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Innovative mobile solutions for vertical greenery in cities

Abstract: The process of urbanization of cities is accelerating every year. However, it is often accompanied by the deterioration of the ecological situation in cities, caused primarily by the loss of green areas. That is why vertical greening of territories has gained popularity as a way to maximize limited space and bring greenery into the urban environment. This work considers the concept of spreading vertical greening of facades, exploited green roofs, and city territories, for which the mobile landscaping structures are proposed as a means that can provide a significant improvement in the air quality of cities and lead to a reduction in electricity costs for air conditioning due to lowering the temperature of walls and roofs of green buildings. In addition, the possibility of using biochar like the composition of soils for vertical gardening and its contribution to a more ecological approach to gardening is being investigated. Economic calculations of the implementation of a mobile vertical greenery system, considering various factors associated with the costs of its installation, operation, and maintenance, showed a payback period of eight production cycles (at a constant market price). The system can operate for two calendar years without major maintenance or repairs. The use of biochar as a part of the soil mixture increases the adaptability of plants and their rapid growth, which financially justifies its use. Also, the proposed mobile greenery systems contribute to the creation of more sustainable, healthy, and comfortable urban spaces, which makes them an important component of modern urban planning and ecodesign. It is shown that 100 such mobile systems in cities provide a total of 750 sq. m of intensive landscaping.

Keywords: vertical greenery systems; biochar, mobile constructions, urban planning, ecodesign.

Introduction

Currently in cities and other urbanized areas, the use of Vertical Greenery Systems (VGS) and green roofs is steadily increasing due to the situation that the environmental impact of buildings on the internal and external climate is becoming more and more evident (*Newton et al., 2007*; *Wong et al., 2010*; *Perini et al., 2013*). This influence can dictate both the choice of plants and design decisions, like the requirements for the care and operation of vertical greenery systems.

Various techniques of vertical gardening have been used by people for centuries, starting with primitive trellis for growing plants vertically. Over time, the materials used in vertical gardens have evolved from simple wooden structures to more sophisticated systems incorporating modern materials. The concept of innovative materials in vertical gardens is extremely significant for understanding the possibility of using such materials in vertical greenery. First of all, it concerns ecological materials that have a minimal impact on the environment during the entire cycle of use. In the context of vertical gardening, this refers to materials that are renewable, recyclable, and non-toxic (*Alexandri & Jones, 2008*).

The practice of vertical greenery, i.e., adding vegetation to vertical surfaces (walls, facades) and even roofs of buildings, includes installing containers with soil for specially selected plants near buildings or using special hydroponics systems to grow plants on walls and facades of buildings.

The main aim of these studies was the possible use of practices of vertical greening of cities, like ways to improve the efficiency of structures for this purpose, by changing not only the forms but also filling containers with soil with the addition of biochar, as one of the most ecological and suitable materials for improving hydrophilic properties of soils.

Technologies for constructing green walls allow to identify and classify greenery systems according to their construction technique and main characteristics. Two main classifications of vertical greenery systems are used: living walls (LWS) and green facades (GFS) (*Saadatian, 2013*; *Koyama, 2018*; *Sheweka, S., & Magdy, 2011*). All of them have differences in equipment, and selection of plants, and, accordingly, the choice of growing soil for them depends on this, too.

According to the principles of selection of compositional combinations, vertical greenery is divided into 3 groups: according to functional, ecological, and decorative principles (*Bass & Baskaran, 2003*). Vertical one, according to the functional principle of selection is necessary due to various factors, which can be heat regulation, noise and dust protection, the need for shadow protection, etc. For plants to effectively perform these functions, their natural characteristics are worth considering: plant density, height, and density of leaves. The ecological principle considers as the main factor the weather conditions that are the best for each type of plant, considering the orientation of the building in the cardinal directions, like the temperature, composition, and fertility of soils used during planting. As for the decorative principle, here the vertical greenery main task is the ability to hide the shortcomings of certain buildings or, on the contrary, to emphasize the peculiarity of one or another facade. In this selection, the texture of plant leaves, their density, and the duration of the flowering period are also very significant, directly depending on the quality of the soils used, since they must retain moisture well, first of all.

Technologically, today there are several main systems of vertical greenery, which are divided according to the principle of operation: hydroponic systems; modular systems (using a substrate); and container systems with various plants (*Dunnett & Kingsbury, 2008*). The effectiveness of the last two greenery systems directly depends on the quality of the environment for growing plants, because it is the place, where plant roots find moisture and nutrients.

The medium most often used is light soil, or it can be normal natural soil consisting of decomposed organic matter with added nutrients. Light soil is a mixture of minerals, peat moss, and compost.

External greenery of facades usually has a very attractive appearance. However, it is worth remembering that it needs plants that can withstand external climatic conditions and will be insensitive to fluctuations in the content of water and nutrients in containers for their growth.

As a rule, undemanding and hardy liana-like plants and succulents are used for such systems: virgin grapes, Amur grapes, aristolochus, moonseed Daurian, honeysuckle, and ivy of various types.

Since plants need to create comfortable growing conditions, an important task is to optimize the design solutions of greenery systems to ensure full insolation, constant moisture, and high soil nutrition, which in turn can ensure sustainable and long-term plant development. An important role is played by the composition of the soil, which can be varied depending on specific climatic conditions and the type of plants that will be planted. First of all, such soil must provide good drainage, retain moisture, and be fertile and light, with the possibility of its further adaptation to specific conditions and requirements. It is also worth considering the presence of an additional load on the specific constructions of buildings and structures and the fact that vertical greenery systems are planned with the minimum allowable volumes of soil. These factors increase the importance of components in the composition of soils, and therefore, may play a decisive role in the success of vertical greenery.

The main components that can be included in the composition of the soil for vertical greenery of various structures are humus, peat, coconut fiber, and other components that provide primarily good drainage and water retention. Adding sand can balance these processes and prevent soil compaction. For this purpose, such light materials as vermiculite and perlite are used, which help to improve the processes of moisture retention and soil ventilation, making them looser and more favorable for the root respiration of plants (*Fitts, 2013*).

Adding organic material such as humus or compost can enrich the soil with nutrients and improve its structure. Depending on the type of plants and existing needs, mineral fertilizers can also be added to the soil to provide plants with the necessary macro and microelements. It is also possible to apply hydrogels – absorbents that help retain moisture in the soil, providing plants with moisture in periods of no precipitation.

However, the system functionality can be disrupted if the water supply is exhausted or the irrigation system fails. In our opinion, this shortcoming can be partially eliminated by adding biochar to it – a porous carbon material made from various plants and wood by methods of thermal decomposition and pyrolysis (heating without oxygen). It is believed that biochar is involved in many biological processes in the soil, so increasing its content leads to an increase in soil productivity (*Al-Kodmany, 2018*). Biochar retains most of the trace elements that were in the original biomass. By increasing the holding capacity of the soil, aerating the soil, and releasing nutrients through an increased pH value, biochar can be used as an effective substitute for peat and can be used for certain plants in vertical greenery. The presence of microbial symbiosis allows certain types of plants to obtain nutrients from pores in the structure of biochar (*Mukherjee & Lal, 2013*). The effect of biochar dosing on plant growth was the research subject (*Gale & Thomas, 2019*). It is worth noting that such use was proposed for vertical greenery systems as a whole. Our previous studies (*Kaynts et al., 2023*) mainly concerned the possibility of using ivy of various species as a base plant for mobile vertical greenery.

Thus, the main question of our investigations can be formulated as follows. Is the use of biochar-supplemented soils appropriate for plants grown in the proposed mobile vertical greenery systems? Can additional costs be offset by benefits in the further operation process?

It was assumed that biochar added to the soil composition for our proposed mobile vertical greenery systems would effectively retain moisture, and the additional costs of creating such systems would be compensated by the benefits of their operation in the future.

Materials and Methods

The task of our work was to check these assumptions and determine the effective amount of biochar introduction into the soil mixture, suitable for vertical greenery with ivy of various species, optimization of the dimensions of containers of mobile landscaping systems, and their possible location in cities. It is worth noting that any landscaping systems are capable of accumulating pollutants over time, which eventually leads to rapid phytodegradation of plants (*Yong Sik Ok et al., 2019*). Systems of vertical greenery, which are not cheap in general, must first of all be stable and durable. Otherwise, all costs for their creation are ineffective, and the green spaces themselves turn into unattractive green areas quite quickly. Thus, the optimization of the composition of the soil and the structures of the vertical greenery system is the driving force for the widespread and effective introduction of vertical landscaping centers in populated areas. It is also worth noting that until now in the literature we have not come across examples of the use of such soil compositions for vertical landscaping within Ukraine.

For our research, we used biochar from Tm Ideale (Ukraine), the main component of which is 92-96% carbon, accumulating in biomass processed by the hydrothermal carbonization method. Soil samples with different biochar content (in the range of 5-50%) were studied under the same conditions of temperature and humidity. An increased drying time was found for all samples. The effective amount of biochar was determined by data envelopment analysis (DEA). It has been experimentally confirmed that replacing 50% of peat with biochar in the soil mixture has a positive effect and prolongs the drying time of the soil. However, additional costs were required due to the cost difference between biochar and peat. It is worth noting that these results are expected to be valid for the climate zones of Central and Eastern Europe.

One of the main problems with vertical greenery is the high initial costs. Installation of special systems, plant support, and maintenance require significant investment. This can make vertical gardening out of reach for small township budgets. However, to a large extent this can be avoided by designing mobile or frame inclusions in the complex green zone of cities, both stationary containers and systems in new buildings, and mobile – small mobile greenery systems.

Thus, this is especially relevant, due to the possibility of cost optimization and unification of the shape and size of such containers, selection of soil composition, and appropriate plants.

Results of the study

In addition to classic vertical landscaping along walls or supports, which cannot always be quickly changed and requires significant material and time costs, the authors (*Kaynts et al., 2023*) proposed the use of a budget design of a vertical greenery system (*Figure 1*), the dimensions of which were determined by the possibility of quick and convenient installation in the central areas of the city, like the variability of its use, as a flower garden or a mini garden in the style of Urban Agriculture. The system can be made from locally available materials from Central and Eastern Europe. First of all, attention was paid to its long-term operation, easy accessibility to plants, and the possibility of integrating a self-watering system. The proposed vertical greenery system has several containers for plants, made of multi-layer plywood fastened with glue and nails. Variations of manufacturing from metal or recycled plastic are also possible, having a great perspective in terms of the ecological use of recycled materials. The supporting frame is made of wood or metal, also it has an integrated drip irrigation system.

Such mobile structures can vary from a trellis to a shelf, and be two-sided or one-sided. The dimensions of the containers are 110 cm in length x 20 cm in width. The containers had soil depths of 5, 7, 9, and 11 cm, respectively. The system's weight was calculated using CAD (Computer Aided Drawing) to support both the weight of the containers with the soil and later with the growing plants.

As a basis for growing ivy, we used a mixture of biochar and chicken manure mixed with peat and garden soil. In our case, biochar additionally performed the function of filtration, increasing the overall porosity of the proposed mixture, and also improving the structure and mechanical load-bearing capacity. The porous structure of this mixture served as a filter material capable of absorbing impurities and pollutants. It is worth noting that water and necessary nutrients are stored in the biochar itself and ensure optimal growth and viability of plants throughout the growing season. In addition, microbial symbiosis is stimulated (*Jacobson & Ten Hoeve, 2012*).

By increasing the water-holding capacity of the soil, aerating it, releasing nutrients, and increasing the pH level, biochar can be used as an effective substitute for peat in the soil mixture. We used Golden Heart ivy seedlings as experimental plants. To ensure the purity of the experiment, the vertical greenery system was mounted under a canopy so that the control crops used only the water supplied during the experimental period.

Plant height, leaf area index - LAI; number of leaves – NL; chlorophyll content – CC; stem diameter SD; root length – RL; fresh weight were analyzed to see if statistically significant changes in plant parameters were observed when biochar was added instead of peat to the soil composition with bird droppings. The results are presented (*Table 1*).

Of the 18 control seedlings, the tallest plants (9 pieces) were those grown in a mixture of garden soil, biochar, peat, and bird droppings, compared to a mixture of garden soil, peat, and bird droppings. The soil mixture, when replacing 50% biochar instead of peat, as the experiment showed, improves plant vegetation.

The proposed designs for vertical greenery are simple and uniform in shape, which allows their production and installation in small workshops, even in schools. The use of such structures simplifies plant care. They can also be used both in private estates and in areas of limited use (in kindergartens, schools, hospitals, gated residential complexes, cafes and restaurants, etc.). It can also be used for growing vegetables or herbs (*Pugh et al., 2012*). The use of such mobile vertical greenery can also serve as a kind of educational bridge to significant transformations in the city's green system.

Despite the environmental challenges cited in (*Manso & Castro-Gomes, 2015*; *Chen et al., 2018*), as far as Ukraine is concerned, there is currently no possibility of significant financing of global green inclusions in the state's city system. Similar to the above prototypes (*Figure 1*), we offer the manufacture and installation of simple and standard systems for the rapid increase of green mass. In addition, the creation of such ones will allow effective training of young people and contribute to the development of the positive ecological trend of Urban Agriculture. The easy-to-maintain system with an area of 2.25 sq. m (1.5 m x 1.5 m) makes it possible to cultivate plants in a volume commensurate with planting on an area of 7.5 sq. m. Thus, 100 such mobile systems provide a total of 750 sq. m of intensive landscaping.

The developed plans-schemes of the proposed arrangement of vertical greenery provide for a short-term increase of the area of landscaping in the center of small towns by at least 2,500 sq.m, part of which will be planted not only with decorative plants but also with plants from the so-called apothecary's garden. In addition, the proposed mobile vertical gardening system with an integrated irrigation system saves land by 70% of the total area. Such an affordable design of vertical gardening can easily be implemented in the conditions of small and medium-sized cities. Quick to install, and small in size, such systems can serve as barriers, fences, shading, and not only as a decorative element. The average costs for installing such a vertical system are shown (*Table 2*).

Discussion

To develop the economics of a mobile vertical gardening system, it is necessary to consider various factors related to installation costs, operation, maintenance, and potential savings since the cost and financial feasibility of the project are of great significance.

From this perspective, using recycled plastic in mobile vertical gardening systems is an important step towards sustainability. It not only reduces the negative impact on the environment but also helps save resources, reduce costs, and support the circular economy. In addition, recycled plastic provides durability and adaptability to designs, making it an ideal material for use in modern landscaping systems.

Conclusion

We consider the trend of improving the microclimate within the city by decorating the facades of buildings with vertical green plantings to be an effective solution that can affect the improvement of air quality in populated areas, as it will reduce the overall level of carbon dioxide (CO_2) and nitrogen dioxide (NO_2), which have a detrimental effect on citizens' health, as the safe level is often significantly exceeded. Plants can improve air quality by reducing the overall content of hazardous substances.

Economic calculations of the proposed mobile vertical greenery system showed a payback period of eight production cycles (assuming a constant market price). The system can stand for two calendar years without any capital maintenance and repair. The use of biochar as a component of the soil mixture increases the adaptability of plants and their rapid growth. It is possible to use inexpensive types of ivy, vines, or other plants, depending on the location and natural conditions in such a mobile vertical greenery system. This work shows that 100 of these mobile systems provide a total of 750 sq. m of intensive greening.

From an economical point of view, the most expensive vertical greenery systems are modular, but it is worth noting that during operation the modular system is flexible and allows for easy replacement of some modules if necessary, and the decorative effect of such a greenery system is at the highest level. In addition, when designing modules, it is possible to use recycled plastic. Thus, recycled plastic ensures the durability and adaptability of the design, making it an ideal material for use in modern greenery systems, and the landscaping method is highly aesthetic. Adding biochar to gardening soil has good potential, but widespread use will not be competitive if considering only its price. However, considering the environmental benefits, the proposed mobile vertical greenery systems can be widely used in cities.

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Appendix

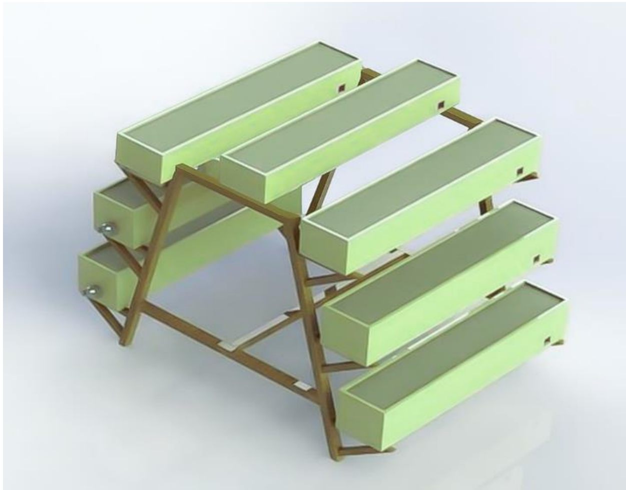

Figure 1. Prototype design of the vertical greenery system

Table 1. Average values of ivy growth parameters

Parameter	Soil mixture (without biochar)	Soil mixture (with biochar)
Fresh weight (FW)	43.577 ± 0.386 (mg)	71.577 ± 0.289 (mg)
Dry weight (DW)	3.263 ± 0.027 (mg)	5.898 ± 0.065 (mg)
Stem diameter (SD)	0.900 ± 0.100 (cm)	1.050 ± 0.100 (cm)
Root Length (RL)	6.607 ± 0.163 (cm)	6.640 ± 0.207 (cm)

Table 2. Average costs for installing a vertical greenery system

Name	Quantity	Price per piece, UAH	Total price, UAH
Pipe 16"	75 m	38,25	2869
Phytocontainers 400*420*32 mm	8 pcs	1912	15296
Soil mixture	200 1	3789	15156
Biochar	20 1	750	15000
Wall profile 3000*100*50 mm	19 pcs	68,84	1308
Mounting for the profile	35 pcs	14,50	508
Bracket for mounting the module	280 pcs	9,17	2570
Water supply timer	1 pcs	1542	1542
Total:			54249