THE USE OF GREEN WALLS TO INCREASE THE PHYTOREMEDIATION OF AIR POLLUTANTS. A REVIEW

ASPECTE GENERALE PRIVIND UTILIZAREA PEREŢILOR VERZI PENTRU ÎMBUNĂTĂȚIREA CALITĂȚII AERULUI

IVAN Elena Ştefania*[1], CICEOI Roxana*[1], *BUTCARU Ana Cornelia*[1], *NIŢU Oana Alina*[2], *STANICĂ F.*[1]**

*Corresponding author e-mail: elena.ivan@qlab.usamv.ro

Abstract. *Europe's future depends on a healthy planet. Urban green spaces play a key role in improving the liveability of our towns. Current climate and environmental challenges require an urgent and ambitious response. Climate change is affecting our society in many ways. Rapid, and widespread reduction of greenhouse gas emissions and achieving a net level of greenhouse gas emissions CO_2 equal to zero have the potential to limit climate change and its effects. That is why, lately, the world is fighting in various forms for the creation of new green spaces, especially in the most crowded urban areas. This paper aims to present a review regarding the green walls used to reduce the buildings energy consumption, to increase the phytoremediation of air pollutants, to increase the biodiversity and to contribute to life quality in the cities by their recreations and aesthetic functions.*

Key words: urban horticulture, biodiversity, vertical gardens, urban horticultural ecosystems

Rezumat. *Viitorul Europei depinde de o planetă sănătoasă. Spațiile verzi urbane joacă un rol cheie în îmbunătățirea locuinței orașelor noastre. Provocările climatice și de mediu actuale necesită un răspuns urgent și ambițios. Schimbările climatice afectează societatea noastră în multe feluri. Reducerea, rapidă și pe scară largă a emisiilor de gaze cu efect de seră și atingerea unui nivel net de emisii de gaze cu efect de seră CO_2 egal cu zero au potențialul de a limita schimbările climatice și efectele sale. De aceea, în ultima vreme, lumea luptă sub diferite forme pentru crearea de noi spații verzi, în special în cele mai aglomerate zone urbane. Această lucrare își propune să prezinte câteva aspect generale referitoare la pereții verzi, structure utilizate pentru reducerea consumului de energie din clădiri, îmbunătățirea calității aerului prin filtrarea poluanților atmosferici, creşterea biodiversității, îmbunătățirea calității vieții prin funcția recreativă si valoarea estetică deosebită.*

Cuvinte cheie: horticultura urbană, biodiversitate, grădini verticale, ecosisteme horticole urbane

[1]The Research Center for Studies of Food and Agricultural Products Quality, University of Agronomic Sciences and Veterinary Medicine of Bucharest

[2]Faculty of Land Reclamation and Environmental Engineering, University of Agronomic Sciences and Veterinary Medicine of Bucharest

INTRODUCTION

Urban horticulture is one of the most important socioeconomic sectors for future city designs (Edmondson *et al.*, 2020) combining economical, ecological, and societal demands.

Urban green infrastructures increase the resilience of ecosystems (Meerow and Newell, 2017), promotes sustainability (Wolch *et al.*, 2014) and maintains the cities 'metabolism' (Kennedy *et al.*, 2011), offering nature-based solutions to specific urban problems. The balance of these demands leads to sustainability.

The production of plants in cities, including those for food, is currently re-discovered in city planning. Being part of typical cities for centuries and forgotten over decades, more and more city designers have space in mind for horticultural production (Edmondson *et al.*, 2020).

From an ecological perspective, urban green spaces are a real moderator of the impact of human activities on the environment, and one of the most impressive categories of green spaces is represented by green walls.

The idea of the green walls has long roots, the first written mention on "dressed house walls" dating back from the 1st century AD (Vágner, 2015).

The idea of green walls was mentioned also 11 centuries ago, when green walls were used by the Vikings, who used stones, lumber and peat bricks to make greener their places (Sadeghian *et al.*, 2016, Safikhani *et al.*, 2014).

The modern use of green walls started with the patent of Stanley Hart White in 1938, called "Vegetation-bearing architectonic structure and system" (Hindle, 2012).

Later, the botanist Patrick Blanc made the first famous 'vegetal wall' by designing the green walls at the Musee du Quai Branly in Paris, starting a 'bio-architechture revolution' (Agiobu-Kemmer, 2015).

Today, the biggest cities in the world are competing on which town has the most impressive and impacting green solution. As green walls have multiple functions, the studies for scientific evidence of their impact are complex.

The quality of these green vertical spaces contributes at improving the identity of cities, by providing essential ecosystem services (Gómez-Baggethun and Barton, 2013; Lafortezza and Chen, 2016; Spanò *et al.*, 2017).

Indeed, if we consider that plants contributes to dampening the inner city traffic noise, we are creating an environment of cooler and cleaner air with less noise, from which people benefit in cities, but also within buildings, as improved conditions allow for extended periods of natural ventilation, thus reducing the amounts of energy required for cooling all year round; and giving building occupants more freedom to control their individual environment by means of healthier and more beneficial natural ventilation (Tilley *et al.*, 2014; Connelly *et al.*, 2015, Péreze *et al.*, 2014).

Noise poses a significant risk to health and well-being in urban societies.

The World Health Organization (WHO) cites noise as a leading environmental nuisance that reduces work productivity, disturbs sleep, impairs cognitive functioning, and can cause cardiovascular disease and contribute to mental illness.

Green facades have many ecological benefits, making them an excellent example of ecological technology.

The addition of new habitats in urban environments, for example, can benefit species affected by habitat destruction and fragmentation. Birds and insects may benefit from these facade plants.

Green facades also benefit the environment by improving water and air quality. Facade plants use and slow stormwater flow before it joins urban runoff (Ottelé *et al.*, 2010).

The WHO estimates that poor air quality led to seven million deaths in 2018; and Yale University's Environmental Performance Index has calculated that over 1.78 billion people have inhaled polluted air over the past decade (WHO, 2019).

The air quality is improved when green walls plants capture fine dust particles and take up air pollutants such as CO_2, NOx, and SO_2 (Ottelé *et al.*, 2010).

Both outdoor and indoor air contamination is one of the issues relying on small particles (such as dust and smoke), biological agents (molds, spores), and different solid or gaseous contaminants such as radon, asbestos, CO, CO_2 (Guieysse *et al.*, 2008).

According to the Center for Public Environmental Surveillance (CPEO), more research is needed to understand the effect of different compounds on the entire ecosystem of which plants may be a part.

At European level, the concept of green solutions has grown precisely because they aim solving or managing major environmental challenges in society. In addition, the Food and Agriculture Organization of the United Nations defines peri-urban agriculture as "agricultural practices around cities that compete for resources (land, water, energy, labor) that could also serve other purposes to meet the needs of the urban population" (FAO, 2021).

The current review aims at listing the advances that have been made in the last decades in the green walls area, with emphasis on the air depolluting documented effects.

MATERIAL AND METHOD

This literature review covers publications on the removal of air pollutants using plants and is based on the databases of ScienceDirect, Scopus, and Web of Science as well as related books.

The main criteria for the selection of the publications were the topic of improving outdoor & indoor air pollution green walls, and the keywords used were phytoremediation, air pollution green walls.

As phytoremediation is relatively new in practice, there are still questions about its wider impact on the environment.

RESULTS AND DISCUSSIONS

Green walls, as we see them today, sometimes referred as vertical gardens or living walls, may look like a new development. Many of them use modular or continuous planted sections.

They are made of pre-vegetated vertical frame modules or planted roofs (flat vegetated wall) that are fixed to a wall or other structures (Leung *et al.*, 2015; Moya *et al.*, 2019; Maslauskas *et al.*, 2015; Gunawardena *et al.*, 2019).

Green walls can be used indoors or outdoors. These structures can also be classified as passive and active green walls.

Passive green wall (or inactive living wall) systems are manufactured in square or rectangular modular panels.

These panels have direct growth media in the form of plants and are connected to a facade or structure of the building and usually to an easy construction system (Tomson *et al.*, 2021; Modirrousta *et al.*, 2015).

A green wall system (GWS) is a wall partially or completely covered with plants that involves a growing environment, such as soil, perlite etc. Many of the green walls also have an integrated irrigation system.

The green wall system represents a way to grow plants either directly on the soil or on some installed structures on the facade of different constructions (fig. 1a) or specially designed construction (fig. 1b).

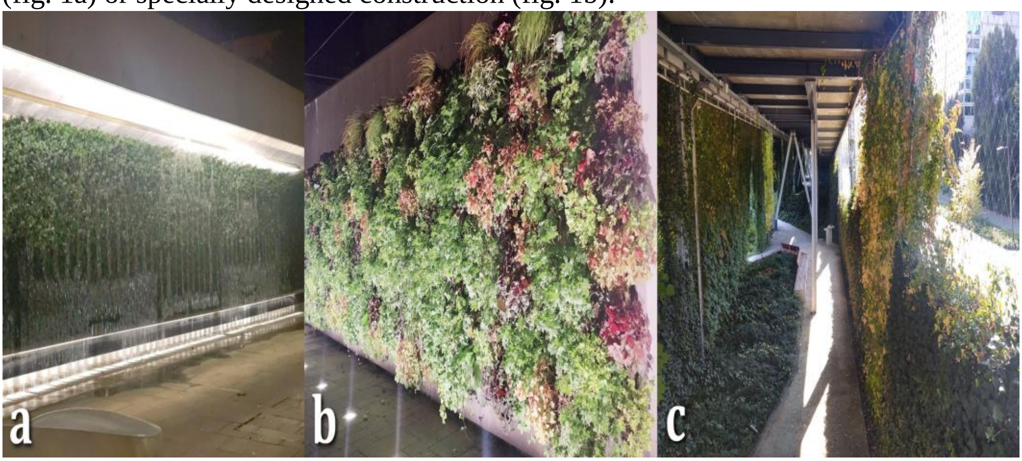

Fig. 1 Green walls on different buildings, in Millenaris Park, Budapest.
a. combination of outdoor green wall with water curtains on a sidewalk;
b. combined outdoor green wall (different species, colors, functions);
c. specially designed structure for separating the tall buildings of the park.

Green walls reduce pollution, control temperature, and increase biodiversity (Pérez-Urrestarazu *et al.*, 2016; Pandey *et al.*, 2015; Safikhani *et al.*, 2014).

The popularity of these vegetation vertical walls is on the rise; they are appreciated not only for their aesthetic value, but also for the environmental and economic benefits (Bakar *et al.*, 2014).

Green walls have a different classification that is based on the type of plants, the structure of the green wall system and the growing environment (Pettit *et al.*, 2018; Safikhani *et al.*, 2014).

Phytoremediation is the phenomenon in which green plants capture and degrade pollutants from indoor air (Wang *et al.*, 2014).

The intensive use of green walls has led to independent development of evaluation requirements, for different parameters (Ravindu *et al.*, 2015).

Studies investigating the factors that affect phytoremediation and their process in pollutant removal are limited.

Among the most important factors are the types of associated microorganisms and plants, the composition of the pollutants and the light source.

Studies have shown that the effectiveness of phyto-remediation has decreased due to competition between rhizosphere microorganisms and plants below the nutrient resource limit.

Plants absorb the pollutants by the root from the soil and water. Root capture is related to pollutants concentration and properties, plant species / composition, exposure time and other system variables (Liu *et al.*, 2017; Soreanu *et al.*, 2013; Su *et al.*, 2015).

Phyto-remediation of contaminated soils accumulates or degrades pollutants by plants. However, in botanical air filters, the application of microbial activity has an important role in removing indoor pollutants.

Biodegradation can also occur through the growth of bacteria in plants. In general, plants and bacteria have the complexity and importance of interactions (Wang *et al.*, 2014).

CONCLUSIONS

Depending on the concentration of contaminants in the soil, phyto-remediation may be limited to less concentrated areas, as plants are limited in the amount of waste they can pick up and process.

In addition, the CPEO warns that large amounts of surface area are needed for phyto-remedial treatments to be successful.

Some contaminants can be transferred to different media (soil, air or water), and some contaminants are not compatible with treatment (such as polychlorinated biphenyls or PCBs).

It is necessary to eliminate high-concentration pollution by plants and to use micro-organisms to increase the resistance of plants to pollutants, especially toxic pollutants.

Available studies also lack detailed phytoremediation mechanisms and chemical property of pollutants.

***Acknowledgments**: "This work was supported by a grant of the University of Agronomic Sciences and Veterinary Medicine of Bucharest, project number Cod 2021-7/2021.07.19, acronim OrchardBioWalls within Joint Junior Competition 2021 and project FDI-2021-0430". Contract nr. 1278/2021*

REFERENCES

1. **Agiobu-Kemmer Sereba, 2015 -** *Living Walls For Healthy Cities*, https://guardian.ng/saturday-magazine/living-walls-for-healthy-cities/.
2. **Bakar N.I.A., Mansor M., Harun N. Z., 2014 -** *Vertical greenery system as public art. Possibilities and challenges in Malaysian urban context*. Procedia-Social and Behavioral Sciences, 153, 230-241.
3. **Connelly M., Hodgson M., 2015 -** *Experimental investigation of the sound absorption characteristics of vegetated roofs*. Building and Environment, 92, 335-346.
4. **Edmondson J.L., Cunningham H., Densley Tingley D.O., Dobson M.C., Grafus D.R., Leake J., McHugh N., Nickles J., Phoenix G.K., Ryan A.J., Stovin V., Taylor Buck N., Warren P.H., Cameron D.D., 2020 -** *The hidden potential of urban horticulture*. Nat Food 1:155–159. https://doi.org/10.1038/s43016-020-0045-6
5. **Gómez-Baggethun E., Barton D.N., 2013 -** *Classifying and valuing ecosystem services for urban planning*. Ecological economics, 86, 235-245
6. **Guieysse B., Hort C., Platel V., Munoz R., Ondarts M., Revah S., 2008 -** *Biological treatment of indoor air for VOC removal: Potential and challenges*. Biotechnology advances, 26(5), 398-410.
7. **Gunawardena K., Steemers K., 2019 -** *Living walls in indoor environments*. Building and Environment, 148, 478-487.
8. **Hindle R.L., 2012 -** *A vertical garden: origins of the Vegetation-Bearing Architectonic Structure and System (1938).* Studies in the History of Gardens & Designed Landscapes 32, 99–110. doi:10.1080/14601176.2011.653535.
9. **Kennedy C., Pincetl S., Bunje P., 2011 -** *The study of urban metabolism and its applications to urban planning and design*. Environmental pollution, 159(8-9), 1965-1973.
10. **Lafortezza R., Chen J., 2016 -** *The provision of ecosystem services in response to global change: evidences and applications*. Environmental research, 147, 576-579.
11. **Leung D.Y., 2015 -** *Outdoor-indoor air pollution in urban environment: challenges and opportunity*. Frontiers in Environmental Science, 2, 69.
12. **Liu G., Xiao M., Zhang X., Gal C., Che X., Liu L., Clements-Croome D., 2017 -** *A review of air filtration technologies for sustainable and healthy building ventilation*. Sustainable cities and society, 32, 375-396.
13. **Maslauskas T., 2015 –** *Green Walls - The Vertical Planting Systems*. VIA University College: Horsens, Denmark; p. 43
14. **Meerow S., Newell J.P., 2017 -** *Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit*. Landscape and Urban Planning, 159, 62-75.
15. **Modirrousta S., Mohammadi Z., 2015 -** *Necessity and Methods of Designing Green Buildings in Cities and its Effect on Energy Efficiency*. European Online Journal of Natural and Social Sciences: Proceedings, 4(3 (s)), pp-304.
16. **Moya T.A., van den Dobbelsteen A., Ottele M., Bluyssen P.M., 2019 -** *A review of green systems within the indoor environment*. Indoor and built environment, 28(3), 298-309.

17. Ottelé M., van Bohemen H.D., Fraaij A.L., 2010 - *Quantifying the deposition of particulate matter on climber vegetation on living walls*. Ecological engineering, 36(2), 154-162.

18. Pandey A.K., Pandey M., Tripathi B.D., 2015 - *Air Pollution Tolerance Index of climber plant species to develop Vertical Greenery Systems in a polluted tropical city*. Landscape and Urban Planning, 144, 119-127.

19. Pérez G., Coma J., Martorell I., Cabeza L.F., 2014 - *Vertical Greenery Systems (VGS) for energy saving in buildings: A review*. Renewable and sustainable energy reviews, 39, 139-165.

20. Pérez-Urrestarazu L., Fernández-Cañero R., Franco A., Egea G., 2016 - *Influence of an active living wall on indoor temperature and humidity conditions*. Ecological Engineering, 90, 120-124.

21. Pettit T., Irga P.J., Torpy F.R., 2018 - *Functional green wall development for increasing air pollutant phytoremediation: Substrate development with coconut coir and activated carbon*. Journal of hazardous materials, 360, 594-60

22. Ravindu S., Rameezdeen R., Zuo J., Zhou Z., Chandratilake R., 2015 - *Indoor environment quality of green buildings: Case study of an LEED platinum certified factory in a warm humid tropical climate*. Building and Environment, 84, 105-113.

23. Sadeghian M.M., 2016 - *A Review on green wall, classification and function*. International Journal of Scientific Research in Science and Technology, 2(2), 47-51.

24. Safikhani T., Abdullah A.M., Ossen D.R., Baharvand, M., 2014 - *A review of energy characteristic of vertical greenery systems*. Renew. Sustain. Energy Rev. 40, 450–462.

25. Soreanu G., Dixon M., Darlington A., 2013 - *Botanical biofiltration of indoor gaseous pollutants–A mini-review*. Chemical engineering journal, 229, 585-594.

26. Spanò M., Gentile F., Davies C., Lafortezza R., 2017 - *The DPSIR framework in support of green infrastructure planning: A case study in Southern Italy*. Land Use Policy, 61, 242-250.

27. Su Y., Liang Y., 2015 - *Foliar uptake and translocation of formaldehyde with Bracket plants (Chlorophytum comosum)*. Journal of hazardous materials, 291, 120-128.

28. Tilley D., Alexander A., Chang A., Price C., Welch A., Wells B., Tjaden S., 2014 - *Green Facades: Ecologically Designed Vertical Vegetation Helps Create a Cleaner Environment*. UM Ext. Publ., vol. Environmen, no. FS-978, 1-6.

29. Tomson M., Kumar P., Barwise Y., Perez P., Forehead H., French K., Watts, J.F., 2021 - *Green infrastructure for air quality improvement in street canyons*. Environment International, 146, 106288.

30. Wang Y., Bakker F., De Groot R., Wörtche H., 2014 - *Effect of ecosystem services provided by urban green infrastructure on indoor environment: A literature review*. Building and environment, 77, 88-100.

31. Wang Z., Pei J., Zhang J.S., 2014 - *Experimental investigation of the formaldehyde removal mechanisms in a dynamic botanical filtration system for indoor air purification*. Journal of hazardous materials, 280, 235-243.

32, Wolch J.R., Byrne J., Newell J.P., 2014 - *Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'*. Landscape and urban planning, 125, 234-244.

33, Vágner B., 2015 - *Green facade fixed in front of sandwich panel measurement of thermal effects of systems* (In Hungarian). University of Technology and Economics of Budapest, Faculty of Architecture, Department of Building Energy and Building Engineering

34. Weisz S., Boromisza Z., 2019 - *Possibilities and limiting factors of green facades in Budapest sample areas (Zöldhomlokzatok telepítési lehetőségei és korlátozó tényezői budapesti mintaterületeken)*. Tájökológiai lapok, 17(2), 255-263.

35. *, WHO, 2019 -** *Air Quality Deteriorating in Many of the World's Cities World Health Organization*. Available online: https://www.who.int/mediacentre/news/releases /2014/air-quality/en/ (accessed on 30 September 2021).
36. *,** http://www.fao.org/home/en/