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7. GREEN FAÇADE

7.1. Introduction

Vegetation has always been used as a functional element of human spaces, for instance it can protect against wind, shade solar radiation, it can improve the microclimate in built environments and define collective and private spaces. However, in recent decades the progressive decrease in green areas and the intensive exploitation of land for food production have significantly compromised the water retention capacity of the land.

This dramatically affects urban areas in case of heavy rains and extreme weather conditions as well as led to a significant decrease in the filtering capacity of plants to remove pollutant dust and produce oxygen. Additionally, the current need of more liveable urban spaces as along with ever-decreasing availability of space for building led to an increase in the demand for existing urban spaces renovation and redevelopment. In these areas the introduction of green spaces plays a key role.

In this context the application of green roofs and walls in buildings becomes fundamental. It assumes an important role in the phenomenon now called Going Green. The benefits of integrating greenery into the building envelope affect several issues: environmental, economic, and social, generally reducing greenhouse gases and pollutants, improving air quality and comfort conditions inside and outside the building, and helping to maintain biodiversity.

The use of green in construction can allow:

- urban heat island effect mitigation: in a temperate climate a 10% increase in green infrastructure could lead to a reduction urban matrix temperature of up to 2.5°C (Cameron et al., 2014);
- improvement in health and well-being conditions: several studies have shown that the use of green areas, or their continuous visions, can bring benefits to health and quality of life;
- air quality improvement: the process of photosynthesis consumes CO_2 and releases O_2; moreover, certain types of plants reduce the presence of particles in the air that are harmful to human health (such as carbon dioxide, carbon monoxide, nitrogen dioxide and fine dust);
- urban decoration: vegetation walls improve aesthetics and create a feeling of closeness to nature in densely urbanised areas;

- ecological value increase: greenery provides water, food and protection for birds and butterflies, safeguarding their survival;
- stormwater resilience improvement: green buildings provide greater control over stormwater, filtering impurities before they enter the groundwater.

Thanks also to the growing attention towards environmental issues, technical green systems are gaining considerable interest and green walls are also becoming more widespread. Green walls are not new to architectural practice, because archetypes of green walls are historically found in basic construction in geographical regions with both cold and Mediterranean climates, but this technology has recently considerably evolved.

In Italy there is a dedicated technical standard (UNI 11235:2015, "Instructions for the design, implementation, control and maintenance of green roofs") for the consolidated techniques for green roofs. Otherwise for green walls there are no standards and the solutions proposed by manufacturers are varied and numerous. It is worth to notice that green wall systems are generally more complex than those for green roofs, both because the vegetation is placed on a vertical surface and because of the relationship between the facade systems and other wall components, such as openings.

It is worth to specify that green vertical systems do not guarantee the required performance for a vertical closure and therefore these must be provided by dedicated layers included in the back-standing load-bearing wall.

Plants are the most important component as well as the most delicate and responsible for the formal success of the green wall systems (Corrado, 2010). They guarantee the functionality of the whole system made of a series of technical elements such as substructures, plants and various components. At the beginning of the project, it is therefore essential to collaborate closely with experienced professionals, as the choice and management of a green wall system implies knowledge that is usually far from architectural practice.

The following aspects should be considered when choosing the essences:

- seasonal vegetative cycle;
- direct solar radiation needs;
- maximum size achievable;
- growth speed;
- leaf density and thickness.

The specific benefits of green wall application can be summarised as follows (Bellomo, 2005; Ariaudo, Fracastoro, 2007; Tatano, 2008; Köeler, 2008; Corgnati et al. 2009; Santi, 2010; Campiotti et al., 2013).

- *Energy saving.* Vertical greenery works as a true insulating surface for external walls. During summer season, overheated façades result in rising rooms internal temperature and consequently increases in energy consumption needed for conditioning systems. This consumption is reduced if the external wall is shaded by a layer of vegetation which considerably decreases the heat flow and, thus, limits the transfer of thermal energy. So, the first mechanism that contributes to summer energy savings is the shading function. Additionally, the green façade allows the presence of an air cavity between the green finishing and the load-bearing wall. During winter season the leaves reflect and absorb the infrared radiation emitted by the building, leading to a reduction in the radiative heat loss of the building. For this reason, green systems bring benefits in terms of energy savings both in Mediterranean and colder climate areas. A significant reduction in wind speed in the air layer close to the outer surface of the wall load-bearing layer is achievable. This improves thermal resistance, thanks to the attenuated effect of air movements on the façades and a reduction in convective heat losses.

- *Building protection*. The building envelope is protected by the vegetation, especially against temperature fluctuations. The latter cause the building materials to expand and contract, compromising the lifespan of the materials.
- *Acoustic insulation*. In contexts strongly affected by city traffic and the related noise, the use of vegetated walls can reduce this problem thanks to the screening effect of the vegetation.
- *Increased estate value*. Various studies have shown that buildings with vertical greenery, especially located in highly urbanised contexts, increase the value of the building by giving quality to the landscape.

In contemporary times, the most important figure in the industrialised development of green wall systems is Patrick Blanc, a French researcher who patented the Mur Vegetal system (Blanc, 2008).

Before him, green wall applications followed an artisanal approach. He proposed an innovative system exploiting the ability of roots to grow without necessarily requiring cultivation soil (technique of hydroponic cultivation). Architects such as Jean Nouvel and Renzo Piano had an important role in the dissemination of Blanc's solution, realising the potential of green walls in architecture and promoting internationally their use. This achievement contributed to the development of subsequent industrialised vertical green solutions and to the spread of the application of greenery on buildings vertical walls.

More and more designers are choosing to adopt these types of enclosures because of their formal qualities, functional characteristics and eco-sustainability. Thanks to the current demand for vertical green solutions, an important activity of industrialisation of solutions, subsystems and components has been started. Today many green façade systems are proposed by the industrial market and include a wide range of greening types.

Any vertical greening installation is composed of 3 sub-systems which, starting from the outside of the enclosure and moving inwards, are:

1. greening system;
2. mediation subsystem with the building;
3. building wall used to accommodate the greening.

There is no univocal classification of green wall solutions in literature (Spagnolli, 1995; Bellomo, 2005; Poli T. 2006; Lambertini, 2007; Bit,2012; Jim, 2015; Santi, 2016) but the first fundamental possible distinction is between:

- vertical gardens;
- vertical green systems.

Vertical gardens are real high gardens, characterised by the presence of vegetal species planted in pots, placed directly in the covering system, or installed on terraces or balconies for the entire height of the building.

As far as vertical green systems are concerned, two further typological categories, differing for the relative executive and planting peculiarities can be identified:

- vegetated claddings (or green façade);
- vertical vegetated closures (or living walls).

The term "vegetated claddings" refers to those façades characterised by climbing plant species, rooted in the ground or in pots, using the walls of the building as a support for their development (called direct); an evolution of this system is the use of grids or support systems where plant can grow, possibly spaced from the wall behind (called indirect).

On the other hands, "vertical vegetated enclosures" consist of modular elements (in general panels) which are mounted on the opaque external wall by a supporting sub-structure. These panels contain the substrate for planting the vegetation. Both the substrate and the plants are then brought up to the full height of the façade. The species used are not climbers, but generally evergreens, and require a suitable irrigation system.

Finally, living walls represent a sub-typology of vegetated vertical closures. Although they are characterised by most of the characteristics of the belonging category, they have specific features which give them an autonomous technological declination. They are made with a textile substrate, without the use of soil. This substrate usually consists of a double layer of synthetic felt. The plants are here placed manually, and the characteristics of hydroponic cultivation are exploited. The latter is based on the use of a nutritive solution to provide for the needs of the plants. In this system, no type of modular vegetation structure is used.

A scheme for the classification of green façade systems follows. It is based on their constructional characteristics (Fig. 7.1).

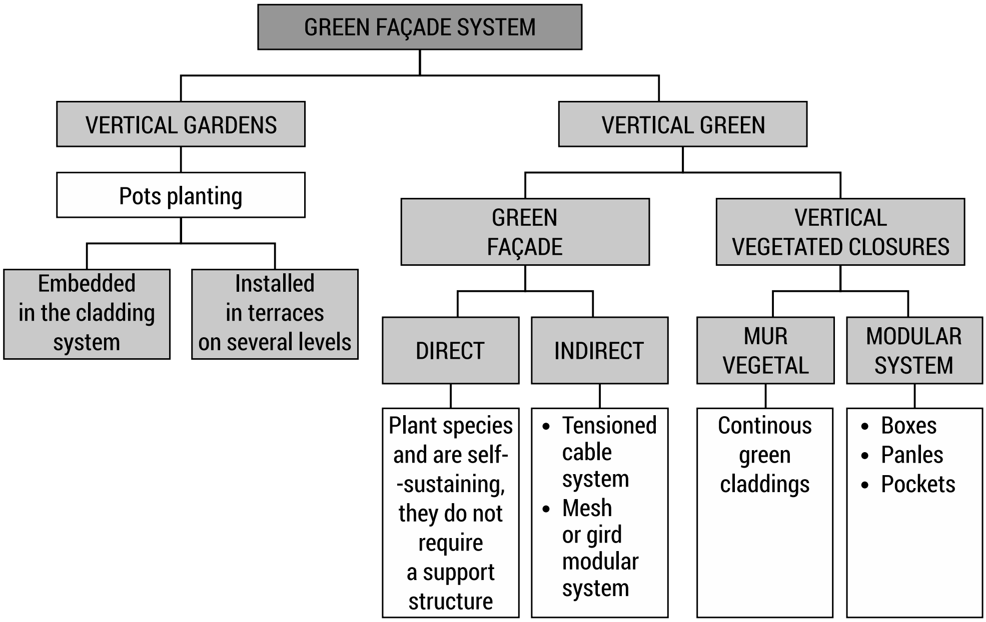

FIG. 7.1. Classification of vegetated façade systems according to their construction characteristic (Source: own elaboration)

7.2. Green Façade

Within the panorama of industrialised products available on the market, it can be said that green façades are the best known and most historicised systems for greening walls. Vegetable cladding has been part of building practice for centuries. Initially, it was made with climbing species directly attached to wall surfaces. Then, it evolved over time through the introduction of a system of mediation between plants and the wall. Thus, because direct interaction could cause problems to building surfaces (e.g., localised disintegration caused by the epigeal organs of plants, the presence of humidity, dirt, etc.). In green facades the plants used are usually climbing plants. Anyway, most plants grow vertically, in search of sunlight as an energy source. Climbing species belong to a wide range of botanical families and can be described as plants "*halfway between a grass, a bush and a tall tree, differing from the latter in the habit of their stems, which are slender and particularly flexible, and therefore require a rigid support to sustain them*" (Bellomo, 2005). Thanks to their physical characteristics and vegetal ramifications, they can climb vertically in different ways. Some of them are self-supporting, as they have aerial or sucker roots, while others, with a tendency to intertwine, require special support elements: these include fickle plants (plants that cling with the aid of tendrils and intertwining species).

The green covering is a relatively simple system. In the indirect types, it consists of a series of substructures and other components that are functional for planting and biological proliferation, additionally to the actual vegetation. These elements constitute the support for the planting of the vegetation and can be substructures with nets, grids or cables, to manage the vegetal ramifications, pots and flower boxes, etc. and a possible irrigation system. When creating a green covering, it is necessary to choose how to install the plants depending on the project requirements. There are basically two options: plants to be placed in the ground or in pots. The second option can include pots located on the ground or, more frequently, above ground, integrated into the technological systems even if planting vegetation directly in the ground is always advisable, in certain conditions potting is necessary such as the following cases:

- when it is not possible to use natural terrain at ground level (condition typical of urban contexts);
- in the case of large walls to be covered, where several green stripes needed to be vertically arranged;
- in cases where the cladding is to be created using plants with a drooping habit, which can only be planted in raised pots.

When planting in pots, it is important to guarantee the proper composition of substrate elements within the pots and a correct balance between draining and water-retaining elements. Generally, the involved layers are:

- vegetation substrate for plant's roots. The substrate is usually made of soil-based materials depending on the species chosen and the requirements (e.g. loam, peat, humus, etc.);
- filter layer, it prevents fine particles of the substrate from descending into the underlying drainage layer and accommodates the anchoring of the root systems. Generally, geotextile materials with adequate tensile, shear and punching resistance, as well as water permeability, are used for this layer;
- drainage layer, which ensures the drainage of water passing through it, since stagnant water can cause root asphyxia. Moreover, the draining layer must inferiorly accumulate reserve water to supply the root systems when needed. The materials used are usually loose materials with high water retention and drainage capacity (such as volcanic lapilli, pumice, expanded clay, etc.);
- possible supplementary layers for specific needs, such as additional water storage mats, sheaths, root barrier layers, etc.

Once the species for greening the façade has been chosen, it is necessary to understand how the plant system must be installed. Thanks to their aerial or suction branches, some plant species can cling and grow vertically depending on their characteristics. While all other types of climbers require a supporting subsystem. However, it is worth to notice that it is always advisable to provide a support system (even in the case of self-supporting species) as aerial roots or suction cups can cause walls damage over time.

Generally, plant growth support system is always needed, adequately designed and sized according to the characteristics of the chosen plant. Each species will require a different support depending on fixing system and growth. The supports can be:

- simple (e.g., nets or tensioned cables fixed to the walls by dowels, rigid metal or wooden gratings, etc.);
- relatively complex (e.g., double layers of nets, projecting shelves containing planters, etc.);
- very complex (such as real spatial structures), depending on the design and planting requirements.

However, these features can be generalised thanks to the common characteristics of plants and their way of growth.

As fickle plants expand vertically, they require vertical linear structures, usually vertically tensioned wire ropes. During the initial phases of plant growth, fickle species can also be diverted along horizontal lines by subsystems such as ties or other, if necessary. For fickle plants of moderate growth, the optimal distance between the vertical supports is 20-40 cm. While for those with vigorous growth, the supports could also be spaced up to a maximum of 80 cm.

Self-supporting plants with tendrils or intertwining plants require supports that combine vertical and horizontal directions. Such supports can be obtained either by tensioned cables or by mesh or grid structures. A combination of rigid horizontal and vertical linear supports made of different materials (wire mesh or polymer matrix structures, electro-welded mesh, etc) can be obtained. The mesh size of the nets can be between 10 and 60 cm, depending on the growth characteristics of the species used.

Theoretically plants with epigeal organs do not require support. But it is always advisable to adopt a support structure that distances them from the wall. Aerial and sucker roots have a very dense spacing between their root organs, and usually tend to spread easily on continuous surfaces. So, the supports for the growth of these plants must allow as much surface continuity as possible. For this reason, close-meshed nets with a pitch of between 2 and 10 cm are often used.

Care must be paid to ensure a suitable distance between the planting material and the building surface. All types of support should be installed a few centimetres away from the rear wall, as they will need to provide a suitable space for plants growth, as well as ensuring that branches and plant organs do not interfere with the wall surface. It is possible to state that each different species would require a different distance from the wall, but some standard dimensions can be adopted (Table 7.1).

TABLE 7.1. Indicative minimum distances to adopt between the plant system and the vertical wall (Source: own elaboration)

Plants type	Distance from vertical wall
Plant species with low or medium growth vigor (e.g. Clemantis, Lonicera)	80 ÷ 150 mm
Vigorous or very vigorous species (e.g. Wisteria, Phalloppia, Celastrus)	150 ÷ 200 mm

In some specific locations of the building (at the ground connection, at the top, in the corner portions and at the interfaces with windows and doors), it will be necessary to adopt some precautions. In general, at the ground connection, if the stem of the plants is accessible, it must be protected with metal elements. At the top it is needed to cover the space between the wall and the plant cladding, especially if the wall may be affected by rainwater leaching. In the corners the continuity of the growth of the plants must be guaranteed. In correspondence with the openings acting with periodic pruning or designing slots that allow the distancing of the plants are the alternatives (Fig. 7.2).

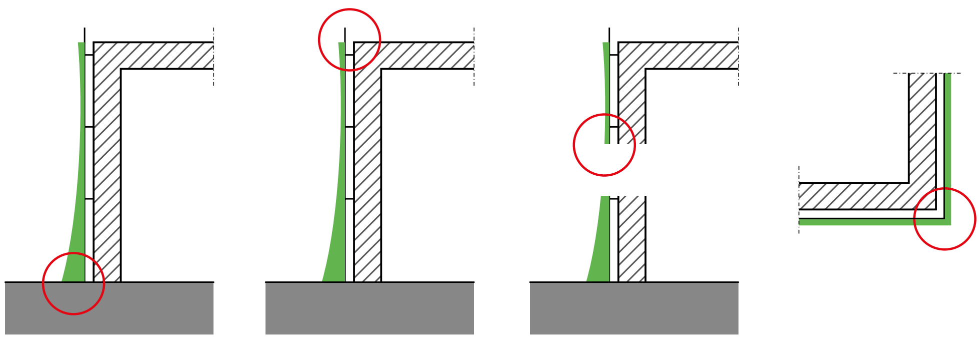

FIG. 7.2. Diagram of the characteristic nodes concerning the connection between the vegetal covering and the building (Source: own elaboration)

The support system must be made from materials that do not damage the vegetation. Unappropriated design choices concerning with support structures sometimes affects plant development. For instance, some species that suffer from high temperatures may not tolerate dark coloured supports. In other cases, some species tend to reject metal structures preferring other materials such as wood or polymers. The support must provide adequate support for the plant system according to the peculiarities of proliferation, different from species to species. For example, an excessive spacing of the support elements may not allow the plant to adequately develop. The substructure of the cladding should also not deform under the weight of the plant and accidental loads. Durability is also an important parameter for cladding support systems: they must guarantee a suitable service life, as well as the maintenance of the dimensional and strength characteristics throughout the entire life cycle. The most used material for the substructures is steel, due to its strength and versatility. Wood and polymers can also be used: they represent an interesting alternative as they combine strength, lightness and versatility of use. For pot plants, the size and shape of the containers will be the most important aspects, as well as the composition of the substrates, drainage, and irrigation system. Environmental factors must also be considered. Only certain species adapt very well to any exposure. A wrong selection of plants, depending on the sun exposure or the climatic and micro-climatic characteristics of the environment, could affect the performance of the plant system.

Types of Vegetated Claddings

The systems involving the presence of support elements for vegetation (indirect systems) will be outlined. In these cases, it is essential to know how the plants cling to the supports (Table 7.2), to guarantee an appropriate choice of the configuration of the substructure and to ensure a continuous distribution of the vegetation on the wall.

The weight of the creepers is another important element to determine when choosing the support structure. It essentially depends on the consistency of woody component and leaf mass. Each species develops with its own volume and density, and the maximum weight of the woody part of a climber depends on the height of the plant and the maximum size of the stems.

TABLE 7.2. Possible configurations of support structures depending on how plant species are anchored to the support (Source: own elaboration)

Ways of anchoring climbers	Types of plant essences	Horizontal distance between elements	Vertical distance between elements	Configuration of supports	Maximum growth height
VOLUBLE	Lonicera, Aristolochia, Actinidia, Akebia, Humulus, Wisteria, Falloppia, Celastrus	H= 200-800 mm	V= 500 ÷ 2000 mm	Vertical ropes Vertical ropes with horizontal supports Inclined ropes	20 m
VITICCI	Rosa, Jasminum, Rubus		V= 500 ÷ 2000 mm	Horizontal ropes Vertical ropes with horizontal supports	6 m

Ways of anchoring climbers	**Types of plant essences**	**Horizontal distance between elements**	**Vertical distance between elements**	**Configuration of supports**	**Maximum growth height**
INTERWEAVING	Ampelopsis, Clementis vitalva, Vitis vinifera, Passiflora	H= 200 ÷ 800 mm	V= 500 ÷ 2000 mm	Vertical ropes with horizontal supports	15 m

The following Table 7.3 summarises the main commercially available technical alternatives of substructure elements for plant claddings.

TABLE 7.3. Table summarising the classification of indirect vegetated claddings systems (Source: own elaboration)

CLASSIFICATION OF SUBSTRUCTURES OF INDIRECT VEGETATED CLADDINGS SYSTEMS					
	SUPPORTING ELEMENTS FOR PLANT SPECIES	*SUBSTRUCTURE MATERIAL*	*FIXING ELEMENT TO LOAD-BEARING LAYER*	*FIXING ELEMENT MATERIAL*	*FIXING TO LOAD-BEARING STRUCTURE*
TENSOR CABLES SYSTEMS	Vertical tensor cables (bi-directional option)	Galvanised and stainless steel	Spacers	Stainless steel	Mechanical/ chemical dowels
	Modular interweaving with vertical tensor cables	Galvanised and stainless steel	Spacers	Stainless steel	Mechanical/ chemical dowels
	Bi-directional tensor cables with metal mesh	Galvanised and stainless steel	Spacers	Stainless steel	Mechanical/ chemical dowels
MODULAR SYSTEMS GRID OR MESH	Bi-directional grid with rigid box	Galvanised steel	Optional brackets and mullions	Galvanised steel	Mechanical/ chemical dowels
	Bidirectional spatial grid	Galvanised steel	Optional brackets and mullions	Galvanised steel	Mechanical/ chemical dowels
	Electro welded mesh with geo-composite module	Galvanised steel	Brackets and mullions	Galvanised steel	Mechanical/ chemical dowels
	Electro welded mesh with rigid box	Galvanised steel	Brackets and mullions	Galvanised steel	Mechanical/ chemical dowels

Some commercially available systems are described below.

Tensor cables systems with bi-directional option
The system presents a lightweight solution adaptable to project needs. All components are made of AISI 316 and AISI 316L stainless steel.

The key element is a system of vertical ropes mechanically fixed at several points to steel spacers bound to the load-bearing layer. The stainless-steel braided cables are 6 wires with diameter ⌀4 mm. Mechanical dowels allow the spacers anchoring to the load-bearing layer. The length of the cables is freely chosen. There are three possible configurations, distinguished by the tensor system at the bottom end and the resulting tension that can be applied to the cable. Depending on the design requirements the system can include horizontal stainless steel stiffening bars with circular cross-section ⌀4 mm, fixed to the cables and spacers by mechanically fixed steel or polyethylene clamps. The high corrosion resistance of the materials guarantees durability and low maintenance (Fig. 7.3).

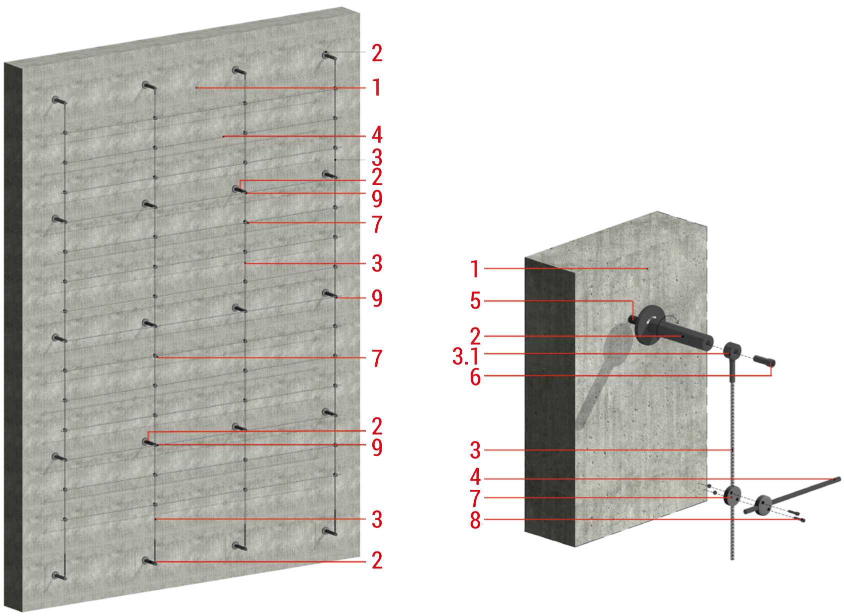

FIG. 7.3. Axonometry and detail. Legend: 1. Load bearing layer; 2. AISI 316 stainless steel spacer; 3. AISI 316 braided steel vertical support rope; 3.1. AISI 316 stainless steel ring for fixing to end spacers; 3.2. Circular profile (⌀4 mm) for horizontal stiffening in AISI316 steel (optional); 5. Mechanical anchor for fixing spacers to the load-bearing layer; 6. Crossed polyethylene or stainless-steel clamp for anchoring the stiffeners; 8. Bolt and nut system for fixing polyethylene clamps; 9. Crossed AISI316 steel clamp for fixing with central spacers; 10. Bolt for fixing steel clamp (Source: own elaboration)

Modular interweaving with vertical tensor cables system
All system components are made of AISI 316 and AISI 316L stainless steel. The basic element is vertical braided steel ropes combined with steel angle profiles horizontally

arranged. The fixing system consists of steel spacers anchored to the wall load-bearing layer by screwing in previously inserted mechanical dowels. The system of ropes is available in three possible variants, differentiated according to the tensor present at the bottom end. Ropes are fixed to the two extreme angle profiles, the upper one by a steel "nail", the lower one by bolts. The latter also allow the definition of the state of tension pre-defined during the design. By adding horizontal bars, connected to the ropes by clamps, it is possible to create grids of different sizes according to the needs and loads deriving from the plant species installed, as well as the requirements of the plant. This system is particularly suitable for medium and large-sized vegetated claddings. The high corrosion resistance of the materials guarantees durability and low maintenance (Fig. 7.4).

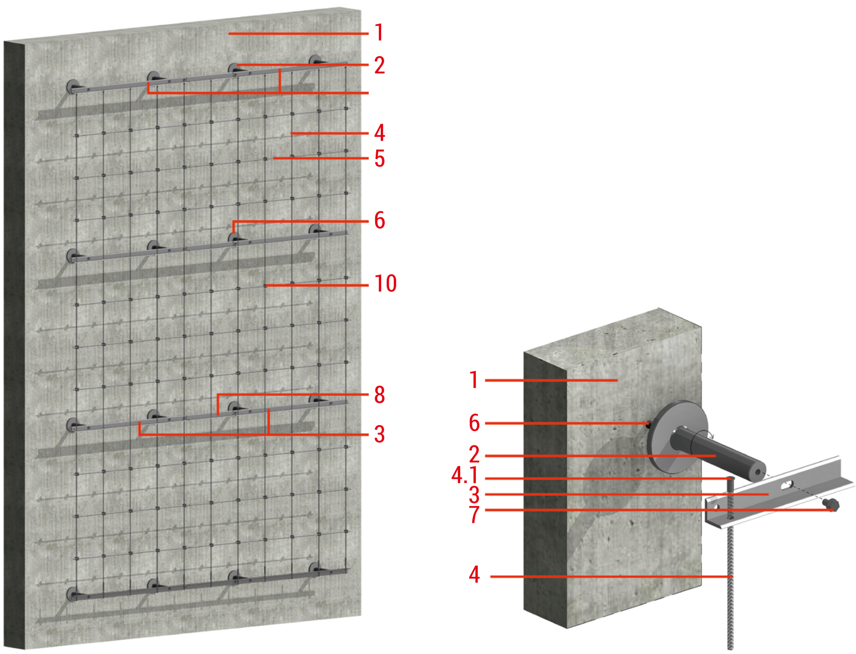

FIG. 7.4. Axonometry and detail. Legend: 1. Load bearing layer; 2. AISI 316 stainless steel spacer; 3. AISI 316 steel angle profile, L section 30x30 mm (4 mm thick and variable length); 4. AISI316 braided steel vertical support rope, circular section ⌀4 mm; 4.1. AISI316 steel nail for upper fixing; 4.2. Circular profile (⌀4 mm) for horizontal stiffening in AISI316 steel; 6. Mechanical dowel for fixing spacers to the load bearing layer; 7. Hexagonal screw for fastening the horizontal profile to the spacers; 8. Horizontal connection element between two gratings, AISI316 steel profile with L-section 30x30mm (thickness 4 mm and length 340 mm); 9. Screw and nut system for fastening the connection element; 10. Cross clamp in AISI316 steel or polyethylene for fixing horizontal stiffeners (Source: own elaboration)

Bi-directional tensor cables with metal mesh

All system components are made of AISI 316 and AISI 316L stainless steel. The mesh, with its spacers and connections, is a modular system adaptable according to the needs of the project. The module consists of steel spacers, fixed to the resistant layer by mechanical dowels. Forks, characterised by variable geometry depending on the number of supported ropes, are attached to the outer spacers by hexagonal head screws. These provide anchorage for the perimeter rope systems supporting the metal mesh. Through mechanically fastened clamps, the inner spacers work as an auxiliary support for the ropes. The cable diameter and mesh size are particularly suitable for climbing plants. The system can be used for medium to large-scale plantings. The high corrosion resistance of the materials guarantees durability and limited maintenance interventions (Fig. 7.5).

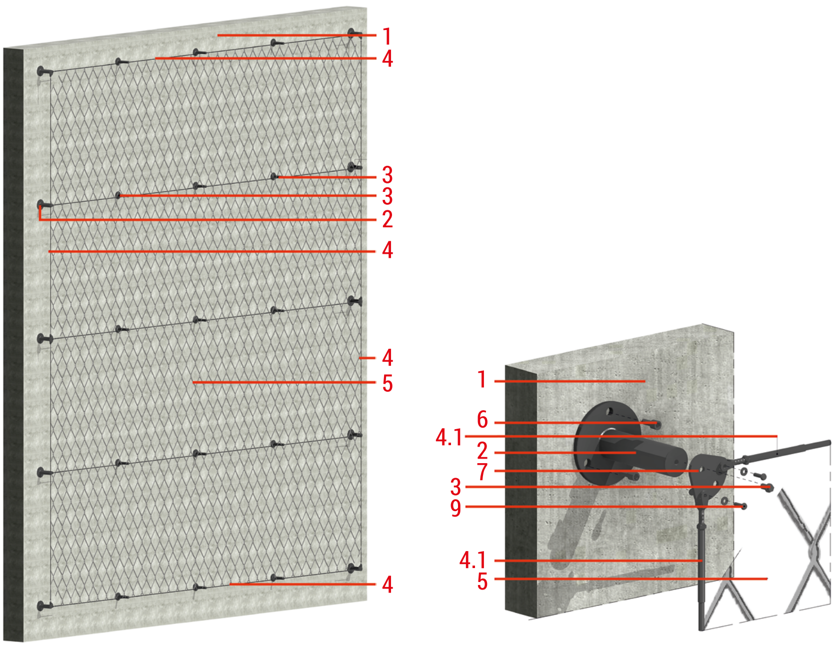

FIG. 7.5. Axonometry and detail. Legend: 1. Load bearing layer; 2. AISI 316 stainless steel lateral spacer; 3. AISI 316 stainless steel central spacer; 4. AISI 316 braided steel support cable, circular section ⌀4 mm; 4.1. AISI 316 braided steel cable; 4.2. AISI 316 stainless steel threaded sensor; 5. AISI 316 stainless steel braided metal mesh; 6. Screw for fastening spacers; 7. AISI 316 stainless steel fork (5 mm thick); 8. Hexagonal head screw for fastening the fork to the spacer; 9. Screw for fastening the support cable to the fork; 10. Single or crossed clamp in AISI 316 stainless steel; 11. Mechanical dowel for fixing central spacers (Source: own elaboration)

Modular system with Bi-directional grid with rigid box
The base module consists of supporting panels made up of a stainless-steel grid framed by metal profiles anchored at the ends to a system of brackets by hexagonal head screws. The two upper anchoring brackets also act as supports for a drilled stainless-steel box where the creepers rooted in pots are planted. The four perimeter support brackets are anchored to the load-bearing wall by mechanical dowels, inserted in suitable slots in the metal profiles. This connection also allows the management of vertical tolerances. Each gridded panel has a size of 90x150 cm. This system is anchored to the façade by a steel frame. The latter provides access for maintenance between the wall and the metal boxes. The system also includes the installation of an irrigation system, related to the drainage one (growing substrate), to install at different levels if necessary (Fig. 7.6).

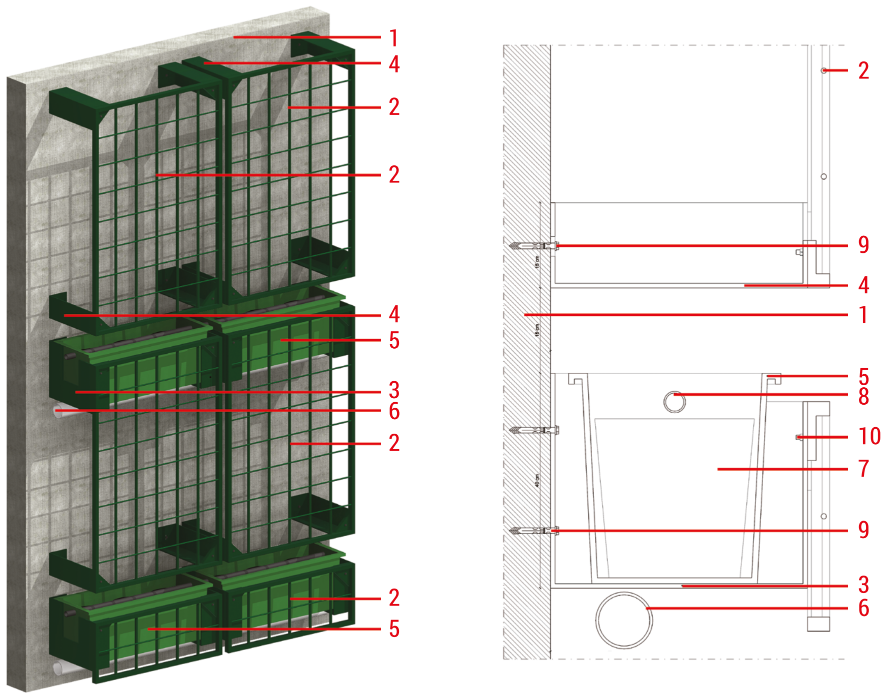

FIG. 7.6. Axonometry and vertical section. Legend: 1. Load bearing layer; 2. Coloured galvanised steel bi-directional grating; 3. Coloured galvanised steel fixing bracket for arranging containers; 4. Coloured galvanised steel fixing bracket; 5. Box; 6. Drainage system: polyethylene profile, circular cross-section ⌀100 mm; 7. Containment vessel made of polyethylene (⌀max 280 mm) with cultivation substrate (soil); 8. Irrigation system: drip line, circular profile ⌀30 mm made of polyethylene; 9. Mechanical anchor for anchoring the brackets to the resistant layer; 10. Hexagonal head screw for fixing the grid (Source: own elaboration)

Modular system with bidirectional spatial grid
It is a system of welded wire mesh panels, used to support the development of climbing plants. The modular panel consists of a 65 mm thick volumetric galvanised steel grid made up of 3 mm diameter rods. The latter are anchored to the substructure by angle-profile brackets, made of coloured galvanised steel, 45x60 mm in section and 4 mm thick, and by support brackets made of shaped coloured galvanised steel profiles, 15x80 mm in section and 4 mm thick. The substructure is built recurring to coloured galvanised steel central T-mullions and lateral L-shaped ones. These mullions are anchored to the load-baring layer by mechanical dowels (Fig. 7.7).

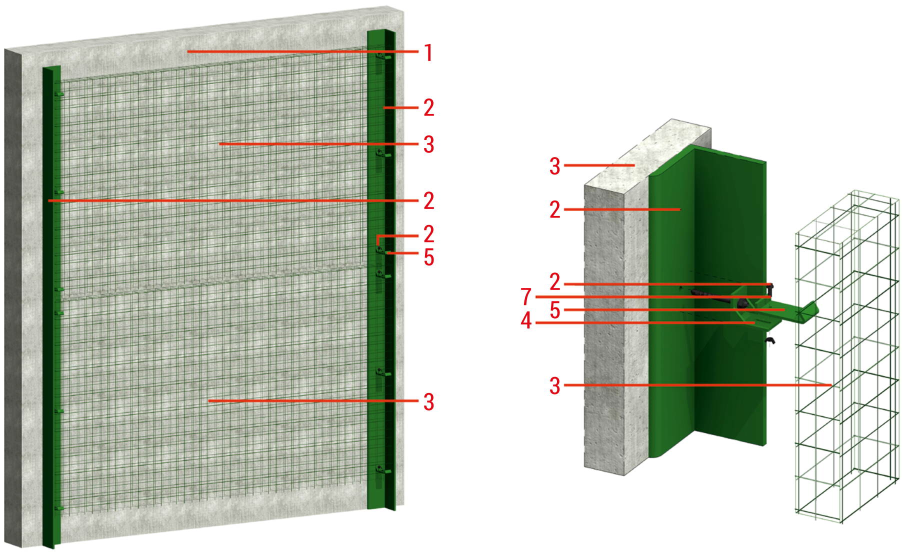

FIG. 7.7. Axonometry and vertical section. Legend: 1. Load bearing layer; 2. Coloured galvanised steel central upright, T-profile, 120 x 240 mm section; 3. Coloured galvanised steel side mullion, L-profile, 120 x 120 mm section; 4. Modular panel: 65 mm thick galvanised steel grating made of ⌀3 mm bars; 5. Anchoring bracket, wing profile with coloured galvanised steel stiffeners, section 45 x 60 mm, thickness 4 mm; 6. Green screen panel support bracket, shaped profile in coloured galvanised steel, section 15 x 80 mm, thickness 4 mm; 7. Screw with nuts for slotted connection of the brackets; 8. Mechanical dowel for anchoring the mullions to the load-bearing layer (Source: own elaboration)

Modular system with Electro welded mesh with geo-composite module
It is a modular system for greenery on façade with climbing plants. It consists of an aluminium box containing the cultivation substrate and electro-welded mesh to provide height support for the climbing plants. The system is supported by galvanised steel brackets and mullions that bears the base module. They are fixed to the wall load-bearing layer using dowels. The system is completed by transoms in galvanised steel corner profiles. Metal hooks are here attached to guarantee support for the electro-welded

mesh inserted inside the box. The system also includes an automated, centralised irrigation system for the supply of water and nutrients (Fig. 7.8).

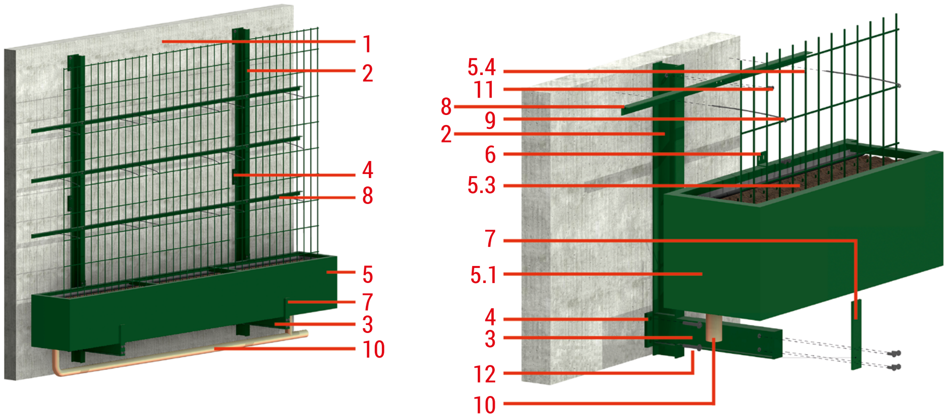

FIG. 7.8. Axonometry and vertical section. Legend: 1. Load bearing layer; 2. Satin-finish galvanised steel upright, IPE120 profile with stiffeners; 3. Satin-finish galvanised steel bracket, IPE120 profile with rectangular plate welded at the head; 4. Plate for anchoring the upright, section 150 x 150 mm, thickness 15 mm; 5. Plant placement form; 5.1 Satin-finished aluminium tank, section 50 x 50 cm; 5.2. Aluminium profile for stiffening the module; 5.3. Cultivation substrate, soil; 5.4. Electro-welded satin galvanised steel mesh, ⌀8/80 mm, 220 cm high; 5.5. Drip-feed irrigation system; 6. Galvanised steel profile for fixing the tank; 7. Galvanised steel profile for fixing the pool, section 300 x 64 mm, thickness 10 mm; 8. Corner profile for fixing electro-welded mesh, section 40 x 40 mm, thickness 5 mm; 9. Flexible aluminium arm for fixing the mesh; 10. Drainage system, circular PVC profile ⌀70 mm; 11. Anchor bolt to the mullion (Source: own elaboration)

Modular system with electro welded mesh with rigid box

It is a modular system designed to create vertical climbing plants. The load-bearing structure is made up of steel C-shaped mullions for anchoring the system. These C-section mullions are fixed to the resistant layer by mechanical dowels. There is also a system of brackets, consisting of a fixing plate (8 mm thick) and a profile with the same C-section, 30 cm long, welded together. The mullions and brackets are mutually bounded by hammer-head screws. Above the supporting brackets there are two corner profiles, necessary for the fixing of the multi-layered element for the insertion of the plants. This element composed, starting from the outer side, by a geotextile containment mat made of coconut fibre and a geocomposite layer longitudinally sewn to obtain cultivation chambers containing a pre-fixed quantity of inert mixture. The latter layer supports an electro-welded and hot galvanised mesh (circular section ⌀5 mm), specially shaped to confine a polyurethane mat containing the cultivation layer for climbing species. The pre-designed modular panel with climbing plants is installed on site and secured to the two perforated corner profiles with stainless steel clamps (Fig. 7.9).

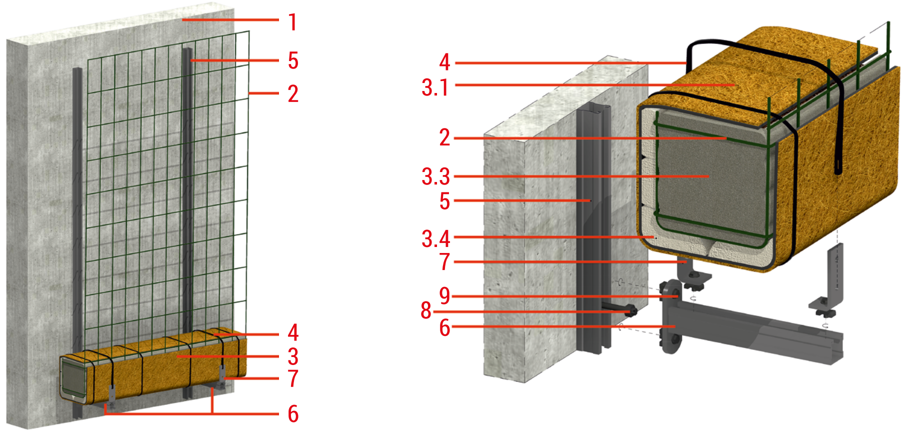

FIG. 7.9. Axonometry and detail. Legend: 1. Resistant layer; 2. Galvanised steel electro-welded mesh, circular section ⌀5 mm; 3. Module; 3.1 Polyethylene cladding panel and coconut fibre geotextile (12 mm thick); 3.2. Cultivation sub-layer; 3.3. Polyurethane containment mat (25 mm thick); 3.4. Geocomposite fabric bag with inert mixture; 4. Stainless steel strap for fixing the module; 5. S250GD steel mullion, C-section profile 9.5x41.3x41.3 mm (2 mm thick); 6. S250GD steel bracket, fixing plate (8 mm thick) welded to a C-section profile 9.5x41.3x41.3 mm (2 mm thick); 7. S250GD steel angle profile, cross-section 105x41 mm (6 mm thick); 8. Dowel for fixing the mullion to the load bearing layer; 9. Hammerhead screw (Source: own elaboration)

7.3. Living Walls

Considering all the different possible types available, living walls present fairly complex technologies which allow the green component and the technological systems to be complementary.

These systems are always dry-assembled and have some invariant or primary elements secondary ones.

The primary elements or layers of a living wall are:

- vegetation layer,
- cultivation layer,
- element of protection from the action of the roots,
- water-tight element,
- supporting and mediating technologies between the green system and the remaining part of the building closure,
- supporting elements,
- irrigation system.

The secondary elements or layers are:

- barrier layer or vapour screen,
- thermal insulation layer,

- vapour pressure diffusion and/or equalisation layer,
- separation and/or flow layer, for the absorption of differential expansion between materials of different origin.

Focusing on the plant layer, the general requirement is to maintain an optimal vegetative state for as long as possible. In relation to the climatic context, the success of the greening layer depends on the synergy between the design and implementation strategies related to the substrate, the plant component and all the related subsystems of irrigation, plant nutrition and drainage of the cultivation layers. As regards planting methods, it is worth to specify that the plants can be arranged on the wall in two different ways: through the direct introduction of young plants on the substrate surface, or through the placing of suitably preformed panels or pre-cultivated portions of the substrate. Depending on these methods, the formal and functional characteristics of the living walls will also vary, especially during the first period of installation. In the first case it will be necessary to wait some time before the wall has adequate formal and functional characteristics, while in the second case the wall will be completely vegetated immediately.

The cultivation layer may be organic (e.g., appropriately designed and mixed substrates with an earthy matrix) or inorganic (e.g., felts, mineral substances, fibres of various kinds, etc.). The material characteristics and thickness must be foreseen and sized according to the plants arranged. Depending on the size and weight of the plants, specific substrates will be required, or substrates with certain characteristics of resistance and water retention. This is because the water and nutritional needs of the plants will vary depending on the size and type of vegetation.

The root inhibitor element is required to provide adequate resistance to the action of the plant's root systems, to prevent it from penetrating into the layers behind it and impair the functionality of the closure. Root protections are classified as mechanical or chemical barrier, depending on the mode of protective action. In the first case, the material that forms the barrier cannot be attacked by the root organs, while in the second option special additives are introduced reacting to the stresses exerted by the roots. There are two methods for creating the root inhibitor apparatus, depending on whether it consists of a separate element or is integrated with other existing layers, which is the most common practice.

The main requirement for the sealing element is being waterproof. Some specificities must be considered in the design phase of the sealing element:

- the sealing element is normally protected from thermal actions produced by solar radiation;
- in some cases it may be subject to root action. This action will take the form of mechanical, chemical and bio-logical stress;
- when placed in direct contact with growing media, it will be subjected to biological and chemical agents due to the substances that make up the substrate itself and/or the compounds that may be supplied to the plants by fertilisation.

The materials adopted for waterproofing green enclosures can be bituminous, polyolefin, PVC, or even breathable membranes, when allowed by the greening technology chosen.

The substructure supporting the greening system is the mediating interface between the waterproofing layer and the enclosure behind it. It must support all the various components that make up the greening system and it is desirable that it ensures a ventilation gap behind the green package, to both guarantee the evaporation of any condensation and minimise the possibility of plant roots reaching the enclosure. The main attention must be paid to the correct structural dimensioning, carried out considering as a permanent load all the volume masses in a condition of water saturation. The substructure must be made of durable and resistant material (such as stainless steel, aluminium, fibre-reinforced polymer materials, etc.).

The irrigation system must provide an adequate quantity of water to the plant species, according to the different specific needs, the installation method, the climatic region and the microclimate of the area. This system consists of an integrated sub-system, composed of technological apparatus such as pumps, pipes, etc. Given the geometric and technological configuration of the vertical vegetated enclosures, it will always be necessary to integrate an automated irrigation system. This is because these green areas can reach a considerable height and use thin cultivation substrates, with a low water storage capacity, and because it is difficult to carry out this operation manually. It follows that the irrigation system is a constituent element of systems in which vertical vegetated enclosures are adopted. The type of irrigation system, the methods and the relative frequency of watering cycles will depend directly on the plant species used and the technology adopted in the substrates, which may include conventional or hydroponic cultivation. The latter cultivation method has become commonplace in vegetated closure systems since Patrick Blanc's patent, as it ensures overcoming many of the constructive and agronomic criticalities associated with bringing natural soil into the wall.

Also, in the case of green vegetated enclosures, particular connections between the green apparatus and other architectural elements must be studied in detail. These are: connection to the ground; at the top; nodes in correspondence of windows and doors and building projections; corner junction between green facades.

Generally, at the ground connection there is a gutter to receive and collect the water percolating from the wall, or an underground drainage system made of inert materials. At the top, there is usually a metal flashing, as in the case of green façades. At the window and door frames there is often a water collection element above the window and doorframes, as well as vertical slats and sills which also act as boundary elements. At the building corners there may be metal angles or panels may be placed ensuring overlapping of one façade onto the other.

Vertical vegetated enclosures can be divided into modular systems and vegetated walls. The first type, characterised by a high level of industrialisation and rationalisation of assembly, is made up of modules containing the substrate, i.e. the layer on which the plants grow, made up of slabs of expanded material or earth, and sometimes includes pre-planting. The second type, such as Patrick Blanc's "Le Mur Végétal" system, is made with a textile substrate, without the use of soil. This layer generally consists of a double layer of synthetic felt in which the plants are placed manually by the operator who inserts them into special pockets between the two fabrics, exploiting the characteristics of hydroponic cultivation. Both systems are integrated with irrigation or fertigation systems to guarantee plant nutrition in an automatic and programmable manner.

Table 7.4 shows, by way of example, some of the essences that can be used in vertical vegetated enclosures as well as some of their characteristics.

TABLE 7.4. Table with the characteristics of some plant species that can be used for living walls (Source: own elaboration)

TYPES OF ESSENCES	DESCRIPTION	PLANT ESSENCES	HEIGHT DEVELOPMENT [cm]	TOTAL WEIGHT [kg/m^2]
HERBACEOUS GROUND COVER	Plants do not develop woody branches; small plants produce compact vegetation	Marsilea crenata, Episcia, Fittonia, Pilea, Sedum spectabile, Vinca	5 ÷ 20	15 ÷ 25
MUSCINALE	Plants with small both stems and leaves, lacking vascular tissues; primitive plant organisms growing in damp places, on soil, rocks and tree bark	Aploide, Dawsonia superba, Sphagnum, Vesicularia	10 ÷ 30	10 ÷ 25
FERN	Plants with fronds. Most varieties have a globular, almost stemless development	Asplenium, Anthurium, Salvinia natans	60 ÷ 120	10 ÷ 20
EPIPHYTES	Plants that do not take root in the soil but settle on the trunks or branches of other plants, using them as support without damaging them or drawing nourishment from them.	Drynaria, Medinilla, Rhipsalis, Clusia	10 ÷ 30	2 ÷ 8
SMALL ARBUSTIVE	Woody perennial bushy species, whose branches separate from the central stem or whose trunk is not present.	Abelia, Berberis, Kerria, Begonia, Buxus Sempervirens, Spirea, Liguraria, Bergenia	60 ÷ 150	20 ÷ 40

Table 7.5 classifies the modular systems of living walls, while the Mur Vegetal have no specific subtypes.

TABLE 7.5. Classification table for modular living wall systems (Source: own elaboration)

CLASSIFICATION OF MODULAR LIVING WALLS SYSTEMS					
	CLADDING SYSTEM	*CLADDING FIXING*	*SUBSTRUCTURE TYPES*	*SUBSTRUCTURE MATERIAL*	*FIXING TO LOAD-BEARING LAYER*
MODULAR PANELS SYSTEM	Recycled polyethylene panel with rockwool growing layer	Supported by the cladding	Mullions and transoms system	Stainless steel	Mechanical/ chemical dowels
	Multilayer panel with rockwool growing substrate	Threaded screws anchored on structural panel	Mullions and brackets system	Galvanised steel	Mechanical/ chemical dowels
SYSTEM WITH BOXES	Shaped box in recycled polypropylene for culture pots	Supported by the cladding	Mullions and transoms system	Stainless steel	Mechanical/ chemical dowels
	Expanded polypropylene boxes containing growing substrate	By gravity through aluminium clip and curved rod	Mullions and brackets system	Alluminium	Mechanical/ chemical dowels
POCKETS SYSTEMS	Rigid EPP boxes with recessed culture pockets	Clips on top edge	Tramsoms system	Alluminium	Threaded screws
	Multilayer geocomposite panel with notched pockets	Box profile on shaped plates fixed with screws	Mullions system	Galvanised steel	Mechanical/ chemical dowels

Some systems available on market are described below.

Modular panels system

It is a pre-designed modular system, including automatic irrigation. It consists of panels made of an aluminium support plate and a recycled polyethylene cladding, perforated to create pocket with rockwool growing substrate for plant roots. The support structure, in front of a hydrophobic polyethylene panel, consists of C-section mullions and transoms made of plates, welded together. The panels are housed in an aluminium frame with hooks on the rear side that allow fixing by gravity to the metal transoms. Cold-folded aluminium sheets are arranged on the sides and at the top. They conceal the irrigation system and delimitate the whole system (Fig. 7.10).

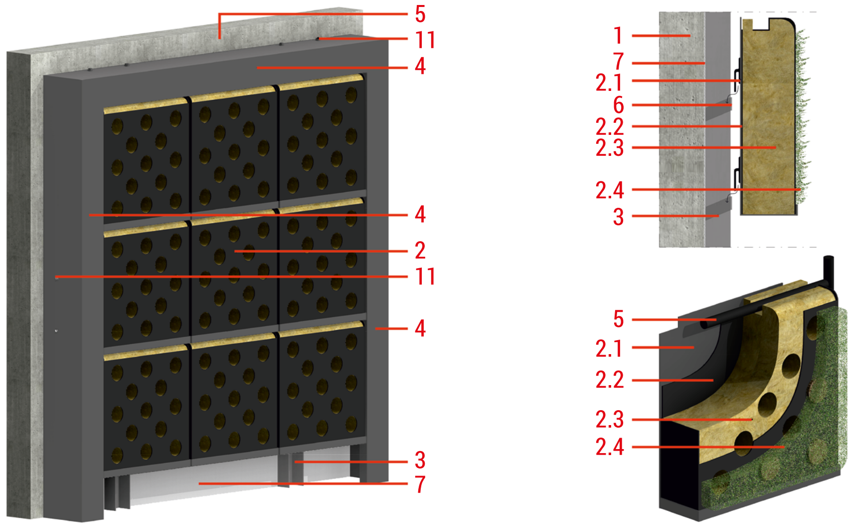

FIG. 7.10. Axonometry, section and detail of the panel. Legend: 1. Load-bearing layer; 2. Panel; 2.1 Aluminium backing sheet, 4mm thick; 2.2. Recycled polyethylene cladding layer, 4mm thick; 2.3. Perforated rock wool growing substrate, 75 mm thick; 2.4. Plants; 3. Mullion, C-section profile 38 x 51 mm, 2 mm thick; 4. Cold-bent aluminium sheet, 2 mm thick; 5. Drip lines irrigation system, circular profile ⌀16 mm; 6. Tramsoms, flat profile 20 x 2 mm; 7. Hydrophobic polyethylene panel, 2 mm thick; 8. Corner profile for sheet metal fastening, L-section profile 70 x 50 mm, 2 mm thick; 9. Mechanical anchor for fixing to the load-bearing layer; 10. Hexagonal screw for anchoring the angle profile; 11. Hexagonal screw for fixing the sheet metal (Source: own elaboration)

System with boxes

It is a pre-designed modular system consisting of shaped boxes made of recycled polyethylene where two to five polyethylene pots (maximum diameter 125 mm) with soil as a growing substrate are arranged. The system is supported by a galvanised steel structure made up of C-profile uprights and transoms (plates). They are fixed to each other and mechanically fastened to the wall load-bearing layer by dowels. A 2 mm thick hydrophobic polyethylene panel is arranged between these two elements. The boxes are hung from the transoms by hooks positioned on the back. The system includes an automated irrigation system with drip lines placed every five horizontal alignments. The containers are shaped to always guarantee a water reserve at the bottom (Fig. 7.11).

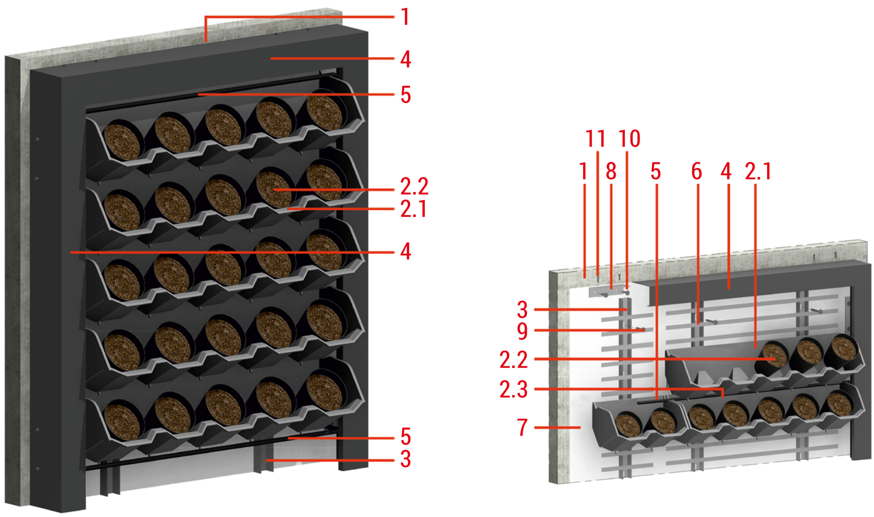

FIG. 7.11. Axonometry and detail of the panel fixing. Legend: 1. Load-bearing layer; 2. Box; 2. Shaped polyethylene container; 2.2. Pot (⌀ max 125mm) with growing medium (soil); 2.3. Water drainage channel; 2.4. Plants; 2.5. Water reservoir; 3. Mullion, C-section profile 38 x 51 mm, 2 mm thick; 4. Cold-bent aluminium sheet, 2 mm thick; 5. Drip lines irrigation system, circular profile ⌀16 mm; 6. Transom, flat profile 20 x 2 mm; 7. Hydrophobic polyethylene panel, 2 mm thick; 8. Corner profile for sheet metal fastening, L-section profile 70 x 50 mm, 2 mm thick; 9. Mechanical anchor for fixing to the resistant layer; 10. Hexagonal screw for anchoring the angle profile; 11. Hexagonal screw for fixing the sheet metal (Source: own elaboration)

Modular multilayer panel system

It consists of a multi-layer module anchored to a back-to-back panel. The support structure is generally made up of galvanised steel t or L-shaped mullions fixed by brackets and mechanical dowels to the resistant layer. Cement agglomerate panels (12 mm thick) are fixed to these elements by self-threading screws. There is an external hydrophobic panel to ensure that the irrigated area remains in front of the support panel. The panel is fixed by galvanised C-section steel transoms which provide support for the base module and the starting point for the irrigation system. The module is a multi-layered element consisting of a recycled polypropylene box containing the rockwool growing substrate. The module is horizontally spaced by the extruded polyethylene geocomposite drainage layer. The standard panels are L60 x H45 cm approximately 22 cm thick and weigh 15 kg (water saturated) (Fig. 7.12).

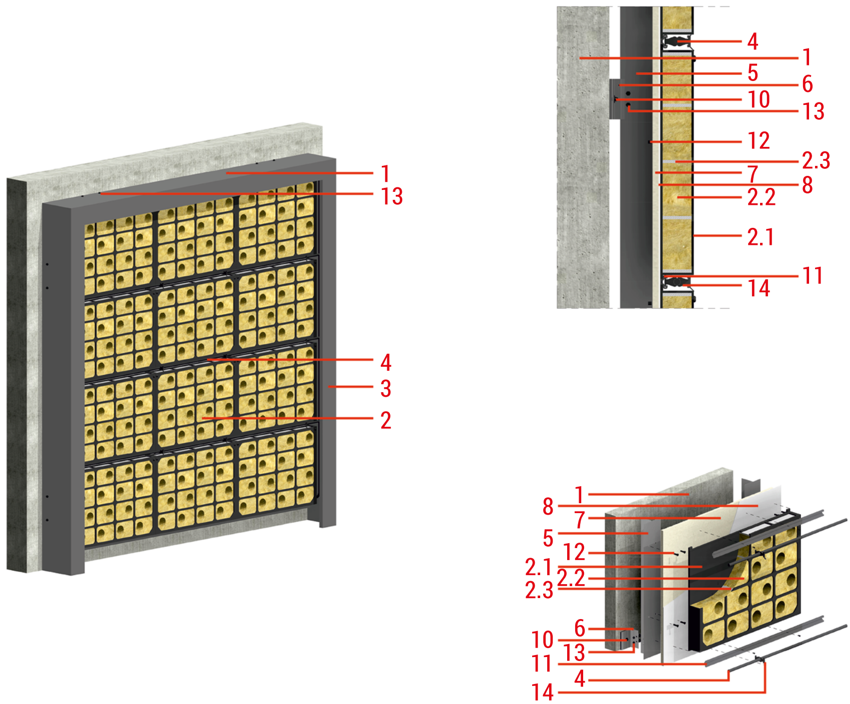

FIG. 7.12. Axonometry, section and detail of the panel fixing. Legend: 1. Load-bearing layer; 2. Panel; 2.1 Recycled polypropylene containment box, 4 mm thick; 2.2. Rockwool growing substrate, 55 mm thick; 2.3. Geocomposite drainage layer made of extruded polyethylene; 2.4. Plants; 3. Cold-formed aluminium sheet, 2 mm thick; 4. Driplines irrigation system, circular profile ⌀13 mm; 5. Galvanised steel mullion, T (or L) section profile 60 x 100 (50) mm, 2 mm thick; 6. Mullion fixing bracket, galvanised steel profile; 7. Cement particle board; 8. Hydrophobic polyethylene panel, 2 mm thick; 9. Corner profile for sheet metal fastening, L-section profile 70 x 50 mm, 2 mm thick; 10. Mechanical anchor for anchoring to the resistant layer; 11. Galvanised steel support beam, C-section profile 12 x 26 mm, 2 mm thick; 12. Hexagonal head screw; 14. Clamp for anchoring the thermal profile of the irrigation system; 15. Hexagonal head screw for anchoring the corner profile (Source: own elaboration)

Boxes system

It is a modular system made up of modular expanded polypropylene (EPP) boxes measuring L60 x W17 x H19 cm containing the growing substrate (soil). Boxes are individually attached to the support structure by adjustable aluminium clips and galvanised steel rods ⌀5 mm. The substructure consists of aluminium mullions with a 48 x 37 mm shaped section that are fixed to the resistant layer by aluminium anchoring brackets and mechanical dowels positioned at various heights. The system includes an irrigation system with drip lines arranged at each level (Fig. 7.13).

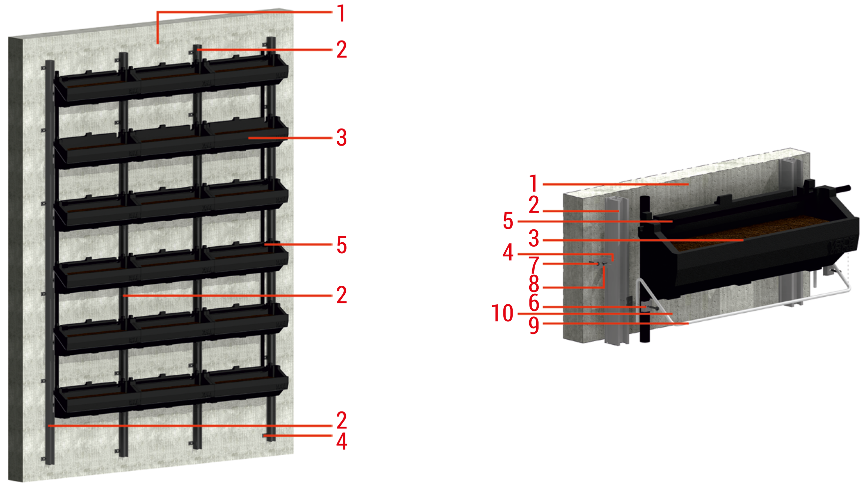

FIG. 7.13. Axonometry and detail of the base module. Legend: 1. Load-bearing layer; 2. Aluminium mullion EN AW 6060-T6, shaped section 48 x 37 mm; 3. EPP modular basin, standard dimensions 60 x 17 x 19 cm (LxWxH); 4. Single anchor bracket in aluminium EN AW 6060-T6; 5. Screws for fixing the mullion; 6. Adjustable aluminium clip with M6 dowel for fixing the modular pool; 7. Mechanical dowel for anchoring to the load-bearing layer; 8. Screws for fixing the mullion; 9. Galvanised steel rod ⌀5 mm for supporting the modular pool; 10. Screws for fixing support bar (Source: own elaboration)

Boxes with culture pockets system

It is a modular system with interchangeable plant boxes characterised by a size of L40 x H40 cm and slots where the plants are arranged. Each row of boxes is placed on a shaped aluminium profile that is both a gutter for water reservoir and support for the boxes. The module consists of a box container with nine EPP pockets, a microfibre panel for irrigating the plants, a stiff polypropylene panel and the growing substrate. The system is fixed by polypropylene clamps and perimetrically enclosed by a folded aluminium profile. The total weight of the module, including the plants, is 35÷40 kg/m^2 (Fig. 7.14).

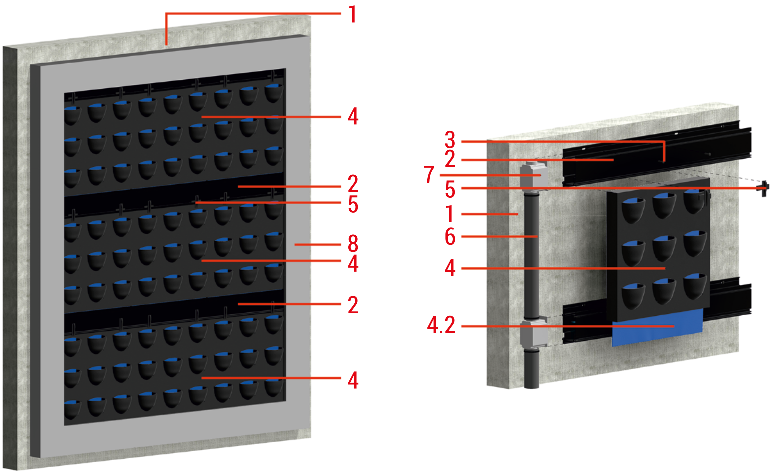

FIG. 7.14. Axonometry and detail of the base module. Legend: 1. Load-bearing layer; 2. Shaped aluminium profile, Al6063 T5: support and water reserve for upper panel; 3. Mechanical anchor for fixing to the resistant layer; 4. Module; 5. Polypropylene clamp for module fixing; 6. Circular profile for irrigation system; 7. Box with pump for irrigation water delivery; 8. Folded aluminium profile for perimeter delimitation (Source: own elaboration)

Pockets system

It is a modular system with mullions made of galvanised steel C-profiles with grooves, fixed by mechanical or chemical dowels to the wall load-bearing layer. Shaped galvanised steel S-section plates for supporting the panel are fixed to mullions with hammerhead bolts. Panel is fixed by gravity by transversal bars inserted in special slots. These support bars have box sections with a rectangular cross-section. They are inserted into slots in the geocomposite panel at the top, at intervals of 190 cm. The fastening is punctual and visible, completed with a second hammerhead bolt inserted at the top once the profile has been arranged on the anchor plate. The panel consists of two bidirectional geocomposite layers and a polyurethane substrate, joined together by discrete quilting with polyester thread. Slots are made in the module to accommodate the fixing bars for supporting the system and the seam is regularly interrupted to allow the transverse insertion of drip profiles for irrigation (Fig. 7.15).

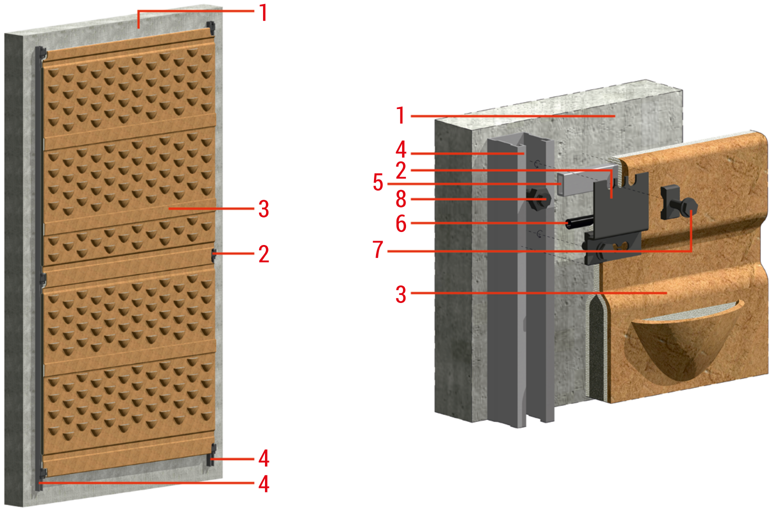

FIG. 7.15. Axonometry and detail of the fastening node. Legend: 1. Load bearing layer; 2. Stainless steel fixing plate; 3. Panel; 4. Mullion; 5. Stainless steel fixing bar, box profile 20 x 9.5 mm (2 mm thick); 6. Driplines (irrigation system); 7. Hammer-head screw for fixing the plate to the mullion; 8. Mullion fixing dowel (Source: own elaboration)

Mur Vegetal

In this system plants grow on panels covered with four layers of felt, using hydroponics techniques. These panels are supported by a modular aluminium frame made up of box profiles measuring 60 x 30 mm, 4 mm thick, spaced from the wall to ensure adequate ventilation. The system is equipped with an automatic control system for the fertigation and lighting cycles. The aluminium substructure holds the plant panels. The substructure is supported by aluminium brackets and anchored to the wall by mechanical dowels. Each panel consists of an aluminium frame and a FOREX sheet covered with 3-4 layers of felt, suitably engraved to create the planting pockets.

According to the hydroponics method, in Each pocket there is a plant (Fig. 7.16).

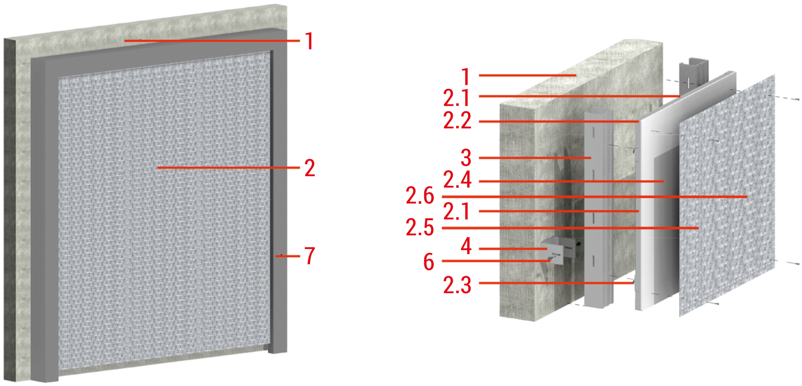

FIG. 7.16. Axonometry and detail of the basic module. Legend: 1. Load bearing layer; 2. Modular panel; 2.1 Bi-directional aluminium frame, box profiles 60 x 30 mm, 4 mm thick; 2.2. Corner joint; 2.3. Plate with gravity anchorage hook; 2.4. PVC stiffening panel; 2.5. Four layers of felt for water drainage, root growth and plant containment; 2.6. Plants; 3. Aluminium mullion, C-section 125 x 100 mm, 8 mm thick; 4. Aluminium anchoring bracket; 5. Mechanical anchor for anchoring to the load bearing layer; 6. Screws for fixing upright to bracket system; 7. Aluminium profile for perimeter containment (Source: own elaboration)

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