Membrane materials for sustainable architecture

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The primary human need of sheltering had produced different solutions according to places, climate and habits.
In the deserts, Sahara, Saudi Arabia and Iran, the black tents were developed by the nomads using camel leather for matching the exigence of roaming in driving the transfers with the animals and to satisfy the need to easily assemble and dismantle homes and transport them for long journeys; the use of tents as a dwelling was also common for housing armies for long periods and in different environmental conditions.
In addition to housing, these structures have always been used as simple shelter from climatic agents.

For tensile structure we mean the construction of covering using a membrane supported by cables or rigid rods, their main characteristic is referred to ability of sustaining loads due the tensile state; other important properties are referred to the possibility of assembling and disassembling with ease, of moving through different places and of covering large spans. Due to the use of thin cables stretched, surfaces can be created able of overcoming the forces imposed upon them.
Until the mid-20th century, due to the low demand and lack of manufacturers of cables there were few technological advances, but, thanks to industrial growth a new developments arose.

In the first models the use of joined cables and very light membranes produced structural deficiencies; the technology thus evolved later with the use of system of steel cables and fiber membranes with a high degree of strength; furthermore the performance of the new structures were improved by integrating layers of waterproof coatings and protection against ultraviolet rays and fire and using materials able to control the reflectivity of tents.
Such progress was only possible thanks to the physical-structural studies initiated by German architect and engineer Frei Otto, who since the 1950s conducted the first scientific studies and the first works of roofing using tensioned steel cables combined with membranes.
Tensile construction can be shared into three categories according to their structure (membrane, mesh, pneumatic), while cables can be classified in those load-bearing or stabilizing; the load-bearing cables take the external loads and the stabilizing cables have the role of strengthening the load-bearing ones.
In last thirty years the tensile membrane structure found a significant place in the contemporary architecture; the producers have adapted to market demands by creating increasingly high-performance products in terms of resistance and durability with the result of greatly widening the field of applications and making the product much more interesting for design purposes.
This change marked a turning point in the design of tensile structures because while in the past they were used only for temporary uses, having become more durable and then economically convenient, they began to be used also in permanent constructions.
Therefore, in the field of stable constructions, the required range of services is also extended, thus opening up a very vast and interesting field of research and development (ElSeragy and ElNokaly, 2006). From this point of view, the understanding of environmental behavior and the performance of the membranes must be adequately explored in order to provide greater comfort for the occupants. Like as permanent construction nowadays it is mandatory also for tensile membrane to perform sustainable energetic behavior to face the need to reduce energy consumption; this theme stress the research towards new materials and structures that meet the occupant's needs and comfort and are at the same time environmentally friendly.
In fact, textile membrane surfaces have low thermal mass and for this reason they let very rapidly the external energy affect the indoor climate; for this reason actually new materials are developing for membrane with augmented thermal resistivity in terms of controlling the thermal gain or loss in winter and in summer.
The thermal conditions provided by a space enclosed by a very thin skin cannot comply the standards of conditioned traditionally enclosed environment; it is conceivable to design the membrane form and orientation and the associated thermal mass to comply different

seasons and climates, maximizing in winter the diurnal solar absorption and save it inside while at night it should retain the day absorbed radiation to heat the interior space. In summer, the membrane should perform in an opposite way; the fabric structure should be oriented to give shade by screening solar radiation and the material should be chosen with regard to the ability to absorb and transmit a minimum amount of solar heat and apposite openings must be provided so that the internal heat finds a place to escape at night. Even if it is well known that tensile architecture was born with the use of natural materials, animal or vegetal, only recently they are re-discovered due to the potential to be softly inserted in landscape whithout producing heavy impacts. Fabric membranes were used to provide adequate shade, channel breezes and define space but very often they worked in a wrong way, even if well placed into the image of these places and events. Of course there is a need for further research into this field in order to understand the effect that the form of the structure will have on its environmental behavior.

The theme of environmental sustainability, and then of energy saving and carbon reduction, has not to be referred only to energy consumption in cooling or heating spaces enclosed into the tents but also to the resource consumption coming from the used materials, the storage, the re-use and the mode of transport.

The importance of optimizing the performance of textile envelopes is thus referred to a wide range of needs; but only recently lightweight architecture began to take in serious consideration the importance of energy saving and environmental sustainability in both destination, as temporary structure and permanent, while for the past only the envelope mass and therefore its thermal inertia were considered useful for this purpose.

In the light of the previous observations it must be considered that in the assessment of the life cycle and energy efficiency of light buildings in terms of performance, all aspects related to the energy consumed, from the "production" phase to that of "use" of the structure and disposal; for the purpose of assessing the overall performance of a building, it is essential to consider both embodied energy and operational energy. In temporary buildings this aspect is even more relevant because the phases of construction and disassembly and reconstruction are repeated numerous times, thus increasing the energy balance of the structures exponentially; in fact, the energy consumed during transport, in the various phases of reassembly, depends on the weight, from the assembly system and from the distance between the installation sites; the design of these structures must therefore carefully calibrate the energy costs inherent, in an atypical life cycle compared to permanent buildings, because the costs of assembly and

disassembly do not amortize over time but, on the contrary, multiply and increase with the wear of the materials.
In terms of thermo-hygrometric comfort in the design of temporary architecture, the following must be considered: environmental factors (temperature, humidity, air speed), external factors (metabolic rate and clothing), biological factors (sex, age, biological characteristics) and psychological factors (cultural background, individual expectations); in fact, the thermal sensation can be very influenced by many environmental and physiological conditions that can determine different levels of comfort as the conditions of use change (De Vita et aal, 2018). With regard to energy efficiency, special attention should be paid to the membrane-bearing structures that collect condensation water on the surface of the membrane and accumulate water as reserve.
The eco-compatible design of tensile structures must take into consideration the geography and the climatic conditions of the places in a very different way from the mass construction because the complete absence of thermal inertia imposes different design criteria related above all to the need to guarantee stable indoor climatic conditions.
Among the temporary and semi-temporary installations, rescue structures occupy a special place, which require markedly adaptability to very different conditions, speed in transport and assembly and guarantee of comfort conditions during the period of use.

These notes want to highlight how tensile membrane structures are a new chapter in the history of building structures.
The interesting developments in the design of the tensor membrane structure can revolutionize the concept of permanent building.
In this context, computer technology with the possibility of modeling structures and their behavior has opened up vast new horizons for design; the possibility of calculating shape and values for projects has determined a new architectural language in which the final outcome of the project and the behavior of the structure are completely predictable and controllable.
The development of software for tension membrane structures practically does not place limits on the design process, the structures can be modeled and calculated in relation to different operating conditions, different installation cycles and different functions. Although there is a lot of scientific knowledge about tensile structures, there are no real design manuals. A standardized approach as well as a global European design verification standard is needed to achieve a harmonized security level.
The tensile structures reflect the needs of modern architecture and are increasingly used thanks to their attractiveness due to the spatial curvature and to the great variety of forms that can be achieved and to the possibility of obtaining large free spans.

Today the area of structural skins is very broad and the membranes are increasingly used; their two-dimensional measurement can be advantageously combined with solar shading and / or solar energy collection. The growing interest in these structures requires a complete standardization that is still lacking in Europe. A work process has been launched by CEN aimed at a future technical specification, and, subsequently, at a new Eurocode part related to the structural design of membrane structures.
The ongoing discussions in the CEN / TC 250 / WG 5 focus on specific aspects of structural design based on the current Eurocode design concept and furthermore, concrete information is provided on important elements of structural membrane design together with basic information on the underlying test methods. The establishment of harmonized design rules requires the simultaneous establishment of harmonized test methods which is performed by CEN / TC 248 / WG 4.

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