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Façade Solar Control and Shading Strategies for Buildings in the Mediterranean Region

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Abstract

In recent years, the growing awareness of the possibilities of biomimetic and adaptive materials in architecture has assumed a fundamental importance in the scientific domain, for the high performance of the building façades from an environmental point of view. To meet the housing and comfort needs in climates, such as the ones in the Mediterranean zones, characterized by ever-increasing temperatures, architectural technology must collaborate with nature in an even more decisive way, through increasingly smart and sustainable solutions. The paper reviews a collection of good practice examples of advances in material science, and the method used is to analyze the current performance of and building envelopes with smart façade skins, in order to suggest some potential applications in the Mediterranean basin and regions of the world with similar climatic characteristics.

The latter case studies, especially, show built examples of adaptive buildings that could be adopted for use in Mediterranean regions. When the climate characteristics are somehow different, the good practices from elsewhere can be implemented in an innovative way.

Keywords

Shading; building envelope; adaptive façade; Mediterranean region, warm climate; biomimetics

1. Introduction

In the last century, the globalization of the building industry and the almost total reliance on building services engineering for internal comfort, have increasingly led to the construction of standardized buildings that are not related to the local climatic, cultural, and material context. Buildings are made the same way in Stockholm and Nairobi, in Shanghai and in Sao Paulo, suddenly sweeping away millennial building principles (Butera, 2004). Until recently architecture was considered almost a sort of challenge launched by man to nature, to demonstrate that they are capable of building and living in any context and in any climate. Air conditioning systems and technology actually make it possible to live under low ceilings in the tropics, behind thin walls in the arctic and under uninsulated roofs in the desert. All precepts for climatic compensation through structure and form are rendered obsolete (Banham, 1969).

However, today, the environmental issue and climate change require radical reflections with respect to the indiscriminate use of energy. Although within a contemporary technical-constructive language and methods, only a renewed design, capable of integrating choices oriented towards the optimization of both climatic and material local resources, can really open up new eco-efficiency scenarios.

1.1. Principles of bioclimatic design and passive buildings

A design attentive to the reduction of energy consumption and living comfort and capable of exploiting local natural resources and the climate is generally based on a bioclimatic approach which aims to address three aspects of the design at the same time: climatic-environmental, typological and technical-construction. If we try to read a connection of Mediterranean architectures with respect to these three facets, it is possible to identify some typical features (Lavagna, 2008).

Mediterranean architecture has always had a climate characterized by notable seasonal variations in temperature, humidity, wind, and solar radiation, which impact the environmental and physical performance of buildings in different ways and requires solutions capable of adapting to these seasonal variations.

In addition to the Mediterranean climate, the individual buildings respond to the microclimatic conditions of the site, that is to the specificity of the individual places in relation to the conformation of the urban or landscape settlement that influences, and sometimes modifies, the typical climatic conditions of temperature, humidity, wind flow and solar radiation, characterizing the single context with local conditions.

With regards to the typological aspects, Mediterranean constructions are characterized by the search for a balance between a compact shape in winter, based on the most advantageous ratio between surface and volume with respect to heat loss, and open in summer, based on the possibility of favoring natural ventilation, with variable spaces, open-closed, between winter and summer: porches, loggias, patios, filter spaces, greenhouses. For instance, the typical Mediterranean typology is the compact but porous house (Fig. 1). The porosity of a building, in this context, describes the fraction of openings in the external envelope used for ventilation. Equally effective is also the in-line or terraced typology, which makes it possible to favor compactness but also to identify two privileged exposures, one to the south (to take advantage of the winter solar gains) and one to north (to have a cool side in summer that triggers natural ventilation through the building).

In Mediterranean architectures, the distribution and orientation of transparent surfaces and their relationship with the opaque surface are particularly critical. Transparency is a very important aspect in relation to obtaining an adequate level of natural lighting and the exploitation of direct solar contributions during winter but requires great control of the solar radiation in summer. Essentially, Mediterranean architecture is therefore characterized by the presence of elements of solar protection, such as shelters and shading devices.

With regard to the control of the technical-constructive aspects, Mediterranean architecture is characterized by the passive use of solar energy through the exploitation of sunlight both directly (through the windows) or indirectly (through the heat accumulators) and by the presence of an adequate capacitive mass (and thermal inertia) to conserve the heat of the winter contributions (solar capture without inertia is ineffective, since the hours of irradiation in winter are few and the transparent surfaces, during the hours in which they are not irradiated, are very dispersing) and dampen temperature peaks (attenuation and phase shift of the thermal wave input) in summer. Mediterranean architecture is, therefore, a traditionally massive architecture, characterized by the use of materials with high thermal inertia, such as stone or brick, in a varied range of construction solutions. To ensure good protection of the building, the orientation, the shape of the building and the characteristics of the envelope building are the aspects on which the designer must focus more (Musco, 2006).

In Mediterranean climates, compactness is advantageous in the winter while porosity is advantageous in the summer: the most interesting examples of Mediterranean architecture try to mediate these opposite objectives, designing elements with variable structure that can allow the closure of atriums, patios, galleries and verandas in the winter while also allowing their opening in the summer.


Figures 1. Typical Mediterranean massive houses

The shape of the building must also be related to the orientation. In Mediterranean architecture, southern exposure is preferred as the surfaces thus arranged receive the maximum winter radiation, while in summer the most affected surface is the roof and those located to the east and west. The Mediterranean buildings are characterized by a conformation that tends to favor the side facing south, in order to capture the sun's rays through the windows in winter, when the sun is low, and easily shield the glass surfaces from the sun's rays in summer, when the sun is high, with horizontal overhangs (balconies, loggias). The east and west sides are limited as much as possible since the openings on these sides carry little energy in winter, when the sun is weak and of limited duration (the solar path in winter is short), and overheating in summer, when the sun is low and goes deep. Generally, the north side, which never receives the sunlight (except at sunrise and sunset in summer), is characterized by openings reduced to a minimum to avoid dispersion and by a significant increase in the thermal insulation of the walls of buildings (Lavagna, 2008).

1.2. Building envelope and thermal comfort in Mediterranean climates

With regard to what has been written so far, it is clear that the building envelope has the task of modulating the external environmental conditions in order to create a more comfortable environment inside. It is a task that it has carried out for centuries, so much so that it has differentiated itself in relation to climatic conditions (2004).

Serra Florensa and Coch identify six main characteristics that define the energy behavior of the building envelope: insulation, heaviness, permeability, transparency, protection from the sun, color (Serra Florensa and Coch 1995). The insulation of the building must be different in relation to the climatic zone and the orientations (for example, greater insulation of the north-facing facades and the roof is required). Reasoning only on the outgoing heat flows in winter and entering in summer, a current of thought has been generated that promotes thermal insulation as the main control element of living comfort and reduction of energy consumption. This interpretation, born in northern Europe, is driving the creation of hyper-insulated environments also in the Mediterranean areas, with the belief that this can allow for more efficient buildings. But the insulation, in Mediterranean climates, is not enough. The wooden envelope, thanks to its insulating power, reduces heat loss to the outside. The stone or brick one does something more: in addition to insulating, it allows - thanks to thermal inertia - to accumulate and release heat, and therefore allows the internal temperature to remain higher than the external one during the night. In a building with very thick walls, when the windows and doors are not always open, the internal temperature in the absence of heating remains almost constant, and very close to the daily average outside (Aelenei, 2016).

In warm climates, the envelope must take advantage of the day-night temperature range, in order to maintain an intermediate temperature between the two extremes inside and prevent the entry of solar radiation. So, in these climates, the traditional house is characterized by heaviness, that is, it is made of heavy masonry to take advantage of the thermal inertia of the structure (Mordà and Duma, 2013; Scarano, 2013).

Erlacher and Erlacher, in the book *Casaclima in massive masonry*, emphasize the advantages of massive construction in Mediterranean areas and propose a manual of construction solutions for obtaining low energy consumption buildings based precisely on the use of thermal mass. In summer, the effectiveness of the thermal mass in Mediterranean climates is linked to the association with natural ventilation. If adequate free cooling at night is not achieved through natural ventilation, by discharging the heat accumulated by the wall during the day during the night, the thermal mass is ineffective for the purposes of comfort and energy saving. Here, then, is another element that characterizes Mediterranean architecture: the permeability of the walls (Erlacher and Earlacher, 2007).

Permeability refers to the presence of openings in the building, which allow the passage of air, and depends on the size and position of the openings themselves. In Mediterranean architectures, a reduced permeability in winter is sought (in order not to dissipate heat) and a high permeability in summer (to improve ventilation) through variable configuration solutions. The openings to the south, south-east and south-west allow the entry of warmer air, while those to the north allow colder air: if placed on opposite facades, they favor cross ventilation in the interior. The permeability and breathability of the facade are important in all seasons, also in relation to humidity control and indoor air quality. Currently, housing models typical of northern Europe are being imported, characterized by a high air tightness to avoid excessive heat loss. However, in this way, in hot-humid Mediterranean climates, there is a risk of a worsening of the indoor air quality, which can only be remedied through sophisticated mechanical ventilation systems.

Mediterranean architecture is also particularly confronted with the management of the transparency of the building envelope. While Nordic buildings are characterized by high transparency, dictated by the search for the maximum contribution of natural light, Mediterranean architecture is characterized by “closed” solutions, where opaque surfaces or at least screened transparencies prevail. Overly transparent buildings, in Mediterranean climates, create unlivable environments due to the greenhouse effect. If this condition can be advantageous in winter, it produces overheating in summer, transforming the rooms into real ovens, which can only be air-conditioned with very high energy costs. Therefore, the design of the size, orientation and position of the windows must address several other important aspects: the winter solar gain, the summer sun and the consequent overheating, natural lighting and any glare phenomena. In the Mediterranean areas, the transparent surfaces of the building are oriented to the south, south-east and south-west to favor thermal gains in winter, providing adequate shading in summer.

One of the main solutions is the correct design of the building envelope which must respond effectively to the control of solar radiation. In regions with warm climates, such as in the case of Mediterranean countries, shading is one of the most important design strategies for controlling exposure and intense solar radiation; it is not a new approach in terms of architectural solutions. Just look at the construction techniques of the Greeks who thought of the development of their cities based on solar availability.

The solar shading element can be fixed, such as overhangs, balconies, loggias, or mobile and are chosen in relation to the orientation. Horizontal shading is used for south-facing facades because the sun is high in the sky, while vertical shading is used for east and west facing facades when the sun is low. To ensure optimal energy efficiency, they must be sized in such a way as to guarantee irradiation in winter and total shade in summer. An objective that can be achieved through the “variable structure” envelopes, achieved thanks to the use of mobile systems that allow to change the ratio between solids and voids, transparency and opacity, insulation of the envelope during the day or over the seasons (Santamouris, 2001).

Mediterranean architecture is characterized, on the one hand, by the use of light colors and, on the other, by the choice of non-reflective materials and surfaces, which could create glare in the surroundings and heat islands. In this regard, studies relating to the control of the microclimate and comfort of open spaces are multiplying in relation to the design choices with regards not only to the morphology of the structures, but also to the materials and colors chosen for the claddings that cover the walls of the buildings and the paving of outdoor spaces. The suitable use of colors for the facades of buildings has been known since ancient times. Colors such as light gray, cream, soft yellow and white are highly reflective and reflect up to 75% of the light that strikes surfaces of that color. In fact, the use of white in the Mediterranean construction tradition is very widespread and is the result of experimentation and a wise use of local materials that today distinguish a very typical architectural style, also meeting requirements of comfort and livability. (Morello and Ratti, 2009).

Since in ancient times the laws of physics were not known but each discovery was made casually or empirically, the reasons that led to prefer white in construction were mainly two:

- easy availability, low cost and simple processing / installation of the available white raw materials;

– having discovered, through its use, that white reflects solar radiation and makes the spaces in which it is used appear larger (Martellotta, 2020).

2. Materials and methods

Obtaining the ideal temperature and lighting levels inside buildings with adequate levels of comfort is fundamental. However, environmental conditions change from context to context and it is clear that every existing or newly designed building must be treated in a unique way.

Therefore, it is essential to focus on the methodological approach of analysis which, according to this contribution, is both multidisciplinary and interdisciplinary. With the support of different disciplines, through the tool of knowledge, we identify the morphological, typological and technical-constructive solutions most suitable for a given context with its typical climate. Furthermore, the design of a protection, a shading, an envelope for buildings located in territories characterized by warm climates as the Mediterranean area is both a technical and aesthetic architectural operation, since the first impact of an envelope is visual.

Reading and interpreting the complex relationships between the natural/climatic context and added anthropogenic systems, defining what to design and build to protect and why, in terms of sustainability, even before knowing how to build, provides a valuable tool for a reliable intervention.

The analysis of the geographical location and the knowledge of the function of the building built or to be built in an area characterized by a warm climate is an investigation tool with generative, morphological, typological, technological and material parameters which, if not adequately assessed, risk to make any functional building envelope project ineffective.

In this article, we have highlighted the main factors to be taken into consideration to design smart solar shading systems and building envelopes in areas characterized by a Mediterranean climate, therefore variable.

The historical, anthropic and climatic aspects that characterize the Mediterranean region intervene both for the value of resources such as history, climate and multiculturalism, and for the critical factors offered by highly anthropized territories and generally resistant to shared transformations. We have correlated the energetic and technical-constructive aspects to those concerning the improvement of the comfort of the contexts, to reach advances in technological culture. The conscious holistic approach to the system of knowledge, methods of fruition and cultural stratifications structures methodologies and phases of the current research.

On the basis of the analysis of some case studies relating to virtuous projects and experiments, conducted in places characterized by warm climates, its potential application in Mediterranean areas is evaluated.

With regards to the place where a building is located, the first phase is to collect data on environmental and climatic conditions, on the type of protection intervention that can be performed, specifying dimensional and cost data, materials and design guidelines.

With regards to the building envelope or shading system, we must collect technical assessments, relating to performance, maintainability, reversibility, duration and effectiveness, both in terms of visual, climatic / environmental impact and its relationship with the landscape. The approach to the concept of protection of living comfort always starts from the deep respect for the place and from the study and knowledge of the identity of the context in which they are located (Norberg-Schulz, 1979). The place is the physical point in which the site is located, the climatic context that characterizes it, the culture that generated it and the contemporary one that should preserve it.

One of the most discussed topics in architecture concerns the common goal of operating in harmony with the environment, having at heart the protection of the building and the context, considering as previously stated, the climate and specific culture of a particular place.

Norman Foster states that the architectural project must be related to the climate and culture of the place (Greco, 2002; Iacobone, 2016). Therefore, in the design of a shading or building envelope we deal with three fundamental issues:

- the relationship with the natural and geographical context, to guarantee the correct urban and landscape integration;
- the relationship with the climate, to guarantee the most adequate protection to preserve the building from atmospheric agents and above all from solar radiation, guaranteeing, at the same time, an adequate natural lighting;
- the function of the building, allowing the perception of what happens inside the building.

As Portoghesi (1999) argues, to operate beyond stylistic fashions and exasperated individualism, today it is necessary to re-propose the persistent validity of archetypes, in a general vision that gives them the authority that can derive from the relationship between History and Nature: to build, consolidate, protect the built environment as part of nature, with which people should ally, always setting different conditions corresponding to different levels of understanding of the relationship between nature and architecture.

We are aware that contemporary architecture is often called upon to integrate physically and constructively with pre-existing structures, which is why a reliable methodology must be valid for both existing buildings and new constructions.

Nowadays, technological innovation is revolutionizing the shapes that surround us. However, often this new global language does not take into account the identity and climatic conditions of a site. The history of local materials, of construction traditions, as well as of tangible and intangible cultural heritage, is a repertoire of signs to always draw on, to operate within every historical-geographical context and, consequently, to realize architectural and structural solutions more reliable and appropriate. This is why the specificity of building envelopes have to be read as a combination of morphological, climatic, usage, management and technical aspects. The results of this study support a better understanding of how to increase the adoption of sustainable interventions in Mediterranean area.

3. Case studies

3.1. Bioclimatic pergolas

The architectural design of a protective canopy or cladding must also take into account the use and consumption of energy in maintaining the comfort of the building and the energy necessary for its use: natural or artificial lighting, ventilation, heating and cooling. The thermal capacities of a shelter represent a fundamental functional aspect on which to reflect. In this regard, the distinction made by Hartwig Schmidt between protection systems that do not delimit the building, the canopies, and closed protection systems, the building envelope, is paradigmatic. In the case of the building envelope, other energy consumption needs arise, not met by canopy systems, such as internal air conditioning, artificial lighting in addition to or in place of natural lighting or entrance lighting. Today, the energy consumed in the production and construction phase with 0 km materials, or local recycled materials such as wood, sand, mud, straw and leaves, is called “embodied energy” (Ranellucci, 2009; Ferrari 2009).

Pergolas, when properly designed, can act as passive solar systems and help reduce thermal loads (Fig.1). When, in addition to being composed of a roofing solar shading system, they include curtains on the sides to screen the sun in summer and windows that allow solar gains during the winter, they become very simple bioclimatic systems, yet capable of providing enormous energy benefits in all seasons.

Traditionally, in the Mediterranean area the pergolas are structures made up of thin vertical supports and a grid of roof beams, which in addition to providing stability to the structure, act as a support for the vegetation. Typically, pergolas are found in gardens and climbing plants characterize the roof, creating a shaded but permeable and ventilated space, in which to shelter from the sun's rays in summer and find relief from the heat.

In less natural contexts, the covering vegetation is replaced by alternative solar shading systems, such as packable PVC fabric or slats. In the most innovative systems, the covering lamellas are adjustable to shield the sun's rays but allow the breeze to pass, and waterproof for preventing the passage of rain once closed.

Figure 2. Vegetable pergola of the Giardino della Minerva, Salerno.

Figure 3. Bioclimatic pergola (Gibus)

The pergolas, which offer protection from atmospheric agents, can be completed with opening windows. The pergola, closed on all sides, with the possibility of opening the windows in summer and combining them with shading awnings, offers an ideal microclimate all year round: in summer, the windows that can be opened favor natural ventilation and the curtains shield the interior of the pergola from the sun. In winter, however, the closed windows protect against atmospheric agents.

There are companies that have patented systems that, in addition to allowing the structure to be delimited with opening windows, integrate systems for the drainage of rainwater for clean architectural results. An Italian company has patented three systems (Side Seal, Twist Motion and Inner Guide) which also make it possible to isolate the perimeter coating and integrate shading blades that rotate to shield the sun's rays. These can be completed by motorized mechanisms, audio and lighting systems. (Fig. 3).

When the pergola is placed next to the building it also helps in reducing thermal loads. It contributes to the improvement of comfort in the building, reduces the need for air conditioning, with positive consequences on indoor well-being and energy saving, and creates a new semi-outdoor environment in which the climatic conditions are as comfortable in summer as in winter.

3.2. The bamboo shell for transpiring buildings in the Mediterranean area

In Mediterranean climate, bamboo is an excellent material for creating breathable buildings in the context of sustainable architecture. An energy-saving breathable building is able to control the internal / external microclimate and to sweat for emitting internal heat and cool naturally.

One of these techniques is borrowed from Japanese natural architecture. In some areas of Japan, the most sun-exposed facades of buildings were covered with an outer shell of bamboo canes. Later, water was poured into the pipes which, by evaporating, allowed the temperature to lower even inside the structure. This technique was borrowed from the Japanese studio Nikken Sekkei with the Bioskin project of Sony City Osaki in Tokyo, in 2012 (Fig. 4). The bamboo canes that define the building envelope have been replaced by thin ceramic pipes, which converge in a collection system of the rainwater. The system allows you to lower the temperature inside the building by 2 ° C, resulting in a reduction in CO_2 emissions due to a reduced use of air conditioning systems (Watanabe, 2001).

Another relevant example of how contemporary architectures are able to reread the local construction tradition in an innovative way is represented by the Bamboo Roof (Fig. 5). It is an installation created in Houston, in Texas in 2002 for Rice University Art Gallery, designed by the Japanese architect Shigeru Ban. He has developed a promising construction method in terms of sustainability and efficiency, that uses bamboo and cardboard tubes for its constructions, both residential homes, buildings for emergency situations, and large tensile structures made with unconventional materials.

The Bamboo Roof is characterized by a free-form roof structure that develops with unlimited geometric possibilities. The concept is both simple and complex at the same time. The structure is created by fitting together a series of units of parts, each made up of four bamboo boards connected together by metal pins. Finally, the corrugated roof is supported by metal supports. Bamboo Roof conveys a great sense of lightness and transparency, so much so that one has the perception of being under the canopy of a forest. These techniques represent an important reflection on the developments in the use of bamboo for construction in Italy.

Figure 4. Bioskin of Sony City Osaki,Tokyo

Figure 5. Bamboo Roof, Houston

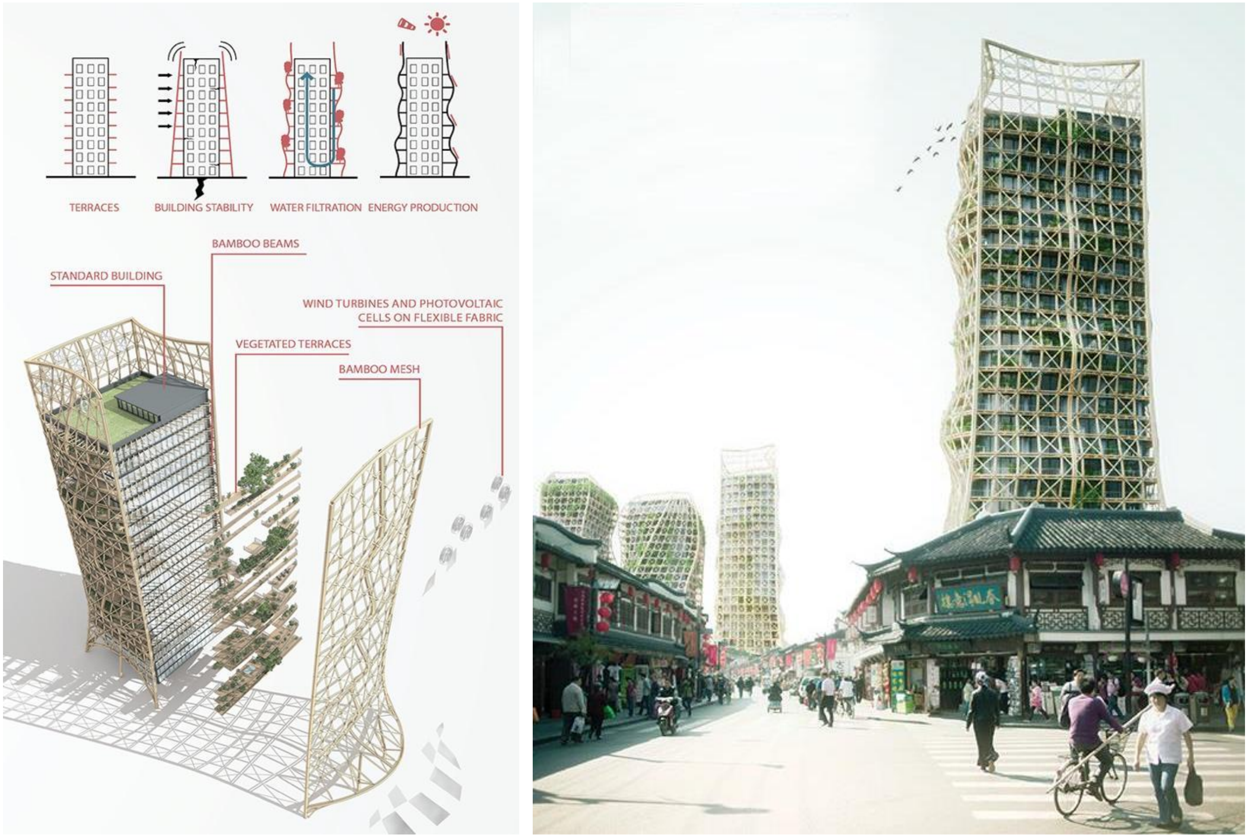

Figure 6. Bamboo forest

In the project of Bamboo forest, the designer Thibaut Deprezo uses permanent bamboo scaffoldings as a driving force to promote the revival of these two tower buildings. Each scaffolding is fashioned to the needs and wants of the building, giving each a unique identity. The bamboo shell allows residents to expand their dwelling outward in the form of fresh air spaces and vertical gardens. Furthermore, towers and bamboo scaffoldings create symbiosis, favoring the stabilization of structures during earthquakes and support an ecological production of energy (Figs. 6).

Figure 7. Bamboo brise soleil in the Stam Europe Green Place office building in Milan

3.3. A good practice in Milan: STAM Europe by Goring and Straja Architects

The Sony City Osaki was built taking into account the exposure of the winds blowing over Tokyo Bay. Therefore, in the direction of the winds, the sides of the building are thinner and tend to stretch on opposite sides. The photovoltaic slats, on the other hand, are on the south facade to collect more sun rays. However, their purpose, in addition to producing energy, is to shield the rooms that overlook this side of the building, which is notoriously warmer.

The same solar shading system was used in Milan. The facade of the Stam Europe Green Place is characterized by an external envelope with a side completely covered with a bamboo brise soleil. Bamboo creates a filter between the outside and the inside. The Green Place on Viale Certosa in Milan remains "covered" by bamboo canes, to obtain a green effect and shield it in the parts most exposed to the sun (Fig. 7).

The building was designed to obtain LEED Gold certification. The ground floors of the building complex are intended for laboratories, main building entrances and a showroom. The floors are all intended for offices. In addition, it is characterized by the widespread use of glass, aluminum, concrete and bamboo string course structures for the shading systems on the east, south and west fronts. Bamboo brise soleil receives a heterogeneous amount of sunshine, thins out, thickens and adjusts according to the inclination and solar radiation, creating a play of density and rarefactions that makes the facades vibrant and changing (Giglio, 2017).

3.4. Adaptive structures and meteorosensitive shelters

Adaptive coverings and innovative shelters react to external stimuli and regulate energy flows, heat, ventilation and lighting in relation to seasonal or daily climatic variations, while still guaranteeing the wellness requirements of the site and users (Reichert et al., 2015). This goal can be achieved with the adaptive architecture, which involves the construction of structures able to change their shape and react to the surrounding environment. The mechanisms of adaptation between organism and environment provide us with, by analogy, a possible key to interpret the interactions that some structures establish with the places where they fall, places full of meaning and characterized by a 'dominant nature' (Di Salvo, Advances in Research for Biomimetic Materials 2018).

In this regard, biomimetic or bio-inspired materials applied in the design are revolutionizing the way we invent, heal ourselves and exploit energy (Pohl, 2015). These are surfaces, envelopes or 'technical skins' made up of special layers, capable of reacting like membranes in which exchanges of attenuated, transmitted, absorbed or reflected energy occur. *Hygroskin* pavilion, designed by Achim Menges of the University of Stuttgart, was commissioned for a permanent exhibition at the FRAC Center in Orleans. Its envelope building has been realized by superimposing a series of wooden spruce panels over a steel structure, in the central part of which very thin triangular wooden sheets are collocated forming particular openings (Fig. 8).

Figure 8. Hygroskin Pavilion, Stuttgart

The millimeter precision with which these elements have been carved, thanks to a 3D laser printer robot, allows *Hygroskin* to react naturally to the change of external weather conditions: simulating the behavior of the scales of the pinecone, when it rains and the humidity increases, the openings close up on themselves; while during the sunny days when the internal temperature increases the thin wooden sheets contract, increasing the width of the openings (Menges et al. 2015).

3.5. The new frontier of parametric architecture for shading

The use of parametric modelling for design allows us to overcome geometric limits and obtain unique shapes and solutions. All thanks to data and parameters that, when modified, create infinite possibilities. New programming and coding languages, modelling and 3D printing, such as *Grasshopper by Rhino*, allow to faithfully reproduce the cellular functions and structures of organisms, as well as the systems of organization and evolutionary adaptation typical of natural habitats. This is the sector in which Biomimetic Architecture, a relatively young science that combines biology and technology, develops (Tedeschi, 2011; Oxman, 2017).

Since the era of industrialization, areas closely related to architecture, such as materials science, engineering and construction, have always been seen as separate disciplines in the logic of a rather linear design process. Current research in computational design reveals the potential of their integration and interconnection for the development of an architectural project, with particular attention to biomimetic and performance-based eco-friendly materials. The high degree of kinematic freedom that is obtained opens up the possibility of building complex, high-performance, single-material structural connections never made before. Buildings become envelopes and structures at the same time (Loonen, 2013; Alini, 2018).

3.5.1. Computational design, the innovation of digital manufacturing for biomimetic buildings

The first prototype of a wooden structure made by a robot in the world dates back to 2014. Thanks to the computational design it was possible to create, for the first time with the aid of a robot, a biomimetic wooden building. The shape of the shell resembles the skeleton of sea urchins, a modular organism composed of individual elements of connected calcium carbonate. Similarly, in the Landesgartenschau Exhibition hall 2014 pavilion designed at the University of Stuttgart (Fig. 9), this structure made up of thin multilayer beech plates is created. These sheets are interlocked with each other by means of jointing on the edges, with a precision never achieved before. Characteristics of materials, measurements and manufacturing principles are part of a simulation and optimization system in which shapes are drawn robotically. This is an interesting project for future development, because it shows the new opportunities that arise from the integration of design, simulation and numerical control manufacturing processes and resource efficient construction from local and renewable sources of the wood. To sum up, the innovation of digital manufacturing is characterized by speed of construction; very precise manufacturing; efficient and advanced detection methods; having a building shell and structure at the same time and striking visual effects inside and outside.

Figure 9. Landesgartenschau Exhibition hall, Stuttgart

3.5.2. Zaha Hadid's architectural and design visions: Al Janoub Stadium, Qatar.

With regard to the characteristics of permeability and porosity, typical of classical Mediterranean architecture, visions of the Zaha Hadid studio deserve a reference, because thanks to these "we were able to move away from closed forms and perimeter blocks to create a buildings and urban landscapes that are porous, accessible and welcoming" (www.zaha-hadid.com). The malleable nature of the architectural material is essential to be adapted to the context. All elements of architecture are becoming parametrically malleable and thus adaptive to each other and to the context (Bifulco, 2019; Peluso, 2019).

In the case of the Al Janoub Stadium (Fig. 10), thought for the World Cup to be held in Qatar in 2022, inaugurated in Al Wakrah in 2019, the Zaha Hadid Architects designed the building in conjunction with a new precinct so that it sits at the heart of an urban extension of the city, creating community-based activities in and around the stadium on non-event days (www.zaha-hadid.com). The shape is inspired by the sails of the traditional Arabian Dau boats, used by the pearl fishermen of the region. The curvilinear roof and exterior reference Al Wakrah's history of seafaring, In addition to giving spectators the feeling of being on a ship.

The entire structure is therefore designed to resemble the hulls of boats overturned and arranged almost at random to provide shade and shelter. Beams placed "in the bow" support the roof system. The main feature of the stadium is the possibility of completely closing the retractable roof with a tensile structure designed by Schlaich Bergermann Partner (sbp.de/en/project/al-janoub-stadium). The roof is made of fabric and PTFE pleated cables, with large arches reaching a length of 230 meters. According to the Supreme Committee for Delivery & Legacy (SC) of Qatar, detailed microclimatic analyses have shown that the shape of the arena, the aerodynamics and the optimal shading resulting from the roof structure, with a minimum amount of glass present, contribute significantly to control the temperature. A roof like this, which encompasses various functions, could be very useful in terms of energy and shading in Mediterranean climates.

Figure 10. Al Janoub Stadium, Qatar

4. Discussion and conclusions

Integrating photovoltaics into building facades in Italy is an interesting and complex challenge. The areas of the Mediterranean, attractive for the strong sunshine, are suitable for an energy issue in step with the times. The identification of integrated systems in the Mediterranean house, through the choice of innovative solutions, will make it possible to transform specific architectural components of the building envelope into energetically active components. In particular, solar screens are configured as a characterizing element of the tradition of Mediterranean living; fundamental response to the energy saving needs of a building, to guarantee shading, solar control and reduction of the thermal load of a building. The UNI 8290 standard for residential houses (www.store.uni.com/catalogo/uni-8290-2-1983) does not consider the shading component and, moreover, in the definition of Legislative Decree 311/2006 (www.camera.it/parlam/leggi/deleghe/testi/06311dl.htm) it is defined as a system applied to the outside of a transparent glass surface.

In Mediterranean architecture, the shading component interacts synergistically with the building envelope. Now, shading is not just the pergola or the garden, but it is often a device, a technique applied to the envelope. So why not consider it part of the envelope itself? If it were part of the transparent facade, it would contribute to the enhancement of thermal resistance; as part of the opaque envelope, it would instead contribute to insulation. On the one hand, we want to grasp the suggestions of tradition, identifying the new needs for an adaptation of the built and a better design of the new. On the other hand, we stimulate the research and cataloging of new materials on the market and characterizing national and international research in order to identify new services to meet contemporary needs.

Buildings built in warm climates are affected by severe overheating problems in summer, which negatively affects people's comfort and health. For these reasons, many users are forced to install cooling systems, leading to an increase in costs, consumption and a meaningful impact on the environment. The examples discussed show the desire to grasp the suggestions of tradition, in response to people's current needs for comfort and well-being. Research and experimentation on innovative materials are carried out starting from the analysis of best practices at national and international level, thanks to which performing performances have been identified, suitable to meet the contemporary needs of climate adaptation, energy efficiency and sustainability.

In Mediterranean architecture, shading systems are configured as a characterizing element of the tradition of Mediterranean houses where the shading component interacts synergistically with the building envelope. Now, usually the system is not just the pergola or the garden, but it is often a device, a structure connected to the design of the envelope. One consideration is that the components could be directly integrated into the enclosure. If, for example, the shading were part of the transparent façade, it would contribute to the enhancement of the thermal resistance. As part of the opaque envelope, it would instead contribute to insulation.

It represents a fundamental answer to the energy saving needs of a building where it guarantees shading, solar control and reduction of the thermal load of a building.

The results put in evidence that different solutions are considered in order to reach a high level of internal comfort in a building, ensuring the designer identifies the best choice of building materials that compose the envelope.

A shading element can also contain integrated photovoltaic elements. The integration of photovoltaic panels in the facades of buildings in Italy is an interesting and complex challenge. The areas of the Mediterranean, attractive due to the strong sunshine, lend themselves to an energy issue in step with the times. The identification of integrated systems in the Mediterranean housing, through the choice of innovative solutions, would make it possible to transform specific architectural components of the building envelope into energetically active components.

To sum up, the case studies serve to understand the potential development of multifunctional adaptive facades, stimulating and promoting the translation of multifunctionality of nature into architecture. Levels of biological organization can help transfer multiple functions into a single, multi-level hierarchical structure of an adaptive facade.

The aforementioned experiments on bio-adaptive structures offer important insights into the potential offered by technological innovation for sustainable protection in the Mediterranean buildings. Digital technologies can help to provide adequate solutions to the formal and technical complexity of protection systems, causing unprecedented changes also in the conservation process: process transformation, digital design (algorithmic, parametric and generative) based on performance, computational design, simulations with virtual and augmented reality, digital manufacturing and new construction methods, which contribute to a paradigm shift in architecture and a transformation of the contemporary practice (Terenzi, 2017; Tucci, 2017; Bilir Mahciek, 2018).

The reflection on some intervention strategies assumes a general character that goes beyond the examples discussed and can offer a register of useful guidelines for all designers, which once elaborated can be used in geographical contexts with similar climatic characteristics.

Innovative applications provide food for thought for an original reading of issues already current for some time on the agenda of those who govern the city and represent a stimulus for new insights on biomimetic-adaptive shelters to be implemented in Mediterranean areas. If the copious literature of the last decade promises a central role in the architecture of this millennium for biomimicry, it will increasingly have to characterize the design of shading or buildings envelopes in warm climates, thus stimulating the development of environmentally responsible, socially reactive structures and revolutionary, radical design solutions.

An important open question is that a successful facade project should meet several functional requirements and regulate multiple environmental factors. In nature, there is a wide range of organisms specializing in different functions. The translation of biological solutions into adaptive facades would benefit from billions of years of evolution.

Multifunctionality in nature is the integration of more than one function into a single system where a unified structure is able to control a variety of functions.

That is why current studies focus on monofunctional elements assembled into a single system, which is subsequently multifunctional. For instance, the components of a window are designed separately to meet different requirements, such as daylight and exterior view controlled by the properties of the glass, while glare and solar gain are controlled by shading. The facade can manage multiple aspects to meet the functional requirements of a building and protect the interior from environmental factors such as wind, precipitation, humidity, outside temperature and solar radiation. Finally, facade systems aim to meet a wide range of various functional requirements which are often contradictory. For example, obtaining optimal illuminance with minimum glare and having a high thermal accumulation with light and permeable structures.

Many considerations on the development of multifunctionality in facades, always thanks to the integration of the lessons learned from biological structures, can pave the way for further stimulating developments in research and experimentation.

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