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ABSTRACT

ENERGETIC OPTIMIZATION OF EXISTING BUILDINGS: DEVELOPING SMART AND INNOVATIVE SHADING SCREENS WITH TENSEGRITY ARCHITECTURE

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ABSTRACT

Sustainable building is one area where innovation is constantly being challenged. Innovation means offering something new or changing what exists in order to achieve new results. At present the hardest goal is transforming the current situation where the construction sector has the highest fossil fuel consumption, is the largest producer of non-reusable waste and the biggest polluter. In fact, the environmental impact of building design and construction is enormous: in Europe buildings are responsible, directly or indirectly, for approximately 40% of total primary energy consumption and for around 36% of CO^2 total emissions.

Sustainability criteria can minimize or eliminate negative environmental impacts through a conscious choice of design and constructive practices better than those commonly in use. This design approach allows a reduction in operating costs, an increase in market value and users' productivity.

Therefore, sustainable design means taking into account (in addition to traditional requirements of security, usability, comfort and management) a number of new requirements related to general building design (shape, floor plan, equipment and distribution), to systems, to building a life cycle (flexibility and reversibility of technological conception) and to indoor comfort. This research proposes a methodology that supports the

development of the design and construction process of new façade components made with a tensegrity structural system.
In order to create artificial places in which to conduct the primary activities of living, human beings have developed increasingly complex envelope systems and components capable of ensuring living conditions fitting each room. Over time architecture has therefore evolved from a simple shelter from the elements (rain, wind, sun, intrusion of people or animals, cold, hot, etc.) to an element representative of society (thanks to formal and material solutions), to an indoor comfort control system (through quantity and quality of light, ventilation, heating and cooling).
The envelope has moved from being an energetically passive to a dynamic and interactive element of the complex energy system that regulates building operation. The gradual freeing of the outer skin from a structural function has had the inevitable consequence of a split between envelope and structure. The envelope is released from the load-bearing structure and becomes a closure element used mainly to adjust energy flows linked to the passage of heat, light transmission for adequate illumination of the interior and the protection of the solar radiation in the months with higher temperatures.
The demand for energy efficient buildings calls for the adoption of active façades that are able to mitigate air conditioning consumption resulting from direct exposure to solar rays, as well as harvest wind and solar energy through on-site wind power generators, integrated photovoltaic systems, and/or solar hot water panels. The dynamic façade system is an innovative solution that meets the current market needs in the building envelope sector. In the last few years, this market sector has been rapidly developing

envelopes that can change colour and form, and improve building energy savings, ensuring a good thermal insulation, as well as decreasing production costs of the building.

We studied the evolution of double-skin façade systems with a view to developing an innovative dynamic sun screen that could change its technological configuration and energy performance during the day.

Adaptive architecture must be considered the future of contemporary architectural research because it can decrease the energy balance of buildings by controlling thermal energy, light energy and sound waves. This research aimed to identify design principles and operative tools for the design and production of innovative building envelopes that could integrate renewable energy, in form of photovoltaic and solar thermal panels.

Sunscreens absorb and reflect incident solar radiation but cannot transfer solar heat gain directly into the building. When sun screens transform incident sunlight into electricity for immediate use or transmit thermal energy into the building by use of electrical or mechanical equipment, they are called opaque sunscreens and form part of an active solar façade.

The first façade system was designed like a set of *Blinking Sails*. The module of this structure is composed of eight bars and five nodes. Node 1 is fixed on the sub-structure, nodes 2 and 4 are constrained to move in the x-y surface, and nodes 3 and 5 are free to move within the space.

This structure is adaptive solar screen that could easily be placed over the building façade to form a curtain wall. Each module is shaped like a rhombus, and by actuating a few strings automatically it is possible to change its configuration by transforming each rhombus into a sail. The

Blinking Sails model is a mobile sun screen with a 100% opaque modules on which, between the diagonals, it would be possible to place dye sensitized solar cells. These cells are semi-transparent and very adaptable to the requirements of this design. Also, the façade is integrated with light sensors and actuators that move panels, thus modifying the shade on the envelope.

We propose a tensegrity sun screen that has minimal mass among all possible tensegrity topologies (configurations of members). The concept of optimality regards the achievement of a design that ensures the smallest use of material, under equilibrium constraints for given external loads and under specified failure mechanisms of the members (bars and cables)

The procedure was performed with the aid of the program Tensopt, which is a Matlab® code that performs the topology optimization of a tensegrity structure. The tensopt code examines a given set of connections between the nodes of a prescribed node set, in the form of compressed members ("bars" or "struts") and/or tensile elements ("strings" or "cables"). The optimal connectivity table is determined through a mass minimization algorithm, which accounts for multiple loading conditions; yield constraints; local buckling constraints in the compressed members; and a global stability constraint related to the magnitude of the minimum eigenvalue of the global stiffness matrix of the structure (eigmin). The buckling constraints are enforced by using an iterative linear programming algorithm. The global stability constraint is enforced by penalizing the mass of solutions that exhibits eigmin lower than a given tolerance.

We examined the motion of the elementary module designed with minimum mass.

Drawing inspiration from nature, the second façade system, the *Fan Fish System*, was imagined like a fish scale envelope. In most biological nomenclature, a scale is a small rigid plate that grows out of an animal's skin to provide protection. The skin of most fish is covered with scales that are partially superimposed. The question was if it could be possible to imagine an active shading system structured like fish skin. Such a skin like structure would be extremely suitable to form a curtain wall of a few metres that could be placed over the building façade. Each scale would be shaped like a fan in order to allow the opening and the closing of the system, which would make the solar screens adaptive. Furthermore it would be possible to place solar panels on the fan slats.

Having completed the design concept, the next step of the research was to work on building a model of the panel in order to understand how it would operate and behave.

The smart skin developed in this research is a mobile sun screen with a 50% opaque module, where a PV or solar thermal panel can be integrated. The façade consists of several “scales” assembled together. The modules are dynamic and can change configuration because the façade is integrated with light sensors and actuators that move panels modifying the shade on the envelope. A dynamic automatic system, that could change its configuration without the regulation of building users, would decrease the building’s heating and cooling energy consumption.

The structure is composed of eight bars and five nodes. Nodes 1 and 3 are fixed on the sub-structure, whereas nodes 2 and 4 are constrained to move on a quarter of the circumference of flat surface. It is possible to define each node’s position by using the following trigonometric equations.

We have investigated an application of morphing tensegrity architecture to design adaptable shading screens for energy efficient buildings. We have designed tensegrity structures that offer portable applications for small spans and in the case of large spans can be easily assembled using prefabricated components. These screens are opened and closed by controlling the elongation in a limited number of cables. The operation of such screens can be powered by renewable energy, derived from photovoltaic panels and/or microeolic power generators. Their aim is to markedly mitigate air conditioning consumption resulting from direct exposure to solar rays, thereby reducing carbon dioxide emissions. The morphing screen analysed in this paper requires minimal storage of internal energy and reduced operation costs due to lighter friction between parts and reduced mass.

The subsequent dynamics approach will evaluate the value of the use of feedback control for the deployable functions, or to adjust the stiffness of the structure (varying the prestress of the cables) to modify stiffness or damping in case of strong wind. Additional future research lines include the design of different deployment schemes and the optimal design of polyhedral envelops of energy efficient buildings, to be carried out by combining parametric design approaches with energy optimization techniques.