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Plants in Architecture and their Integrative Role in Energy Efficacy

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1 ABSTRACT

Planting on building roofs and facades could be a way to deal with global climate changes in urban environments. Energy efficacy of this type of building is higher too, since the green roofs and green facades are a specific thermal insulation. This method of environmental quality improvement is of high importance, taking into account the growing shortage of green areas in large cities. Green roofs and facades with adequate hydraulic solutions for water drainage will partly bring back the nature to towns.

Different examples of application of such a method throughout the world present the way in which our cities could be tranformed into cosy homes at relatively low costs, by creating humane conditions and definitely higher quality of environment in urban areas. This article will show how planners can help cities find the way to a successful future.

2 INTRODUCTION

The environmental effects of human activities, in the context of world's expanding cities and city regions, is to be seen as a key issue for planners around the globe. It is those cities and agglomerations that are undoubtedly the source of a large share of greenhouse gas emissions that underlie climate change; at the same time, these are the places that are often the most vulnerable to its effects.

Time is short and if we are to avoid the worst effects of anthropogenic climate change, we must act, and act quickly. The challenge is to use (and reuse) our resources, including land, much more efficiently and, in particular, to move toward low carbon cities.

Architects and town planners need to make such projects which organize cities as smart, sustainable and integrative – and livable. One of the possibilities on the way to find successful future is to develop Urban and Environmental Technologies with lots of plants. The objective is to increase the ratio between park areas and those covered by concrete and asphalt, to the benefit of park areas. Within the best practices for "livable cities of tomorrow", there is a method of plants incorporation into architectural and urban units. In addition to all aesthetic and functional effects, roofs and facades covered with plants are an additional thermal insulation layer, which upgrade the energy efficacy of buildings.

3 SUSTAINABLE DEVELOPMENT IN ARCHITECTURE AND TOWN PLANNING

While searching for new town planning concepts, the environmental balance needs to be maintained as much as possible. Sustainable development as the prime moto of all projects in urban areas imposes strict criteria of environmental quality preservation. If current status is unsatisfactory, it is necessary to find the methods and space for planting and recultivation, on constructed buildings and terrains, thus establishing harmony between natural and constructed environment. This report shall present several different variants of planting on roofs in urban areas from global practice, as examples of energy efficacy upgrade.

Nowadays, the man is drastically separated from nature by structures which he himself has built. The nature is pushed back to outskirts of towns and therefore the town planners and architects need to deal with conception of contemporary methods of planting on flat roofs and facades, as one of the ways to retrieve the lost ecological balance in towns. An analysis conducted in 25 German towns showed that almost 40% public areas are occupied by buildings or sidewalks. In some towns, this percentage is even 50%. This percentage has doubled in the last 30 years.

Due to ever more present disturbed balance of towns, architects and developers are facing the task to plant the existing roofs and facades, and in case of new architectural and planning solutions, to envisage areas for plants, which is even easier to do in design stage.

4 ENERGY EFFICACY AND ALL FAVOURABLE EFFECTS

Green facades and roofs act as thermal insulation and produce an outstanding cooling effect, i.e. maintenance of achieved ambient temperature. Green lining on facade produces cooling effect in summer, and enhances thermal insulation in winter – in fact, it has a favourable effect on indoor climate throughout the year. Inhabitants of green streets are more active, and consume less water. Air temperature is lower. Energy loss during winter is also possible to reduce by the same green lining.

Vegetation in front of facade acts as an important thermal insulation. Air cushion created between leaves and walls reduces the heat loss coefficient of the walls: air is an additional thermal insulation layer.

5 cm thick static air layer has a heat conductivity coefficient of approximately 2.9 W/m2K, which corresponds to the one of double window glass. Protective effect is particularly high on the sides which are exposed to wind, because it reduces the cooling effect of the wind.

The basis for such a new approach is the important fact that leaves act as a live “solar collector”. This “solar collector” achieves optimal follow-up with daily and annual cycles, providing the following advantages: in summer, when the sun is high, leaves spring up and behave as ventilation shutters, acting as a partition between the plant and building, while cooling the air which enters the house. Conversly, in winter, when the sun is low, leaves of evergreen carpet – due to low hydrostatic pressure – press together and bend downwards, creating a layer of air insulation.

Aerodynamic, physical and morphological properties of leaves define the passive capacity to retain the warmth of plant surfaces. Those are: leaf colour (ability to reflect), size and position of leaves, weight, density, aerodynamic properties, as well as wind resistance.

Heat loss in a house caused by wind may reach even 50% of total heat loss, depending on the position and structure of the building. It is very important to ensure maximum protection of facades against wind. Closed, evenly distributed vegetation on facade significantly reduces the cooling effect produced by wind. Thick, uneven leaf carpet in front of facade acts as “wind breaker”. Besides, vegetation protects against heavy rains and prevents mortar wash off, thus considerably reducing the wall erosion.

Temperature of classic facade which is not in shade during summer may reach up to 40-45ºC. This is extremely high temperature, which can be lowered by vegetation. Air temperature underneath green plants is much lower than in the same environment which is not exposed to sunshine. The reason is not only the parasol effect, but also the special leaf structure. Leaves reflect approximately 10% sunshine – less if leaves have smooth surface, more if their surface is rough – and absorb about 70%, and accordingly, solar energy shall heat the surfaces shielded by leaves only 20%. Luxuriant vegetation creates shade and reflects large quantity of sunshine, and at the same time takes away the heat from surroundings by evaporation.

Evaporation – produced by leaves of green plants – takes away the heat from surroundings, while air humidity grows. The larger the leaf areas, the more intensive the process. On the other hand, vegetation contributes to reduction of air humidity where necessary, because the leaves absorb vapour, which drops condensed on the ground appearing as water drops.

Thermally insulated flat roofs lined with bitumen layer may warm up to 60ºC during an averagely hot summer day in Central Europe, at air temperature of 25ºC, whereas under extreme circumstances this value may reach even 80ºC. The result is warm vertical air streaming, which further leads towards raising of dust specks from the street, thus creating pollution and vapour bell over the town.

Velocity of vertical air stream is much higher in front of facades compared to air movements over the roofs, so that large quantities of dust and particles transported by this air stream enter the flats through open windows. When vegetation covers the walls, there occurs turbulence which causes polluting particles to stick to the leaf surface or else the leaves absorb them. Vegetation lowers the air temperature, particles are stopped on leaf surfaces, and that reduces their density and velocity.

Bearing in mind the above facts, more and more green roofs and facades shall be needed, because this method is the most efficient one in the struggle to improve climatic conditions in towns.

Leaves are capable of sound reflection and absorption. Leaf structure absorbs and transmits – and thus reduces – a part of acoustic energy, and the rest gets reflected.

The wind moves the leaves of green plants, they collide and emit even, calming rustle, which suppresses a part of irritating hazardous everyday sounds – this is the phenomenon of masking. The leaf layer in front of facade, particularly the thick and dense one, reacts to sound waves by motion. Efficiency of green facade protection against noise depends on the sort of plant, size of leaves and season of the year. Research has found that leaves reduce the noise quantity by about 5 dB. Reaction of living creatures to factors of changes in environment depends on ecological awareness of subject living creature. Green facades may be created in various ways, and the plants used may possess various favourable properties. First of all, all characteristics of particular plants and local conditions must be harmonized, partly in order to use the advantages offerred by green facades, and partly in order to avoid possible damage to both (buildings and plants).

Air purifying effect is often subject to scientists' disputes. The referent measure specified in literature is 0.5 kg dust specks per m2 a year. Comparative measurement of dust and particle contents retained in the air was done in avenues with lines of trees and in greenless streets. The results show that particle contents in avenues are by two thirds lower than in treeless streets, thanks to large leaf surfaces. Dust and particles of pollution remain on leaf surface, and then the rain washes them off to the ground. Leaf surface absorbs hazardous gases contained in the air. They remain on leaves also in autumn, when the leaves start to fall, and again end up on the ground.

During 12 hours of daylight, the leaves produce about 4 litres of oxygen per square metre of leaf surface, at average. A man consumes 175 kg of oxygen a year at average, which is about 335 litres a day.

Based on specified data, oxygen production by green facade can be easily calculated. If ivy as facade plant forms leaves 10-15 cm thick, it means that there are approximately 3-5 cubic metres of leaves per square metre of wall. It comes out that ivy produces about 12-20 litres of oxygen per square metre of wall a day. Main issue in towns are not the low contents oxygen in the air, but high degree of its pollution.

From the viewpoint of an architect, the challenge is found in the possibility to underline the contrast between stability of structure and constant changes which are inherent to live plants: geometrical forms can be softened by mobile forms of vegetation, and structural elements can be shielded or emphasized by it. Tiny, large, sporadic or thick vegetation can emphasize powerful or subtle wall structures.

A layer of vegetation can fully or partly cover a building like a fur cloak. Using green plants, it is possible to form outfalls, circular structures and other interesting forms without intricate structural elements.

On the scale of values of a human who lives in town, the fact that his residence is surrounded with vegetation or located nearby a park represents a special quality. This advantage raises the value of the building itself.

5 CRITERIA FOR SELECTION OF PLANTS

When choosing and planting the vegetation, it is necessary to take into account the following factors which influence the micro-climate: temperature, light, humidity and air quality.

Temperature is one of the main factors when choosing plants for planting, if we eliminate climatic conditions. In Central Europe, with moderate climate, it is natural to select plants resistant to cold (those which can survive at the temperature of -20ºC).

The most important source of light is the sun, which radiates and heats, but also causes photo-chemical reactions. Intensity of light which reaches the ground surface depends on the ray angle, atmospheric capacity to absorb light and shelter effect. In Central Europe, there is generally enough light for photosynthesis everywhere; nevertheless, plants should be carefully selected due to unfavourable orientation of certain facades.

Humidity is very important, because the balance in water use represents an important prerequisite for survival of all living creatures. From the aspect of water demand, there are huge differences between particular sorts, and it is well-known that redistribution of water resources is extremely uneven depending on the place and season. Since sufficient water quantity is an irreplaceable condition for plant development, it is necessary to provide additional irrigation in dry seasons.

Due to high degree of pollution and high contents of sulphur-dioxide in air, extremely resistant plants shall more easily adapt to town conditions, especially in the town centre and streets with heavy traffic (e.g. nearby traffic lights).

6 GREEN ROOFS THROUGH HISTORY AND NOWADAYS

Green roofs originate from ancient times. Since the beginning of history of architecture, they were to be seen almost always and everywhere. Roof gardens and roof terraces first appeared in Near East, where buildings traditionally have flat roofs. Roofs with tended vegetation were mentioned even in the Old Testament.

Hanging gardens also originate from the East: they were grown in Assyria and Babylon, in furtile valleys of Tigris and Euphrates. Terraces over arches and columns were overgrown with plants and irrigated. The most famous are the Hanging Gardens of Semiramis, which are proclaimed the seventh wonder of the world.

Growing of pot-flowers on terraces and flat roofs of buildings became customary in the Mediterranean and in ancient Greece and Rome: it was established as a part of Adonis cult, and spread far and wide afterwards. In ancient Rome, a town enclosed in walls, the high costs of walls construction made residential blocks a usual form of construction. Building roofs were often used as gardens, with flowers, bushes and trees grown in flower-stands. Similar gardens were tended on roofs of cellars, partly or fully dug into the ground. The floating garden trend was introduced in Greece, with appearance of gardens on ships. On the ship of Emperor Caligula, grape-vines and fruit-trees made the shade. Roofs and terraces decorated with plants are presented also in Byzantine miniatures.

Roof gardens, terraces and hanging gardens appeared in the age of Renaissance in the parts of Europe with mild climate. This trend, based on ancient tradition, was adjusted to climatic conditions of the region. Technical and architectural solutions were developed to enable growing of plants without pots. Hanging gardens were designed with flower-stands placed on the level of roof plane.

With evolution of botany, the number of grown plant species increased. Roofs and terraces have been decorated with flowers, trees, bushes and grape-vine. This “fashion” spreaded from Italy to the kingdoms in the north of Europe (e.g. the Kingdom of Sweden), always in harmony with local climatic conditions. At the time, construction of roof gardens was a privilege of royal families, aristocracy and rich citizens.

With development of bourgeoisie, the demand for roof gardens grew ever more frequent. The deed of Berlin master Karl Palitz titled “Natural Roofs Made of Volcanic Cement or Modern Hanging Garden” from 1867, as well as the invention of Paris gardener Monier, reinforced concrete, were revolutionary in architecture. The building with flat roof which represents the symbol of modern architecture is based on their achievements. Famous representatives of this trend like Le Corbusier, Walter Gropius and representatives of Bauhaus movement (the same as Frank Lloyd Wright and others in America) designed roof gardens on their buildings. In his theoretical works, Le Corbusier defines roof garden as crucial living area of urban population in future.

Decorative plants on roofs were tended also by peoples of north Europe – on Iceland and in Scandinavia – within their traditional architecture. The reason is not primarily aesthetic: level of thermal protection of roofs covered by peat and grass is so high that these buildings do not need intensive heating even in severe winter periods.

Green roofs are mostly applied on flat roof systems, both on high buildings and on underground structures such as garages, subways or trade centres. They are possible to implement on slanted roofs too, but there are constraints regarding the slope and fixing of green layer. In case of flat roofs, there are practically no constraints.

7 EXPERIENCE WORLDWIDE

Buildings overgrown with vegetation change their appearance as the seasons change, and create a natural sensation of pleasure with constant changes in their fragrances, colours and appearance.

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Fig.1. Green roof of Chicago City Hall, Illinois – in early spring and late summer

Green roof is a roof of building or house which is partly of fully covered with earth and vegetation, or plants seeded on water-roof membrane. They can also include roof protection, drainage layer and irrigation system. Gardens in containers – flower-stands or large pots, do not belong to green roofs, although there are contradictory opinions on that.

The term green roof may imply a roof which uses a kind of green technology, such as solar panels. Green roofs are also called eco-roofs, roofs with vegetation, live roofs.


Fig.2. Newfoundland – a Wiking house
Fig.3. Green roof L'Historial de la Vendée

Planted roofs have been known for hundreds of years, both in cold climate of Iceland, Scandinavia and Canada, and in hot climate of Tanzania.


Fig.4. Green roof – a church on Iceland
Fig.5. House with green roof in England

In classic workmanship of flat roof, thermal insulation is under the waterproofing, which means a deficiency in its mechanical and thermal protection. Therefore, it is recommended to use the system of inverse roof when constructing roof gardens, using extruded polystyrene – the only thermal insulation which can spend the lifetime in wet conditions, with no significant impact on its thermal properties.


Fig.6. Roof garden Manhattan
Fig.7. Music Academy of Sidney

8 BELGRADE EXPERIENCE

In Belgrade, such roofs are rare and currently exist only on two buildings, on Kalvarija and in Zemun. They are presently being constructed on the roof of one house in Medakovic, one of the residencies in Uzicka Street, and on residential buildings in the streets of Baje Pivljanina, Svetozara Markovica and another building on Vracar. Investors of these works are private entities, and the gardens do not exceed 150 square metres. One square metre of green roof in Serbia costs at least 40 euros. The proposal to plant green roofs on Belgrade buildings, following the example of other towns in the world, has been recently initiated by residents of the Municipality of Vracar.

9 AESTHETICS AND ECO-SYSTEMS OF GREEN ROOFS AND FACADES

Green roofs have been known for hundreds of years, both in cold climate of Iceland, Scandinavia and Canada, and in hot climate of Tanzania.

In such parts of towns worldwide where there are green roofs and facades, it has been found that there has occurred improved air quality, better temperature control, extension of lifetime of roof waterproofing, better micro-climate, reduction of rain sewerage engagement, filtration of atmospheric water and improvement of its quality, absorption of town noise and dust.

The process of carbondioxide and oxygen exchange, done by plants in order to nurture and grow, since the carbondioxide becomes absorbed and oxygen released in daytime, represents a solid reason to set planting on roofs and facades as an important goal, when searching for new trends in architecture and town planning. One smaller tree, with crown circumference of only 4m, produces as much oxygen as an adult consumes during one day.

There is also the aesthetic component, and creation of potential areas for sports and recreation. Those can be botanical gardens, space for scientific research and tranquil oases, with specific eco-systems of town, where insects and birds may live. Buildings overgrown with vegetation change their appearance with change of season, and create the sensation of natural changes in fragrances, colours and appearances.

From architectural point of view, there is a challenge in the possibility to underline the contrast between stability of structure and constant changes which exist in the nature of live plants: geometrical forms may be softened by mobile forms of vegetation. Construction elements may be shielded or emphasized by vegetation. Selection of vegetation (tiny, large, sporadic or thick) can emphasize or cover wall structures. The vegetative layer may fully or partially cover the building. By utilization of green plants, it is possible to shape hydrotechnical drains and outlets, circular structures and other interesting forms without intricate and expensive construction elements.

10 PLANTING METHODS

There are two major planting methods, depending on the direction of plane system:

- horizontal gardens, green flat roofs and
- vertical gardens, green facades.

Gardens on the roof, as parts of nature relocated from environment to the roof, may be grass, meadows with meadow flowers, decorative shrubs, rockery, trees, fish ponds, paths and, if required, footways. They are applied on flat roof systems, on high buildings and underground structures, such as garages, subways, trade centres, etc. It is possible to use them on slanted roofs, but there are some constraints in terms of slope and fixing of vegetative cover. In case of flat roofs, there are practically no constraints.

Roof garden is a limited green area on top of a building, below or above the ground level. Plants are not directly planted into the ground. Roof garden is always an integral part of roof system, in fact a superstructure of basic water and thermal insulation with which it makes a unique composition, including:

- roof structure with or without thermal insulation
- waterproofing, with or without required root protection (depending on type of waterproofing)
- membrane
- drainage layer, with possible water retention

- separation / filter layer
- special substrate which does not have to be, or to contain earth
- plants.

Green roof is a building roof which is partly or fully covered with earth and vegetation, or plants planted on water-roof membrane. It may include roof protection, drainage layer and irrigation system. Gardens in containers, flower-stands, or large pots do not belong to green roofs, despite contradictory points of view. The term green roof may imply a roof which uses a form of green technology, such as solar panels. Green roofs are also called eco-roofs, roofs with vegetation, live roofs.

Vertical garden implies planting into terrain, containers or vertical hydroponic systems. This is a live facade lining with all advantages of roof garden, but it is not horizontal, does not have statical impact on additional load and does not affect the costs to any considerable extent. Plants suitable for this kind of planting include a wide range of annual and perennial creepers, which can be grown not only on facades but also for creeping over the roof. Impact assessment studies for envisaged landscaping works shall be made in compliance with global criteria /2/.

Materials recommended for construction of such roofs include layers and activities related thereto, which make a roof watertight:

- construction materials: waterproofing, thermal insulation, separation and drainage layers,
- bio-materials: substrate, water retention layer, plant material, seed quantities and kinds;
- nutrition and maintenance: fertilizers, treatment of green areas, watering, additional sowing and planting.

Technically speaking, there are two major types of green roofs, in terms of requirements of layers and designed plants, as well as requirements of maintenance of entire system:

- Low requirements – extensive roof gardens
- High requirements – intensive roof gardens.

In case of extensive roof gardens, substrate does not need to be very high - sometimes only several centimetres of special mixture of humus and hydroscopic materials (expended clay, perlite, etc.) are sufficient for growing of certain plant species on such a roof. Height of substrate for most grasses, sedums, moss, flowering plants and some minor bushes (e.g. various mini cultivates of Pinus and Juniperus order, or species such as Buxus sempervirens, Cotoneaster, or Pyracanta), does not need to exceed 18 to 20 cm.

Intensive roof gardens include planting of larger bushes, or minor trees in substrate mixture 6 to 60 cm high, or even higher. This gives rise to imagination, allowing for planting of pear and apple trees, or oaks, maple and pine trees, hedges and flower beds, even forming of small biotops.

Sometimes for planned garden with large trees there are channels in concrete slab which enable required depth of earth for planting of trees. Planting of high trees requires special attention due to exposure to wind.

Combination of extensive and intensive garden is possible by levelling of terrain with artificial hillocks, which ensure required depth of substrates at the spots where larger plant species are planted. Taking into account the height of buildings on which the planting is performed, sometimes it is necessary to anchor the plant by concrete or stone weights hidden under the earth, and sometimes they are used as decorative element, forming a stone flower-stand around the tree, which provides additional protection against excessive drying of earth in an unnaturally thin layer.

Since all the layers needed for plant life necessarily assume a moist medium, structural layers of roof must be formed with special care.

Waterproofing, however perfect it might be, is not necessarily resistant to penetration of roots. Weak points are joints. Therefore, it is recommendable to ask for manufacturer’s advice as to whether it is needed to use corrosion protection for their insulation or not.

In classic workmanship of flat roof, thermal insulation is located under the waterproofing, which means deficiency in its mechanical and thermal protection. For that reason, it is recommendable to use the inverse roof system when constructing roof gardens, using extruded polystyrene – the only thermal insulation which can spend a lifetime in wet conditions, without significant impact on its thermal properties.

11 CONCLUSION

"Towns keep expanding, which causes disturbances in the quality of environment. Instead of become familiar with nature and its laws, the man has started to degrade and pollute it intensively" /1/.

One of the possible ways to increase energy efficacy, improve quality of environment in towns and return to the lost ecological balance, is construction of green roofs and facades. Nowadays, the increased number of various tended plant species offers large possibilities for covering of roofs, facades and terraces with flowers, trees, bushes and grape-vine. The contemporary methods presented in the article show that growing of plants on architectural structures does not cause any problems, and in fact represents an advantage, considered from various points of view. Green roofs and facades are one of the ways in which urban areas struggle against global climatic changes.

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