SLICE
Solar Lightweight Intellingent Component for Envelopes

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Object of the research

The research concerns the study of an innovative composite material in which a high efficiency photovoltaic system is incorporated, for the realization of adaptive architectural envelopes. The final intent is to develop a component capable of adapting to user needs by varying its performance, assuming different configurations thanks to a computerized actuator system powered by the same integrated photovoltaic system. As the component is energy self-sufficient, it is adaptable to various applications: from the creation of responsive solar shading elements to the design of off-grid units, capable of self-assembly. In recent years, the demand for adaptive systems for architecture has grown considerably, sometimes characterized by materials such as to improve their sustainability in the production cycles and in the subsequent phases of use. It is therefore important to reduce energy expenditure and the impact of human presence on the surrounding environment, a process that passes through the progressive subtraction of weight and the lightening of the mechanical components for the implementation of motion.

For decades, architects and researchers have looked at the possibility of conceiving buildings endowed with intelligence and capable of reacting to external stimuli, architectural complexes whose "skin" as in a living being could provide an answer to changing environmental conditions (Wigginton and Harris, 2002). The term adaptivity refers to the ability of an object to perceive any alteration of the surrounding environment and respond to it dynamically (Shahin, 2019). Conventional buildings are often conceived as static structures designed following dynamic mathematical models, such as those based on the study of solar radiation and wind. This type of approach, however, dissociates the structure from the surrounding environment. It is therefore necessary to create buildings capable of relating to the context, assimilating information, and learning from it. Within this framework, a high-performance envelope that integrates management systems for daytime lighting, shading and natural ventilation, offers the opportunity to significantly reduce the consumption of a building (Sadineni, Madala and Boehm, 2011). Far from being a simple external cladding, the facade becomes a vital component that continuously interacts with the surrounding environment. This type of casing is usually characterized by the following properties:

1. deny the passage of air and humidity
2. allow proper natural ventilation in order to improve the temperature and quality of the indoor air
3. allow the diffusion of natural light inside
4. prevent overheating due to excess solar radiation
5. acoustic insulation of the inner spaces

These performances are strongly conditioned by the climate, the intended use of the building, its orientation, and the energy load of the equipment, as well as of course the type of facade. Nowadays the addition of new functions is increasing, such as the integration of new energy saving solutions or better still the production of energy from renewable sources (Velikov and Geoffrey, 2012). Thus, the facades have been transformed into much more complex systems, overcoming the very concept of envelope. Photovoltaics are therefore added as an active and relevant component from an architectural point of view (Heinstein, Ballif and Perret-Aebi, 2013).

State of art

With the introduction in the 1990s of amorphous flexible silicon cells, experiments aimed at offering new solutions for the integration of solar technology in building components began. The first photovoltaic textile structure called "Under the sun" dates to 1998 (Fig. 1a). It was built in the Cooper-Hewitt National Design Museum in New York and consisting of a 9.7 m high enclosure equipped done of amorphous silicon solar cells of 120 μm thickness, encapsulated and laminated on shaped fabric panels (Orhon, 2016). The firm Carl Stahl Architektur GmbH for the central courtyard of the Peace and Security Building of the African Union Addis Ababa (Orhon, 2016) designed a 25x20 meter photovoltaic sail with 445 blue transparent OPV (organic photovoltaics) modules, capable of shading and simultaneously providing sufficient electricity for the interior lighting of the building.

Among BIPV solutions there is the "textile solar system" developed for the prototype Soft House (Fig.1b) in Hamburg, designed by the Kennedy & Violich Architecture studio (Premier and Brustolon, 2014). The building has a wooden load bearing, that is characterized by a dynamic façade with solar shielding with vertical bands. In numerous research the fields of application of responsive facades have borrowed from the ancient art of origami the idea of creating folding photovoltaic surfaces, responsive but above all simple to move and transform. It is the case of the concept of the Prevalent design studio (Australia), which develops the theme of origami with an original photovoltaic folding screen prototype that guarantees electricity production without significant reductions in brightness for indoor environments.

Methodology

SLICE consists of a pre-folded surface in flexible material with the integration of a high-efficiency photovoltaic system. The experimentation passes through the simplification of the production process. It has been adressed to the adoption of highly available materials to be able to conceive a range of products for casings with different performances. The objective is to make the operation of active shielding elements or low-cost responsive roofing systems more sustainable, especially from the energy point of view.

It has been chosen a flexible substrate in order to obtain an extremely thin component that can be bent with a precise tessellation. Thanks to this it assumes an additional resistance and a bending direction required for its kinematics. Two different reinforcing fabrics, a hemp fabric and a glass fiber, were selected so that two different levels of mechanical strength as well as environmental sustainability has been tested.

For the matrix the results of two different polymers were compared: EVA (ethyl-vinyl-acetate), widely used in the composition of photovoltaic panels as a glue (Omazic et al., 2019), and SEBS (styrene-ethylene-butylene-styrene), with good resistance to abrasion and UV.

In order to optimize the performance of the material, PVF (Polyvinyl fluoride) was tested, a thermosetting polymer used in the production of solar panels as the flammability-lowering coating layer, with excellent resistance to atmospheric agents and dirt, as well as most chemical compounds (Sharma and Chandel, 2013).

The production parameters to be changed for material optimization through the vacuum lamination process are:

- matrix-reinforcement ratio
- duration
- temperature
- agents for detachment from the machine.

At the end of the definition of the composite material stratigraphy, the first experimental tests were started for its mechanical characterization process with uniaxial tensile test according to UNI EN ISO 527-4 and UNI EN ISO 527-1 for the determination of the Young E modulus and the shear modulus G (Rodonò et al., 2019). Taking into account the geometry identified for the type of casing, the choice of photovoltaic technology was focused on the integration of first generation silicon solar cells. At first, they were tested for the optimization of the production process of traditional polycrystalline silicon photovoltaic cells. In order to obtain high flexibility, excellent bendability and good resistance to external agents, high-efficiency monocrystalline silicon solar cells with back-contact technology have been used (Singh, Sharma and Banerjee, 2016) (Fig. 2).

First results

Six samples were made to test different material stratigraphies, the interpenetration of the matrix with the reinforcement fabric and the definition of the production parameters. Once the final stratigraphy, consisting of reinforcement fabric in hemp and EVA matrix, was identified, samples were made for its mechanical characterization. The results of mechanical characterization tests show characteristics of the composite material comparable with those of the composite materials commonly used in textile architecture (Rodonò et al., 2019).

In collaboration with Meridionale Impianti S.p.A., research project partner, a 1:1 scale prototype was developed (Fig. 8) aimed at simulating the operating cycles of the component. For the tests concerning charging and handling cycles of the system, the 20x40 cm simple bellows folding sample was equipped with two SunPower Gen I monocrystalline silicon photovoltaic cells and fiberglass reinforcement and was connected to a Microelectronics ST SPV1040T battery charging circuit and a 3.7 V 2250 mAh 8.33 Wh lithium battery model 18650CA-1S-3J. A shield with Arduino Mega 2660 (Fig. 3) board was then made with an input reading for control buttons, limit switch and I2C sensing chip for monitoring voltage and charge/discharge current on the battery, load voltage and current (geared motor) and current of the two photovoltaic cells. The component kinematics was made with a mechanical system on 550 mm Mini MGN12H linear guides for 3D Printers, whose carriages are fixed to a pair of 852 mm long, closed-loop Tiptiper 2GT-6 belts for motion synchronization, operated by four aluminum 20-teeth and 5 mm-bore pulleys GT2 SIENOC, one of which is directly fixed to the shaft of a POLOLU-2205 150:1 Micro Metal gear motor LP 6V (Fig. 4).

The prototype was tested with the use of a sunlight simulation lamp to check for proper functioning of the electrical connections after the rolling and folding processes. Reading the data shows how the electricity produced is largely sufficient to power the handling system and how the need to deploy the layers in the optimal position for recharging can only be limited to a few hours of the day.

The program code will be implemented in order to provide for different settings, aiming at optimizing the morphology of the component for battery recharging or orienting it to favor the thermal and/or lighting comfort of the areas concerned in relation to the accumulation state of the battery system. To do this, the connection of a current sensor to the panel output and a tilt sensor on a single flap will make it possible to record the input values that the processing system will use to manage the correct opening of the component.

Fig. 1
(a) Under the Sun Pavilion- Cooper-Hewitt National Design Museum New York 1998;
(b) Kennedy & Violich Architecture- Soft House, 2013 (http://www.kvarch.net.)

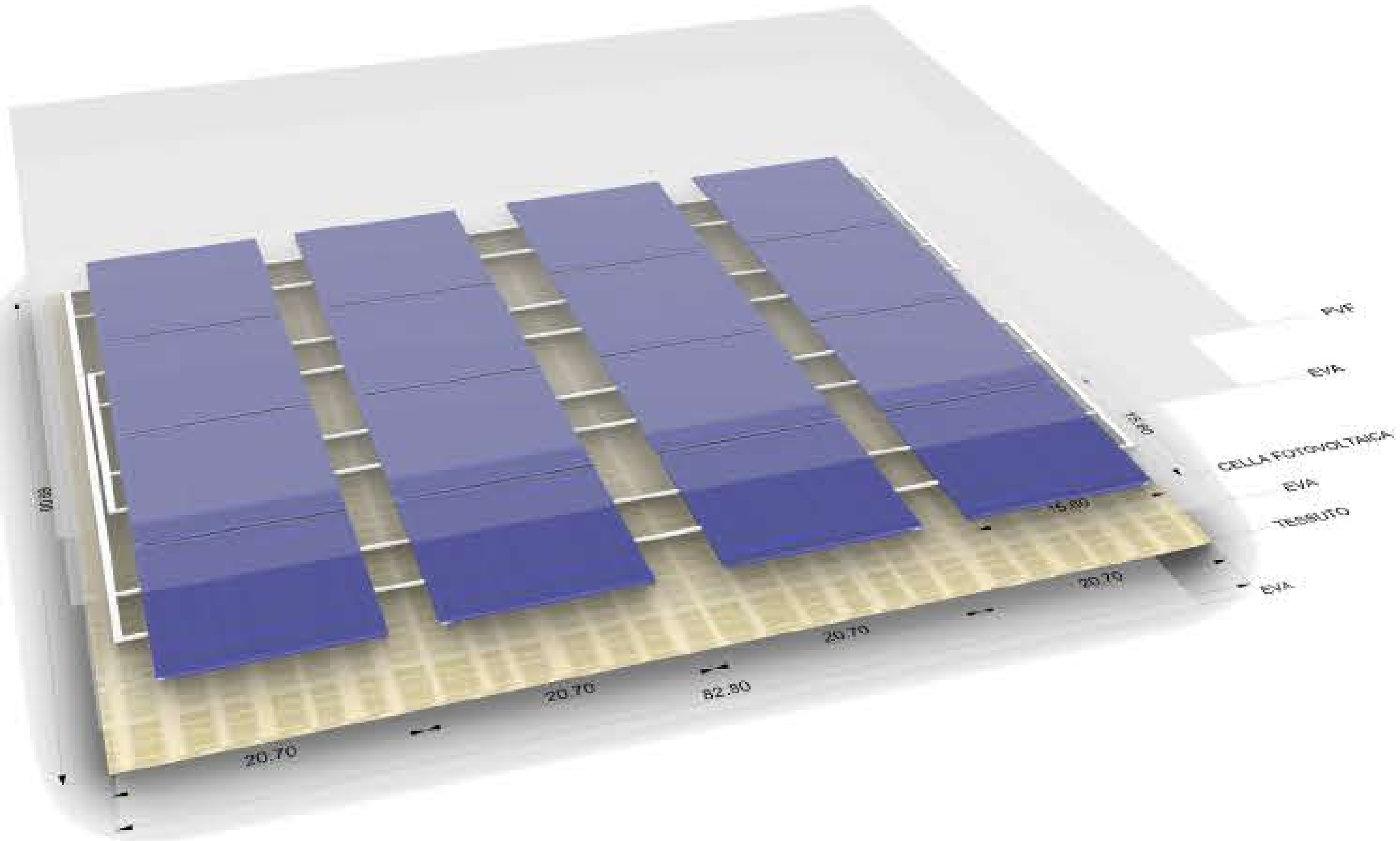

Fig. 2
Material sample with insertion of photovoltaic cells and its stratification

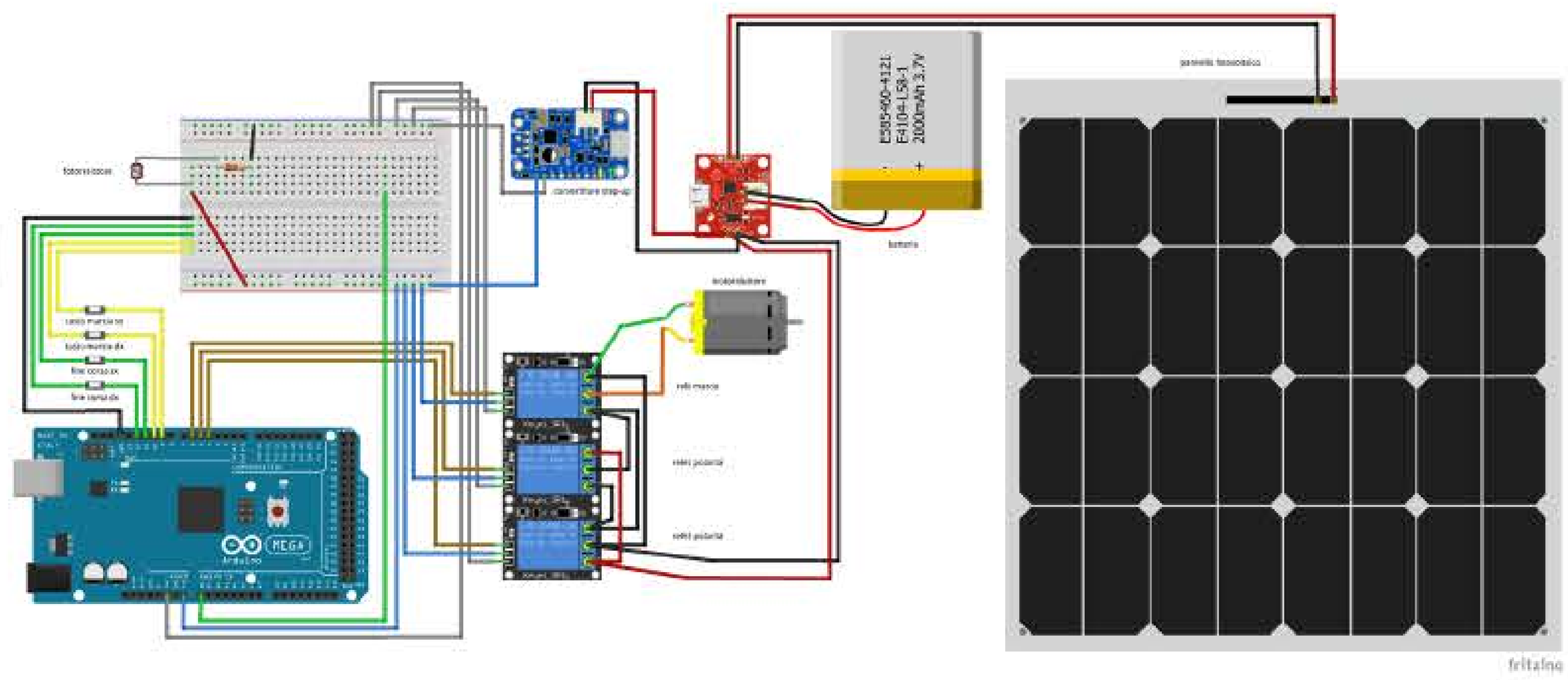

Fig. 3
SLICE prototype control system circuit

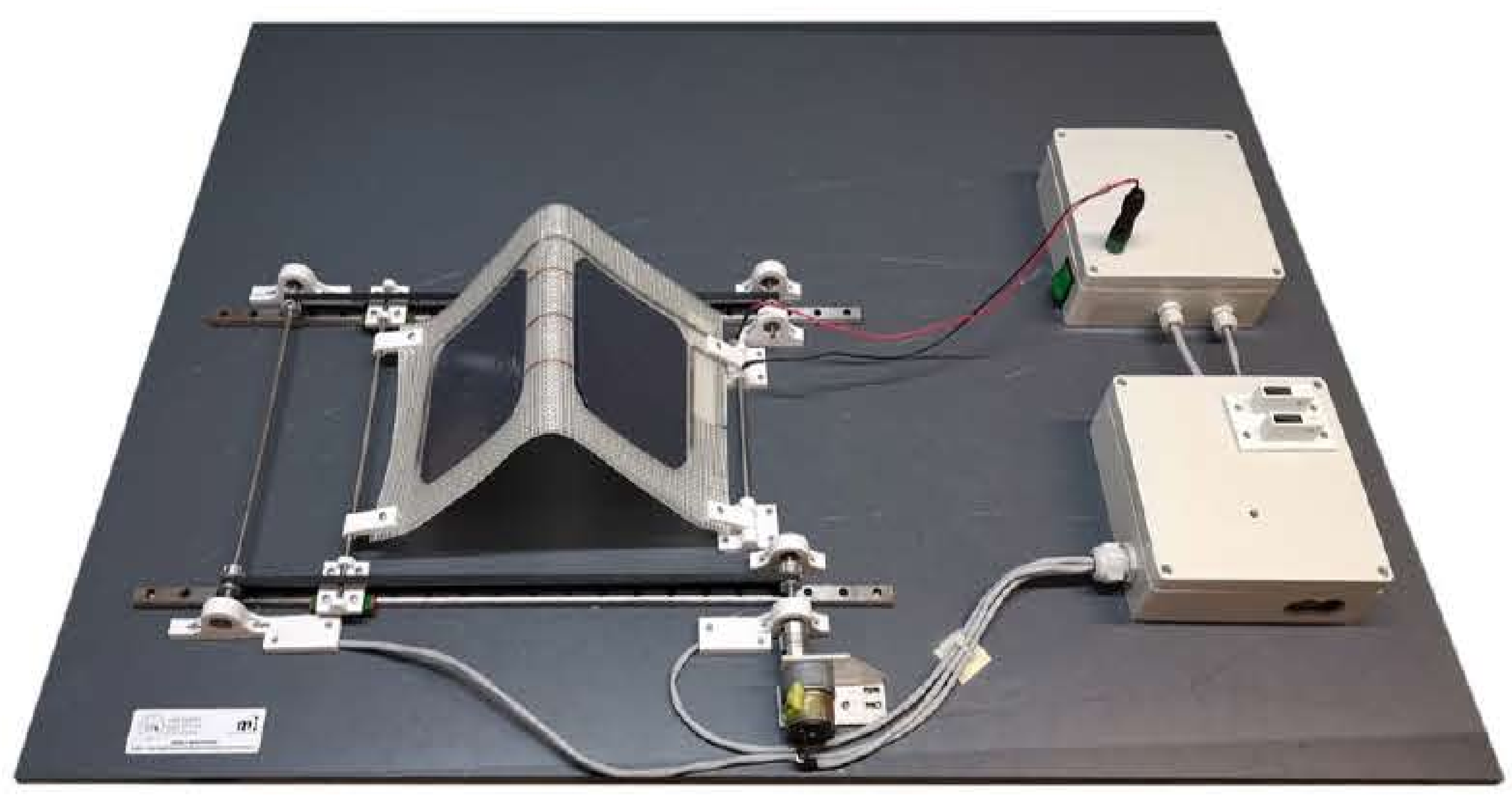

Fig. 4
The SLICE prototype made with fiberglass fabric reinforcement and monocrystalline silicon solar cells.

References

Alaaeddin, M. H. et al. (2019) 'Photovoltaic applications: Status and manufacturing prospects', Renewable and Sustainable Energy Reviews, 102(October 2018), pp. 318–332. doi: 10.1016/j.rser.2018.12.026.

Gallo, P. and Romano, R. (2017) 'Adaptive Facades, Developed with Innovative Nanomaterials, for a Sustainable Architecture in the Mediterranean Area', in Procedia Engineering. doi: 10.1016/j.proeng.2017.04.289.

Gaspari, F. and Quaranta, S. (2018) 2.5 PV Materials, Comprehensive Energy Systems. Elsevier Ltd. doi: 10.1016/b978-0-12-809597-3.00215-7.

Heinstein, P., Ballif, C. and Perret-Aebi, L. E. (2013) 'Building integrated photovoltaics (BIPV): Review, potentials, barriers and myths', Green, 3(2), pp. 125–156. doi: 10.1515/green-2013-0020.

Van Kerschaver, E. and Beaucarne, G. (2006) 'Back-contact solar cells: A review', Progress in Photovoltaics: Research and Applications, 14(2), pp. 107–123. doi: 10.1002/pip.657.

Moloney, J. (2011) Designing Kinetics for Architectural Facades: State Change. Oxon: Routledge.

Omazic, A. et al. (2019) 'Relation between degradation of polymeric components in crystalline silicon PV module and climatic conditions: A literature review', Solar Energy Materials and Solar Cells. Elsevier B.V., 192(May 2018), pp. 123–133. doi: 10.1016/j.solmat.2018.12.027.

Orhon, A. V. (2016) 'Integration of Photovoltaics into Tensile and Inflatable Structures', Solar Conference &Exhibition, Turkey, (September), pp. 454–462.

Premier, A. and Brustolon, V. (2014) Photovoltaic Awnings and Fabrics : Some Case Studies, Tenda International.

Rodonò, G., Sapienza, V., Recca, G., Carbone, D.C. (2019), A Novel Composite Material for Foldable Building Envelopes, Sustainability, 11, 4684.

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