Lacoste designed a white, short-sleeved, shirt with an unstarched, flat, protruding collar, a buttoned placket, and a longer shirt-tail in back than in front (known today as a "tennis tail"). He also created new loosely-knit pique cotton knitted fabric called of the special weave called *jersey petit piqué*, which was material of a specific properties for the time. The reason why he entered the world of innovation and created a "new" shirt more suitable and comfortable closer to a requirement of an professional tennis player, is that he himself knew the best how cumbersome and uncomfortable the classic tennis outfit was at the time.

The process of designing the protective clothes starts with problem exploration and analysis. This is the starting point where the characteristics required of the new protective product and its specialized design is determined and defined with the potential users. In this initial step a few categories has to be determined:

- The type of user requiring protection; the gender, age, size, shape, lifestyle and socio-economic group of the proposed user is, plus an analysis of users clothing preferences. This data may be gathered through interviews, direct and indirect observation and questionnaires.

- The activity of the user; analysis of the activity of a protective clothes user is essential to be determined, and the analysis of the product can be taken only afterwards. Ergonomic and physiological factors affecting the design and use of protective clothing has to be determined, such as range of movement, temperature variations or, for example, specific medical condition. The design must meet the challenges specific in particular occupational activities, and the impact of environmental factors such as airflow, extreme cold or a range of chemical hazards must be also taken into account.

- Legislation and standards governing protective clothing; a review of national and international standards for sizing, material testing, garment manufacture and product labeling must be studied and followed to establish a set of criteria forming the design of protective clothing. The outcome of this stage enables successful product and system characteristics to be identified.

In the research which designer performs, also reviewing, analyzing and comparing between earlier and existing products, is essential. A review of previous products provides an opportunity to identify and evaluate the process followed in reaching previous design solutions. Based on the criteria formed using the research data required from the user group and activity analysis, the level of protection required is
determined. The outcome of this stage enables successful product and system characteristics to be identified. Gathering of initial information should include: user profiles; product price, size and color ranges; new and existing materials, thread and fastening components; manufacturing processes; garment labeling regarding aftercare; fashion and design content. Based on research at trade fairs and sampling, a comprehensive study of contemporary fashion, color, texture, line and silhouette trends, and relevant cultural contexts, informs the final selection of product characteristics, both functional and aesthetic.

After a preliminary research a more practical actions should be done to meet the project objectives. In this stage innovations can be introduced. Evaluation and selection of proposed designs, and also the manufacturing of prototype, follows afterward. Preparation for manufacturing the prototype includes a preparation of modified size chart, shape profile and block pattern incorporating the age and size range of the user group, the range of movement identified in the activity analysis and the product type. After the evaluation and testing of prototype, which include a testing against the set of criteria identified in the design brief, preferably by trials with the user group. If prototype shows satisfactory performances for the specific group of users and their specific hazards, the actual production process will started.

3. A Scheme of Protective Clothing Design Requirements

Protective clothing design method concentrates multidisciplinary skills for the development of new products with high technological content. During the whole process, design supports all the actions from the initial idea and concept definition, considering new materials, continuing with the feasibility analysis, up to the final product production and its optimized industrialization plan.

Innovation process starts from the definition of the project requirements, paying attention not only to the properties that need to be obtained in the final product, but also evaluating, through a detailed feasibility analysis, all the necessary materials, equipments, machinery, manufacturing procedures, standards to be respected, etc. related to the specific product's application field.

An in depth study of the state of the art is usually performed, involving both similar products, already present on the market, and materials, technologies, machinery and accessories required for the achievement of the final product. Through a “Technology Transfer” approach, the study will analyze not only a specific sector, but all the possible solutions (already exploited or not) able to respect the defined requirements.

Then Concept development, Design studies, Simulation and Modeling will contribute to finish the whole project, evaluating all the aspects related to a New Product's development. Assembly studies, design, definition and optimization of the manufacturing system, tests and iterative actions will bring to the prototype's production and to the final engineering phase.
In the last step of Design Method all the optimized manufacturing procedures, useful for the New Product's production at industrial level, are collected in a functional handbook and strategies for the final product's industrialization and commercialization are evaluated and applied. Evaluation of marketing and economic aspects is applied to each step of the Design Method, from the first raw material analysis and selection, to the definition of the optimized industrialization plan, in order to develop innovative, functional and marketable products.[2]

Figure 1: GZE's Design method and related activities

Nowadays, a companies that are involved in protective product development projects, follow different approaches, strictly connected among themselves, for the development of innovative products and processes: the first one involves the Design of New Products based on some Smart Materials, to find innovative applications through the development of a specific demonstrator; the second one starts from a Specific Request of the client that could involve the solution of a specific problem or the development of “something innovative”. The objective is to
give commercial opportunities to “pure research”, through the perfect integration of material sciences, engineering and design creativity for the development and manufacture of a practical and touchable Demonstrator. In fact, the exploitation of materials and technologies still at lab scale, during the development and manufacturing of a potentially marketable product, is able to stimulate their production at industrial level and, hence, their growth on market. Besides comments and suggestions obtained by Researches, Engineers, Industrial Producers and End Users on the final Demonstrator can contribute both in finding new potential applications for the exploited material and technologies and in promoting the commercialization of that New Product.

Development of new functional products starts from the study of a specific material, its technical characteristics and properties, its availability on the market, its health and safety aspects, its price, its potential workability in existing processes, its current use, being also aware of the importance of experimental analysis for the development and improvement of new products and processes. Through this first evaluation step some Smart Materials are selected as the most promising ones to be transferred in certain application fields. At this step the close collaboration between different skills, including technicians, engineers, designers and market experts, is essential to proceed from the concept definition to the final product manufacturing.

Shape, dimension, positioning and functionality of each part of the product will be “translated” into drawings and schemes and design solutions are suggested for the perfect integration of the materials and the maximization of the functionality. During the project, in fact, specific design solutions are studied and suggested for the modification and/or integration of the new material into the selected application field, always paying attention to all the aspects related to the product's further commercialization.

Continuous researches on new assembling methods, technologies, processes and techniques, as environmentally friendly as possible, is continuously carried out as well as studies on innovative equipment able to increase the workability of the Smart Materials. In order to guarantee the maximum functionality of the Demonstrator particular attention is also paid to other aspects like ergonomic comfort (if wearable), user friendliness, aesthetic effect (marketable product), etc.

3.1. Customer requests

Highly developed professional design method allows also offering a consulting and supporting services, accumulating experience about market requirements, always paying attention to all the socio-economical aspects for the development of a product at industrial level.
The first step for an efficient consulting activity is the understanding of the client's requirements: this will permit to make clear, in the mind of the designer, the concept of the product they'll have to obtain. This action is not ever easy, especially when the client would like to obtain a not well defined "innovative product".

Some instruments could help and optimize the exchange of information: interviews (containing specific questions about objectives, time, investments, type of end-users, evaluation of the productive process including machinery, process parameters, productivity, restrictions) and the capability to "translate" from the industry's language to a technical one. In fact, often, the customers express the properties that they want to obtain in the final product in terms of general characteristics (stronger, lighter, comfortable, easier to work with, cheap) and/or comparisons with other commercial products; while the technicians refer to fixed parameters (tensile strength, density, breathability, no toxicity), measurements units and/or standards to be respected. The continuous communications and the perfect integration of these two different points of view is fundamental in order to develop a product able to satisfy the customer's requests while helping the researchers in the choice of the most suitable materials and technologies.

Afterwards, following the same approach to the New Product development, the defined requirements will be then “translated” into drawings and schemes and preliminary design studies are carried out. Smart Materials will be, hence, evaluated in function of the best compromise among performances, availability on the market, potential health and safety aspects, price and workability in existing processes.

At this point a custom made process will be planned to modify/integrate Smart Materials into a marketable product by an industrial scale process. Custom made development is the most difficult step, so, when possible, the manufacture of the prototype is performed directly at the customer's plant and through a direct contact with the client and its technical staff, in order to avoid possible problems connected to the further industrialization of the manufacturing process. In fact several problems are usually met when new materials, coming from lab scale production, are applied to industrial plants. Especially in textile fields, the development of a new manufacturing system is often related to great amounts of required raw materials, costs of the machineries and time spent for the definition/optimization of process procedures and for workers' training. In this case the exploitation of engineering expertise, related to studies, simulation, modeling and design of new equipments and tools, facilitates the possible modification and/or setting up of the new process parameters. Besides, the constant collaboration between the Researchers and the Workers will contribute in the definition of the most suitable manufacturing methods, exploiting the expertise and experience of the producer, involving the technical staff in the suggestion of possible solutions and increasing, in this way, the acceptance of the new technology from all the employees.

Through an iterative process, continuous corrective actions are suggested in order to obtain the final optimized prototype, ready to be produced at industrial level and compliant with the process requirements. At the end, all the optimized process procedures are summarized in a sort of handbook for the customer's use containing design of the model, pattern preparation, evaluation of required
DESIGN OF PROTECTIVE CLOTHING
Giada DAMMACCO; E TURCO; Martinia Ira GLOGAR

materials, positioning, integration, assembly techniques and final testing results. An
evaluation of the obtained improvements, both in terms of manufacturing process
(faster, easier, linked to a reduction of waste, automatable,...) and performances of
the final product, is performed in order to validate project's results and to prepare a
suitable communication plan, able to promote the new product into a specific
market.

4. Study of Some Examples of Clothing System and
their Functionality and Protection Properties

4.1. Suit for the extreme environmental conditions of coldness

Starting with the example of a suit designed for the extreme environmental
conditions of coldness, designed for professional climbing Mount Everest
expeditions, but as well suitable for the Arctic or Antarctic expeditions, it would be
interesting to present a short chronology of protective clothing for the conditions of
extreme coldness, illustrating the path of general development.

Roald Amundsen, being the leader of the historical expedition to Antarctica that
actually reached the south pole in 1911., can also be considered as the pioneer in
developing a "design system" for protective clothes for extreme conditions of
coldness, at that time. For example, the ski boots that he designed were the first
project of protective equipment designing and were product of two years' testing
and modification in search of perfection.

Figure 2: Amudsen designed boot

The materials that were used at that time to form a basis of the expedition polar
clothing relied on natural fibers such as wool and cotton. Clothing was layered so
that air could be trapped between the layers. However, in the early period it was
difficult to find totally windproof or waterproof fabrics. One of the weakest point of
the protective suits of that time was lack of a fixed hood which was too close fitting.
This meant the body was not entirely covered and parts of the neck could be
exposed as the unfixed hood moved. In addition, this allowed the warm air to
escape, reducing the warming action of the layers.
By the time of the 1930s, the system of mesh underwear was developed. This was a vest made from open weave cotton strands with a woolen vest immediately outside, resulting in the all-important stable layer of air. Clothes worn over this would open at the neck so that a vent could be made in case of sweating; allowing a release of moisture as well as cooling the wearer down. Also, in this period the explorers wore a hood attached to their outer windproof layer, edged with fur. Also the insulation at the bottom of the boot was increased and in extremely cold weather an over-boot of canvas and leather was worn on top of the boots.

Period after II world war brought a great shift in clothing techniques and a development in new materials and methods which revolutionized polar clothing. The greatest shift was a move from natural to manufactured fibers to provide a basis for clothing. So, with the development of new materials these could be applied to aspects of clothing that explorers already knew were problematic.

The first outfit made from manufactured fibers was made from a rubberized nylon material to make it waterproof and windproof, the inside of the trousers was also lined with a lighter weight rubberized material. This substantially increased the waterproof and windproof properties of the clothing beyond that of the traditional wool and heavy cotton.
Through 70es and 80es, layering again was a fundamental principle in the clothing. During the Transglobe Expedition (1979-82) the five layered clothing system was worn to trap the heat. Two of the expedition members topped this with a wolf skin parka, made in the indigenous fashion. What these men had learnt was that the indigenous peoples of the north have knowledge about what to wear in extremely cold weather. Without such knowledge, these people would not have survived. Also at that time the expedition wore three layers of footwear, with mitts, caps, goggles and facemasks. But problems of sweating effects and also the effects of the cold were still significant requiring constant research and constant improvements. The windproof extensions that were designed on the jackets would move when skiing, which would allow wind to enter the jacket top, reducing the insulation effects of the layers. The problems with face protection also continued in the modern times despite adequate preparation.

Figure 5: Transglobe Expedition 1979-82

So continuous researches on new assembling methods, technologies, processes and techniques, as environmentally friendly as possible, are continuously carrying out as well as studies on innovative equipment able to increase the workability of the Smart Materials. In order to guarantee the maximum functionality, the particular attention is also paid to other aspects like ergonomic comfort (if wearable), user friendliness, aesthetic effect (marketable product). [3]

The following examples are some state of the art protective product for the conditions of extreme coldness developed as the result of a detailed research projects led by the Italian design company Grado Zero Espace, which has been pioneering high tech performance wearables. They excel in finding new applications and design solutions to scientific innovations.

### 4.1.1. State of the Art Example of Jackets for Extreme Ambient Conditions

Interesting research project that started from the evaluation of an high performance insulating material used by NASA in their space suits and its modification to be integrated in textile field, actually resulted with the development of new materials and products.
A design team has studied the aerogel material to develop lightweight and high insulating liner for protective garments, exploiting the experience of thermal protection in spacecraft. The aerogel is a substance like a gel whose liquid component has been replaced by gas, and the result was a material composed of 90-99.8% air, with typical densities of 3-150 mg/cm³. The material obtained is considered the most efficient insulating materials in the world (Thermal Conductivity 0.003 Wm⁻¹K⁻¹). [4]

So the first integration trial of designing a high – performance jackets for the conditions of extreme coldness involved the simple insertion of the crumbled aerogel crystals between two impermeable fabrics for the development of a padded jacket named Absolute Zero.

![Figure 6: Absolute Zero Jacket by Grado Zero Espace](image)

All the problems met during the manufacture of the first demonstrator were communicated to the suppliers, trying to stimulate the development of suitable solutions. This contributed to the definition, development and successive industrial production of the Aerogel Blankets, a composite of silica aerogel and fibrous reinforcement with a non woven structure able to turn the brittle aerogel into a durable, flexible material.
After some other integration experiences, Aerogel Design System has been developed which enabled a creation of a padding warranting softness, flexibility and breathability, together with Aerogel's thermal insulating characteristics. All these properties were achieved in an extremely reduced thickness, while dust production and desiccant touch were eliminated by the development of specific patches containing a proper combination of thin aerogel blankets, soft paddings and tight but breathable fabrics.

On the basis of the first Absolute Zero trial further research and solution finding continued aiming to design and produce a jacket able to respect the severe requirements of the Antarctic Expedition. The jacket had to guarantee to the explorer to traverse the continent, climb the mountains or ski to the South Pole remaining warm and safe inside technological comfort. The result was Absolute Frontiers jacket, using a proper combination of high performance materials, including the flexible aerogel insulating blanket as padding.
Although solving some problems related to the multilayer development and washability of the garment, the dust production and desiccant effect of the aerogel were still drawbacks during the manufacturing and handling of the final product.

After some integration experiences, a special method named Aerogel Design System has been developed enabling a creation of a padding warranting softness, flexibility and breathability, together with the Aerogel’s thermal insulating characteristics. This technology was applied for the development of the Quota Zero jacket, designed for high altitude mountain-climbing. Quota Zero jacket is a multilayer jacket designed for expedition use where the extremes of weather, terrain and temperature demand the highest level of performance. It was selected by ADI Design Index in 2008 as one of the best made in Italy product.

The GZE design team, lead by Giada Dammacco, decided to focus on keeping the material as light as possible whilst maintaining very high thermal performance. In this way the number of layers required is reduced in comparison to traditional equipment, which is still too heavy. A new innovation is the integration of the glove with the sleeve, thereby avoiding the problem of losing a glove due to strong winds (Pro-Hand© system); a decentralized vertical zip dedicated to the implementation of the security systems, in order to avoid the lifting up of the jacket during the climb; a 3D extremely breathable fabric (reducing excessive sweating on the back); an elasticized fabric able to guarantee an optimal mobility and a reinforced fabric placed on the shower protecting from the abrasion of the backpack.

![Quota Zero Jacket features scheme and positioning plan](image)

Figure 9: Quota Zero Jacket features scheme and positioning plan

The inclusion of materials that are light while being highly insulating through advanced thermal properties has made it possible to fulfill this requirement. Using thin layers of microporous and non-porous membranes and wind resistant textiles,
it was possible to optimise breathability and lightness, which are very important for climbers who have to make extreme physical efforts whilst being weighed down with heavy equipment on their backs. The structure consists of multiple layers of fabric. The external layer is impermeable and wind resistant whilst the inner layer is thermally insulating.

OUTER SHELL - Waterproof, breathable, seam sealed
- Hybrid membrane. Micro and Non-Porous structure
- Bielastic stretch fabric on the shoulder blade
- TURTLESKIN, ultra reinforced fabric on shoulder.
- Tridimensional fabric on upper back, High breathability
- PRO-HAND system: Glove/sleeve with Velcro closure
- Grip extra support under the glove
- Left Zip closer
- Central opening for climbing rope
- Two lateral pockets
- Waterproof zipper
- Anatomic Elbow welds for articulation
- Stitchless and fully welded
- All zippers ad-hoc made
- Fully adjustable, attached drop hood

INNER LAYER - Thermally insulating
- Aerogel Design System
- Anatomic study. Thermal zone
- High comfort wear
- High performance insulation materials
- BLU AIR: experimental version

Quota Zero Jacket, besides the internal ergonomic removable aerogel padding based on the developed Aerogel Design system, includes other high performances materials. The structure consists of multiple layers of fabric composed by an external layer consisting in a wind resistant, waterproof but breathable orange fabric, containing a proper textile membrane, a 3D extremely breathable fabric for the optimization of the moisture management (reducing excessive sweating) on the back, a properly positioned elasticized fabric able to guarantee an optimal mobility, a reinforced fabric on the shoulders where the back-pack is carried, a more rigid material for the elbows and extra support under the gloves; the inner layer, instead, provides the thermal insulation by the proper positioning of Aerogel Design System patches.
As mentioned an in depth analysis of the athletes requirements brought to the development of specific design solutions like the patented Pro-Hand© system and the integration of ropes inside the jacket. [6]

Pro-Hand© system invention consists in the realization of a garment provided with a sleeve having a portion integrally attached to a covering glove. The garment offers the possibility of taking off the covering glove without having to take off the sleeve, of wrapping the glove in such a way that is not an encumbrance when climbing and also of protecting the glove against rain when so folded back. Another
important choice has been the design of a special opening for the rope that avoids the lifting up of the jacket during the climb. A special waterproof and windproof zip was so dedicated to the implementation of security systems inside the garment improving mobility and comfort of the climber.

Figure 12: Special opening for the rope of a Quota Zero Jacket

Figure 13: Details of Quota Zero Jacket

The first step of the Quota Zero's design involved a careful human thermal scan in extreme cold conditions and during physical activities. Such studies helped in defining the proper positioning of the padding, considering some body's areas that mostly need thermal protection, as well as other regions characterized by the need of higher breathability. Some other studies of body's movement were performed with the important help of professional climbers, in the way to optimize gestures and avoiding hindrance and poor freedom of movement. Results of these studies were integrated during the assembly of the final garment. Besides, special attention
is given to the impermeability of the stitching through the use of advanced joining technologies.

4.1.2. Balaclava especially designed for high attitude use (K-Cap)

Balaclava is a form of cloth headgear that covers the whole head, exposing only part of the face. A K-Cap that is going to be presented is balaclava designed especially for high attitude use. It is being developed as part of a project for the design and development of specialized clothing equipment to be used during a scientific expedition on Mt. Everest. The balaclava has come to symbolize a new concept of protective clothing. The innovation in the materials used and the design itself makes this an example of how even an old object such as this can be made new. [7]

Figure 14: K-Cap selected by ADI Index 2006

It consists firstly of a memory membrane fabric, which modifies its physical structure according to variations in temperature, copying the behaviour of the human skin. Secondly, it has two layers of bielastic fabric that render the structure active, allowing complete freedom of movement. This item is thus technologically very advanced and extremely comfortable to wear.
The innovations in terms of materials and protective technologies are improved breathability using the latest next – generation polymer and improved anatomic comfort through the synergy between design and new modeling solutions. The next – generation polymer that is used is a shape memory polymer that have the capability of changing their shape in response to external stimuli, one of them is temperature. The shape-memory effect is not related to a specific material property of single polymers, but instead is realized from a combination of the polymer structures and their morphologies. The phase responsible for the highest thermal transition, such as highest melting point among all the phases, is the basis for the permanent shape. Above this temperature the polymer is completely in the melt state. While the glass transition temperature of the other phase can be used as a molecular switch for a temporary shape. This material, in fact, after processing into a form, assume a permanent shape which can be deformed to produce other shapes and then, by applying heat, is able to return to its initial shape.

4.2. Special Sailing Suit Development – S1 Suit (GZE)

Development and design process of a special sailing suit that is going to be explained and presented in a following chapter, is an excellent example of how design can help in the respect of specific requirements determined by the athletes, bringing to the development of smart solutions able to improve the functionality of an already developed product. In this case a strict collaboration with the sailor Pia L'Obry permitted to achieve specific functionalities for a sailing suit resulting in a development of a special suit named S1 Suit. The aim was to find a solution and to answer on as much as possible special requirements and needs specific for solo Atlantic Ocean crossing.

![S1 Sailing Suit – First version worn by Pia L'Obry](image)

The problems met during the trial of a first version stimulate further collaboration with the potential user in order to develop even more suitable solutions with integrated different technologies and miniaturized electronic devices.
After a preliminary experience with the first version, some specific problems connected to the sailor's safety and comfort were identified: first of all the necessity of a technology able to guarantee, from the support helicopter, the athlete's visibility also in adverse weather conditions; second, the request of soft, light materials able to protect knees and elbows from the impacts maintaining at the same time a good sailor’s mobility.

Thanks to these specific requests and in depth studies about current and innovative solutions, several innovations in terms of materials and design were developed including: the integration of the gloves with the sleeve (Pro-Hand© system), that avoids the problem of losing them due to strong winds, and the proper insertion, in some specific parts, of a shock absorber foam able to protect the body from impacts. [8]

Figure 16: S1 Sailing Suit – improved version with specific innovative solutions incorporated

A thermo-active breathable textile membrane was used to guarantee the best moisture management; in fact it adapts its molecular structure and permeability according to thermal variations providing besides marine salts resistance.
Thermal responsive membrane (polyurethane – based shape memory polymer) is unique, new, high performance material that features temperature sensitivity. Novel characteristic means that the material can be used to make comfortable garments that are watertight without clamminess. To maintain a comfortable environment within garments the SMM (Shape Memory Membrane) is designed to react at a transition temperature which adapts the state of the material to variations in the internal and external environment. When, following strenuous activity or changes in the external environment, the temperature inside the garment reaches the transition temperature, the material automatically becomes either more waterproof or more permeable to water vapor.

This updated version of S1 Sailing Suit contains an electroluminescent flexible film applied along the backbone and controlled by a switch inside the pocket. This will permit to increase the visibility in sea from the support helicopter also in adverse weather conditions, without affecting mobility of the sailor.

4.3. Designing of a “Hydro Jacket” – Improved Equipment for Fireman’s Activities

Hydro jacket is designed to give more comfort and safety to the Fireman's activities in the city. The aim was to develop a thermal and moisture management layer based on a fabric coated with a water absorbing polymer to be easily integrated in current protective clothing. The external layer reflects the UV rays and a FR coating is activated by the heat of a fire. The second layer works as heat dissipater and thermal barrier. The design of the lining allows the best moisture management, with the help of the Safe Hydrogel Padding.
Figure 18: Hydrojacket

Hydrogels are hydrophilic polymer networks that are able to swell and retain large amounts of water and maintain their three-dimensional structures. The term Hydrogel is used at the same time for the dry substance and for the water charged gel. These polymers do not dissolve in water; upon swelling, they increase in volume, but keep their shape without breaking up.
Safe Hydrogel padding structure is composed by an interaction between materials with specific roles. The objective was to develop a thermal and moisture management layer based on a 3D warp-knitted fabric coated with a water absorbing polymer, to be easily and cost effectively integrated in current protective clothing manufacturing and maintenance activities.

**Figure 19:** Schematic description of a Hydro Jacket textile structure [9]
The lining is composed by a lightweight, double weave knitted fabric having a FR polyester hydrophobic layer on one side and a Kermel V50 hydrophilic layer on the other. This flameproof textile structure was developed in order to avoid wet feeling on the skin, creating an active suction channels that transport the moisture away from the body. This surface is then coated, by slightly modified resin coating process, using Hydrogel powder with small particle size and a special PU melt matrix.

Hydrogel are hydrophilic polymer networks that are able to swell and retain large amounts of water and maintain their three-dimensional structures. Responsive hydrogel found many different applications also because of their bio-compatibility: in diapers, in cosmetic and pharmaceutics products, in wound dressings and in fire protection.

![Figure 20: Hydrogel polymer](image)

Finally, just to avoid the scattering of the swollen Hydrogel particles out of the FR plain fabric, a multilayer quilted fabric was realized using a FR cotton fabric. The whole design construction allows so the best functionality of the moisture barrier, increasing comfort and safety in fire fighter's protective clothing.
4.4. Designing the Overall with Specially Designed Cooling System – for Conditions of High Temperatures

Another interesting example of innovative approach and design solution for specific problem and requested requirements, is a case of finding a solution of a flame resistant, comfortable and most of all cooling suit for the mechanical engineers that servicing the cars during the car races. So, the idea was to create an hyper-technical overall for use in conditions of high velocity and heat, maintaining the efficiency of movement of the mechanics.

The challenge was to design and manufacture a thermo – regulating garment, offering fire protection and a comfortable working temperature for the whole team servicing the racing car, whose overalls have the same safety standards as the pilot's. The team of designers offered the solution: 50 metres of plastic tubing, 2mm wide, installed in overalls. The result was a miniaturized air conditioning system, offering maximum comfort when working under extreme heat.

![Figure 21: Description of a forming a plastic tube serpentine integrated in a 3D fabric.](image)

The cooling system is based on icy gel cooled water running through a serpentine of plastic tubes mentioned, that is placed on all strategic points to assure comfortable body temperature maintaining the efficiency of movement of the wearer. The tubes are connected to an ultra light battery and a micro pump inserted inside the light weighted backpack.
Figure 22: Miniaturized air conditioning system constructed as a lightweight backpack

Figure 23: a. Flame resistant overall with cooling system network inserted; b. new version of a backpack with miniaturized air conditioning system
As it can be seen on the picture, the serpentine of plastic tubes are placed on upper front of a body and on the legs above the knees, at the front and at the back. To assure the efficiency of the movement, in the parts that covers the elbows, lower waist, knees and groins, is not inserted the plastic tube net. [10]

4.5. Motorbike Jacket Designed for Hyper – Sportive Bikers

The example of a motor jacket named Liquid Jacket (LQ Jacket), that will be explained and presented in this chapter, is a perfect example of fashionable style meeting the innovative technologies and protective properties.

Styled with a retro 70's look, Liquid Jacket is ultra – modern and on the cutting edge of materials technology. It is designed and manufactured using the ultimate materials technology together with an innovative manufacturing process. The jacket is made from ultra – thin leather that is combined with a unique material that has high thermal resistance. The process of bringing these two materials together has enabled the use of extraordinarily thin leather, whilst increasing its elasticity without affecting its durability.

Figure 24: LQ Jacket

The jacket contains several innovations in terms of materials and protective technologies.
First, an electroluminescent film is integrated on the back of the jacket. The film is fed by a power head (AA batteries, 1.2V, 6x3x2.5 cm), placed inside an internal pocket and able to control luminous intensity and frequency. This element solved the visibility problem with a flexible and washable system and it represent the perfect combination between vintage style and innovative technologies.

**Figure 25:** Electroluminescent film integrated on the back of the jacket

As it has been said, the jacket is made by ultra-thin leather, treated with Liquid Shell coating, making it UV and abrasion resistant, while maintaining its softness and touch, and combined with a high thermal insulating material.

**Figure 26:** Liquid Shell leather treatment

Liquid Shell is the name of a patented deposition method of protective treatments, coming from building sector, and consisting on deposing a thin layer of an opportune polymer on a leather support. The application of the Liquid Shell treatment allows a marked increase in the leather properties, bringing to excellent resistance to abrasion, to UV-A and UV-B ray, good resistance to acid and alkaline sweat. All these improvements in the physical and mechanical properties are performed preserving the flexibility and the softness of the natural support, enriching the product by an excellent lightness. The final product combines the great aesthetic effect with an effective performance increase. The treatment,
therefore, allows the use of thinner substrate layer, bringing to an increase in the flexibility and elasticity. The tenacity, tear and salinity resistance of the Liquid Shell treated leather makes it an ideal material for extreme sports and suggests its use in the marine environment, where the surfaces are usually subjected to wear and thermal range.

Further, the properly positioned anatomic patches composed by one of the most advanced shock-absorbing system are integrated in a jacket construction. These elements are flexible and soft under normal conditions but become rigid in proportion on impact, brought to an increase of motorcyclist safety, maintaining at the same time a good mobility.

![Figure 27: D3o smart shock absorbers](image)

Shock absorbing patches are made by d3o technology. This material has a special molecular structure that is able to immediately react to impacts. In normal conditions the molecules have a certain freedom of movement, but, when subjected to an impact, they lock very quickly, in order to form a protective barrier able to absorb and dissipate energy. As soon as the impact has passed, the molecular structure immediately unlock to provide softness and flexibility. The material is breathable, washable and customizable in anatomic 3D shapes, ready to be integrated into sport garments.

### 4.6. Non Stitched Water Proof Jacket

In Europe several tens of millions of workers operate in dangerous environments and require protective clothing. Additionally there is a large market for outdoor waterproof sports and leisure wear.

In these applications highly engineered fabrics provide a barrier to particles, liquids or gases. The main limitation however is the joining of these fabrics as sewing penetrates the material and resealing is required in a second taping process.
Alternative sealing methods using hot melt adhesive tape are emerging, but these all use an additional layer between the fabrics at the seam. The current procedures are time consuming, highly labour intensive and the use of tape is limited in applications using complex 3D seams. Additionally, because of the limited peel strength of taped seams and the continuous bending of the joints during use as well as maintenance and washing, the sealed seam often delaminates.

Laser welding offers a method of making sealed seams without using additional film at the joint. The process melts a thin layer of the fabrics without affecting the outer surfaces by transmitting the laser energy through the outer fibers. The process is also suitable for automation. This results in a joint that has a greater flexibility and softer feel than is made with other welding methods. The outer texture of the fabric is also retained. [12]

So the specific task was to design and manufacture an non stitched waterproof jacket suitable for the outdoor workers on the airports. The special requirements considering the potential users were satisfactory visibility, waterproof and windproof properties and waterproof stitches.

Laser welded water proof jacket, constructed based on specified requirements contained several innovations in terms of material and design solutions.

![Figure 28: Specially designed laser welded protective raincoat](image)

Fabric with special properties was developed to provide improvements in performance and laser processing capability. New barrier fabrics have been specified specifically for laser welding applications, having the same polymer on both faces and laminated layers with good transmission of the laser beam.

Jacket design was modified to have seam designs and forms more suited to a laser welding fabrication. Additionally the total number of seams was reduced. A series of fabrication steps was developed starting from a pattern for the trunk followed by attachment of cuffs, pockets, collar and lapels.
5. Conclusion

Protective clothing has a long history. Already the armour of ancient warriors and the medieval knights may be designated the first real protective clothing. But the considerable improvement in development of protective clothing is shown over the last few decades. From the use of normal clothing with some protective properties until the conception of complex, multifunctional protection systems using sophisticated modern materials and manufacturing techniques was a long way to go.

Protective clothing is used to achieve safety for people in professional and other surroundings. Safety being defined as "Freedom from unacceptable risk of harm" can be achieved at two levels: first, processes, equipment and products have to be made safe, which means that they have to be conceived in such a way that any risk of harm is excluded or spatially separated from the people involved. Second, if for any reason persons nevertheless have to come near to the source of risk, they have to be protected by appropriate protective equipment. From this concept we can see that the use of protective clothing is clearly not the first choice among the safety measures. However, it is nevertheless a very important measure and protective clothing of all kinds will in the future be of growing importance in the occupational sector as well as in the field of leisure and sport.

Looking at the general tendencies in the development of protective clothing, one can see that in the beginning people were looking at the protective properties of normal clothing, which they then tried to improve in one way or other. At a later stage, specialized materials with optimized protective properties were developed and used for the manufacture of protective clothing. These were defined as technical textiles. Later it was realized how strong the influence of the manufacturing on the protective properties of the ready-made garments is. Therefore, protective clothing is now developed more and more as a complete protective system, using modern materials, sometimes also the so-called intelligent materials. This trend will continue and even become stronger in the future.

The variety of end use sectors has widened in the course of time. Whereas in earlier times the occupational sector dominated, nowadays the use of protective clothing in the leisure and sports sectors has gained great importance. This is due to the fact that the modern society sets a high value on leisure activities and extreme sports. On the technical side, the requirements protective clothing has to fulfill have become much more complex. When in the beginning only the protective function was dominating, today the combination of requirements on comfort and fashion makes the development of a modern protective clothing a complex task.

Design process in nowadays protective clothing production considers the product development process appropriate for protective clothing with increasing synergy between fashion considerations, functional design, advanced technologies, smart materials and innovative approach. The specific requirements on protective properties of professional or every day clothing differs significantly so designing a specific protective clothes requires numerous researches and acquiring knowledge form the field of different
technologies, nanotechnology, engineering, smart textile and textile with special properties production, etc. Designer working in a field of protective clothing must excel in finding new applications and design solutions with integrated scientific innovations.

Successful design of protective clothing considers the synergy of materials, technologies and aesthetics. In protective clothing design follows the materials and it gives a strong identity to the final product.

In a process of designing clothes with highly specified protective requirements new technologies or treatments stemming from the combination of proper materials and design construction must be developed.

The relationship between technology and design is crucial and the disciplines are strictly linked to each other. The role of design is to make the technology easy to use.

6. References

2. Grado Zero Espace, Design method, brochure available from the website http://www.gzespace.com
3. Piero Meucci, Laura D’Ettole, Anna Letizia Marchitelli, L’avventura dell’innovazione, viaggio nella creatività dei toscani, 2011
8. Elena Turco, Grado Zero Espace’s Design Method applied on new product’s development and consulting, TZG paper, 2010