Membranes: a challenge for Environmental Sustainability

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Designing according to the indications of Sustainable Development is no longer an option: Architects and Engineers are called to respect not only the principles of economy, which have always characterized one of the main - if not the only - orientation criteria for design choices, but also and above all those of *sociality* and *environmentality*. Just the term environmentality - that is the substantivation of the adjective environmental - is not, as it seems, a neologism born after the publication of the Bruntland Report in 1997 [Bruntland, 1987]; it is a term already used by Heiddeger in his studies on Ontology [Heidegger & Mazzarella, 2008], and taken up in 1944 by Carabbellese in his interesting article, in which the Italian Philosopher relates the words Conscience and Environment in this way: «my work with conscience is not satisfied by a specific environment, in which in fact it is found, but it demands the environmentally as it is: the environment is not only a fact that I observe in my work with conscience, it is also and mainly an essential requirement of it»[Manno, 2002]. In this paper, Conscience and Environment are connected by a cognitive link, because the first, understood as «awareness [...] of the external world» [Vocabolario Treccani, 2010], can only occur in relation to the second, in its meaning of «space that surrounds us»[Vocabolario Treccani, 2009]. However, here it is the temptation to interpreting Carabbellese essentence differently, connoting the terms in another way, in order to create an ethical Conscience-Environment relationship, attributing to the conscience the meaning of «Awareness of the moral value of one's own way of acting» [Enciclopedia Treccani, 2011], and environment as a whole of «all biotic and abiotic variables or descriptors in which an organism lives and with which it interacts during its existence» [Enciclopedia Treccani, 2011]. This lexical shift naturally has the aim of reinforcing the concept for which Sustainable Development is more a moral duty that technicians and designers must satisfy, than a regulatory obligation[1]. But the ethical declarations, certainly necessary to guide the design choices, are not the only ingredient of Environmental Sustainability, which needs above all adequate technical know-how; however, the difficulty of the problem does not allow to solve it by applying simple recipes, as evidenced by the complexity of Environmental Quality Assessment systems such as, for example, the Itaca Protocol and its regional variations[2], the BREEAM[3] certification, the LEED-GBC[4], by mentioning the most known ones. Unfortunately, too often one of the ways that designers use is banally constituted by the choice of materials - or production techniques –at high performance, an evolution of the concept of High Tech that, since the 70s, seems to keep the promise of obtaining interesting features, also aesthetic. However, these solutions often involve high environmental costs, if evaluated over their entire life cycle: from production, till expensive and complex maintenance, till demolition, their performance advantage, in an estimation of costs/benefits, is not enough for compensating for high charges to occur.

In the common imagination, also the structures with membranous behavior, i.e. where the tension regime is distributed parallel to the surface [Balis Crema, 2013], like shells and tensile structures, fall into the hi-tech category: mainly for the their unusual appearance, due to the presence of the characteristic curvatures, formally very far from the frame construction systems so rooted in our figurative repertoire. And yet their mechanics partly recalls that of the domes made of non-tensile materials, which are therefore part of our construction tradition, in which the distribution of forces has been known for almost two centuries [Méry, 1840] and it is precisely that of a membrane. Certainly it is true that from the point of view of pure form, for tensile structures more complex surfaces are used, such as those of minimum, ruled and double curved surfaces [Capone, 2018]; but it is also true that the same surfaces were generated - in an approximate way - with graphic or empirical methods even by the ancient builders, who used funicular models; these geometries were then overturned with respect to the horizontal plane to obtain the corresponding compression model. For simplicity of construction, the structures were shaped like circumference's arches - easier to make - but it was verified that the crossed polygons, generated by the funiculars, passed through the central core of inertia of the stones, which in this way were never tensile stressed [Méry, 1840].

fig.01 - Funicular model preserved in the crypt of the Sagrada Familia in Barcelona [De Pisapia, 2015]

Perhaps the only element of contemporaneity that can be objectively attributed to membrane structures is for using high-performance materials, because from the first birth of textile structures, by Vladimir Shukhov, strips and steel slabs were used to support fabrics [*Padiglioni alla All-Russian Exhibition*, 2005]. The system, patented in 1895 by the Russian architect, made use of this new and, for the time, innovative material[5], but it should be noted that the idea originated from the *kibitka*, a tent typical of nomadic populations, made of pylons of wood and felt: a traditional work built with materials with a high level of naturalness. While on one hand I would like to emphasize the *continuity of innovation*, and how much it draws ideas and resources from the past, on the other hand it is certainly true that the interpretation of the kibitka was brilliant and very original, in which for the first time in the world a

fig.02 - The Shukhov Rotunda [Shukhov Rotunda, 2019] and, down, a kibitka *[Viviendas tradicionales de los pueblos de Rusia, 2019]*

hyperboloid surface was used in the central part of the structure [*Shukhov Rotunda*, 2019].
Moreover, while in the tensile structures the sheets participate to the mechanical strength of the construction, in the kibitka - and in all the *tent-structures*[6] - these are only of completion, whose weight is carried by the wooden lattices, making them from the structural point of view closer to the spatial trusses, and therefore also to *geodesics*. Although for these latter domes it is not always possible to find a tension regime of membranous type, the affinities that bind them to tensile structures are different, and in particular according to the: (i) technical perspective, because they are often made using the same materials; (ii) technological perspective, as roof - frequently considered both temporary solutions; (iii) perceptual perspective, since even if structures of colossal dimensions are sometimes realized, they always recall a sense of great lightness; (iv) morphological perspective, because they are linked to problems of minimum distance/surface, as the term “geodesic” suggests[7]. It is therefore natural that an interesting transfer of knowledge in both directions has occurred over years, and that the great architects who in the second post-war period accelerated their development (Richard Buckminster Fuller on one side and Frei Paul Otto on the other), have some interesting points in common, because in addition to having been teachers at the University of Washington in St. Louis in the late 1950s, and having studied spatial lattices, they carried out - separately - particular studies on pneumatic structures [*Frei Otto*, 2019], subcategory of tensile structures and, in general, of membranes [*Pressostrutture, strutture pneumatiche e cuscini*, 2015].
The great notoriety of the works created by the Master of Chemnitz has certainly contributed to affirming in the collective imagination of architects and engineers that the "membranes" are the tensile structures of Frei Otto: a sort of *technical synecdoche* for which its constructions have become emblematic of the whole category to which they belong. This also explains why the membranes are generically, and inexpertly, included in hi-tech, because it automatically recalls the abacus of materials used by the great German designer, in which - both for the historical period in which he worked, and sometimes for the colossal dimensions of its achievements - there are always very high performance, but absolutely not eco-sustainable products.

fig.03 - Munich Olympic Stadium. Frei Otto, 1972

Excluding *ex-ante* the use of membranes in high environmental sustainability constructions is certainly a dangerous logical short circuit that must be avoided, for at least one fundamental reason. Most of the membranes have a very high *mechanical efficiency*, because with an almost negligible weight they can withstand considerable overloads [Capasso, 1998]. This is due not only to the use of high-performance materials, but above all to their shape: when using striped generating surfaces, with a family of curves that directs the concavity upwards, the tension regime that develops along them will be traction. For this reason, these supporting curves are not subjected to instability problems, which instead affect inflexed or compressed structures, and for this reason they can reach extreme slenderness, to the advantage of lightness. The textile architecture, indeed because of the innate limit of sheets and ropes not being resistant to compression, and that of rigid shells, but designed to be subjected to traction alone, make it possible to obtain this fundamental performance thanks to their shape; this performance is also a very important indicator of eco-sustainability because it allows to reduce both the quantity of material required in the construction (saving material resources [Francese, 2007]) and the amount of volume physically occupied by the technical elements (saving used space): so it becomes strategic to remove the obstacles that today prevent a greater diffusion of the membranes.
First of all, the control of the shape is not simple because the geometrical generators are complex, since minimum and double curvature surfaces are used, but also due to the great deformability that characterizes textile materials. In this case, the classic rules of Science of Construction - which apply to most common construction materials - cannot be used, and the more complicated relationships of non-linear statics must be used.
Fortunately, however, computer-aided design allows better control of the problem, allowing the differential problems at the base of highly deformable membranes to be resolved quickly. Of course, using the appropriate software is not a sufficient condition: membranes require specialized skills that must be acquired in an appropriate manner, but the knowledge and use of adequate programs allows, even for unskilled professionals, to be able to freely experiment with different formal solutions, assisting their creative process. Facing the power of these tools, which can be used today by any personal computer, the skills demonstrated by the brilliant designers raise even more for, at the end of the 19th century, they were able to imagine and build membranes with the use of empirical and rudimentary computing systems.
The second deterrent to the use of membranes is certainly linked to the material with which they are made. If the shells - as rigid elements - require techniques that fall within the category of contemporary construction practice, such as steel and reinforced concrete for which studies have already been underway for years to develop ecological alternatives[8], the conversion into

environmental key of the materials used in textile architecture seems more difficult. If for cables, struts and rigid supports, steelis normally used, whose production is progressively reducing the impact on the environment [Meneghello, 2017], for the sheet instead very often synthetic products are used, belonging to the family of polyesters on which a layer of PVC[9] is frequently applied on the sheets themselves [*Tensostruttura*, 2019]. Indeed the discovery of the technique of welding between sheets in thermoplastic material - such as polyesters - which took place in the 1960s, gave development to pneumatic structures with applications ranging from design to architecture [Cosrini, 1967].
These plastics, oil-derived (a resource that has geological formation times [*Origine del petrolio*, 2000]), and practically perennials (in the marine environment it takes 450 years to decompose, but the monomers of which they are made never decay [*Tempi di degradazione nelle acque*, 2019]) have a very strong impact on the environment, both during extraction/refining and at the end of life, and for this reason common sense suggests avoiding them in any way[10]. Plastic is the third most widespread human material on earth, exceeded only by steel and concrete [*I numeri della plastica nel mondo*, 2015]; but it is the first in the form of waste because it is used to make objects of short, if not very short duration. The buildings have an extremely long life (well over a hundred years): the recycling in the construction field allows therefore also to obtain the advantage of storing and using this material for long periods, raising the level of ecosustainability.
Textile architecture, thanks to the dry and pneumatic assembly techniques, are often used for temporary works, sometimes only seasonal, for which steel and polymers tare badly suitable, for they can be considered sustainable when used for a time, long enough to amortize the high environmental production costs. In this case, it is possible to use alternative solutions, such as - for example - wood and natural fibers. In particular, wood has a specific tensile strength higher than that of the steel (for example, the fir tree of choice S25 is 47% more powerful than steel S355[11]), so, although in absolute terms it is certainly less resistant than metal, in its range of use it allows the creation of lighter elements. For the textile component, we recall that hemp fiber has for centuries been the preferred material for making ropes for marine use, which are still in production; in the same way, hemp sheets are available in numerous weights, with strength and appearance considerably different.
Various studies are available on the possibility of using natural fibers (hemp, linen, agave, jute, sisal, wool and even silk) as a structural reinforcement, to be inserted in cementitious or lime-based matrix [*Rinforzo strutturale con materiali compositi*, 2019], reflecting the great resistance that these materials are able to offer. Shigeru Ban, a Japanese architect specializing in the use of inexpensive and highly recyclable materials, has often used polycarbonate membranes supported by bamboo or cardboard tubes, but has also created temporary structures

such as the Japan pavillion for Expo 2000, made entirely of paper, cardboard and bamboo, thus demonstrating the concrete possibilities that offer alternative materials if their performances and potential are known[12].
The considerations here carried out are of technical nature and allow to evaluate the eco-sustainability of the membranes. But the Environment is not only a set of biotic and abiotic components against which to perform cold measurements: it is also and above all a system composed by a network of social, cultural, formal relationships that characterize a place and make it unique, recognizable, different from the others.

fig.04 - Japan pavillion, Expo 2000 [Shigeru Ban Architects, 2015]

The considerations here carried out are of technical nature and allow to evaluate the eco-sustainability of the membranes. But the Environment is not only a set of biotic and abiotic components against which to perform cold measurements: it is also and above all a system composed by a network of social, cultural, formal relationships that characterize a place and make it unique, recognizable, different from the others. In a famous essay, Christian Norberg-Schulz indicates this system as the Genius loci, as that “opposite one” with which man must come to terms to acquire the possibility of living [Norberg-Schulz, 1979]. A work that declares itself to be *highly environmental* must have not only the technical, numerical and quantifiable requirements that literature and the standards provide: it must be able to dialogue and harmonize with the *Genius loci*, it must be part of the environment system without producing changes or revolutions. The most important question to ask, therefore, is the following: how can membranes fit into a particular natural-built/formal and social-cultural context? Fortunately, there are no pre-established formulas or algorithms: the answer is a function of numerous factors, both endogenous, for they are related to the place of intervention, and exogenous, because they are due to the skills of the designers. And certainly,

the shapes of membrane structures, made in textile architecture such as *tensil* and *pneumatic structures* [Crielesi & Landucci, 2006], by following mathematical surfaces dependent on a great number of parameters, allow to obtain an infinite range of combinations.
Sensitivity, poetics, know-how, but mainly the professional's *know-why* will guide the project choices, to obtain constructions able to match and mimetically merge with the territory that receives them, avoiding those self-referential, decontextualized and globalized works, which are considered versatile and suitable for each place, but which instead are inadequate in all contexts.

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Notes

1 - As required by Article 34 of Legislative Decree No. 50 of 2016, which specifically refers to the contents of the Ministerial Decree Amb. 11/04 /2008.

2 - See http://itaca.org/valutazione_sostenibilita.asp

3 - See https://www.breeam.com/

4 - See http://www.gbcitalia.org/leed

5 - Steel in construction only spread in the second half of the 1800s with the introduction of blast furnaces [*Breve storia delle costruzioni in acciaio*, 2014].

6 - This term is currently used in the commercial sphere to indicate above all assembled garden tents, even large ones [*Tensostrutture o Tendostrutture: due universi differenti*, 2015].

7 - In differential geometry is in fact indicated as the geodetic line the curve of minimum length connecting two points belonging to a given surface [Vocabolario Treccani, 2018].

8 - See, for example, the availability of eco-cement on the market for materials that claim to be ecological [*Eco cemento*, 2016] or the development that can be observed in the sustainable production cycle of steel [Meneghello, 2017].

9 - In tensile structures are also used glass fibers coated with silicone or PTFE, but also only expanded PTFE [*I materiali per le tensostrutture: tessuti spalmati con trama e ordito*, 2015].

10 - If we consider that from 1950 to the present 8.3 billion tons of plastic have been produced in the world, of which 6.*3 billion are still missing in the environment* [Geyer R., Jambeck J.R. & Law K.L, 2017], it is understandable how, if production was stopped immediately, this quantity - appropriately recovered and recycled - would allow a 20-year autonomy with respect to the current consumption rates (equal to 310 million tons) [I numeri della plastic nel mondo, 2015].

11 - Recalling that the specific fracture resistance is the ratio between specific weight and tensile stress [Petrucci, 2008]; using the yield stress value (thus assuming a diagram of tension / deformation of the triangle-rectangle type), a value of 4611 meters is obtained for steel (with a density of 7850 kg/m^3), while for the fir (with a density of only 375 kg/m^3) it reaches 6798 meters.

12 - The paper membrane was then coated with PVC to make it fireproof.