TECHNICAL TRANSACTIONS | CZASOPISMO TECHNICZNE
ARCHITECTURE | ARCHITEKTURA
10-A/2014

MARIA KMIEĆ*

GREEN WALL TECHNOLOGY

TECHNOLOGIA ZIELONYCH FASAD

A b s t r a c t

Green walls are used as one of methods which for many years have been used to enhance the appearance of building elevations. They make it possible to introduce greenery into urbanised areas, which are often limited by the size of the building plot. They add an excellent aesthetic dimension to the so called 'blind' walls found in city centres. Green walls not only bring with them an element of beauty and integration with nature, but by being used to a wider extent, could also have a positive impact on the city's micro-climate. Various technologies enable the creation of green walls on the outside of buildings as well as in semi-open spaces and interiors. In this paper, five different techniques of setting up living walls are described, from the relatively simple technique of planting climbers that easily cover bare walls to modular panel systems or green wall systems with flower pots to 'living wall' solutions and finally, to Patrick Blanc's highly sophisticated patented vertical garden technology.

Keywords: *green wall*, *vertical gardens*, *technology and construction*

S t r e s z c z e n i e

Zielone fasady to kontynuacja stosowanej na przestrzeni lat metody używania roślin do wzbogacenia elewacji budynków. Dają możliwość wprowadzania zieleni do przestrzeni miejskiej, często ograniczonej przez wielkość działki. Są doskonałym elementem estetyzacji „ślepych" ścian występujących w śródmieściach miast. Zielone fasady wprowadzają nie tylko element piękna, integracji z przyrodą, ale zastosowane na szerszą skalę mogłyby mieć także pozytywny wpływ na mikroklimat miasta. Różnorodne technologie zielonych fasad umożliwiają tworzenie ich na powierzchniach ścian zewnętrznych, w przestrzeniach półotwartych oraz we wnętrzach. W niniejszej pracy zostało opisanych pięć technik zakładania zielonych ścian, od relatywnie prostej techniki sadzenia pnączy, która pozwala w łatwy sposób pokryć puste ściany, poprzez systemy modułowe z paneli, ścianę opartą na ruszcie konstrukcyjnym z donicami, nowoczesne rozwiązanie „żyjącej ściany", aż do opatentowanej technologii pionowych ogrodów Patricka Blancka.

Słowa kluczowe: *zielona fasada*, *pionowe ogrody*, *technologia i konstrukcja*

* M.Sc. Eng. Arch. Maria Kmieć, Ph.D. student, Institute of Building Design, Faculty of Architecture, Cracow University of Technology.

1. Introduction

Green walls (vertical gardens) have in recent years become an interesting method of spatial design, combining the natural environment with urban space especially in places where there is not enough space for greenery. This constitutes a large problem especially for the housing environment, where green walls play an important role. People desire to be surrounded by nature even if for economic reasons, they are forced to live in cramped, large agglomerations. An efficient way of improving the quality of life is the introduction of plant-life in various forms like, for example, greenery on building elevations[1].

Nature itself is the inspiration for vertical gardens. In many places in the world, we can admire vertical lawns on mountain paths; plants such as climbers, moss and lichen growing on rocks; and coastline cliffs decorated by carpets of multi-coloured flowers. Climbing plants have for a long time been used to decorate walls. Another method includes planting trees or bushes by the walls of building. This requires carefully securing the root system for it not to damage the walls of buildings and the appropriate fixing of plants to walls. Hedges and easy to nurture hanging plants are basic examples of vertical garden inspirations. Grass roofs are popular in Norway. Despite the simple technology used for this interesting solution, they are very durable[2].

Placing greenery on the elevations of buildings has a lot of advantages. It enables the integration of the natural environment with the urban environment in places where there is not much free space. The vertical positioning of plants facilitates the washing away of impurities and requires much less water than horizontal gardens. Green walls significantly improve the look of cities, especially when they are placed on blind, bare walls. At the same time, they constitute an additional biologically active surface, which is very important for the ecosystem.

Due to the growing interest in green walls in recent years, both amongst designers and potential clients, a large number of technological solutions have emerged:

1. Facades with climbers planted at the base of walls.
2. Modular systems from grid panels.
3. Green wall systems with flower pots.
4. The so called ‘living walls’.
5. Patrick Blanc’s technology.

Each of the above-mentioned techniques requires the use of different techniques to fix plants to the ground as well as dilate elements used to sprinkle and dispose of water.

2. Facades with climbers planted at the base of the wall

Climbing plants (lianas) are characterized by thin, fast growing stems which are unstable, this is why they have tendrils which support them. Climbing plants attach

---

[1] T. Malec, *Ogrody wertykalne w przestrzeni polskich miast*, Czasopismo Techniczne, z. 6-A/2012, Kraków, 299-305.

[2] W. Kosiński, *Pionowe ogrody – idea, technologia i estetyka na nowy wiek*, Czasopismo Techniczne, z. 2-A2/2011, Kraków, 109.

themselves to the ground by using prehensile organs or by entwining themselves around a support. Climbing plants climb in particular ways:
– entwining plants – by wrapping themselves around a support,
– climbing plants – by attaching themselves to the ground with the help of tendrils, for example, the grapevine,
– climbers supporting themselves with the help of prehensile roots or surfaces adjacent to the ground, e.g. ivy,
– stretching plants – by leaning their stems against objects placed beneath them or supports with the help of tendrils, spikes, thorns, for example, climbing roses[3].

Climbing plants have been used in various forms of applied and decorative arts for centuries. Information about the use of grapevines in arcades dates all the way back to Egypt, around 2600 B.C. In Babylon and Ancient Greece, both grapevines and ivy played an important role. In those times, plants were cultivated in containers. The Romans took over the cultivation of plants from the Greeks. The first descriptions of 'green works of art' come from those times. Pergolas were built for protection against the sun, giving shade to courtyards and roads. After the fall of the Roman Empire, there was less interest given to climbing plants. The next references to them come from the Middle Ages. Initially, climber plants were only used in castle gardens for decorative purposes, only later did gardens appear in front of city walls. In the times of Renaissance espaliers, pergolas, arcades and arcade alleys were built. In the Baroque period, a trend emerged for arbours surrounded by hedges, with bushes and trees appropriately trimmed. In the 17th and 18th centuries, many new species of plants were imported into Europe, and by the 19th century, all known species of climbing plants were available. The beginning of the 20th century saw climbing plants being used widely to combine architecture with nature. In this time, many publications on this topic appeared in specialist magazines. This dynamic rise of interest in using climbing plants in architecture was halted by World War I. In the 20-year period between the two World Wars, a new building trend based on the use of rock surfaces was not conducive to incorporating green vertical surfaces into the newly built urban structures. In recent years, when ecology has begun to perform an important role, greenery in architecture has become a factor in solving the problem concerning proximity to nature[4].

The appearance of supporting constructions for climbing plants are determined by many factors. These are, amongst others, the size and rate of plant growth, blooming time or the type of prehensile organ. An appropriate solution should ensure that the construction lasts many years. By taking the species of plant and the climate into consideration, one should foresee if the framework will be visible for a certain period during the year or not. This has an influence on the appearance of the support. The selection of the size of its elements, which depends on the species of climbing plant, is also important[5]. Existing building elements such as balconies or pergolas can serve as supports for the plants to climb on.

---

[3] R. Baumann, *Domy w zieleni*, Warszawa 1991, 18.

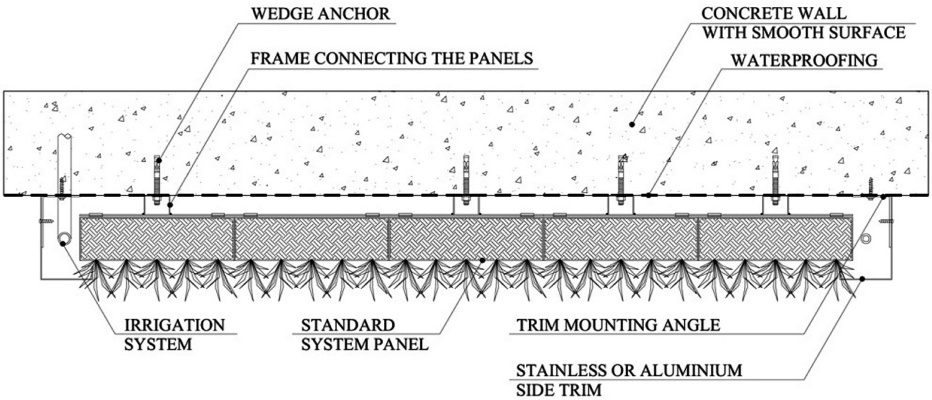
[4] *Ibidem*, 18-24.

[5] K. Łakomy, W. Bobek, *Nowoczesne systemy konstrukcji pod pnącza – technologie, rozwiązania i problemy projektowe, dobór roślinności*, Czasopismo Techniczne, z. 2-A2/2011, Kraków, 135-144.

Pergolas are the most popular of these. Pergolas are constructed with two vertical columns connected with cross-beams. These can be made of wood, steel or other materials. Trellises are older constructions consisting of posts supporting one or two beams. A lattice or interwoven pieces of steel or natural materials can be attached between the posts, enabling the growth of climbing plants. Wall constructions may be made from different materials and can have different shapes and sizes. For smaller climbers, nets or lattices are used as wall constructions, while for bigger climbing plants, walls constructions are made from metal or mixed supports. The supporting elements should be fixed at a distance from the walls. This allows climbing plants to freely wind themselves around the construction[6]. Climbing plants can be planted in flower-pots or other containers as well as in the ground. Plants planted in the ground are usually thicker and their roots are less exposed to frost.

3. Modular systems

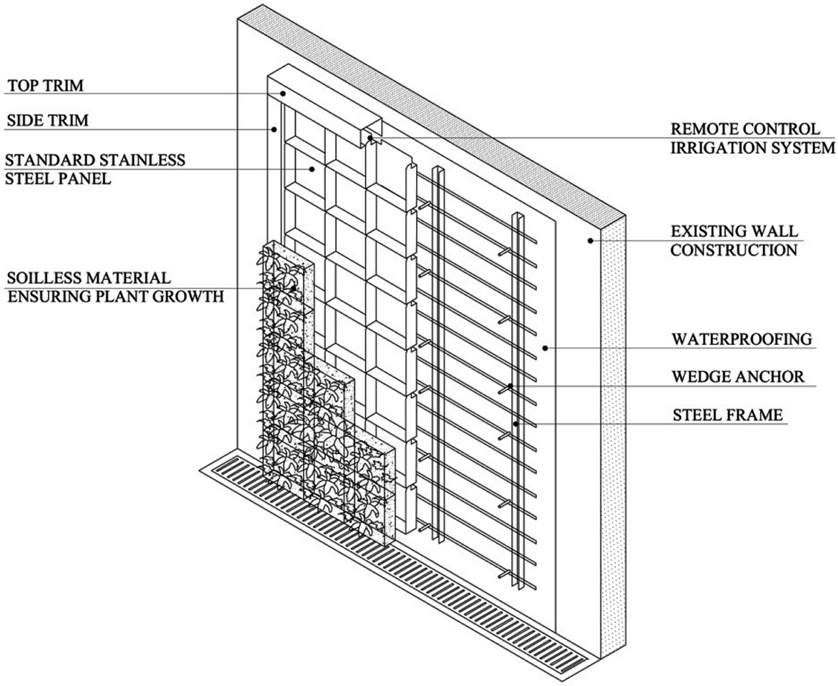
Modular system solutions can be applied on every surface and in every climate. They are very resistant to strong winds and rain. Illustrations 1 and 2 present the construction of such systems.



Ill. 1. A modular green wall horizontal section (source: http://gsky.com/green-walls/pro/, access: 12.11.2012)

This system consists of five basic parts:
– panels made from stainless steel,
– soilless material ensuring plant growth,
– plants specially cultivated to be resistant to the effects of atmospheric factors,
– a computerized vertical irrigation system with temperature and moisture sensors,
– wall frame assembly (the frame can be made from wood or stainless steel).

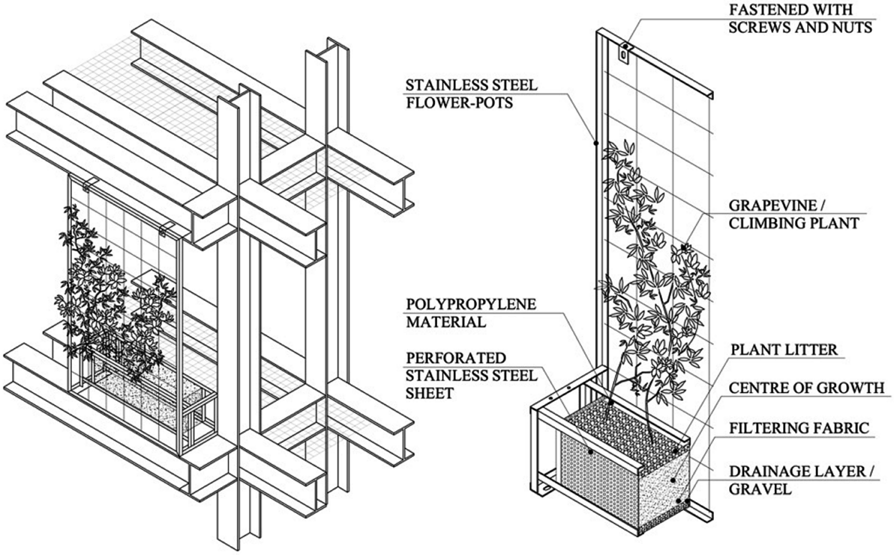
6 J. Borowski, P. Lachota, *Zastosowanie roślin pnących i okrywkowych*, Warszawa 2004, 65-78.



Ill. 2. A modular green façade solution (source: http://gsky.com/green-walls/pro/, access: 12.11.2012)

4. Green wall systems with flower-pots

In cases where the size of the building is not determined by the size of the plot, a solution increasing the size of its dimensions can be applied on building elevations. A special system is constructed alongside the walls and is fixed to the building construction. Flower-pots are placed on this system and secured by bars. This system is usually made using post and lintel stainless steel technology. It can be at a small or large distance from the building with technical platforms used for the purpose of plant growth control and conservation. In this case, an automatic irrigation system ensures good plant growth. Water is transported to the flower-pots through small pipes made from plastic. Additional heating cables are equipped with temperature sensors which prevent the plants from freezing. Illustration 3 presents a steel grid wall with pots.



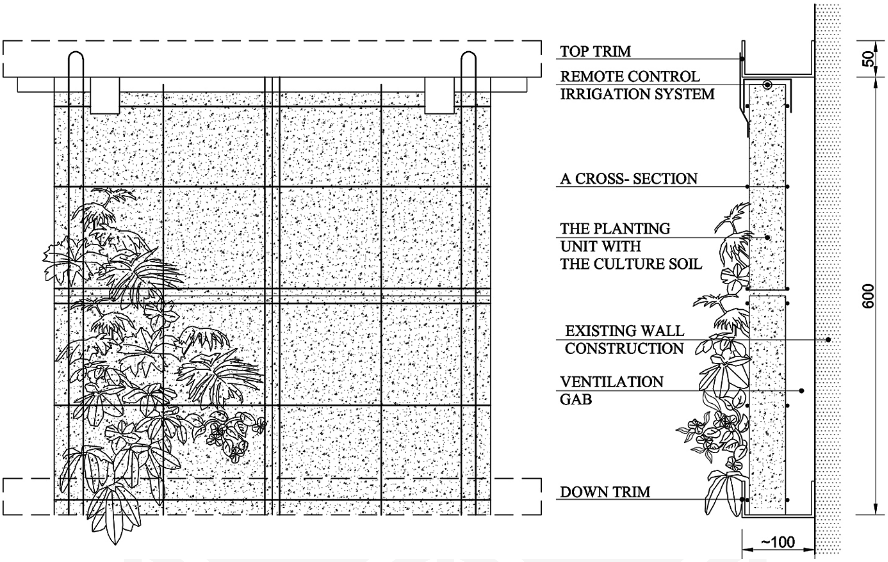
Ill. 3. Solution based on a steel grid wall with pots and a technology platform from gSky Plant Systems Inc. (source: http://gsky.com/green-walls/basic/, access: 12.11.2012)

5. 'Living wall'

'Living walls' are a more advanced technology in which the plant roots' ability to grow across flat surfaces is used. This can be done in various ways. These constructions differ to those technologies mentioned above because constructive elements are used to a much lesser extent. Plants are planted in special containers and are appropriately suited to the climatic conditions provided with access to light. During their growth, the plants become rooted in system inserts similar to garden foam. These inserts are attached in carrying frames fixed to the construction. Irrigation devices and heating cables can be used in this situation. This is a very flexible system due to its light weight and capacity to make the entire surface green[7]. An example of a 'living wall' is the Parabienta Living Wall System. The system is designed by the Japanese company, the Shimizu Corporation. The solution combines panel type planting units to form a wall. Culture soil forms the base of the planting unit which is fixed with mounting rails. The units are additionally strengthened vertically. The planting units are suspended on bands. Various kinds of plants can grow on this construction depending on plant life conditions they require. The planting units can be easily moved or exchanged during its construction or conservation. This solution is presented in Ill. 4.

---

[7] K. Barnaś, *Elewacje zielone – nowoczesne technologie w projektowaniu i wykonawstwie*, Czasopismo Techniczne, z. 2-A1/2011, Kraków, 10-11.



Ill. 4. Parabienta's Living Wall System by the Shimizu Corporation (source: own elaboration)

6. Patrick Blanc's technology

On the basis of many years of studies and numerous travels to tropical rainforests, Patrick Blanc described the most simple solution in his patent entitled 'Design for growing plants without soil on a vertical surface'. In this document, he presented a structure consisting of a vertical surface covered with felt, which is a substitute for soil and retains water. The whole structure consists of a framework from a vertical PVC sheet additionally covered in polypropylene foil. Two layers of felt are attached with the aid of fasteners. The plants require access to light, carbon dioxide and mineral-enriched water. The construction possesses an automatic plant water moisturizing system regulated by a moisture meter.

The roots develop not in a capacitive but on a flat surface, unlike many other soilless cultivation systems where the roots grow inside a capacity filled with certain substances (for example peat, mineral cotton, coconut fibre, or polystyrene mixtures). The weight of the whole vertical installation is very significant. Thinner materials like felt are not deformed by changes of temperature. Micro-fissures between fibres can expand in freezing conditions without changes to its general structure. This is because fibres are nonstructural woven materials. The durability of the material is strengthened with polypropylene foil placed between the fabric and PVC sheets.

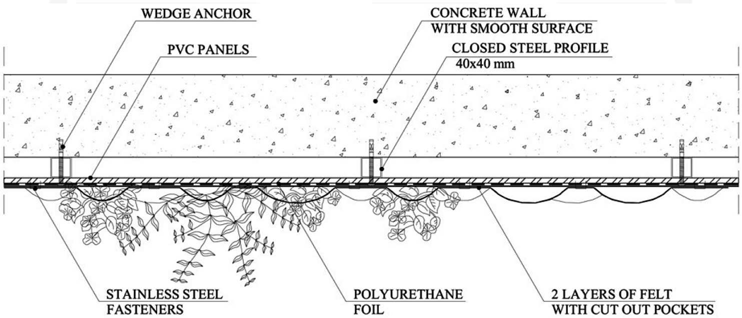
Felt does not decompose because it is made of acrylic fibres. Of all the elements of the vertical garden, only felt has an influence on the plants' biology. In its fibres, the roots can grow and become rooted, and absorb water and nutrients. In reality, this fabric can be compared to a thin layer of algae and moss growing on rocks and tree trunks. Different species of plants in the vertical garden grow into the fabric just like they would grow into beds of moss on a rocky surface. In order to facilitate plant installation, the fabric consists of two layers fixed (with stainless steel fasteners) to a durable PVC construction with a layer of polyurethane foil. In the first layer, vertical openings 5 cm to 10 cm wide are cut, depending on the dimensions of the plants. Soil is removed from the plants and their roots are placed between both layers.

Initially, fibres and steel fasteners hold the plant. Later the roots start to grow in all directions. The roots grow into the fabric and entwine around the fasteners. Thanks to this process, the plant is able to hold itself. Some of the shrubs' roots can be as much as several metres long. The completely open structure is only limited by its dimensions. This enables the shrubs and small plants to coexist, because the fabric is able to evenly distribute water and nutrients in its entire surface. The entire exchange between plant roots, water and air occurs in the irrigation fabric. In the fabric, an interaction occurs between microorganisms and plants, this enables the roots to absorb more water and mineral salts.

Microorganisms interacting with the roots can convert toxins (such as pesticides, different organic mixtures and volatile organic compounds) emitted by industry, vehicles and the biological activity of humans and animals into less harmful substances. City dust is an additional impurity. Electrostatic forces keep this dust on the surface of leaves. In vertical gardens, dust washed out by rain, gathers in the felt. There, it is decomposed by microorganisms into substances which the plant can absorb. This irrigation fabric becomes a certain type of ecosystem in which different biological processes occur. It is irrigated by a plastic tube made of low density polyurethane which makes it more resistant to deformations caused by water freezing. This tube is arranged horizontally and has 2 millimetre openings placed every 10 cm. Water is supplied to the plants at an appropriate pressure, 3–5 times a day, depending on the time of year. Each irrigation lasts from 1 to 3 minutes. To maintain mineral balance in the root systems, a fertilizer is applied which is much more diluted than that used in farming or gardening. If rain-water is used for irrigation, the density is even lower due to the fact that such water contains calcium carbonate which partly prevents the absorption of useful ions. Depending on exposure to the wind and sun, time of year and if water retention is used, a vertical garden requires a daily amount of 0.5 to 5 litres of water per metre squared.

A vertical garden must have its own construction. This structure consists of a stiff, water-resistant, non-toxic material. Blanc initially used wooden panels, attempting to recreate tree trunks that exist in the natural environment. With regular irrigation, they lasted 3–5 years. He then started to use PVC, which turned out to be ideal. With 10 mm long fasteners, the wooden panels are able to withstand a weight of 100 kg/cm^2. A stiff PVC panel can be directly attached to a wall supporting a vertical garden. Circulation of air between the wall and the PVC panel is, however, recommended. One of the various solutions to this is a framed construction made of metal pipes (aluminum, galvanized or stainless steel) which is attached to the wall. This construction has a rectangular grid built from pipes with square cross-sections, each 4 cm long. The connected pipes form a grid of dimensions 60 × 60 cm. Sometimes, constructors prefer to install vertical pipes with horizontal bars attached to where the PVC panels abut. The panels are riveted to the metal pipes. Silicon is used to seal pipe connections and protect them from water. The weight of the vertical garden is quite low. 10 millimetre PVC panels weigh 7 kg per m^2. One must add 3–5 kg/m^2 for irrigating fabric, depending on how much water it contains, and 1 to 5 kg/m^2 for the plants (depending on the species). This gives an average of 15 kg/m^2 for a structure enabling the growth and long-term stability of the plants. The whole construction together with the metal frame may weigh from 20 to 50 kg/m^2. Patrick Blanc's green wall solution is shown in Ill. 5. Plants together with irrigating material, a 1 cm panel and a 4 cm gap created by the metal frame, constitute a solid insulation from the cold in winter and the heat in summer. The vertical garden may serve as part of a renovated old and abandoned building, giving insulation, visual comfort and better air quality.

Patrick Blanc uses several criteria in order to plan the sequence, arrangement and selection of plant species used for each project. The most important criteria being geographical location, latitude, and the direction of light towards which the garden is exposed[8]. In turn, as far as internal gardens are concerned, the same climate can be ensured in every location. A comfortable temperature for humans is around 20 degrees Celsius. This is comparable with the temperature of forest undergrowth (a layer in the ecosystem consisting of bushes) in tropical forests at a height of 600 cm to 800 cm. The case is similar with the amount of available light possibly achieved in closed spaces (1,500 to 2,000 lx, which is 1.5% to 2% of full sunlight). Relative humidity amounts to around 50%, whereas in the tropical forest undergrowth, it ranges between 85% and 95%. Low humidity is unfavourable for plants since it exposes the plant to dryness. A vertical garden has its own micro-climate in relation to the surrounding level of humidity. The fact that the irrigating fabric is constantly moist, and that plants release water back outside, improves the conditions of growth for the whole garden and enables more delicate plants to be cultivated which would not survive in ordinary flower-pots.



Ill. 5. Patrick Blanc's green wall solution (source: own elaboration based on Patrick Blanc's book *The Vertical Garden. From Nature to the City*)

All the selected species in each project are arranged in a particular sequence. This is selected depending on the climatic conditions occurring in different parts of the vertical garden, and also on the rate of growth and the aesthetic and structural aspects of each

[8] P. Jodidio, *Landscape. Architecture Now!*, TASCHEN, 76-81.

species. As far as external gardens are concerned, Blanc attempts to recreate the plant strata occurring on cliffs. This means that plants are fully exposed to wind and sun at the top, and at the bottom, the rock base which is partly embedded in undergrowth (a layer of bushes) and protected from wind and big changes in humidity and temperature. In internal gardens, Patrick Blanc prefers to plan the strata which occurs in forest canopies. An appropriate combination of species in a vertical garden is an important factor contributing to the general impression of the whole garden. The combination must result from an understanding of how the plants evolved. A garden must look to be thriving already several weeks after installation and should grow and create the same impression for many years. The plants planted next to each other should grow at a similar rate in order to avoid competition for space and subsequent overcrowding. Plants in high gardens must be able to withstand strong winds, large fluctuations in temperature and the drying out of irrigation material between watering. To achieve a harmonious plant combination, one must take into consideration the spatial characteristics of each plant, the way it branches out, where and how its roots naturally grow, leaf density, dimension, size, texture and colour of leaves, and how they absorb and reflect light. Plants are arranged on the basis of their ecological, structural and chromatic characteristics, giving each vertical garden a unique identity which changes over time.

Vertical gardens must be nurtured because they are a collection of living organisms. An efficient system of irrigation should be constantly ensured for at least several days, especially in summer. If need arises, additional light should be given. Technical maintenance of the garden involves several annual inspections, usually once every three months for external gardens and two for internal ones. Some species require little special care. Species with well-developed shoots, such as shrubs, need to be trimmed with garden shears to prevent them from branching out too much. The branches of shrubs should be no longer than 2 metres to minimize the movement of the plants' centre of gravity in relation to their supporting vertical garden[9].

7. The properties of green walls

Vertical gardens play an important role in cities and possess certain functions:

– a psychological function – based on strengthening the relationship between humans and nature,
– an aesthetic function – improving the aesthetic attributes of the building and integrating it with the environment,
– an ecological function – leading to the improvement of air parameters and the micro--climate,
– a technical function – protecting against wind, sun, dust and performing the role of acoustic, thermal and water insulation[10].
– an ecological function.

---

[9] P. Blanc, *The Vertical Garden. From Nature to the City. Revised and Updated*, London–New York 2012, 97-103.

[10] W. Celadyn, *Architektura a systemy roślinne. Studium relacji między elementami architektoniczny-mi a roślinnymi*, Kraków 1992, 16-18.

All methods of constructing green elevations have their pros and cons. Climbing plants do not require a lot of planting space. The roots of climbers growing in close proximity to the building collect water from the ground and dry out the foundations. The area of greenery protects plaster from rainwater damage. Plants do not heat up as fast as other elements of the building during sunlight. Thermal insulation results from the high content of water in plants (about 90%). The green wall significantly influences the temperature inside the building. In summer, it protects the building from direct sunlight and excessive heat, whereas in winter, it allows direct sunlight to shine through[11]. Plants decrease the loss of heat thanks to a layer of stagnant air created between the plant layer and the other element. Air-purification is another advantage – the leaves trap particles of dust and other harmful substances, the entire residue is washed down into the soil by rainwater. Climbers also improve the acoustic insulation of the building. The level of noise suppression mostly depends on leaf density. Apart from the numerous advantages of climbers, there are also disadvantages. Above all, it is the time it takes for the entire wall to become green- in comparison to new vertical garden technology, it takes much longer. Climbers also require appropriately designed, durable supporting constructions on which they can grow.

In the module solutions, the elevations become green quite quickly and evenly. Such solutions, however, cause other problems, like e.g. maintaining irrigation installations and supplying nutrients. All these solutions limit the possibility to renovate the walls. Depending on the walls' technical condition, plants may or may not damage them. Therefore, the walls should be renovated before. Nonetheless the plants blossom, change their leaf colour, and have a positive influence on the mind and body. The buildings become more natural and human-friendly.

Within the scope of research, scientists from the University of Siena and Vienna conducted an assessment of green wall energy consumption. The aim of the study was to evaluate the environmental cost as well as the cost of creating a green wall from plant cultivation to constructing structural elements to green wall conservation. Another objective of the study was to determine the benefits of green walls for the environment. All calculations were made on a hypothetical building with a volume of 1,000 m^3 and a facade with an area of 98 m^2 facing South. The results showed that in specific conditions, such as: a Mediterranean climate and a south-facing facade, green wall technology can indeed save energy, mainly by cooling the building and providing air circulation. Furthermore, results showed that when considering energy, the same amount of energy required to construct a green wall is saved by the building over a 25-year period[12]. Additionally, green walls have other environmental advantages, namely:

- a change in local microclimate,
- local temperature reduction,
- air quality improvement and pollution decrease,

[11] I. Małuszyńska, W.A. Caballero-Frączkowski, M.J. Małuszyński, *Zielone dachy i zielone ściany jako rozwiązania poprawiające zdrowie środowiskowe terenów miejskich*, Inżynieria Ekologiczna, nr 36, 2014, 40-52.

[12] R.M. Pulselli, *Emergy based evaluation of environmental performances of Living Wall and Grass Wall systems*, Energy and Buildings, 73, 2014, 200-211.

– acoustic insulation,
– biodiversity,
– enhancement of the aesthetic conditions of the landscape,
– building protection against rain, hail and UV rays.

Another important aspect of green walls is their economic benefit, mainly associated with thermal insulation. In the summertime, plants shade walls and they cool buildings due to the presence of water vapour. In turn, this leads to a decrease in wall temperature and a reduction in building overheating. It is most advantageous for green walls to face south as plants are then in the sunlight most of the day. In the winter, green walls ensure thermal insulation, maintaining a protective barrier between the floor and the wall, thus decreasing wall convection.

8. Summary

Green facades, used for centuries to make residential palaces more beautiful, have been introduced into urban areas in the 20th and 21st centuries. This is the result of new technology. They are currently being designed not only for commercial, but also residential purposes. Vertical gardens are proof that cold, bare walls can give many species of plants the opportunity to grow. City walls can become mini-botanical gardens. Each wall can display the flora typical of a given region. The appropriate selection of plants can give many different species the possibility to grow together in a small area. This can be done by taking into consideration plant growth surfaces, which prevents competition for space.

Climbing plants and walls are most frequently seen based on framed constructions with flower-pots. This is due to their technological simplicity and relatively low costs. In comparison with the most expensive technology, for example, Patrick Blanc's vertical gardens, climbing plants growing out of flower-pots and winding themselves around frameworks fixed to walls are a remarkably simple solution. Many advantages originate from this simplicity. Their maintenance is low-cost. It is limited to regular watering of plants and seasonal pruning of branches. Secondly, climbers do not occupy much space. Moreover, a construction consisting of lines, nets and supports is not required in many cases. This is the case with stone walls, bricks and durable plaster. This significantly simplifies the process of constructing vertical gardens, as certain climbing plants are able to cling onto vertical surfaces. The lack of necessity to build an additional carrying construction significantly lowers the cost of the entire enterprise.

The second group of solutions comprises systems that use complicated constructions. These include the module constructions mentioned earlier and Blanc's technology. These systems enable the use of those plants which would not be able to grow on vertical surfaces. These are still rarely found in Polish conditions, but constitute an interesting alternative to the traditionally used climbing plants. The possibility of using such species is associated with higher costs due to complicated constructions and the process of cultivation which requires access to plants on ladders and not only at ground level as in the case of climbers. The best or at least most original visual effects are achieved with expensive and complicated vertical garden solutions.

All types of green wall described in the previous chapters differ from each other when it comes to construction and price. The cheapest solution is to plant climbers. The next low-cost solution is a green wall system with flower-pots followed by modular systems together with 'living walls' and Patrick Blanc's technology. It is, however, impossible to compare the maintenance cost of each type of solution, as each has specific requirements. Basic conservation entails: trimming plants; removing old leaves; exchanging wilted and diseased plants; irrigation system inspection; construction inspection to eliminate corrosion. Other essential maintenance work includes the conservation of irrigation, fertilisation and lighting systems- such work is done at height. In autumn 2013, on the corner of 83 de la Rue d'Aboukir in Paris, a new Patrick Blanc wall was revealed. Its total area equals 250 m^2 and includes over 256 different plant species. The undertaking cost 175,000 USD, 700 USD per square metre, not including labour costs[13]. It is a high price to pay, however, turning an empty wall into a forest is priceless.

Today, when over half of the world's population lives in cities, we must show that nature can find a place for itself in urbanised environments. Its inclusion would teach city dwellers to be more sensitive towards protecting what is left of the natural environment. It may well be that with the increasing use of green walls in our country, more expensive and effective methods, such as Patrick Blanc's technology, will be applied.

References

[1] Barnaś K., *Elewacje zielone – nowoczesne technologie w projektowaniu i wykonastwie*, Czasopismo Techniczne, z. 2-A2/2011, Kraków, 7-13.

[2] Bauman R., *Domy w zieleni*, Arkady, Warszawa 1991.

[3] Blanc P., *The Vertical Garden. From Nature to the City. Revised and Updated*, Wydawnictwo W.W. Norton & Company, London–New York 2012.

[4] Borowski J., Lachota P., *Zastosowanie roślin pnących i okrywkowych*, Wydawnictwo SGGW, Warszawa 2004.

[5] Celadyn W., *Architektura a systemy roślinne. Studium relacji między elementami architektonicznymi a roślinnymi*, Wydawnictwo Politechniki Krakowskiej, Kraków 1992.

[6] Hohenadel K., *Replanting the World's Concrete Jungles*, One Wall at a Time (source:http://www.slate.com/blogs/the_eye/2013/09/18/patrick_blanc_s_newest_vertical_garden_greening_urban_walls_around_the _world.html, access: 11.10.2014).

[7] Jodidio P., *Landscape. Architecture Now!*, TASCHEN, 76-81.

[8] Kosiński W., *Pionowe ogrody – idea, technologia i estetyka na nowy wiek*, Czasopismo Techniczne, z. 2-A2/2011, Kraków, 105-125.

[9] Łakomy K., Bobek W., *Nowoczesne systemy konstrukcji pod pnącza – technologie, rozwiązania i problemy projektowe, dobór roślinności*, Czasopismo Techniczne, z. 2-A2/2011, Kraków, 135-144.

[10] Malec T., *Ogrody wertykalne w przestrzeni polskich miast*, Czasopismo Techniczne, z. 6-A/2012, Kraków, 299-305.

[13] K. Hohenadel, *Replanting the World's Concrete Jungles*, One Wall at a Time.

[11] Małuszyńska I., Caballero-Frączkowski W.A., Małuszyński M.J., *Zielone dachy i zielone ściany jako rozwiązania poprawiające zdrowie środowiskowe terenów miejskich*, Inżynieria Ekologiczna, nr 36, 2014, 40-52.

[12] Pulselli R.M., Pulselli F.M., Mazzali U., Peron F., Bastianomi S., *Energy based evaluation of environmental performances of Living Wall and Grass Wall systems*, Energy and Buildings, 73, 2014, 200-211.