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Vertical greening systems as an inherent feature of sustainable smart city

Considering the processes of social and climate change at the global level, more and more cities worldwide have reformatted development strategies to implement «smart» reforms to ensure sustainable development, increase energy production by expanding renewable resources, and improve waste management. Upgrading to a smart city means improving urban residents' quality of life by providing cultural, economic, and social development opportunities in a healthy, safe, and inspiring environment. An analysis of the most effective initiatives within the concept of «smart» city, related to the development of «green» buildings with special emphasis on the concept of vertical landscaping. The detailed characteristic of positive effects from the installation of designs of a «green» cloth is given. Among the above advantages of implementing these technologies, reducing pollutant emissions, which are the greenhouse effect's driving forces, and energy savings are the most significant. Based on the results of the analysis of the effectiveness of the implementation of the concept of vertical landscaping, proposals for the development or improvement of strategies for sustainable development of urban areas with an emphasis on «green» and «smart» technologies.
Keywords: smart city, green technologies, the concept of a smart city, the concept of vertical landscaping, vertical landscaping.

Problem statement. The concept of a «smart» city is a logical result of the growing demand for efficient use of limited resources. The means of production are exhausted and limited. With this in mind, there is a growing need to promote renewable technologies to reduce the cost of goods and services in the narrow sense and preserve the ecosystem globally. «green» technologies occupy a prominent position in the concept of a «smart» city. Given the high concentration of internal combustion engines in modern urban units, introducing «green» technologies will save money and improve the ecosystem's quality. In the long run, such technologies will reduce climate change.

An essential component of «green» technologies is the vertical landscaping of buildings and structures. Vertical landscaping of modern architecture and engineering works is actively attracting the world community's attention and the commercial sector in particular. In recent decades, there has been a realization that vertical living green spaces improve the overall appearance of objects from any perspective and effectively absorb harmful noise and sound vibrations. Vertical landscaping is positioned in economic, social, and environmental contexts as a means to mitigate the greenhouse effect, adapt to climate change, increase the intensity and volume of air purification in densely populated areas, instilling an aesthetic appearance in landscaping. However, despite the wide range of benefits from vertical landscaping technologies, these innovative solutions are characterized by a shortage of investment and political lobbying.

The concept of vertical landscaping significantly complements the «green» component of the «smart city. Due to many advantages of facade landscaping and a large number of technologies for applying plants to walls, there are barriers to active operation of vertical green areas: the need for maintenance, clearing areas from falling leaves, the likelihood of damage to wall structures, increasing insects and unforeseen additional costs. It is associated with these factors.

Analysis of recent research. Analysis of recent studies shows an increase in the negative impact of world population growth on climate change **[1; 2]**. Taking into

account the low level of energy efficiency of buildings, structures, and transport systems, about 70% of emissions of environmental pollutants are carried out by modern cities [3; 4]. Besides, cities consume about 60% of all energy produced globally [5; 6]. Every year about 12.6 million people die as a result of pollution of the ecosystem [6]. With this in mind, the concept of a «smart» city is the most promising way to improve cities' quality of life by providing a safe environment [7; 8]. The main directions of development and supplementation of the concept of a «smart» city are information networks, hybrid and electric transport, «smart» systems to prevent freshwater loss during transportation, advanced lighting systems that monitor traffic load and current air pollution [9; 10]. However, researchers pay little attention to landscaping technologies in highly urbanized areas. Vertical landscaping requires special attention, as it allows to increase the concentration of green areas without the need to create horizontal green areas.

The paper purpose is to identify prospects for the adaptation of «green» technologies in the context of vertical landscaping concept in the concept of «smart» city.

Major research findings. For centuries, vertical landscaping technology has been based on the fact that plants are planted along buildings' walls. The rapid flowering of vertical landscaping fell on the development of portable vessels, which form a network designed to accommodate plants and feed them with water and minerals. For the first time, a large-scale eco-project related to vertical landscaping was implemented in the Kreuzberg district (Berlin, Germany) [1, p. 63]. This project was implemented in 1984 to determine the potential of vertical landscaping. According to the project, the houses' facades were covered with ivy and wild grapes (Parthenocissus quinquefolia), planted in flower pots along the facades and at the facades themselves [2, p. 190].

The Austrian artist, designer, and architect Friedensreich Hundertwasser took a permanent position on urban settlements' greening. In 1986, he designed a complex of 52 residential buildings with wavy facades and roofs. The artist contrasted himself with rationalism and functionalism – the characteristic features of the twentieth century. He insisted that the right to decorate one's own home is inalienable and inherent in everyone. Hundertwasser's creative and architectural activity avoids straight lines in his architectural projects and plant trees on houses' roofs and windows. The architect's legendary work is the Gundertwasserhaus in Vienna, the third most visited tourist attraction in Austria after Schönburn and Salzburg. Hundertwasser offered society a new architectural solution that combines complex concrete and iron structures and a tightly intertwined web of lush plants.

Vertical landscaping of facades can be done by placing on the walls of tanks/vessels with plants. This method is called container planting: containers are fixed on the wall, in which both curly and ordinary plants are planted [5, p. 88]. Containers for vertical landscaping can be made of metal, plastic, or ceramic. Wooden boxes or cement pots also serve the purpose.

Dichondra, whose leaves have a pleasant silver hue, chlorophytum, and many hybrid species of petunias – Fortuna, Calibrachoa – are perfect for container planting. Thus, part of the wall can be covered entirely with greenery (for example, the corner of the building), and the rest of the facade can be shaded by sprawling plants such as climbing roses. They hold their roots well and cling to the wall, so there is no need to worry about the reliability of such a landing.

Lattice-wire constructions are priority technologies of vertical landscaping. The blocks of modular systems are strong, light, and consist of three-dimensional

panels made of galvanized and welded to each other steel cables that hold the weight of plants. This system is designed to keep the green facade away from the wall surface, not to accumulate close to the facades' surface. This technology creates the necessary space for plant growth with a sufficient number of elements to which the plantation can be attached. Blocks of modular systems can cover large areas; moreover, they can be adapted to surfaces of any shape, taking into account convexities, bends, sharp corners, and other elements of architectural solutions [6, p. 190].

Lattice structures are designed to support fast-growing plants with thick leaves. Wire-rope constructions are designed for slow-growing plants that require better structural support due to smaller intervals between wire elements. Both structures are based on flexible steel cables and additional support equipment. Various sizes and patterns of structures freely repeat the landscaping object's shape due to its flexibility and elasticity, which is achieved by tensioning the cables and their immobilization with clamps [7, p. 232].

Vertical landscaping of buildings provides economic and environmental benefits and the aesthetic appearance of urban areas. Benefits vary depending on buildings' characteristics, landscaping technologies, structures, and frameworks for keeping the living canvas, selected plants.

Vegetation occupies large areas of the planet Earth, even though these areas are declining annually, which leads to global warming, melting glaciers, accumulation of carbon dioxide in the atmosphere, global warming, and the formation of pores in the ozone layer. Thus, the importance of vertical landscaping cannot be overestimated. Hardwood absorbs carbon dioxide (CO_2), nitrates (NO_3), nitrites (NO_2), and other pollutants in large quantities, filtering and filling the biosphere with a resource to support the life of living organisms [5, p. 45]. The green facade can block the movement of pollutants and buildings and structures, immediately filtering them and enriching the environment with oxygen.

In 2010, Professor Michael Sternberg discovered that the concentration of heavy metals on green facades in areas of active transport equipped with internal combustion engines is much higher than on the green carpets of areas that have come under less pressure from the tumultuous and relentless car industry. A vital function of the leaf cover is the absorption of carbon dioxide and, through photosynthesis, oxygen production. Excessive accumulation of gaseous particles leads to deterioration of lung function, respiratory and cardiovascular diseases. In addition to the detrimental effects on living organisms, excessive, untimely absorption and utilization of gas particles accelerates metals' corrosion, contributes to damage to painted surfaces, destruction of surfaces of sculptures, and other human-made objects damaged by dirt on their surface. [2, p. 190]. Improving the quality of air masses through green facades will directly benefit people suffering from long-term diseases. There will be a reduction in smog formation. Corrosion problems will become less threatening, a critical need for an urban city and its infrastructure, vulnerable and sensitive to air pollution [2, p. 194].

Thus, despite its fantastic ability to eliminate melancholy, processing them into useful natural resources, vertical green canvas also saves densely built-up urban areas, compensating for the lack of regulatory landscaping area per person new green facades.

Green facades create their specific microclimate, which is utterly different from external conditions. Depending on the landscaping object's height and location, the green facade is exposed to sharp temperature fluctuations, gusts of wind, and direct sunlight. The climate of the facades of buildings is low to desert,

so it is necessary to use plants, taking into account all the factors of influence and risk.

Concrete and glass coverings of vertical surfaces weakly hold rainwater, immediately direct it to the drainage system. Plants can retain water droplets on the leaf surface longer than the materials of the external coating of buildings and structures, improving the process of evaporation and humidification. The result of this phenomenon is the mitigation of the climate of the urban area. The space between the green facade and the wall is filled continuously with fresh air. Thus, «stagnant» air creates an insulating effect, preventing heating of the warm season walls. Besides, the green canvas prevents the walls from heating by absorbing direct sunlight's energy, reducing the room temperature. In the cold season, the vertical facade reduces the impact of cool air on buildings' walls, preventing them from cooling quickly and, consequently, lowering the temperature inside a stationary object.

Red areas indicate a lack of living space and a high degree of absorption of solar energy, while the blue-green area signals a low level of heating of the building surface.

Another way to prevent the walls from heating up is to evaporate. Most of the material that creates the outer layer of walls and facades greedily absorbs solar radiation. Living green carpets will prevent overheating buildings' surfaces, reducing heating and accelerating heat transfer, which is vital for urban areas. Significantly heated surfaces of buildings lead to an increase in air temperature at night due to intense heat transfer [10, p. 60].

Of the solar energy that reaches the surface of the leaves, 5-30% is reflected into space, 5-20% is used for photosynthesis, 10-50% is converted into heat, 20-40% is consumed to carry out the evaporation process, 5-30% is transported irreversibly through the leaves [9, p. 56]. In urban areas, evaporation and living space reduce the amount of solar energy absorbed by hard surfaces. Moreover, hard surfaces are protected from the effects of ultraviolet radiation, which degrades the structure and strength of hard surfaces. From an economic perspective, the cost of maintaining a stable, safe condition for the hard surfaces of buildings will be reduced if a green shield protects such buildings.

Plants can absorb, reflect and diffuse noise: this effect is positively reflected in urban areas, reinforcing comfort and coziness. The efficiency depends on plants' type, planting density, location, and frequency of sound waves [2, p. 190].

Vertical facades reduce the frequency of noise coming from both the middle of the room and from the outside environment. Green walls provide the building with a sound barrier, which significantly reduces noise and vibration of the environment (by 40 Dz) [4, p. 50]. A small green barrier in the middle of the building, which covers the workplace, reduces noise by 5 Dz [4, p. 50].

One of the most significant advantages of a green facade is its water supply system. The water used for irrigation of the vertical facade is not fully absorbed by it. As a result, residues accumulate at the lowest level, filling special tanks. After that, the collected water mass, filtered through the green facade, can be reused in the home or for irrigation. The green fasade is also provided with rainwater, which helps save electricity for pumping water for the fasade from the general water supply.

Plants prevent the entry of dust and dirt into the room due to the humid environment created by their leaf cover. Also, plants help reduce the number of harmful microorganisms by secreting juice. Protection against dirt and dust is manifested in improving air quality by absorbing toxins and carrying out

photosynthesis. Considering the premises filled with plants, it should be noted that the probability of mold or bacteria is reduced by 50-60% percent [9, p. 150].

As mentioned above, lowering the air temperature around the house's walls by 0.5 C will reduce electricity consumption by 8%. Increasing the temperature by 1 C will increase electricity needs by 2-4% for urban areas. With an increase in air temperature by 0.5-3 C, the urban area needs 5-10% more electricity to cool buildings [3, p. 12].

The need for green facades can be traced in the following logical chain: a reduction in electricity consumption will reduce production at thermal power plants, which will require less coal to operate and thus less air pollution. Improving air quality in urban areas will increase the cost of buildings and structures located within them [6, p. 46]. Studies by American and British scientists have shown that the cost of a building equipped with a green facade increases by 6-15% [5, p. 90].

Aside economic effect of green facades is the high cost of installing them. The initial investment is significant. However, given that buildings and structures are assets that serve for decades and even centuries, profitability will be reflected in electricity costs and real estate sales.

In addition to the ability to compensate for the lack of regulatory space per person, a green facade reduces energy consumption and increases real estate costs.

Conclusions. The history of facade landscaping began long before our era. Babylon is considered the source of this idea and the first technology for digging vertical living walls. The need for green facades was due not only to the aesthetic appearance that the building acquired. In the process of development of science and society, the number of reasons that determine the need for green facades has expanded: thermoregulation, weakening the fluidity of global warming, cooling of urban areas. Vertical landscaping fully complies with the principles of the concept of a «smart» city. Environmental, economic, and social benefits from the implementation of vertical landscaping technologies allow us to assert their high value within the concept of a «smart» city.

Currently, known designs and technologies for growing facades are not exhaustive: the development of light and durable materials, nutrients to accelerate growth will expand the range of products in the market of vertical landscaping. The technologies and designs used nowadays allow to grow a green wall of any form, height, and complexity. The investment made in a green facade is profitable if we consider it in the long run. Moreover, the value of a real estate shrouded in green elements is growing significantly. Thus, facade landscaping brings significant benefits from an economic, social, environmental, technical, and architectural perspective.

The most convincing motive for planting vertical living walls is to improve air quality, reduce electricity consumption and save the standard area of landscaping per person. It is worth mentioning that living walls can replace adult trees in terms of oxygen production and absorption of harmful substances, dust, and dirt. Growing a green wall takes much less time than an adult tree, so vertical facades are ideal for urban areas where there is a shortage of space, a small number of greeneries, and a significant excess of population and real estate growth compared to green space. Balancing the regulatory area of landscaping can be done by growing green facades.

Considering the situation observed in the new residential areas of Ukrainian cities, total construction leaves little room for vegetation, even if the norms of landscaping correspond to the population, becoming effortless. High-rise buildings absorb a considerable amount of solar energy, which will be emitted into the

atmosphere during the day's dark period. The stagnant, hot night air has a detrimental effect on the human body. If increasing the landscaping area due to living facades does not prevent the absorption of solar energy by high-rise buildings, it will at least speed up forming fresh, cool air.

To implement the possibility of growing green facades in Ukraine, it is necessary to amend the relevant laws and adjust building codes. Legislative changes need to be made for urban areas, where tall buildings in need of supporting structures predominate and the care of these plants, their irrigation, and fertilization. Accordingly, such measures will impose an additional tax burden on the population. On the other hand, new jobs will be created, and the savings in electricity and gas in winter will outweigh the costs of maintaining vertical facades. Besides, support systems will be built for the long term.

Because the volume of transport with internal combustion engines is continuously increasing, it increases the environment's pressure. There is a need to improve the use of productive deciduous areas. Located along noisy and polluted streets, the plants work at full capacity, absorbing all harmful substances. In this case, greenery prevents emissions from entering the atmosphere, instantly dispose of them. In turn, this is a contribution to the fight against global warming.

Modern technology, powerful technology, and knowledge have crystallized high-strength and complex materials and structures to construct and construct real estate. First of all, a real estate object should have a presentable appearance that will correspond to the modern post-industrial world's high technologies ideas. Living walls will give the harsh reinforced concrete masses a natural look, improve the environment's quality, and show that man is transformed from an exploiter and robber of nature into his guardian and protector.

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Пінь А. М. Системи вертикального озеленення як невід'ємна компонента сталого розвитку «розумного» міста.

З огляду на соціальні та кліматичні зміни в глобальних вимірах, кількість міст, які прагнуть до переформатування стратегій розвитку, помітно зростає. В умовах сьогодення серед стратегій розвитку домінують так звані розумні реформи, оскільки вони охоплюють цілі, які концепція розумного міста містить повною мірою. Зокрема, реформи спрямовані на забезпечення та підтримку сталого розвитку, збільшення частки відновлюваних ресурсів у загальному обсязі виробництва енергії та покращення управління відходами. Підвищення рівня розумного міста означає підвищення якості життя громадян шляхом надання можливостей для культурного, економічного та соціального розвитку в безпечному, надихаючому та здоровому середовищі. Аналіз найбільш ефективних і креативних ініціатив щодо встановлення тенденції «зеленого» будівництва для просування концепції розумного міста свідчить про високу ефективність «зелених» технологій. Особливе значення для цього дослідження має вертикальне садівництво / озеленення. Існує безліч доказів того, що вертикальне садівництво є одним з невід'ємних компонентів стратегії розвитку, спрямованої на досягнення формату розумного міста. Отримані дані відображають низку позитивних ефектів від вертикального озеленення щодо життя та добробуту. Серед цих переваг найбільш видатними є економічні та екологічні. Вертикальні сади дозволяють зменшити споживання енергії, а екологічні наслідки включають зменшення викидів CO_2 та інших забруднюючих екосистему речовин. На основі аналізу ефективності, що випливає з реалізації концепції зеленого садівництва, розроблені рекомендації щодо забезпечення сталого розвитку урбанізованих територій із використанням зелених і розумних технологій.

Ключові слова: розумне місто, зелені технології, концепція розумного міста, концепція вертикального озеленення, вертикальне озеленення.

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