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# Vertical Turf For Green FaÇades: a Vertical Greenery Modular System Integrated To the Building Envelope

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## ABSTRACT

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The research has identified a green modular system integrated into the building envelope, designed to facilitate installation and maintenance, with competitive performance compared to other existing solutions; a system that wants to improve performance and flexibility of vertical applications, experimented on buildings, on the market, and able to adapt, above all, to the needs of the building process. It is important to distinguish architectural aesthetic requirements from those of the building process; the former aim to have an authentic vertical garden, with different kinds of plants where nature dictates the rules, the latter aims to achieve the economic sustainability of vertical greenery systems.

This paper provides an analysis of a technique based on the installation of plant bearing modular panels with turf on substructures also provided with a micro-irrigation system, which allows the construction of a modular coating, characterized by reduced thickness, that can also be integrated with other materials; installation is quick and simple, since the panel comes perfectly planted on site. In addition to that it allows, from a botanical point of view, resorting to types of grass selected with a view to climate, exposure, environmental adaptability, color and shape. A comparative analysis of this green

façade is also presented compared to other existing case studies, from a constructive and managerial point of view, highlighting both its economic and architectural advantages.

**Keywords:** vertical greenery systems, building envelope, green walls, built environment, living walls, façades, building surfaces, ecological engineering



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# VERTICAL TURF FOR GREEN FAÇADES: A VERTICAL GREENERY MODULAR SYSTEM INTEGRATED TO THE BUILDING ENVELOPE

Giovanni Santi,[1] Angelo Bertolazzi,[2] Giorgio Croatto,[2] Umberto Turrini[2]

## ABSTRACT

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## KEYWORDS

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# 1. INTRODUCTION

The problem of energy reduction of buildings is one of the main issues both in new buildings and in the redevelopment of existing ones. According to data provided by the European Union, in fact, buildings are responsible for 40% of total energy consumption, of which about 70% is used to heat and cool indoor environments, with serious impact on the external environment, for example the UHI. As the rate of new construction will not increase significantly over the next 30 years, the greatest focus is on existing buildings, which represent more than 17% of the EU's primary energy-saving potential up to 2050 (Highfield & Gorse 2009; Carotti 2011). The priority of these issues was underlined both at European level,[3] and within the Roadmap for Europe Efficient[4] (EUR-lex 2017), and through the projects of FP8-H2020, within which a considerable part of the resources were allotted to Energy-efficient Buildings (EeB) and Nearly-zero Energy Buildings (NZEB) programs.

Due to the exploitation of non-renewable material resources, land use, energy consumption related to all phases of the life cycle of a building and the production of demolition waste materials, the construction sector is certainly one of the main protagonists of the environmental question. According to the 2017 report by Exxon Mobil, global energy demand is expected to increase by 20% up to 2040, due to the increase in population and increasing standards of comfort (Exxon Mobil 2017).

The building envelope assumes the role of a connector element between the internal and external environment, able to respond appropriately to climatic and environmental stresses (Brookes & Grech 1990; Brookes & Meijs 2008; Lovell 2010; Hachem-Vermette 2018). This role can be achieved thanks to the geographical location of a building or by using multiple materials with different features that are purposely tailored. In terms of realization of construction, form and technique, can assume different values in the panorama of architectural production and housing, the building envelope sometimes becomes the symbol of the quest for transparency and lightness; sometimes its role is to look like a plastic mass before being invaded and seized by nature.

Abandoning the transparency myth commonly associated with high-tech, in favour of the discreet opacity of a green façade, it is possible to follow a sustainable path for the construction of new buildings and for the redevelopment of existing ones, in order to reduce the demand for energy of cooling systems, mitigate the UHI and improve the thermal energy performance of buildings. In this context, new building techniques based on the use of green material and recent experiences in the field of vertical greening systems integrated into the building envelope, where the natural elements become a new project material, successfully contribute to achieving these goals by connecting to the building through an innovative support system and a system power supply (Bellomo 2003; Blanc 2006; Blanc 2008; Buchanan 1991; Cook 2007; Dunnett & Kingsbury 2004; Serafy 2006; Tong 2013; Van Uffelen 2011; Van Uffelen 2017).

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3. The main directives at European level are: Directive 2009/28 / EC—RES (Renewable Energy Sources) on the promotion of the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77 / EC and 2003/30. Directive 2010/31 / EC—Recast EPBD (Energy Performance Building Directive) on energy performance in buildings (recast). Replaces the Directive 2002/91 / CE of 16 December 2002—EPBD (Energy Performance Building Directive). Recommendation (EU) 2016/1318 laying down guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all newly constructed buildings are almost zero-energy consumptions.

4. In relation to the H2020 objectives, as regards the building sector, the European Union has identified, the need to: build zero-consumption buildings and increase the renovation rate of existing buildings; avoid further land occupation (eg for uncontrolled urban sprawl), avoid uncontrolled urban growth on fertile soils; recycle construction and demolition waste (70% up to 2020).

Within this framework, successful contributions were provided by new building techniques such as the use of green material in new buildings and recent experiences in the field of vertical greening systems integrated to the building envelope, where natural elements become a new material project attached to the building through an innovative system of support and system power plant. The aim of this research is to study a new green vertical construction system, compared to similar ones on the market, verifying its compliance with design, durability, and maintenance requirements. The latter considerably important point is still under experimentation and subject to constant change, with considerable scope for improvement and application performance. Within a framework in which research and requirements of the lowest power and maximum efficiency of the skin of buildings, not only must comply with laws and provisions,[5] but also take into account better knowledge about the environment, ecological respect and economic saving. There are several studies that have developed the theories of vertical green systems from the point of view of thermal (Alexandri & Jones 2008; Kontoleon & Eumorfopoulou 2010; Cheng et al. 2010; Wong et al. 2010; Pérez et al. 2011; Koyama et al. 2013; Mazzali et al. 2013; Cameron et al. 2014; Hunter et al. 2014; Coma et al. 2017; Paschoalino de Jesus et al. 2017), acoustic (Wong et al. 2010) and ecological (Marc Ottelé et al. 2010; Prodanovic et al. 2017; Collins et al. 2017) evaluation; however, from the point of view of the ability to respond to the needs of the construction process, such as simple installation and maintenance, transport and optimization of the cost-benefit ratio (Perini & Rosasco 2013), research needs further development and there are no guidelines dedicated to the construction of vertical green cladding available to designers, especially regarding the choice of the most suitable system.

This paper investigates a modular cladding system for façades that includes the installation of modular panels, covered with grassy turf, and fixed on on-site substructures, equipped with a micro-irrigation system, thanks to which it is possible to create a "natural" fitting façade. This system is able to change its behavior in real time, thanks to the natural properties of plants, an alternative to recent adaptive façades, able to increase the capacity of the building envelope in terms of environmental sustainability such as: mitigation of the effects of UHI, reduction of urban fine dust, increase of the building energy performance, and positive psychological effects on people. At the same time great attention was paid to the architectural aspects of the green façade and its potential in the formal redevelopment of the building through the use of herbaceous species selected with a view to climate, exposure, environmental adaptability, color and shape.

## 2. MATERIALS AND METHODS

### *2.1 The green wall in building construction: technologies and performance*

Resorting to green façades within urban areas provides benefits in environmental terms and can be considered on most buildings; this is certainly important if we take into consideration the high density of buildings in contemporary cities—66% of the world population will be living in cities by 2050 (United Nations 2015)—and the relative greater availability of vertical surfaces than horizontal ones. The latter tends to decrease as we move away from the suburbs, so that the availability of land free of exploitation lies, undoubtedly, on vertical surfaces.

5. Compare for example the UNI EN 15251:2008 "Criteria for designing the internal environment and to evaluate the energy performance of buildings in relation to indoor air quality, environmental temperature, lighting and acoustics," or the Italian national legislation D.M. 192/05, D.M. 311/06 and D.M. 06/26/2009.

In this respect, the "green skin" can become an instrument of microclimatic and environmental control, as well as a material for the building envelope to be used for commercial advertising applications or to communicate messages, but also as a source of oxygen and other environmental benefits.

Studies currently underway have pointed out that green walls have beneficial effects on heating phenomena especially in urban canyons, where temperature can be subject to a 10 °C decrease from 30 °C even in extreme situations (Alexandri & Jones 2008; Kontoleon & Eumorfopoulou 2010; Cheng et al. 2010; Wong et al. 2010; Pérez et al. 2011; Koyama et al. 2013; Cameron et al. 2014; Hunter et al. 2014; Coma et al. 2017; Paschoalino de Jesus et al. 2017) (Figure 1). These positive outcomes in terms of thermoregulation and oxygen production are due to solar radiation. In particular, we should work on the effect of phototropism—the foliage follows the sun sloping—and guidelines for optimizing the radiation absorbed and the phenomenon of evapotranspiration and photosynthesis reckoning the high $CO_2$ absorption capacity of a turfgrass in a year (Monteiro 2017).

The main types of green walls can be identified according to (Bellomo 2003; Bonato 2007):

1. the positioning in relation to the building (as a division between two non-confined spaces, or as a division between a confined space and the outside);
2. the type of support of the plant species ("natural" anchorage, produced by the plant, or anchorage by means of a support structure which in turn is anchored to the building system);
3. distribution and extension of the mantle (percentage and type of area covered);
4. growth (from bottom to top—climbing species—or from top to bottom—hanging down species);
5. depending on the planting (whether in the ground or in pots);

**FIGURE 1.** Shanghai World Exposition 2010, Green Living Wall for Theme Pavillion.

In particular, the systems available today are classified according to points 1, 2 and 5. Within the category of vertical greenery systems integrated into the building envelope, from the point of view of the relation with the outside, they are mainly divided into external/external separation, defined as "plant screens" or "green façades" and consisting of loggias and balconies, and non-habitable elements of separation between inside/outside, defined as "green walls" and consisting of green elements with substrates with reduced thickness, with placed in pots, the ground or the hydroponic wall. The latter type is currently undergoing developments and improvements, in particular with respect to irrigation and maintenance systems (Santi 2016).

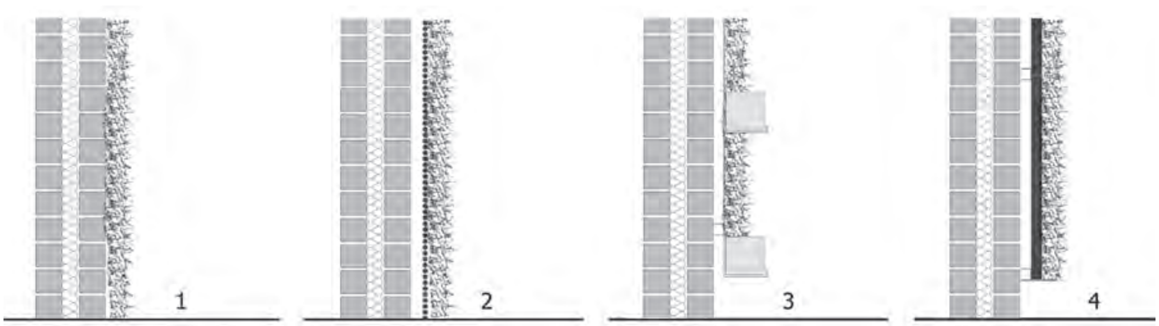
As regards support, the systems are divided into (Figure 2):

- direct façades, where the plant is grown directly along the external wall of the building;
- indirect façades, where the plant is grown on a support structure made of plastic or metal;
- façades with planters, where the plants are grown in containers placed at different heights, with integrated irrigation and nourishment systems;
- façades with panels, where the plants are distributed on layers of soil arranged regularly on the panel itself, with integrated irrigation and nourishment systems.

The choice of the type of green façade depends on the analysis of different factors:

- the morphological conformation of the building organism and the geometric complexity of the façade;
- the height of the building;
- the physical and mechanical characteristics of the façade;
- the manner of transpiration of the envelope;
- the type of plant and method of bracketing the species to the masonry support or to any additional support;
- the time the species is positioned in relation to the surface to be covered, which must be evaluated according to the energy performance to be achieved.

**FIGURE 2.** 1) Direct green façade, the plants grow rooted on the ground directly along the outer wall of the building. 2) Indirect green façade, consisting of a support structure in plastic or metal where the plant, rooted on the ground, rests and develops covering the façade. 3) Green facade with planters, composed of containers placed at different heights of the façade, where plant species are planted that are fed and watered thanks to an irrigation system integrated into the system. 4) Living wall with panels, is composed of layers of soil in which the plants are placed fertilized by a special irrigation pipe.



The standard UNI 11235: 2015 "Instructions for Design, Execution, Control, and Maintenance of green roofs," replaces the previous UNI 11235: 2007, defining the design, execution, and control criteria and maintenance about green roofs, depending on the particular climatic, construction and employment contexts; meanwhile, in Italy there is no legislation for vertical greenery systems (green façades and living walls) except for various technical specifications. It is also very interesting to compare green living walls with the current legislation in terms of requirements and benefits of curtain wall for the building envelope, UNI EN 13830:2015, and with the required class, requirements classes and requirements defined by UNI 8289:1981 (safety, welfare humidity, heat resistance, air cleanliness, sound insulation, look, feel, durability, ability to support suspended loads, safety during operation, energy saving). The list of requirements for each class that meets all the technical elements is articulated, referring to the phases of operation, production and installation and management; green living walls, applied to the building envelope, should therefore be compatible with these requirements and performance of traditional vertical side walls. Vegetated walls integrated to building envelope, may be substantially comparable to curtain walls, and they can be readily assembled leaving a space between them and the underlying structure. The vestments surface plants are characterized by a modular system with a dry-assembled supporting structure that consists of:

- continuous elements made of felts and geotextiles on which plants grow and placed on PVC panels, or discontinuous elements, namely modular prefabricated containers for the planting of greenery;
- substructure produced by metal uprights connected to the underlying structure of systems with point-fixing of chemical/mechanical elements sized according to an analysis of the loads;
- element container connecting system to the substructure;
- irrigation system consists of a series of dripping wings that allow the distribution of water.

These key elements can become sustainable features in terms of recycling, material recycling and the irrigation system becoming compatible with the needs of the system.

Companies currently on the market use different technologies but essentially conform to the previous list, so a comparison regarding the container element, the plant material base, substrate feeding and fastening systems to the structure is feasible.

The first type, a continuous one, is the hydroponic system, "Le Mur Végétal" by Patric Blanc (Figure 3) for the Musée du Quai Branly designed by Jean Nouvel (1999–2006), consisting of a set of supporting elements, two felts of reinforced polyamide, and in-between pipes for irrigation, a polypropylene geotextile, the PVC foam support panels which are fixed to a metal frame. One of the major advantages is the ability to use an extremely large diversity of plants and it is light-weight; on the other hand, the most important disadvantage is that it is a not modular system.

In the case of discontinuous elements—second type—modules are real boards with cavities for the accommodation of individual plants, or containers made of galvanized steel-cage. The first model can be in the polypropylene or high density polyethylene—even recycled—modular boxes, each one from 6 cm up to 8 cm thick. The second model, can be a modular structure with metal cage type *greenbox* with a medium containing function of the plant for plant growth. These systems are around 20 cm thick and have considerable weight of about 45 kg/sqm.

**FIGURE 3.** The Musée du Quai Branly, in Paris (Project by Jean Nouvel, 2004) is covered by 800 sqm of vertical green. Nutrients for plants are primarily distributed through an irrigation system that cycles water from the top of the system. The continuous flow of water causes extensive wet parts even on the spaces below; for this reason it is necessary to place a water collection grid at the base of the façade. Detail of two felts of reinforced polyamide, containing pipes in the middle for irrigation, a polypropylene geotextile, and the PVC foam that support panels which are fixed to a metal frame is shown.

This type of discontinuous element has been used in important buildings by authoritative designers, in all Jean Nouvel's, in Paris in the Musée du Quai Branly and in Sydney in The Central Park Display Pavillion, or Herzog & De Meuron with the Caixa Forum in Madrid, and large-scale works such as in major cities such as Singapore, notably the Tree House Tower, and Hong Kong with many companies producing green technological systems.

For the development of this system, the main systems of living walls have been studied:

a. "Le Mur Vègètal®" by Patric Blanc composed of three parts: a PVC layer, one of felt and a wire mesh, a self-supporting system, without soil, which can also be hanging down. The plants grow according to the principles of hydroponics, on a mantle of polyamide felt supported by a PVC and metal framework within which flows water enriched with fertilizers.
b. Systems characterized by low-density modular container elements such as:
    - the Canadian "G-Sky®" (green wall panels) with 30 × 30 cm and 10 cm thick stainless-steel container panels, where the culture substrate and a drip irrigation pipe are

arranged, providing housing for 13–25 plants. The plant species used are mainly decorative foliage shrubs (euonymus celastraceae jap.albomarginatus used for hedges or fencing elements) and ground cover plants (hedera or gaultheria procumbens). The plant system is therefore similar to hedge plants placed vertically in container modules. The panels are then fixed by means of a supporting metal substructure through rails on which they can slide. The system maintenance and inspection program is very frequent in the first year of installation (up to 17 inspections a year). The system is guaranteed by a one-year contract. The system is not very flexible; it is not possible to subdivide the panels and fixing is provided only through the rails on which the panels slide.

- The Canadian "ELT Easy Green®" (Elevated Landscape Technologies) is a system characterized by a modular pre-vegetative panel anchored to a substructure. The panel, in HDPE (high density polyethylene), is made up of 45 cells, not communicating with each other, which host the culture substrate and the plants. They are 50 × 64 cm and 5 cm thick. The panel provides accommodation for punctual fixation but is seldom divided into submodules. It is suitable for the dense planting of different plants, due to the high number of cells, and this entails more demanding maintenance of the plant system.

The main difference between the two systems is the type of containers for plants, a felt mantle for the system, or the use of modular containers, equipped with more cells for housing, for systems. The evaluation of the weight of the system is of considerable importance concerning the dimensioning of the bracketing to the supporting structures behind, and this varies depending on the species used, the thickness of the nutrient substrate for the plants, and the degree of hydration of the system. The study focused on the two systems with regard to the use of modular elements (panels) of different sizes and thicknesses that are difficult to divide into sub-modules, a necessary condition for guaranteeing the system's technological flexibility; also important is the presence of a different number of cells inside the panels that allows a lower or higher density of allocated plants (Table 1).The current state of the art does not show, to date, a well-defined assessment of maintenance costs, as these vary according to the specific

**TABLE 1.** Summary comparison of the analyzed systems.

| System | Thickness | Weight Plant component and maximum saturation support | Dimensions panel | Numbers of cells panel | Numbers of plants |
|---|---|---|---|---|---|
| Le Mur Vègètal | 50 mm total | 15 kg/sqm | — | — | variable |
| G-Sky® | 89 mm panel | 13 kg one panel<br>117 kg/sqm | 300 × 300 mm | 12 | 9/13 up to 25 |
| ELT Easy Green® | 50 mm panel | variable | 500 × 640 mm | 45 | variable |

project. The necessary maintenance can be subdivided, substantially, into ordinary and extraordinary depending on whether it is constantly required during the useful life of the system or if it is required due to unexpected events. Overall, the greenery system is the most challenging to manage because it is linked to the vagaries of a living entity unlike the inorganic technological system, and the burden of care increases as the variety and types of plants vary.

- The ordinary maintenance related to the plants involves the control of the vegetal layer and the substrate, including the correct working maintenance that includes: irrigation, nourishment, and possible pruning.
- Extraordinary maintenance tends to block the phenomena of external aggression through phytosanitary actions and interventions to fend off parasitic attacks of weeds, up to the substitution of deceased plants.

### 2.2 Vertical turf system analysis

The critical analysis of some vertical green systems on the market showed that:

- systems that resort to modular panels guarantee the technological flexibility required by construction requirements;
- need for reduced thickness of the façade system;
- modular panels must be able to be subdivided into sub-modules to ensure better adaptability to the dimensions of the façade to be covered;
- the need to have a uniform plant material to contain maintenance operations, reducing the ongoing running costs;
- the uniformity of the plant material can also guarantee the fulfillment of the aesthetic design requirements if compared with those of a non-organic material (the same chromaticity of a metal, stone, plaster, etc.)

An application of vertical green living walls is the turf used in the building envelope. The research has identified a constructive system capable of responding not only to the energy performance requirements, but also to precise assembly, management and maintenance needs. The research also led to the creation of a prototype that allows monitoring the performance of the façade and the management aspects of the system.[6]

The idea behind the proposed system was that of a turf, not a garden as in the case of "Le Mur Vègètal," with its architectural, aesthetic, botanical and ecological adaptability to the extreme world of architecture and compatible with the building and the requirements of the site and maintenance. This technique, in fact, allows the realization of a coating, including curtain walls, characterized by reduced thickness, integration with other materials, speedy and simple installation—the panel arrives on site fully-turfed—and modular, in botanical terms it allows

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6. The system is called the *6th Point. The vertical turf* is the result of the *Tecology* concept, conceived in 2006 by the architects Giovanni Santi (Department of Civil Engineering, University of Pisa) and Marco Giambi. For the development and implementation of the idea the Pacini Ortovivaistica Company (leader in the production of turf) and prof. Marco Volterrani (CeRTES Sports Grassland Research Center, University of Pisa). The system is covered by an international patent «n°PCT/IB2008/001323», inventors M. Volterrani, M. Pacini, G. Santi, M. Giambi. The *Tecology* concept *System 6th point, the vertical turf* was selected by the technical jury, led by the commissioner general of the Italian Government Beniamino Quintieri, in March 2010, for the exhibition *Italy of Innovators* by the Italian Government, Ministry for Public Administration and Innovation, for the 2010 Shanghai EXPO with the theme *Better City, Better Life*. The uniqueness and innovation of the System has been widely reported and documented both in the press conference for the presentation of the event, by the Minister for Public Administration and Innovation Hon. Renato Brunetta, and in national newspapers and sitography.

**FIGURE 4.** Installation of vertical turf with different species of grass.

the use of selected types of grass according to climate, exposure, environmental adaptability, color and shape (Figure 4).

\The constituent elements of the system are:

1. the cladding panel, a standard bee-hive element 600 × 400 mm by 60mm thick, where the biowaste material—grass type *erbavogliosystem*®[7] is housed using macro and micro thermal species—in recycled polypropylene (type Estaprop® mod. H1040TG, a homopolymer at 20% mineral filler with excellent physical and mechanical characteristics) with empty weight 2,6 kg, and stable to UV sun rays; this is modular and dividable into sub modules. Housing the horizontal irrigation pipeline, the panel with drainage and conforming function provides connections to the metal structure on the wall behind. In the front part, housing for lining materials or hinges, even of a minimum thickness,

7. Patent n° WO 2006/067557–PCT/IB2005/003000, "Method for making a turf."

can be inserted for fitting façade openings. The weight of the single panel with turf and maximum degree of humidity is about 8,5/10 kg. A finite element analysis has been conducted to verify mechanical and thermal stress of the single panel, especially where it is fixed. The panels can be transported in carts or pallets (cart size 1400 × 550 × 2200 mm, weight 40 kg, maximum load 20 modules in 10 shelves, full load weight 240 kg–200 kg + panel weight. Pallet 1 dimensions are 1200 × 800 mm., maximum load 70 stacked modules, full load 700 kg. + panel weight. Pallet 2 dimensions are 1200 × 800 mm., maximum load 40 modules stacked with spacers, full weight load 400 kg. + panel weight). These dimensions are very important for the management of the building construction site (Figures 5–6);

**FIGURE 5.** Above: the executive drawings of the turf containment panel, front, back and ribs. Below: the panel is modular and therefore easily sectioned according to construction requirements. Drawing of a typical façade with the main points of discontinuity and location of the sub-panels of the panels.

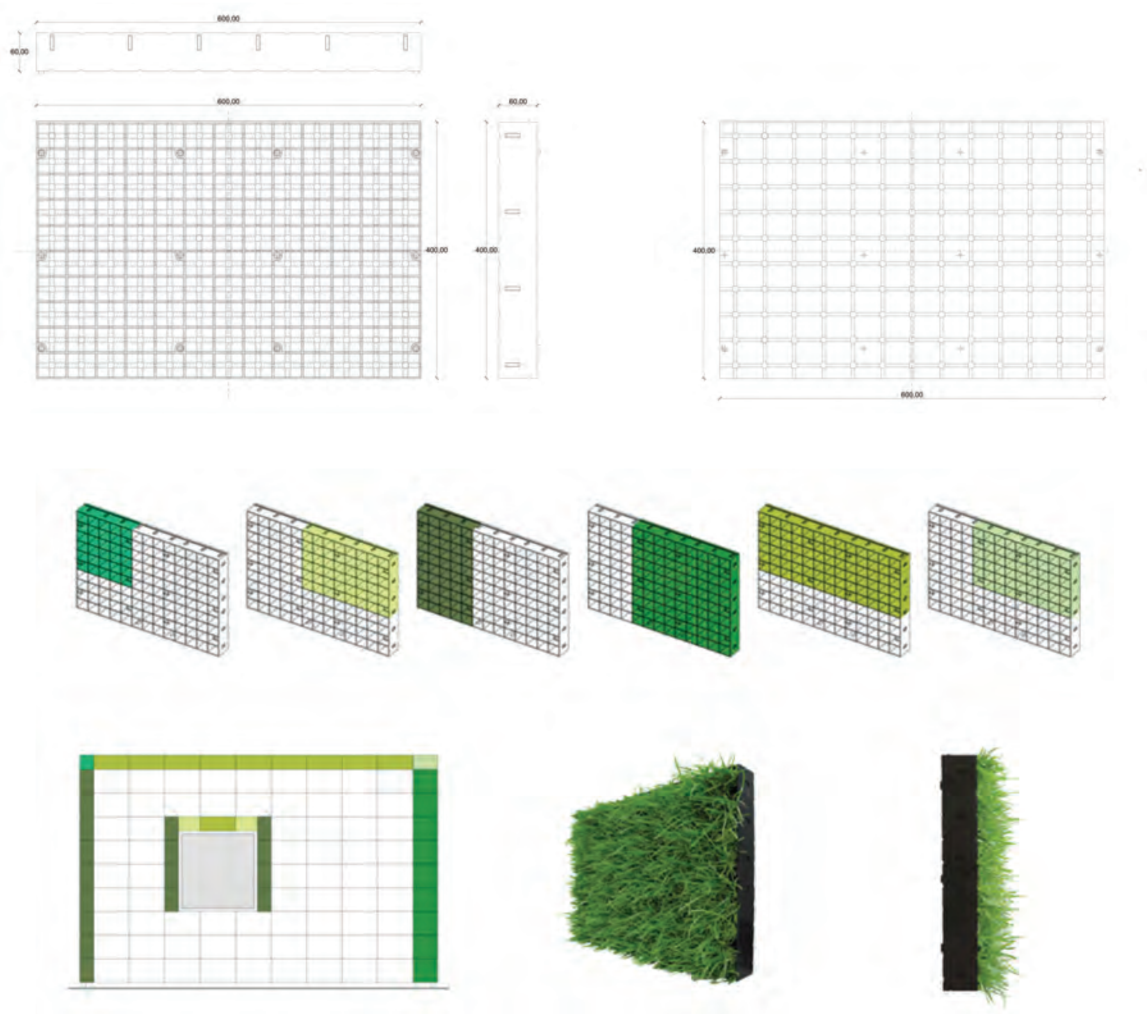
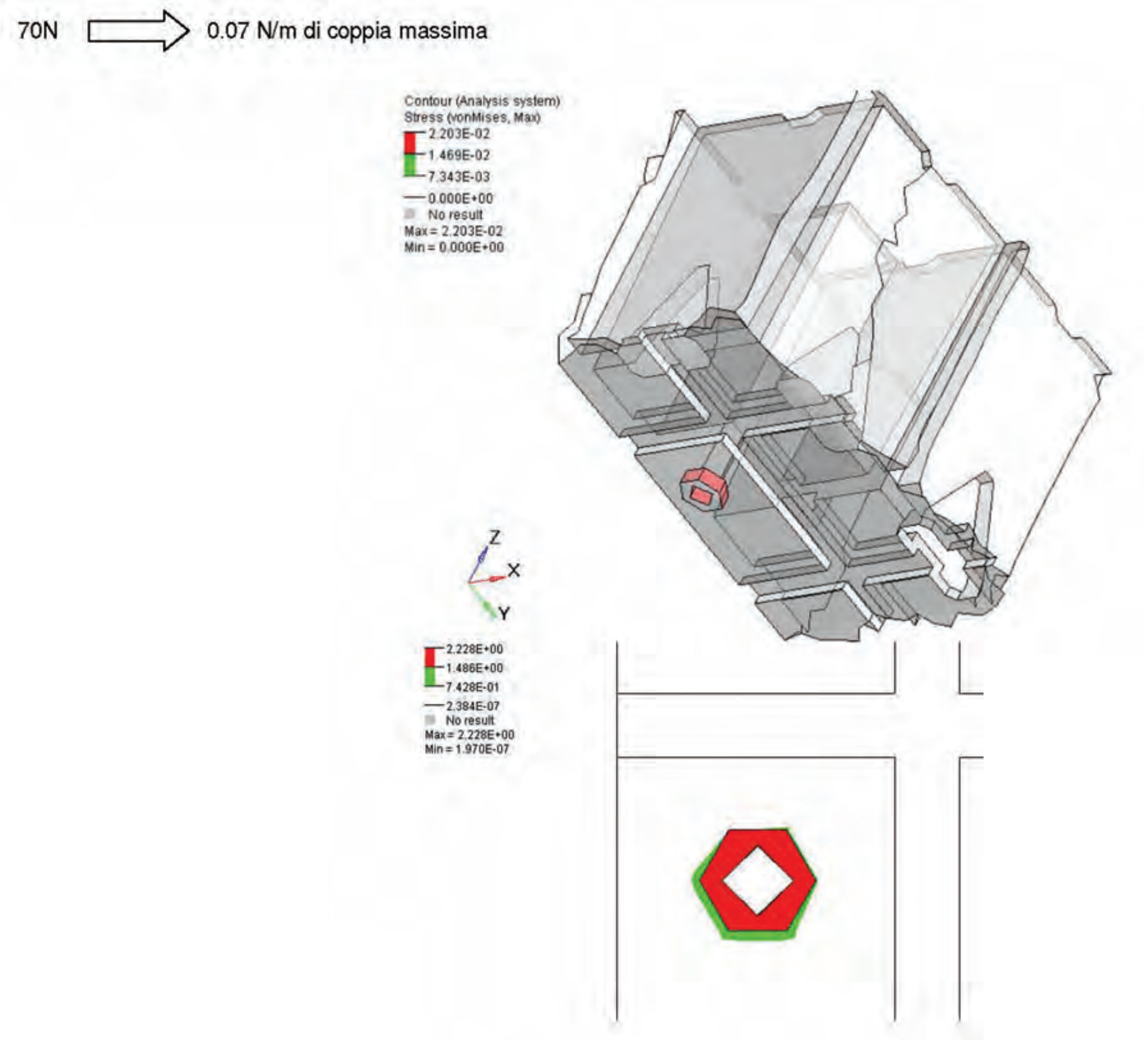


FIGURE 6. The calculation model of the panel, based on the finite element theory (FE), has been studied, starting from the geometric data, using elements of the solid type at 10 nodes with isoparametric formulation. In the figure, the area most stressed by the single fixing point is identified. There is a verification of the maximum tightening torque of the fixing screws with a max applicable load 70N–0.07 N / m of maximum torque.




2. the substructure, of bracketing to the wall, is constituted of aluminum elements, which guarantees lightness, low thermal transmittance, and quick installation facilitated by the settings of the sliding fixings providing for compensation of thermal expansion. Specifically, the cladding panels are fixed to vertical aluminum profiles "T" 20/10 and "L" 30/10 with longitudinal streaks to reduce thermal bridges and the formation of zones of weather moisture. Mounting the posts on the facade is done through aluminum brackets with a clamp bracket clip that allows quick and easy setup components. Between the bracket and the building wall are placed special plates and clips in polypropylene, thermostop, to avoid any future problems linked to thermal bridges. The

final fixing of the profiles to the brackets is done by means of stainless steel self-primer screws for metal, of brackets to the supporting structure, made in the same material; varying according to the material. Finally, the panels are fixed to the substructure by perforated steel 4,8 × 45 mm auto screws, in austenic and pointed steel carbon, hex head with integrated washer (Figures 7–11);

**FIGURE 7.** Plan detail of the fastening of the vegetated panel to the metal substructure and to the rear wall with the angular connector, to another panel, obtained by inserting special polypropylene clips for the connection of the tinsmiths.

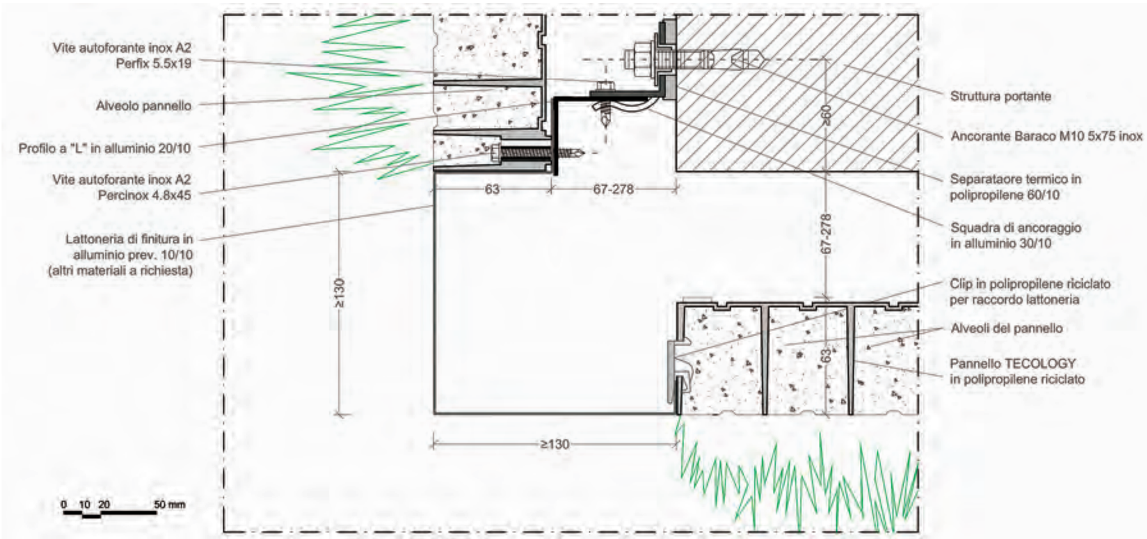



**FIGURE 8.** Detail of the fixing points of the panels.

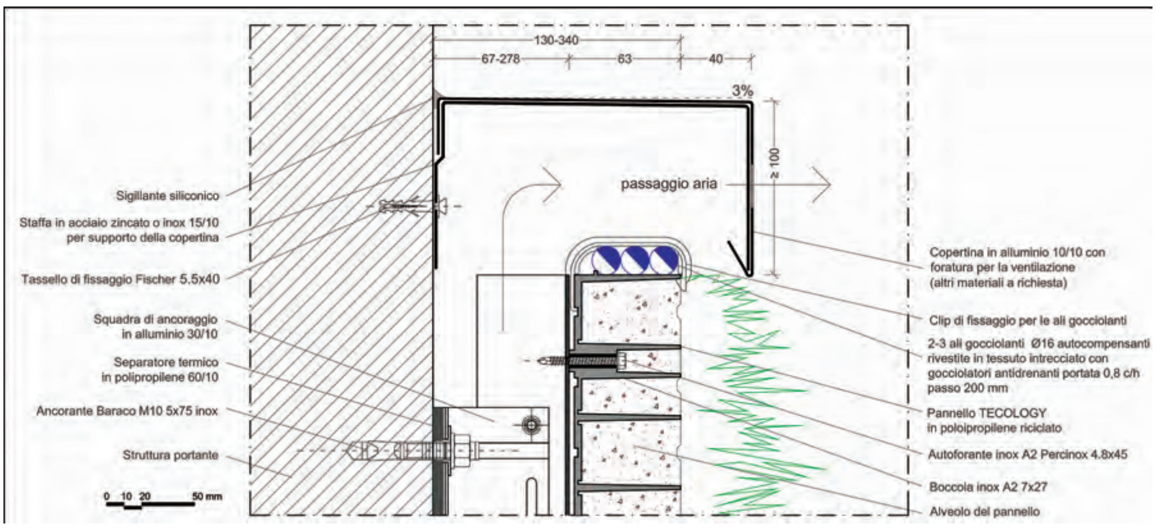
**FIGURE 9.** Completion of the façade system: the panel is mounted on the "T" uprights, which in turn are fixed to the wall clips.

**FIGURE 10.** The finished façade cladding, depending on the size of the air chamber behind it, is about 130 mm thick.

**FIGURE 11.** Wall installation with vertical turf with its irrigation and fertilization system integrated into the façade system.

3. the irrigation system is integrated with automated-systems fertilization, ensuring optimum water supply enriched with the nutritional elements needed for the health of the plants. The system consists of a series of drips that guarantee homogeneous distribution of water, allowing a constant flow, being, in addition, self-cleaning, self-compensating and anti-draining. The brain of the irrigation system is an electronic automatic programmer that regulates the frequency and quantity of the water supply calculated, by controlling both solenoid valves and humidity sensors pumps housed inside the tank (Figure 12).

**FIGURE 12.** Creation of turf envelope on existing wall subject to experimentation.



The wall system planned as bearing vegetated panels provides that a dripping wing should distribute water starting from the top of the wall, and thanks to gravity, it guarantees the right water supply to the underlying panels. Over 5 metre-high walls need several independent irrigation lines to preserve a humidity level that is never limiting for plants and roots in the growth substrate. The growth substrate has a capacity of water storage that can meet the needs of plants for longer or shorter time periods, depending on water consumption caused by environmental conditions: sunny days and suckers require higher water consumption and frequent irrigation may be necessary. By periodically cutting grass, it is possible to curb its length especially in the period of increased growth, or with species that grow more vigorously. One aspect to consider is that, depending on species and climate, grass growth might be a few cm per month.

The thermal benefits verified through measurements carried out on different greening systems with different plant species—tropical, ground cover, perennial herbaceous plants—(Alexandri & Jones 2008; Kontoleon & Eumorfopoulou 2010; Cheng et al. 2010; Wong et al. 2010; Pérez et al. 2011; Koyama et al. 2013; Cameron et al. 2014; Hunter et al. 2014; Coma et al. 2017; Paschoalino de Jesus et al. 2017) show how systems with vegetated modules with an average plant thickness of about 12 cm are more performing. The turfgrass characterized by the use of macrotherms, species suitable for warm or temperate climates, has an optimal growth temperature between 25 and 30 °C and during the spring-summer period there is maximum vegetative activity. These species slow down growth at temperatures below 20 °C, until a complete growth arrest occurs at about 10 °C, conditions in which, if the growth of the plant organs is excluded, the turf preserves its aesthetic characteristics almost unchanged. When the temperature drops below 0 °C, the leaves lose their green color and the plants stop their living functions which causes the turf to look like a dry surface; a condition that lasts, depending on the species, from three to four months in the coldest season, and like in many tree species, the green and vital aspect is restored with the arrival of spring. In

**TABLE 2.** The annual frequency of the irrigation, fertilization and cutting treatments that affect the system.

| | J | F | M | A | M | J | J | A | S | O | N | D | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MICROTHERM | occasional | occasional | 1-2 times a week | 1-2 times a week | every 1-2 days | every 1-2 days | every 1-2 days | every 1-2 days | 1-2 times a week | 1-2 times a week | occasional | occasional | irrigation |
| MACROTHERM | occasional | occasional | occasional | 1-2 times a week | every 1-2 days | every 1-2 days | every 1-2 days | every 1-2 days | 1-2 times a week | occasional | occasional | occasional | |
| MICROTHERM | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | fertilization |
| MACROTHERM | not necessary | not necessary | not necessary | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | ~ 1/month | not necessary | not necessary | not necessary | |
| MICROTHERM | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | pruning |
| MACROTHERM | no cuts | no cuts | no cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | potential cuts | no cuts | no cuts | no cuts | |

Legend:

every 1-2 days | 1-2 times a week | occasional

~ 1/month | not necessary

potential cuts | no cuts

the following table (Table 2), it is possible to make a comparison, depending on the herbaceous species used, on the annual frequency of the main necessary maintenance treatments that affect the system, namely irrigation, fertilization, cutting; it is evident that the macrotherm species, which are well suited to the growth in the cells of the modular panels, need less care, especially in the warmer months in hot-temperate climates, for example in Italy.

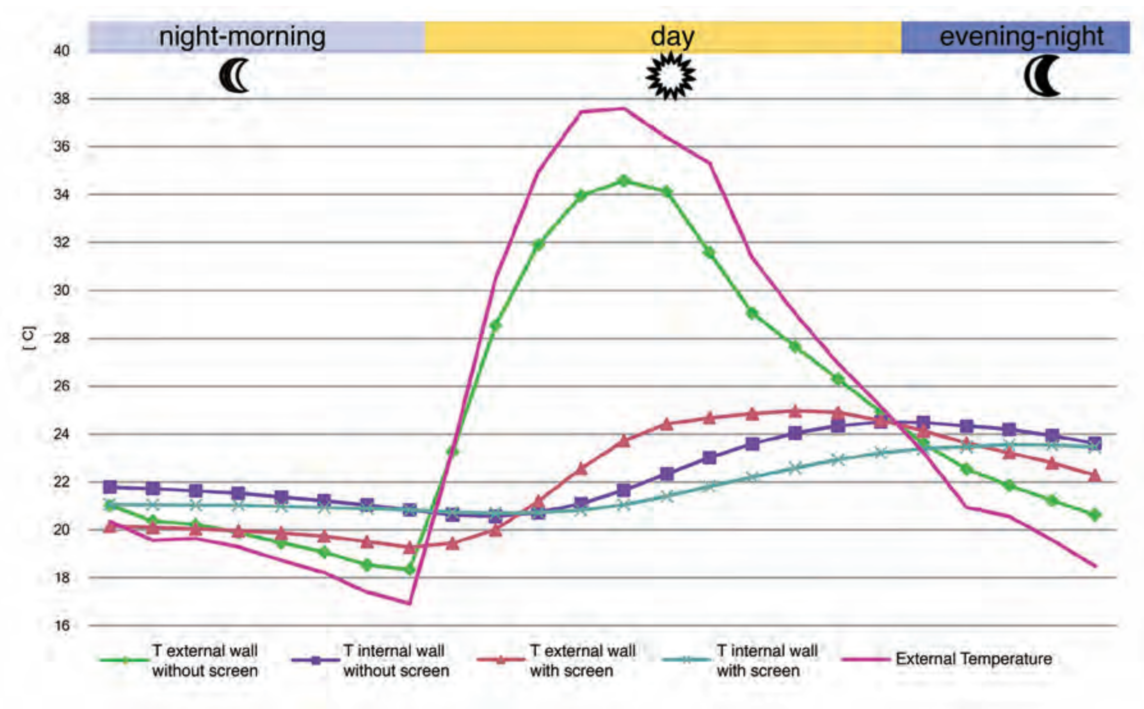
About system thermal performance, during research on a wall of the study composed of the system described above and placed on a non-insulated wall structure, it was possible to collect extremely useful information for evaluating the potential of the system.

Screen-less walls are most affected by solar radiation and during the night it has been noticed that the green wall tends to keep its external surface temperatures higher than those of non-screened walls (the green layer prevents the back wall from giving off the heat stored during the day at night while maintaining high temperature). Essentially, it showed how the system will reduce green surface temperatures of a façade by about 10 °C. Especially on days with strong solar radiation, while in the less sunny and cooler days, the system ensures good insulation while maintaining higher temperatures by about 2.5 °C above the bare wall (Mazzali et al. 2013) (Figure 13).

The environmental climatic benefits of the analyzed system vary according to many factors: the plani-volumetric conformation of the building or of the structure behind it, the size and the material of the panels that contain the substrate and the plants, the type of substrate and plants housed.

The choice of plants was one of the primary elements. Nevertheless, the requirements of the architectural project must be taken into account and therefore both the building and

**FIGURE 13.** Diagram of surface temperatures recorded on the hottest day of the experimentation.



agronomic needs must be respected; it will also be verified that the drying, growing, sprouting or non-uniform growths do not come into conflict with the designer's expectations. In this context, a prior consideration of the maintenance aspects of the entire system is required, linked both to the irrigation system and to the agronomic plant that are sized according to the project.

## 3. RESULTS

The experimentation results are reported in (Tables 3–4). For all the vertical green systems on the market today the most delicate aspects are undoubtedly those related to their maintenance and management, limited to the plant component, plant engineering related to the irrigation system and fertilization with phytosanitary treatments and cutting. The façades bearing modular panels have a high plant cost compared to those with climbing green or with green in pots, but they guarantee greater performance in terms of energy-saving and noise reduction, thus with considerable economic returns on the energy consumption of the building since they can be assimilated to advanced technological systems with ventilated façades. The system proposed, unlike the other similar ones, denotes greater technological flexibility and is therefore capable of responding better to the needs of the project thanks to the use of a modular panels, even divided into submodules, which arrive on site already vegetated with plant material, turf, and therefore guarantees full uniformity of coating (Figure 14).

One key aspect of the studied system is the modularity of the housing panel of the plant part that ensures the system is technological flexible which may be difficult to find in other greenwalls systems; another positive aspect is the presence of communicating cells that promote the growth of the root system of plants. Finally, a particular conformation of the panel, which makes it easily mountable, transportable and able to integrate with other building materials is important. All these features create a continuous envelope with high performance capacities that naturally interacts with the environment, and renders it as an important passive system for the exploitation of solar energy, an adaptive capacity both in new buildings and retrofit works. Other aspects to consider are of the architectural and maintenance nature. The use of turf for

**FIGURE 14.** Evaluation framework of benefits and costs related to the types of green walls analyzed.

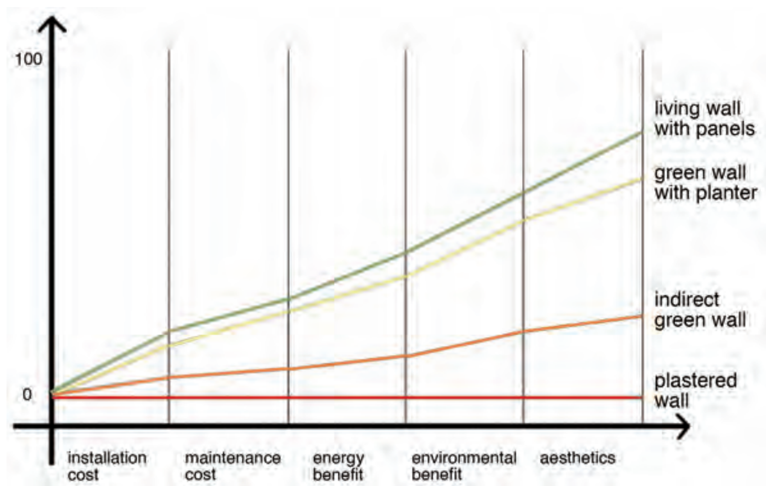


**TABLE 3.** Cost analysis according to energy saving.

| Cost/Benefit | Direct green wall [€/sqm/year] | Indirect green wall [€/sqm/year] | Green façade with planters [€/sqm/year] | Green façade with panels [€/sqm/year] |
|---|---|---|---|---|
| Energy saving, heating | 7.43 | 7.43 | 6.25 | 17.60 |
| Energy saving, air conditioning | 1156 | 1156 | 973 | 1851 |

**TABLE 4.** Cost of construction and maintenance of green facades.

| Green system | Type of costs | Costs €/sqm |
|---|---|---|
| Direct green wall | Installation: planting, soil preparation. | 30/40 |
| | Maintenance: pruning (annual). | 3 |
| Indirect green wall | Installation: installation of plants and support structure, soil preparation. | from 40 to 75 depending on the material used |
| | Maintenance: pruning (annual). | 3 |
| Green façade with planters | Installation: installation of plants, containers and supporting structure, irrigation system. | from 100/150 to 800 depending on the materials used |
| | Maintenance: pruning, irrigation, replacement of pipes and plants if necessary (annual). | 10 |
| Green façade with panels | Installation: installation of plants, panels and supporting structure, irrigation system. | from 400 to 1200 depending on the material used |
| | Maintenance: pruning and cleaning of panels, irrigation, replacement of pipes and panels if necessary (annual). | 25 |

homogeneous surfaces similar to a non-organic material yet different from other greenwalls with different plant materials that do not allow this. From a maintenance perspective, the chosen plant material, the turf, requires less future maintenance than other greenwalls vegetation, with the possibility of replacing any damaged turf portion in a more quick and cheap way.

## 4. CONCLUSIONS

The method described above involves providing a vegetated surface in various spatial positions, such as turf which-in vertical position or otherwise oriented in space involves panels for housing seedlings made up of a plurality of identical cells. The cells have the function of receiving a growth substrate and a seedling rooted in the substrate. In this way, the plurality of juxtaposed cells contains corresponding seedlings, creating a uniform vegetated surface that hides both the seedling tray and the cells. The seedling tray can be cultivated in a greenhouse, or outdoors, in a production plant, and then be used to provide a vegetated surface, juxtaposing a large number of seedling trays, along both long and short sides. In particular, cultivating in the cells a grassy species for turf, a real modular turf can be obtained. The seedling tray is connected to a support mounted on a wall or on another structure that can be covered, with the possibility to obtain turf oriented in any desired way.

The climate benefits of green vertical environmental systems applied to the building envelope, change depending on many factors: the conformation volume of the building or structure behind, size and material of the panels containing the substrate and plants, the type of substrate and plants housed (Bellomo 2003, Blanc 2006, Blanc 2008, Buchanan 1991, Cook 2007, Dunnett & Kingsbury 2004, Serafy 2006, Tong 2013, Van Uffelen 2011, Van Uffelen 2017). In fact, it is worth noting how the thermal benefits verified through measurements carried out on different greening systems with different plant species (Alexandri & Jones 2008; Kontoleon & Eumorfopoulou 2010; Cheng et al. 2010; Wong et al. 2010; Pérez et al. 2011; Koyama et al. 2013; Cameron et al. 2014; Hunter et al. 2014; Coma et al. 2017; Paschoalino de Jesus et al. 2017) show how systems with vegetated modules with an average plant thickness of about 12 cm are performing. The choice of plants is one of the primary elements, because the conditions should be assessed for their environmental and microclimatic growth, and so it is necessary to evaluate exposure to sunlight, maximum and minimum temperatures reached, exposure to wind and urban pollution. It should also deal with the requirements of architectural design and of the building process, and then it is necessary to verify that drying, sprouting, or uneven growth does not come into conflict with the expectations of the designer. In this framework, after considering maintenance of the entire system linked to how much irrigation plant is needed, vegetable materials such as homogeneous lawns can provide positive answers to satisfy economics and project management architecture.

A decisive role in the capacity of the system studied to meet the needs of building feasibility is also its ability to adapt to the project requirements in terms of technological flexibility. The panels used for housing plant material, innovative in their shape, especially as regards communicating cells, can be subdivided into sub-modules, depending on the needs of the façade and easily fixed to the substructures thanks to the fastening points strategically placed on the panels. These aspects are not found in the other similar systems analyzed except with extreme maintenance difficulty, i.e. fixing and reassembling. In terms of maintenance, the chosen plant material, the turf, requires less future maintenance than other greenwalls vegetation, with the possibility of replacing any damaged turf portion in a more quick and cheap way.

The vertical turf system, applied to a building, like other architectural technologies, must guarantee energy-efficiency and low environmental impact, and it must conform to the requirements of the various national and local regulations in terms of:

- Site inclusion (geographical location and climatic data, verification of the exploitation of renewable energy sources, assessing the availability of natural light, determination of the zoning acoustic detection of noise levels);
- Bioclimatic and energy requirements (shading of summer and winter daylight control, impact on adjoining buildings, thermal inertia for summer air conditioning, comfortable interior spaces, energy consumption, emissions)

- Integration of technological systems;
- Materials and construction types (use of bio-friendly materials, recyclable materials, materials free of toxic emissions)
- Protection of soil and water resources (the management and reuse of rainwater)
- Quality of building (waste management in general, sound insulation, integration with solar technologies, user manual for users)
- Management of the site (planning the management of building waste, waste-water treatment strategies)

The results demonstrated that a technique based on the installation of vegetated modular panels with turf on substructures allied to the integration of a micro-irrigation system allows the construction of a reduced thickness and weight per sqm and with a rapidity and ease of installation that can positively meet construction requirements of a modular envelope. Moreover, the use of turf, from an architectural perspective, allows the construction of homogeneous surfaces similar to a non-organic material yet differently from other greenwalls with different plant materials that do not allow this.

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