Sustainable City- Green Walls and Roofs as Ecological Solution

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Abstract. The impact of urban development on the natural environment creates unique challenges for architects and the need to seek a change in design strategies by building green and sustainable buildings. Designing and displaying green elements such as roofs and walls becomes an important element in this sense. Greenery plays a very crucial role in the city space. Green roofs and walls are the missing link between the built environment and the natural environment. They can complement urban greenery. This paper aims to show the possibilities of green roofs and walls solutions in the city, their aspects and impact on the environment and people. The research method is based on the analysis of selected existing objects with greenery solutions and showing their role in creating a sustainable city. The analysis shows that the green roofs and walls offers many environmental, social and economic benefits. They have the ability to improve the microclimate and increase air humidity. Thus, they affect the health and well-being of the city's inhabitants. This technology should be considered a valuable part of the design process to tackle climate change and the energy crisis. Green roofs and facades are passive techniques and provide benefits in reducing the energy requirements of buildings, among other things, but also play a role in shaping a better visual aspect of the city. In the 21st century, people are slowly beginning to realize the advantages of green architecture, which is considered a new perspective also for the urban heat island problem. Thus, the living roofs and walls are of major importance as part of a sustainable strategy for the urban environment. Sustainable cities will exist when society makes an informed choice to move towards a more sustainable lifestyle. The green roofs and walls these are the solution for the future, for better quality of life.

1. Introduction
In recent years, designing and displaying green elements such as roofs and walls have become important in urban landscapes. These elements can increase the city’s environmental value. Greenery in the built environment is an important element of sustainable development and, therefore, sustainable, and healthy city.

For many years, progressive urbanization has harmed the city environment. For this reason, architects and city planners have begun to introduce new concepts and projects that are more environmentally friendly and can improve the quality of life of city residents. Overcoming the existing environmental problems has become the key to achieving sustainability in cities. The definition of sustainable
development assumes that the needs of the current sustainable city residents must be met without reducing the opportunities of the city’s future residents. Consequently, many challenges need to be overcome for cities to continue to provide the right conditions for living and working. Another important element is also the energy efficiency and promotion of the development of energy-saving technologies enabling energy recovery, improving air quality, supporting the recovery of building materials, and limiting materials damaging the natural environment and enabling the protection of the ecological zone.

This paper aims to present examples of the implementation of green building solutions in cities and their environmental benefits in terms of sustainable development. When creating sustainable cities, we think about the future. At the same time, society is paying more and more attention to the problems of our planet. Green solutions in buildings become an important element and a rescue for regaining balance in the environment. Through the ultimate potential of green roofs and walls to promote sustainable development, they are very important.

A huge number of buildings are being built around the world, and the challenge is to build them intelligently with minimum consumption of non-renewable energy, minimum pollution production, and minimum energy costs. Other important issues are increasing the comfort, health, and safety of people living and working in these constructions.

2. The genesis of green roofs and walls
The tradition of creating green roofs derives from the distant times of antiquity, as it existed already five thousand years ago in Egypt, where the population planted the roofs of their houses. Due to the dense development of cities that could not grow beyond their existing walls, the construction of private roof gardens was popular [1]. Even then, attention was paid to creating a harmonious, natural surroundings of buildings. The first commonly known example of the use of greenery in architecture from the Mesopotamian area is the so-called Hanging Gardens of Babylon. This was the result of the Babylonians’ excellent ability to irrigate land and construct engineering structures. It is known that from the 3rd century BC, the Romans grew grapevines that climbed walls and special trellises. They used supports that allowed the plants to form the shape of a wall, a system called “palmette”.

The industrial development in the 20th century, and in particular the emergence of reinforced concrete, contributed to the popularization of the idea of flat roofs. In the 1920s, architect Le Corbusier recognized the roof garden as an important point in the program promoting new architecture. On the other hand, the first steps to promote structures in which plants could develop freely creating vertical surfaces took place in the first half of the 20th century. Thus, various methods of turning roofs and facades green, which are more and more popular all over the world (and recently also in Poland), are not a new idea. Later, until the mid-1970s, intensive green roofs, i.e., usable roofs, were built. To further popularize green roofs, more economically viable construction systems were developed. Thus, at the beginning of the 1980s, the first extensive (light, inexpensive, ecological) green roofs were created, where the focus was not so much on usability, but on ecology and economy.

More intensive implementation of green roofs started in German-speaking countries in the 1970s [2]. Around the same time, green roofs gained popularity also in France and Switzerland.

Vertical gardens began to appear in the 1970s. In turn, the trend for the first vertical green walls was spread by a French botanist Patrick Blanc in the 1990s.

3. Terminology and possible applications
All over the world, big cities like New York, Melbourne, London, and Paris are introducing more and more greenery into their urban landscapes. These are both green roofs and green walls of buildings. These cities usually lack space for parks, and this kind of greenery associated with buildings can arise
in densely developed city centers and apply to both new buildings and the existing constructions. There are several terminologies for green roofs. Green roofs are also named “eco-roofs”, “living roofs” or “roof gardens”, and are roofs with plants in their upper layer [3,4].

Plant-covered roofs can be extensive, semi-intensive and intensive. They mainly differ in the type of vegetation and the way of use. Extensive green roofs have a low construction height below 15 cm [5] and they are planted with plants having lower vegetation requirements, i.e., plants that can cope without excessive care by humans. They are plants with a high regeneration capacity, adapted to extreme climatic conditions, e.g., mosses, sedum, etc.

Semi-intensive green roofs are constructed with a height between 16 and 20 cm. It is also possible (apart from grasses) to incorporate higher plants such as shrubs and perennials. Limited watering and maintenance are required. It is possible for people to access.

Extensive roofs are the most popular type of green roofs used on terraces in residential buildings as well as on garage panels and industrial constructions. They are the so-called maintenance-free greenery. Extensive roofs are characterized by lower vegetation and smaller water demand. In the case of such roofs, a very important element is the appropriate selection of the vegetation and drainage layer, which allows, through its accumulation capacity, to provide the plants with adequate water supplies. Extensive green roofs weigh less and are appropriate for large-sized rooftops while the process of their construction is technically simple and allows for implementation on sloped roofs [6].

In turn, intensive green roof systems allow the planting of some shrubs and even trees. Of course, they require a lot of care, irrigation, and a sufficiently strong supporting structure. However, they provide recreation and rest areas comparable to city parks. In intensive green roofs, an important factor, apart from the effective drainage of surplus water, is also its accumulation in a properly selected part. This water resource is used for optimal plant vegetation during periodic rainfall shortages.

The term “green wall” covers all forms of wall surfaces with plants. Also known as vertical gardens, they refer to the facades of buildings, vertically covered with vegetation. Such gardens fall broadly into two groups: green facades and living walls. The former ones are elements of the structure covered with climbing vegetation, the roots of which are in the ground. Vertical gardens can be created using all kinds of nets, fences, and metal tube structures that support the vertical growth of plants. However, it will be a kind of garden where the plants are planted directly into the ground, not in hanging panels.

Living walls, on the other hand, are more technologically complex. They usually have modular panels and special irrigation structures. Although there are many systems in which they are maintained, all of them require a lot of resources. Ready-made panels and pocket planters are very popular. The advantage is the variety of products with different dimensions. They are easy to assemble by fixing the panels to the walls using screws. To protect the wall against moisture, a PVC board should be installed between it and the panel. Ready panels are equipped with plant irrigation systems, and seedlings should be placed directly in appropriate “pockets” or sleeves.

Patrick Blanc, mentioned above, is a well-known creator of vertical gardens. In his concepts, he used plants of various forms and colors of leaves and flowers, ideally suited to the climatic conditions of a given place. He started to use stainless steel ropes for the construction of facades, and in the early 1990s, he introduced innovative mesh and modular grating systems. Blanc has designed a unique alternative to traditional soil cultivation - a non-woven, practically soilless system that provides the plants with an optimal amount of water on an ongoing basis. The structure of his vertical gardens is
made of a metal frame to which PVC panels are attached. A double layer of felt mat is attached to them. Felt mats are made of recycled clothes from artificial materials which makes them a durable substrate (imitating soil) for plants. In its outer layer, holes are cut into which the cuttings are inserted. Over time, their roots grow into the mat, creating a compact whole. The green wall has an irrigation system that brings water with a minimum dose of fertilizer to the plants. That small amount of nutrients allows the plants to develop and prevents them from overgrowing. Rainwater may be used to water the garden. This method is often used by architects in sustainable architecture projects.

4. Contemporary examples of good practices in cities
All over the world, many facilities conducive to the formation of sustainable environment have been constructed. New technologies for growing plants on the roofs and walls of houses popularized this phenomenon. Green roofs have been built in many major cities such as Singapore, Hong Kong, New York, and many more. Vertical gardens have also begun to appear more and more often.

In Europe, technologies for the construction of green roofs and walls have gained great recognition. They result directly from new laws introduced and governmental financial support offered for such projects. This is visible in countries such as Germany, France, Austria, and Switzerland [7].

In France, we can find many examples of buildings with green roofs and walls. Paris often referred to as one of the most beautiful cities in the world, is also distinguished by a special approach to arranging green areas. “Paris Garden Cultures” (Les Paris-culteurs) is an action designed to turn the city green over the course of several years. An interesting example of a green wall is the building of the Musée du quai Branly in Paris. It was designed by the architect Jean Nouvel, but the author of the green wall is the aforementioned Patric Blanc.

The Seine-facing facade is one great green wall of 200 meters in length and 12 meters in height. The plants used there are planted in special boxes, which in turn are affixed to the façade [8]. An interesting example of a green wall is also the vertical garden on the northern wall of the Halles d’Avignon shopping arcade in Avignon. It was also designed by Patrick Blanc. An interesting fact is that the green wall present there is an area of about 600 square meters, with 1 square meter of the structure weighing 30 kilograms. On each square meter, around 20 plants were planted. It is a large plain of greenery that brings huge environmental benefits.

In Germany, there is a conscious policy for turning cities green. The model cities in which the strategy to support the construction of green roofs is carried out are Hamburg, Bremen, Stuttgart, and Munich, and in the field of green walls - Hanover and Munich. Similar activities supporting the development of green roofs have been carried out for a long time in London, Basel, Chicago, and Portland. In Copenhagen, the Adaptive Climate Plan was created, assuming many green initiatives and projects counteracting the negative effects of climate change. A green roof program was created and from 2010 it has been decided that all newly built and modernized flat roof buildings should be turned into green roofs. Moreover, the obligation to create green roofs exists in most local development plans.

Another example of this initiative is also Berlin, where buildings with green roofs with a total area of 40,000 square meters were built next to each other on Potsdamer Platz [9]. In turn, in Hamburg, the BIQ building designed by Splitterwerk Architects and the Arup Group has a system of green facades filled with algae, which also produce some of the energy needed for the building.

In Spain, the most interesting example is the CaixaForum (figure 1), the art and culture center in Madrid run by the “la Caixa” Foundation. The building was enriched with a green wall located on the
southern square. A huge number of plants consisting of 250 species are planted on it without soil and vegetating only based on water and nutrients provided. The structure was designed similarly to the previously mentioned projects by P. Blanc. According to Wojciech Kosiński [10], greenery integrated with houses in the sense of horizontal (roofs) and vertical (walls) plant tissue plays an invaluable role.

It is worth mentioning that Paris has planned “green” buildings of 100 hectares by 2020, while London hopes to make itself the capital of the world's first National City Park where more than half of the city's area is turned green by 2050 [11].

In London, we can also find impressive living walls of buildings. One example is the Athenaeum Hotel, a five-star hotel overlooking Green Park. In 2009, a living wall, i.e., a vertical garden, was installed on a part of the facade of the north-eastern corner of the hotel. It very quickly became the symbol of the building. This vertical garden is 30 meters high, has 260 species and 12,000 plants. The aluminum shell, properly attached to the wall of the building, is covered with plastic, i.e., synthetic felt, in which roots can develop. Given that the green wall has as many as ten stories, the vegetation varies on different levels.

![Figure 1. The building CaixaForum in Madrid was enriched with a green wall located on the southern square, Source: author's archive](image)

Another example of a vertical garden can be found on the facade of the Mint Hotel in central London, near one of the biggest tourist attractions - the Tower of London. The vertical garden extends there from the second to the eleventh floor. It is a lively, beautiful, green wall, which is currently one of the largest green walls in Europe. It was built based on metal frames and an irrigation system that supplies water and minerals to the evergreen plants. Various bulb plants and ferns grow in the shade.

For years, the Singapore city-state has been paying attention to creating greenery, not only as urban parks and botanical gardens but also by constructing living vertical walls and green roofs. Singapore aims to become a “Garden City” using green spaces to connect communities, enrich biodiversity and improve the climate. An interesting fact is that green roofs have been installed even on public buses as plants can help to reduce the temperature inside them. In addition, a green roof was also installed on the top of a bus stop in Kuala Lumpur.

Canada also has an idea of “green cities”. An extensive, long-term program has been adopted in Vancouver. The concept of the revitalization of Vancouver developed according to the principles of
sustainable development is the evidence of the achievement of full success in this aspect. The novelty is the designation of green roofs for crops and allotments that residents can use for work and leisure. Community (vegetable and flower) gardens grown in designated areas among residential and service buildings are also becoming more and more popular. In this city, the Semiahmoo Library boasts a beautiful green wall made of not only perennials but also shrubs and small trees.

All activities aimed at improving the environment are appreciated, as evidenced by the awards granted to the projects. Last year, The Garden House in Beverly Hills, California, received the Award of Excellence 2020. The planted green facade consumes the entire length of the building, encasing the windows, balconies and curving at the intersection of two major cross streets. The system is hydroponic and recirculates from a large holding tank at the bottom of the basement floor, pumping water up to the top of the wall and wicked down throughout the felt layers [12].

There are several successful implementations of green architecture in Poland, too. One of the examples is the University of Warsaw Library, which has both a green roof and green portions of the walls (figure 2, figure 3). The walls are made of patinated copper, and their green color harmonizes with the greenery of the plants. Facades are covered with copper nets that support vines.

The garden on the roof of the University of Warsaw Library is considered one of the most beautiful gardens in Europe. It was the first Polish project to use green in an intensive form on the roof. There are various types of vegetation, paths, sculptures, and even a stream cascading down into the ground-level gardens. This place has recreational, cultural, and social functions. It is visited by students, residents, and tourists, and serves as a popular spot for photoshoots. The ecological and economic function of this place is also important. The green roof compensates for losses in the biologically active slopes used for the construction of the library. It is also important that it reduces heating and air conditioning expenses (by up to 30%), collects rainwater, and suppresses noise [13].

Another example in Warsaw is the green roof at the ARKADIA shopping center, which was built in an extensive system. Yet another example of a green roof can be found in the Copernicus Science Centre, which is also open to the public. In Wroclaw, the green roof complex was built on multi-family housing located in the very center of the city. However, these roofs are not made available to residents, as their function is only to improve the aesthetic values of the buildings and improve the local microclimate.
In Lodz, the author’s hometown, the Hanging Gardens apartment complex located on Tuwima street in the very center of the city will have green roofs, too. This project aims to start turning the city center green.

5. Benefits of using green solutions in buildings and their importance for sustainable development

There are many sustainable advantages of green solutions. The most important environmental benefits of the use of green roofs and walls are related to improving the microclimate, reducing the urban heat island effect, improving thermal insulation properties, reducing the building's energy needs, reducing temperatures, improving the water balance, reducing the amount of rainwater discharged by rainwater drainage, improving the air quality (CO₂ absorption, oxygen evolution, reduction of dust and pollutants released to the air). An additional advantage of vertical gardens (and vegetation in general) is their positive influence on the climate by regulating air humidity and lowering the temperature. In cities, it is an invaluable property. Strongly urbanized areas suffer from the effects of the phenomenon known as the “Urban Heat Island”. In the case of building surfaces, the installation of green roofs or green facades can be used to reduce the temperature of the environment and the building [14]. Research conducted in New York showed that during a hot summer afternoon standard roof surface temperature can be up to 40°C higher than the surface temperature of a green roof [15]. On average (according to measurements conducted in July 2003), the surface temperature of a standard roof was higher by 19°C in the daytime and lower by 8°C at nighttime compared to a green roof. On the other hand, the temperature inside the building covered by a green roof was on average 2°C lower in the daytime, and about 0.3°C higher at nighttime. In warm climates, green roofs potentially reduce the indoor temperature by shading the rooftop layer and preventing it from the direct influence of solar radiation [16]. In the energy consumption of the buildings, one of the vital factors is thermal comfort because that shows the occupants’ satisfaction.

Finally, green roofs are often seen as an opportunity for supporting the process of receiving sustainability labels, such as LEED or BREEAM. This indirect policy, which comes from the sustainable building assessment movement, promises to be fundamental for the diffusion of green roofs. The studies discussed above show the importance and advantages of living walls or roofs as part of a sustainable strategy for the urban environment. The undoubted advantage is also the improvement of the aesthetics of the space (the visual aspect), the possibility of hiding installation devices located on the roof and creating characteristic plant elements that distinguish individual buildings. In the case of green walls, it is possible to cover less interesting parts of the facade or hide its shortcomings. Walls with plants also provide additional, effective sound insulation. Green roofs, in addition to their function of retaining water and increasing biodiversity, are the missing link between the built environment and the natural environment, which is essential for sustainable human life in cities. Green roofs are often indicated as a valuable solution for resolving the issue of the lack of green space in urbanized areas. Besides, green roofs increase the fire resistance of the roof, reduce noise (from approx. 20 dB to as much as 50 dB), and gain new functions, e.g., as recreational spaces.

Nevertheless, each solution also has drawbacks and in the case of green roofs, these are mostly: high design and construction costs, condensation of water vapor in the insulation, water stagnation, risk of plant roots breaking the insulation layer. Apart from that, intensive green roofs require more maintenance and costly renovations. While green roofs have higher initial costs than traditional roofing, green roofs have a diverse array of potential benefits.

Vertical gardens, on the other hand, not only improve the quality of life of city residents but also reduce the harmful effects of their activities on the environment and support local biodiversity. As such, they satisfy the human need for communing with nature.
6. Conclusions
Green walls and roofs can bring significant environmental, social, and economic benefits. This technology should be recognized as a valuable part of the design process aimed at tackling climate change, solving the energy crisis, and building sustainable cities.

Green infrastructure can play many functions and provide numerous benefits in modern cities. Also, the environmental benefits of green roofs and walls are not limited to new buildings only.

Thus, the living roofs and walls are of major importance as part of a sustainable strategy for the urban environment. Sustainable cities will exist when society makes an informed choice to move towards a more sustainable lifestyle. The green roofs and walls these are the solution for the future, for better quality of life. For a broader implementation of the process could be for example, by subsidies from the local government.

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