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Composite solar façades and wind generators with tensegrity architecture

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ABSTRACT

The urgent need for sustainable buildings calls for the adoption of active building façades that harvest wind and solar energy through on-site wind power generators and solar panels. Particularly interesting is the use of tensegrity structures for the construction of renewable energy supplies, due to their easy integration with solar and acoustical panels, which can form special rigid members of the structure. The present study deals with the design of active façades based on tensegrity units, which supports shading devices and/or solar panels. The tensegrity units are foldable and deployable and are controlled by stretching or relaxing selected cables. Wind generators to convert the strain energy stored in the cables of wind-excited units into electrical power are also designed. The proposed structures offer portable applications for small spans and are easy to assemble using prefabricated component parts in the case of large spans.

1. Introduction

Sustainable building is one area where innovation is constantly being challenged. At present the hardest goal is transforming the current situation where the construction sector has high fossil fuel consumption, is one of the largest producer of non-reusable waste and one of 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 [1,2]. The European Union is imposing increasingly stringent obligations on member countries in terms of energy efficiency and reduction of climate-altering emissions [3].

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 [4]. 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 [5].

A recent study has investigated the use of tensegrity structures for the construction of active solar façades of Energy Efficient Buildings (EEB) [6]. A tensegrity structure (or system) consists of a rigid body system (tensegrity configuration), usually loaded in compression, which is stabilized through the insertion of prestressed tensile cables (or strings) between its elements [7]. Some of the main advantages deriving from the use of tensegrity architectures in EEBs are the following:

- it has been shown that the tensegrity architecture provides minimal mass structures for a variety of loading conditions, including structures subject to cantilevered bending load; compressive load; tensile load (under given stiffness constraints); torsion load; and simply supported boundary conditions (e.g. a bridge), without yielding and buckling [7–9];
- the special ability of the tensegrity architecture in integrating control functions within the design of the structure: in controlled tensegrity systems the mechanics of the controller

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and the structure can naturally cooperate, through the *change* of the configurational equilibrium of the structure, as opposed to traditional control systems, where often the control pushes *against* the equilibrium of the structure [11];
- the possibility to look at a tensegrity building as a multiscale sensor/actuator, which in particular features highly nonlinear dynamical behavior [12–15];
- the possibility to harvest energy from the environment (such as, e.g., wind and seismic energy), through the conversion of the mechanical energy stored in the structure into electric energy [16,17];
- the possibility to construct controllable tensegrity façades, wings, and ventilated walls around the building [6];
- the easy integration of tensegrity structures with solar and acoustical panels, which can be identified with special rigid or deformable composite members of the structure [6,7,18–22].

The present work continues the study initiated in Ref. [6], by proposing a methodology that supports the development of the design and construction process of new façade components with tensegrity architecture (see the discussion in Sect. 2). The concept of the examined tensegrity façade system, whose activation motion mimics the dynamics a blinking sail, is presented in Section 3. In Sect. 4 the activation mechanisms of an elementary module of such a structure is presented. The uses of the proposed façade system as a dynamic sun-screen or a wind-energy harvesting device are respectively illustrated in Sects. 5 and 6. The main conclusions of the present study and directions of future work oriented to the application of tensegrity architectures to design of next-generation façades of EEBs are given in Section 7.

2. From structure to envelope

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.

An overview of the constructive scene shows that new types of double skin smart envelope must be able to form any kind of shape, even the most complex, as well as protecting the external surfaces of the building from sunshine.

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 [23–26].

In compliance with the standards set out in European and Italian Laws, and according to the operating principles of tensegrity, innovative smart façade systems are developed in the present work, in order to evaluate the potential effects of applying this envelope technology. These external architectural solutions would increase the value of buildings in terms of function, aesthetic and smart energy design [27–30].

3. From idea to project

We studied the evolution of innovative façade systems with a view to design novel dynamic sun screens and wind energy harvesters that can change their technological configurations and energy performances 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 [31]. 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.

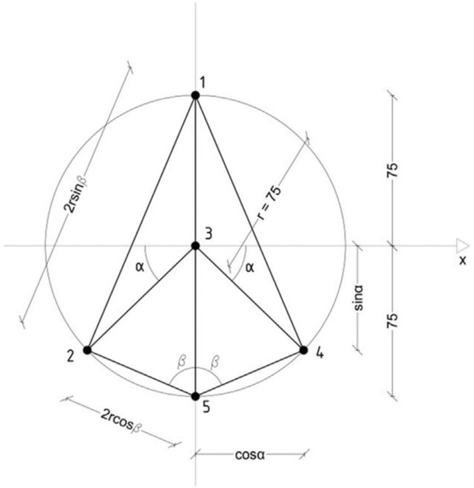
Sunscreens absorb and reflect incident solar radiation but cannot transfer solar heat gain directly into the building. When sun screens transform incident sunlight into electricity for immediate use or transmit thermal energy into the building by use of electrical or mechanical equipment, they are called opaque sunscreens and form part of an active solar façade. In this research, we designed two innovative prototypes according to the fundamentals of the tensegrity structural system [7].

The façade system that we study in this work is designed like a set of *blinking sails*, which is inspired by the wave-powered station-keeping buoy with tensegrity architecture illustrated in Chapter 1 of reference [7], and a recent US patent on a blinking sail windmill [32]. The module of this structure is composed of 6 bars (compressive members), two cables (tensile members) and five nodes. Node 1 is fixed on the sub-structure, nodes 2 and 4 are constrained to move in the x-y plane (parallel to the building façade), node 5 is constrained to move along the z-axis (perpendicular to the building façade) and node 3 is free to move within the space. The design of the elementary module depends on two angular aspect variables α and β, which define the node coordinates as shown in Fig. 1. Our next developments assume $\alpha = 0$ and $\beta = 45^\circ$ in the undeformed (planar) configuration of the blinking sail module.

We will see later on that the blinking sail structure illustrated in Figs. 1 and 2 can operate as an adaptive solar screen (cf. Sect. 5) or a wind harvester device (cf. Sect. 6). In both cases, such a structure is equipped with bendable, composite photovoltaic modules [18–21], and/or fiber-membrane sails [22]. Each elementary module of such a façade system is shaped like a rhombus (Fig. 2) and is actuated by controlling the elongations of selected cables, in such a way that the motion of the structure mimics a blinking sail (cf. Sect. 4).

4. Activation mechanism

Let us examine the motion of the blinking sail elementary module described in the previous section, which is produced by applying suitable elongations to the cables 1–3 and 3–5. At the current time *t*, the elongation rate of the *m*-th element connecting nodes *i* and *j* is given by the *compatibility equation*



node 1	0	r	0
node 2	-rcosα	-rsinα	0
node 3	0	0	0
node 4	rcosα	-rsinα	0
node 5	0	-r	0

0<α<|π|

Fig. 1. Blinking sail façade system – geometry of the elementary module.

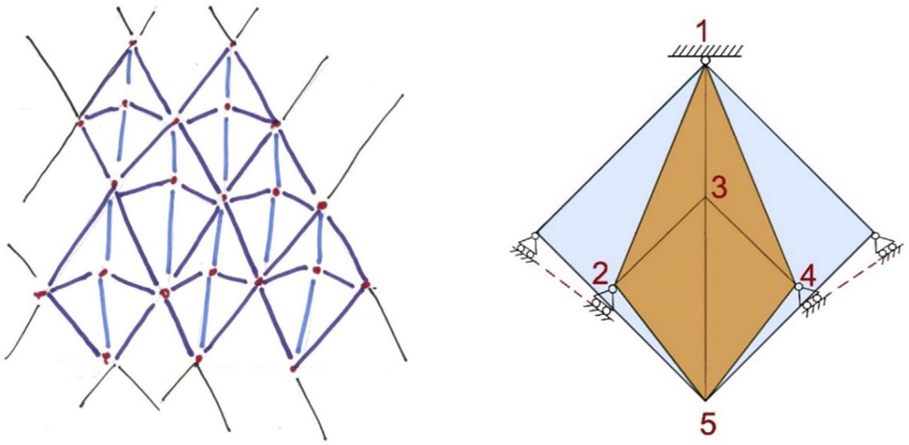


Fig. 2. Conceptual (left) and mechanical (right) models of the blinking sail façade system.

$$\dot{e}_m = \left(\dot{\boldsymbol{u}}_j - \dot{\boldsymbol{u}}_i\right)\cdot\boldsymbol{a}_m \tag{1}$$

where $\dot{\boldsymbol{u}}_i$ and $\dot{\boldsymbol{u}}_j$ denote the velocity vectors of the nodes i and j, respectively; $\boldsymbol{a}_m$ is the unit vector parallel to segment connecting such nodes (pointing towards node j); and ℓ_m is the current length of the element.

Upon assembling the free (i.e., unconstrained) Cartesian components of the velocities of all the nodes into a global velocity vector $\dot{\boldsymbol{q}}$, and the elongation rates in all the bars and cables into a vector of control variables $\dot{\boldsymbol{e}}$, we can rewrite the compatibility equations of the overall structure into the following matrix form

$$\mathbf{B}\dot{\boldsymbol{q}} = \dot{\boldsymbol{e}} \tag{2}$$

where $\mathbf{B}$ denotes the instantaneous *kinematic* (or *compatibility*) *matrix* [6].

Let us now consider a prescribed time history $\dot{\boldsymbol{e}} = \dot{\bar{\boldsymbol{e}}}(t)$ of the control variables. The motion generated by such an actuation strategy of the structure is computed from the integral equation

$$\boldsymbol{q} = \int_0^t \dot{\boldsymbol{q}}\ \mathrm{d}t = \int_0^t \mathbf{B}^{-1}\dot{\bar{\boldsymbol{e}}}\mathrm{d}t \tag{3}$$

where $\mathbf{B}^{-1}$ is the inverse of the kinematic matrix $\mathbf{B}$ in correspondence with the current configuration of the structure, which it is assumed exist.

The examined actuation mechanism of the blinking sail module is illustrated in Fig. 3. It is generated by actuating the cables 1–3 and 3–5, through the application of the elongation histories indicated in correspondence with the different panels of Fig. 3. The remaining members of the module remain unstretched during the motion of the structure illustrated in Fig. 3. By suitably changing the tension in the cables 1–3 and 3–5, it is seen from such a Figure that the nodes 3 and 5 moves outward along the z-axis (with respect to the building surface), while nodes 2 and 4 move in the x-y plane by producing the folding of the module, whose deformation resembles that of a sail inflated by the wind. The aspect angles of the module initially assume the values $\alpha = 0$ and $\beta = 45^\circ$ (top-left configuration in Fig. 3), as we already noticed, and assume the values $\alpha = 45^\circ$ and $\beta = 38^\circ$ in the fully folded configuration.

5. Blinking sail solar façade

The activation mechanism illustrated in Fig. 3 is at the basis of the solar façade system illustrated in Figs. 4 and 5. Such a smart skin of an EEB consists of several rhombus-shaped elementary modules assembled together. The modules are dynamic and can change configuration according to the actuation mechanism in Fig. 3, by

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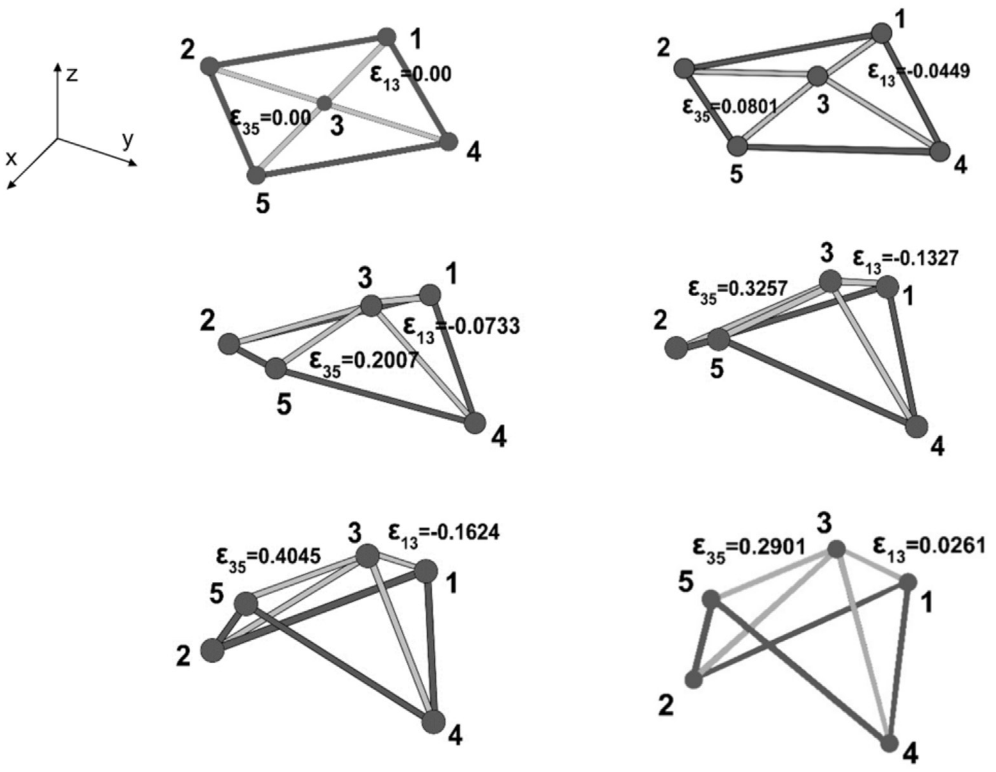

Fig. 3. Activation mechanism of the Blinking sail module.

Fig. 4. Blinking sail solar façade: fully-closed configuration.

modifying the shading properties of the envelope. Fig. 4 shows the fully-closed configuration of the blinking sail solar façade, while Figs. 5 and 6 shows partially- and fully-open configurations.

The blinking sail screens are composed of by a collection of foldable ("origami") eyes (rhomboidal modules) equipped with bendable, composite photovoltaic modules in correspondence with the perimeter bar elements [18–21], and/or fiber-membrane sails [22]. Such modules are opened (i.e., folded out) at night, and are progressively closed during daylight hours, through the actuation strategy illustrated in Sect. 4. The screens are designed to reduce the solar irradiation of the served building, and to produce marked decreases in air conditioning consumption. The implementations show in Figs. 4 and 5 refer to a potential application of the blinking sail solar façade in the campus of the University of Salerno (Fisciano, Salerno).

6. Blinking sail wind energy harvester

The blinking sail wind energy harvester consists of a system of foldable modules similar to that of the façade illustrated in the

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Fig. 5. Blinking sail solar façade: partially-open configuration.

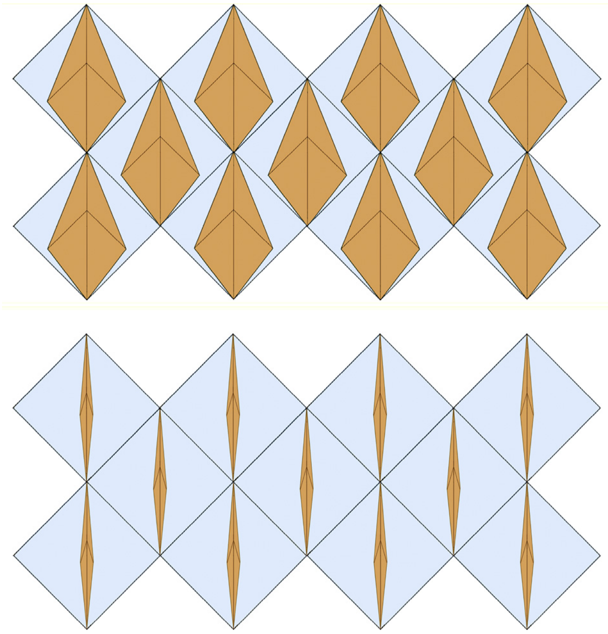

Fig. 6. Front views of partially- (top) and fully-open (bottom) configurations of the blinking sail solar façade.

previous section, which is now designed to convert wind-induced motion of a membrane attached to the generic module into electrical energy. The blinking sail module is formed in this case by all stretchable elements (strings) attached to a rigid truss protruding from the served building (cf. Figs. 7 and 8). Such cables are connected to a fiber-reinforced membrane sail [22] that is inflated by the wind. Additional cables attached to the module wrap around a generator rotor (Fig. 7). The wind-flow induced elongations of such cables rotate the generator, creating power for immediate use of the served building, to operate solar façades, etc. In addition, the aeroelastic flutter of the wind-excited membrane, eventually equipped piezoelectric or electromagnetic actuators, can be employed to harvest supplementary energy from wind [16,17]. Fig. 7 shows the functional diagram of the elementary module of the wind-energy harvesting façade, which is inspired by the wave-powered station-keeping illustrated in Chapter 1 of reference [7]. Fig. 8 instead illustrates potential applications of the blinking sail wind energy harvester in correspondence with blind façades of residential buildings serving the campus of the University of Salerno (Fisciano, Salerno).

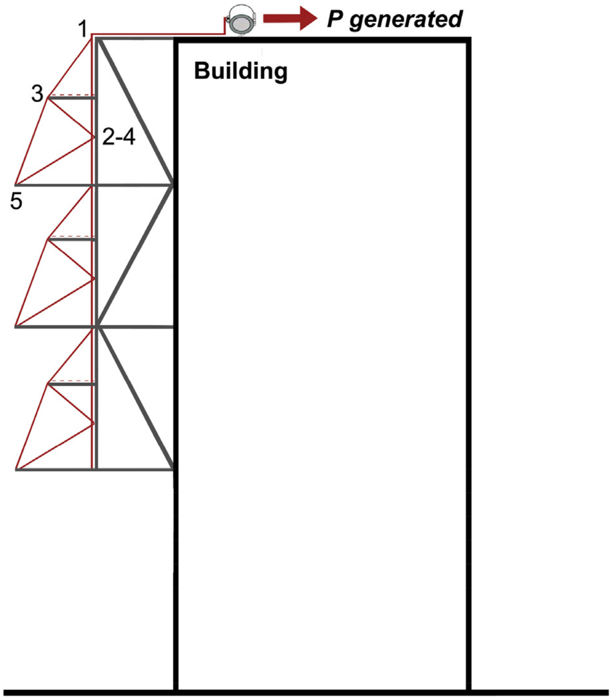

Fig. 7. Functional diagram of the wind-energy harvester module.

7. Concluding remarks and future work

We have formulates tensegrity solutions for the design of active façades that are able to harvest wind and solar energy through on-site wind power generator, and offer portable applications for small

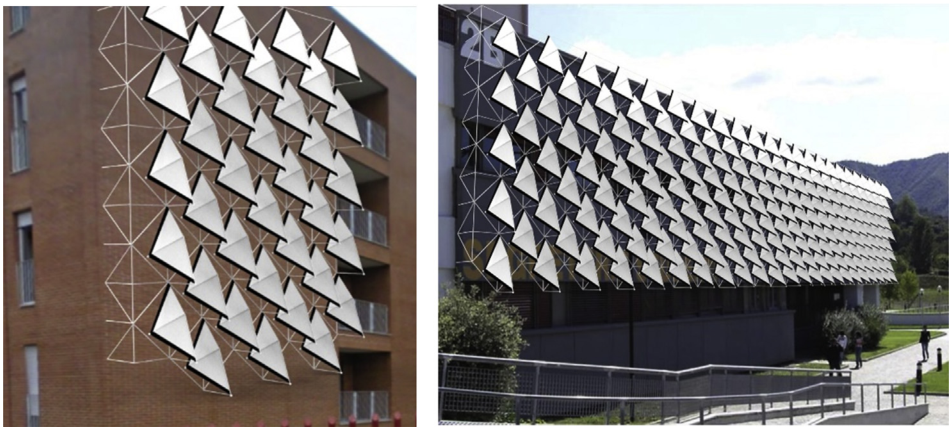

Fig. 8. Blinking sail façades working as wind generators.

Fig. 9. Fan-fish façade concept: fish scales, fan and overlapping fans.

spans and in the case of large spans can be easily assembled using prefabricated components.

The adoption of active shading façades allows the reduction of energy consumption and significantly reduce carbon dioxide emissions of buildings. The proposed tensegrity sun screens are opened and closed by controlling the elongation in a limited number of cables (cf. Sect. 5). Such screens are controlled by stretching or relaxing selected cables, and are used to orient the solar panels towards the sun, and/or to build innovative wind generators, which convert the strain energy stored in the cables of wind-excited units into electrical power. The elongations of the cables rotate an external generator, creating power for the operation of the building (Sect. 6).

A new tensegrity façade system that we address to future work will be designed like a fish scale envelope (*Fan-Fish System*, cf. Fig. 9). 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 fishes is covered with scales that are partially superimposed. We aim at the design of 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 can 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

Fig. 10. Physical models of the elementary modules of the fan-fish façade system.

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the solar screens adaptive (Fig. 10). Furthermore it would be possible to place solar panels on the fan slats. Some initial prototypes of elementary modules of a fan-fish solar facade are illustrated in Fig. 10.

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 [8–10] with energy optimization techniques [6]. The use of additive manufacturing techniques and recycled materials for the design and fabrication of next generation of solar façade also awaits attention [33–41], with the aim of developing sustainable kinetic membranes and panels with high thermal insulation properties.

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References

[1] Lombard LP, Ortiz J, Pout C. A review on buildings energy consumption information. Energy Build 2010;40:394–8.

[2] European Commission. HORIZON 2020 work programme 2014-2015, PART 5.ii. 2014. p. 98.

[3] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

[4] Schittich C, editor. Detail: solar architecture. Birkhäuser: Edition Detail; 2003.

[5] Raji B, Tenpierik MJ, van den Dobbelsteen A. A comparative study: design strategies for energy-efficiency of high-rise office buildings. J Green Build 2016;11:134–58.

[6] Fraternali F, De Chiara E, Skelton RE. On the use of morphing and wind stable tensegrity structures for shading facades of smart buildings. Smart Mater Struct 2015;24:105032 (10pp).

[7] Skelton RE, de Oliveira MC. Tensegrity Systems. New York: Springer Science+Business Media; 2009.

[8] Skelton RE, Fraternali F, Carpentieri G, Micheletti A. Minimum mass design of tensegrity bridges with parametric architecture and multiscale complexity. Mech Res Commun 2014;58:124–32.

[9] Carpentieri G, Skelton RE, Fraternali F. Minimum mass and optimal complexity of planar tensegrity bridges. Int J Space Struct 2015;30(3–4):221–44.

[10] Carpentieri G, Skelton RE, Fraternali F. A minimal mass deployable structure for solar energy harvesting on water canals. Struct Multidiscip Optim, Online First: DOI:10.1017/s00158-016-1503-5.

[11] Skelton RE. Structural systems: a marriage of structural engineering and system science. J Struct Contr 2002;9:113–33.

[12] Amendola A, Carpentieri G, De Oliveira M, Skelton RE, Fraternali F. Experimental investigation of the softening-stiffening response of tensegrity prisms under compressive loading. Compos Struct 2014;117:234–43.

[13] Fraternali F, Carpentieri G, Amendola A. On the mechanical modeling of the extreme softening/stiffening response of axially loaded tensegrity prisms. J Mech Phys Solids 2014;74:136–57.

[14] Fraternali F, Senatore L, Daraio C. Solitary waves on tensegrity lattices. J Mech Phys Solids 2012;60:1137–44.

[15] Fraternali F, Carpentieri G, Amendola A, Skelton RE, Nesterenko VF. Multiscale tunability of solitary wave dynamics in tensegrity metamaterials. Appl Phys Lett 2014;105:201903.

[16] Dinh Quy V, Van Sy N, Tan Hung D, Quoc Huy V. Wind tunnel and initial field tests of a micro generator powered by fluid-induced flutter. Energy Sustain Dev 2016;33:75–83.

[17] Arroyo E, Foong S, Wood KL. Modeling and experimental characterization of a fluttering windbelt for energy harvesting. J Phys Conf Ser 2014;(1):557. art. no. 012089.

[18] Shin KB, Kim CG, Hong CS, Lee HH. Thermal distortion analysis of orbiting solar array including degradation effects of composite materials. Compos Part B Eng 2001;32(4):271–85.

[19] Groenewolt A, Bakker J, Hofer J, Nagy Z, Schlüter A. Methods for modelling and analysis of bendable photovoltaic modules on irregularly curved surfaces. Int J Energy Environ Eng 2016:1–11. Article in Press.

[20] Jackson EM, Laibinis PE, Collins WE, Ueda A, Wingard CD, Penn B. Development and thermal properties of carbon nanotube-polymer. Compos Part B Eng 2016;89:362–73.

[21] Gan L, Shang S, Yuen CWM, Jiang S-X, Luo NM. Facile preparation of graphene nanoribbon filled silicone rubber nanocomposite with improved thermal and mechanical properties. Compos Part B Eng 2015;69:237–42.

[22] Malpede S, Baraldi A. A fully integrated method for optimising fiber-membrane sails. In: 3rd high performance yacht design conference 2008; 2008. p. 47–56. HPYD 2008.

[23] Baldinelli G. Double skin façades for warm climate regions: analysis of a solution with an integrated movable shading system. Build Environ 2009;44:1107–18.

[24] Mainini AG, Poli T, Zinzi M, Speroni A. Spectral light transmission measure of metal screens for glass façades and assessment of their shading potential, SHC 2013. In: Proceedings of international conference on solar heating and cooling for buildings and industry. Freiburg; September, 2013.

[25] Bianco JM, Buruaga A, Roji E, Cuadado J, Pelaz B. Energy assessment and optimization of perforated metal sheet double skin façades through Design Builder; A case study in Spain. Energy Build 2016;111:326–36.

[26] Mammoli A, Vorobieff P, Barsun H, Burnett R, Fisher D. Energetic, economic and environmental performance of a solar-thermal- assisted HVAC system. Energy Build 2010;42:1524–35.

[27] Green Building Council Italia, U.S. Green Building Council. Green building nuove costruzioni & ristrutturazioni - ristampa 2011. Rovereto: Green Building Council; 2010 [in Italian].

[28] Asdrubali F, Baldinelli G, Bianchi F, Sambuco S. A comparison between environmental sustainability rating systems LEED and ITACA for residential buildings. Build Environ 2015;86:98–108.

[29] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.

[30] Magrini A, D'Ambrosio Alfano FR, Magnani L, Pernetti R. Various approaches to the evaluation of the energy performance of buildings in Italy-some results of calculation procedures application on residential buildings. In: Proceedings of CESB 2010 Prague - central Europe towards sustainable building 'from theory to practice'. Prague; june-july; 2010. p. 1–8. Code 105800.

[31] Pizzi E, Iannaccone G, Ruttico P. Innovative strategies for adaptive buildings in large cities. Int J Hous Sci 2012;36:99–107.

[32] Al-Azzawi, J.S, Blinking sail windmill, Google Patents, 2010, https://www.google.com/patents/US7780416.

[33] Amendola A, Nava EH, Goodall R, Todd I, Skelton RE, Fraternali F. On the additive manufacturing and testing of tensegrity structures. Compos Struct 2015;131:66–71.

[34] Amendola A, Smith CJ, Goodall R, Auricchio F, Feo L, Benzoni G, et al. Experimental response of additively manufactured metallic pentamode materials confined between stiffening plates. Compos Struct 2016;142:254–62.

[35] Fraternali F, Farina I, Polzone C, Pagliuca E, Feo L. On the use of R-PET strips for the reinforcement of cement mortars. Compos Part B Eng 2013;46:207–10.

[36] Farina I, Fabbrocino F, Carpentieri G, Modano M, Amendola A, Goodall R, et al. On the reinforcement of cement mortars through 3D printed polymeric and metallic fibers. Compos Part B Eng 2016;90:76–85.

[37] Singh R, Singh S, Fraternali F. Development of in-house composite wire based feed stock filaments of fused deposition modelling for wear-resistant materials and structures. Compos Part B Eng 2016;98:244–9.

[38] Farina I, Fabbrocino F, Colangelo F, Feo L, Fraternali F. Surface roughness effects on the reinforcement of cement mortars through 3D printed metallic fibers. Compos Part B Eng 2016;99:305–11.

[39] Singh R, Kumar R, Feo L, Fraternali F. Friction welding of dissimilar plastic/polymer materials with metal powder reinforcement. Compos Part B Eng 2016;101:77–86.

[40] Singh R, Singh N, Fabbrocino F, Fraternali F, Ahuja I. Waste management by recycling of polymers with reinforcement of metal powder. Compos Part B Eng 2016;105:23–9.

[41] Boparai KS, Singh R, Fabbrocino F, Fraternali F. Thermal characterization of recycled polymer for additive manufacturing applications. Compos Part B Eng 2016;106:42–7.

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