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THE USE OF VERTICAL GARDENS AS A NETWORK OF URBAN NAVIGATION ELEMENTS WITH A POSITIVE IMPACT ON BIODIVERSITY AND MICROCLIMATE IN A DENSE URBAN ENVIRONMENT

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Abstract

Horizontal green areas are becoming valuable, yet extruded spots, and their constant elimination at the expense of commercial and housing developments is disrupting green infrastructure. Interlocked existing urban structures seldom allow for the creation of parks and larger green open spaces, which could provide a habitat for a wide range of insects, birds, and other small animals. The lack of green spaces causes urban heat islands (UHI) over the cities. Vertical gardens are alternative solutions for urban areas, where it is not possible to increase biodiversity by creating new horizontal green areas. They effectively utilise surfaces that would otherwise be unused and transform them into effective green infrastructure elements.

Using the example of the historical city district of Bratislava, i.e., Old Town (Staré Mesto) in Slovakia, we present an alternative approach for resolving the lack of green areas. A case study was conducted to create a map of all the potentially suitable areas for the construction of vertical gardens. We divided these spots into three groups, i.e., walls, columns, and free-standing structures and proposed construction methods for each type. Regarding the placement of potentially suitable areas along the roads connecting important transport hubs with the city centre, we created an original proposal for a district-wide network of vertical gardens as orientation elements for tourists and residents with significant aesthetic merit as well as ecological and hygienic values.

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Key words

- Vertical gardens,
- Green walls,
- Densely urbanised cities,
- Urban heat island mitigation,
- Urban design,
- Living walls.

1 INTRODUCTION

The constant expansion of densely built-up areas caused by intensive urbanisation eliminates green areas and contributes to a loss of biodiversity and the overheating of cities compared to surrounding rural areas. Developing various construction and innovative methods could mitigate some of these issues caused by urbanisation. The absence of conventional green spaces or locations for creating new ones is leading us to find alternative solutions to urban greening (Susca *et al.*, 2022). One of those measures involves vertical gardens or living wall constructions. This approach is still relatively new, with only limited research regarding its benefits to the urban environment and its application in local and national policies (Liberalesso *et al.*, 2020). A review study by Balany *et al.* (2020) shows that only 4.3% of reviewed papers examined living walls as a green infrastructure strategy. Moreover, another analysis of green infrastructure incentives in 113 international cities shows no par-

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ticular living wall promotion policy (Liberalesso *et al.*, 2020). Considering the relatively significant number of building surfaces suitable for creating living walls and their presence on the street level, such a measure shows great potential in mitigating heat stress, increasing biodiversity, and creating a better urban environment (Emilsson *et al.*, 2007).

The aim of this paper is to offer a brief description of current findings regarding the positive effects of vertical gardens to mitigate urban heat islands (UHI), and improve energy efficiency, microclimates, and greywater treatment (Ruiz-Valero *et al.*, 2023). Moreover, we propose a strategy that uses bare facades, columns, walls, and other existing urban structures and transforms them into effective green infrastructure elements. An added value of the research is our original proposal to use vertical gardens as a network of orientation points from the main traffic hubs, i.e., railway and bus stations, public transport interchanges, and passenger port, to the historical centre of Bratislava, thus creating an urban navigation system.

1.1 Positive impact of vertical gardens

Densely urbanised areas lack biodiversity; hence, vertical gardens provide opportunities to create habitats for birds, butterflies, bees, and other small insects (Elgizawy, 2016). When designed correctly, vertical gardens could have a significant impact on improving biodiversity in urban areas (Thorpert *et al.*, 2022). Using bare structures with no ecological value and changing them into green sites could help create a network of connecting stops between larger green areas. Studies indicate that when combined together, these small patches could have a major positive effect on increasing biodiversity (Vega and Küffer, 2021). The lack of green spaces allow hot air to accumulate above the city and it causes urban heat islands (UHI) over the cities. An urban heat island is caused by various factors, mainly heat absorption and its subsequent release by sealed surfaces such as roads, pavements and building facades (Taleghani, 2018). Plants can absorb solar radiation for their vital functions, which help the surrounding microclimate by evaporative cooling (Qin *et al.*, 2012; Majorošová and Mazancová, 2020) and an increase in albedo. Materials such as asphalt and concrete have an albedo of 0.1-0.4, respectively, while green walls have one of 0.7-0.85. With increasing albedo values, on a scale of 0-1, heat absorption, and subsequently emissions, decrease (Berardi *et al.*, 2014). Another secondary contributor to UHI is the use of air conditioning. The rise of urban temperatures can increase demands for cooling, thus contributing to greenhouse gas emissions. Furthermore, heat waste from air conditioning aggravates the UHI effect (Susca et al, 2022) and increases the urban temperature by 0.5°C (de Munck *et al.*, 2013). Analyses show that installing green walls can reduce heating and cooling energy demands by 16.5% and 51%, respectively (Susca *et al.*, 2022). Moreover, research has shown that during the cooling season in a Mediterranean climate, green facades can have an energy efficiency of 34% (Pérez *et al.*, 2017) and living wall systems one of up to 59-66% (Manso *et al.*, 2021). Vegetation and substrate act as insulation, provide shading of the wall surface, and absorb solar radiation, thus alleviating overheating of building interiors and reducing cooling demands in the summer (Shafiee *et al*, 2020). On the other hand, winter field measurements have shown an increase of near-wall temperatures by 1.26°C (Daemei *et al.*, 2018) or even 2°C, compared to a bare control wall, thus proving efficiency as a passive energy-saving measure (Vox *et al*, 2018).

Several studies have proved the positive impact of green walls on surface temperatures and surrounding microclimates, including a decrease in average urban temperatures by 1.37°C (Manso *et al.*, 2021). An experiment conducted in Catalonia, Spain, (Coma *et al.*, 2017) showed reductions of 16.5°C in the surface temperature on a south wall, 4.5°C on an east wall, and 6.5°C on a west wall. Hoelscher *et al.* (2016) reported decreases in exterior surface temperatures in Berlin by up to 15.5°C and by 1.7°C on interior. An experiment in Bari, Italy, shows a maximum surface temperature drop of up to 9°C on a south wall (Vox *et al.*, 2018), similar to an Illinois experiment by Susorova *et al.*, (2014). Other research from Thessaloniki, Greece, reports an average surface temperature reduction of 5.7°C, varying from 1.9°C to 8.3°C (Eumorfopoulou and Kontoleon, 2009). Perez *et al.* (2014) stated that the surface temperature decreased by 1.7°C to a maximum of 13°C.

According to Oquendo-Di Cosola *et al.* (2022), their results show different values for various climate types. Depending on the construction method, a wide range of values is presented even though measured under identical circumstances. In humid tropical climates, the reduction in the temperature varies between 1.1°C – 14°C for continuous green walls, when using materials such as felt, which supports roots and lets plants grow naturally, and from 6.1°C up to 20.8°C for modular green walls, which are formed by modular substrate-filled, pre-planted pot units. An even more significant decrease was observed in continental climates, where modular types showed a reduction between 8°C and 31°C, while continuous green walls mildly decreased the surface temperature by 0.8°C to 2.1°C. In a Mediterranean climate, both modular and continuous systems show reductions of up to 20°C, in an oceanic climate up to 15.5°C, and in semi-arid climates by 2.5°C (Oquendo-Di Cosola *et al.*, 2022).

Green walls also have potential in natural domestic greywater treatment. Roots and porous media could function as a biofilter treating wastewater through oxidation, filtration, microbial assimilation, etc. (Manso *et al.*, 2021). Research shows an 80-90% removal of total suspended solids, a 30-50% removal of total nitrogen, a 15-30% removal of total phosphorus, a 20-80% removal of E-coli, a 30-70% removal of chemical oxygen demand, and more than a 90% removal of biological oxygen demands (Ghaitidak and Yadav, 2013; Prodanovic *et al.*, 2017).

Other research shows that increasing humidity could lower temperatures in an urban environment. According to a study from Iran, relative humidity near a vegetated wall was up to 9.3% higher than the control bare wall and 7.3% higher at a 0.5m distance from the green wall (Shafiee *et al.*, 2020). Plants absorb carbon dioxide for photosynthesis, thereby producing oxygen and biomass, which also positively impacts a microclimate (Stemberg *et al.*, 2010). Foliage can retain dust particles that are subsequently washed down to drainage systems (Kuhn and Bass, 1999). Studies show that vegetated areas have only 10-15% dust particles compared to areas without any vegetation (North American Wetland Engineering, 1998).

Studies regarding the positive effect of green walls on the environment still need to be expanded, and they need to be the subject of further and more complex research. However, we can state that such a measure positively impacts the urban environment and its microclimate and increases the aesthetic and economic value of buildings (Fig. 5,6) (Hadba, 2017). They improve the overall appearance of cities and positively impact the human psyche (Sheweka and Magdy, 2011). One of the most valuable advantages of vertical gardens is their placement on vertical structures, which does not require taking up valuable land space. Instead, they give value to places that would otherwise be unused such as facades, walls, or columns. Vertical gardens also increase the economic value of buildings and neighbourhoods (Perini *et al.*, 2011). This technology is still a relatively rare and unusual sight to the public eye; hence, its limited use has been seen in an urban environment. Nonetheless, it could be perceived as a benefit since the unconventional appearance of such a design attracts tourists, making these buildings modern-day monuments and subsequently popularising green architecture.

2 METHODOLOGY

2.1 Selection of the research area

This paper is focused on the use of an alternative form of vegetation in a dense urban environment. It is a new way of green areas in the cities. Problems connected to dense urbanisation also occur in Slovakia.

We used the Old Town district of Bratislava, the capital of Slovakia, as a pilot case study for implementing green walls around the city centre. The methodology is based on our knowledge of the principles and values of vertical gardens. Densely locked-in historical urban structures in the Old Town do not allow for the creation of valuable new green spaces; on the other hand, these structures contribute the most to the UHI effect. Therefore, vertical gardens are ideal in this case, as they do not take up any space or land.

We defined area borders using the official cadastral boundaries of the Old Town district. Since it is a historical part of Slovakia's capital, the historical context of the area and its relations and values in the past were also analysed to create a design that does not interfere with its character. The use of green walls in the historical city centre and its surroundings could not only benefit biodiversity and the microclimate during hot summer days but also effectively increase the aesthetic value of abandoned or deteriorated buildings, which have a negative impact on the overall appearance of one of the most visited parts of the city and the whole country as well. We analysed the green environment of Old Town and focused on all the green spaces and elements present in this part of the city. Due to the lack of green areas, we chose the most densely urbanised area of the Old Town, i.e., the historical centre, as the main area of interest.

2.2 Data collection in Bratislava, Slovakia

Firstly, we got data from the Slovak Hydrometeorological Institute, which provided surface temperature analysis data collected in August 2018. The data were from the satellite

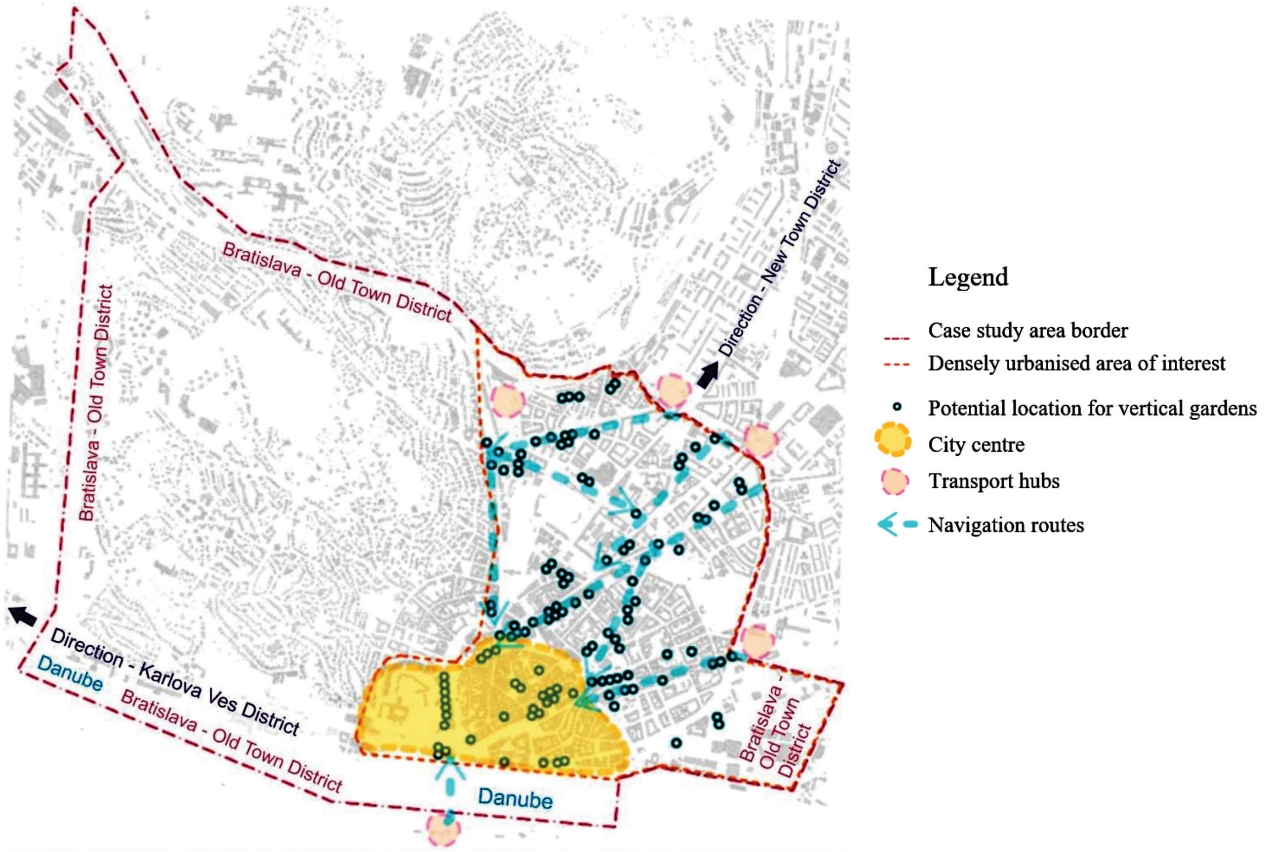


Fig. 1 *Map of the Old Town Bratislava District, marking all the potential areas of interest.*

Landsat 8, and the temperatures were measured at 0:00, 8:00, 12:00, 15:00 and 18:00. These measurements showed that the historical part of the Old Town is most prone to overheating, with up to a 10°C difference between the area of interest and rural areas (Holec, 2018).

As our next step, we collected data in situ and created a database and photo documentation of all the potential spaces suitable for vertical gardens. Those data collection field trips took place from September to November 2019. Then, we designed a map marking all the potential areas of interest (Fig. 1).

2.3 Choosing the type of construction

Lastly, we chose three different vertical structures that could be appropriate for the Bratislava environment and created three case studies that could be used as examples of design patterns for all the potential spaces featured on the areas of interest map. These three structures are: green walls, green columns, and free-standing green structures because there are many spots, where these tree types are applicable in Bratislava Old Town District.

Inspiration for the development of green walls comes from natural parasitic climbers and vines, especially in a tropical environment. These species are adapted to growth on rocks or other plants and receive nutrients from the atmosphere or rain. Vertical gardens can be divided into two primary groups, i.e., green facades and living walls (Brković Dodig *et al.*, 2019).

Green facades are the most affordable type of vertical gardens (Ottelé *et al.*, 2011). They are considered to be simple solutions created of support systems such as wires or trellis systems for climbers and vines, which not only support plants but also enable the use of climbers without adhesive pads (Fig. 2). They create an air gap between a wall and vegetation, which protects a facade from severe weather conditions (Baran and Gultekin, 2017). Walls and facades directly covered by such plants are also categorised as green facades (Fig. 3) (Manso and Casto-Gomez, 2015). Plants can be planted directly into the soil near a wall or into pots. In the case of their use on high-rise buildings, pots can be constructed at different altitudes (Fig. 2) (Dunnet and Kinsbury, 2008).

Living walls are complex systems of plastic pots and modules or felt pockets (Fig. 4); they are always combined with irrigation and are secured on a metal frame, allowing for the use of nonclimbing species, grasses, shrubs, or succulents (Francis and Lorimer, 2011). The whole system is automatically controlled by a unit, which determines the dosage of fertilizer and water demands (Mir, 2011). We can state that green facades are simple and cost-effective solutions that do not require intensive care. However, they have a limited height; the selection of plants is narrowed only to climbers. The desired full-grown effect is achieved in years or decades. Living wall systems have a considerably higher initial cost but offer more planting options with various types of plants in different patterns. They do not have any height limitations, and the desired effect is achieved practically immediately. The plants are always watered and fertilised through an automatically operated irrigation system; hence they do not dry out and can provide a lush effect for decades. Constant irrigation and the freshness of the plants helps prevent a fire hazard, which is often associated with green walls. The differentiation overview by Mir is shown in Tab. 1 (Mir, 2011)

Evolving technologies can enable the use of different plant species. However, their selection should not only be based on aesthetic values. Essential factors in determining suitable species are the microclimate and the watering and sunlight requirements (Pérez-Urrestarazu, *et al*, 2016). Plants selected for vertical gardens should be lightweight, with a shallow root system and ideally evergreen to keep the desirable effects in the winter, too. The selection of long-lived, rigid, and durable species decreases the costs of further replacement (Sarkar, 2018). Living walls offer the benefit of a wide selection of plants. Wildflowers, grasses and other plants that attract pollinators should be chosen to maximise the potential biodiversity of vertical gardens (Ivan *et al.*, 2022).



Fig. 2 *Indirect green facade, Vienna (Zaťovičová, 2022)*

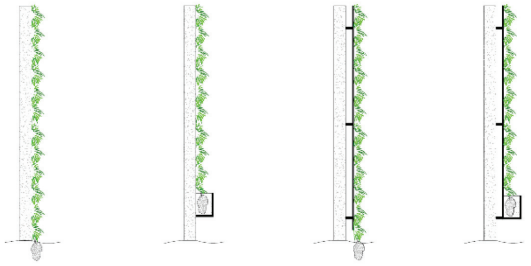
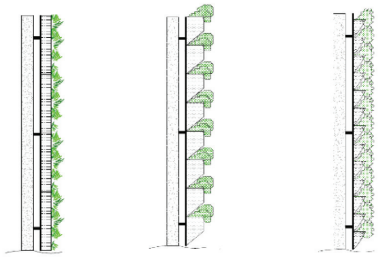


Fig. 3 *Direct green facade,Vienna (Majorošová, 2012)*



Fig. 4 *Living wall, London (Majorošová, 2012)*

Tab. 1 ***Types and Characteristics of Vertical Gardens*** *(Mir, 2011)*

Green facade	Living wall
	

Type	direct	direct	indirect	indirect	mat	pocket	plastic
Rooting in	ground	pot	ground	pot	textile	textile	soil
Support system	-	-	wire	wire	textile	pockets	modules
Plant type	climbers	climbers	climbers	climbers	up to shrubs	up to shrubs	up to shrubs
Air gap (mm)	0	0	50-3000	50-3000	>50	>50	>50
Vegetation thickness (mm)	200	200	100	100	≤400	≤350	≤450
Max height (m)	30	30	30	30	any	any	any
Weight (kg/m^2)	>5,5	>5,5	>54,3	>4,3	40-60	100	150
Irrigation	rain	system	rain	system	system	system	system
Full-grown in (y)	30	2-3	30	2-3	<1	<1	<1
Cost (€/m^2)	30-45	200	40-75	200	350-750	500-1000	400-600
Prefabric/In Situ	in situ	in situ/prefabric	in situ	in situ/prefabric	in situ	in situ	prefabric

3 RESULTS

The final design was created for a densely urbanised area of the historical city centre, which serves as a primary focal point for tourism and social life in Bratislava and is visited by many residents and tourists. We created a complex network of various vertical garden solutions on all the potentially suitable surfaces determined in the case study. Regarding the location of these potential spots on the main routes connecting important traffic hubs, such as bus and railway stations or public transport connection stops in the city centre, we proposed the idea of designing a navigation system using vertical gardens as direction points to the city centre to create an aesthetically appealing and ecological form of navigation system (Fig. 5). These points are frequently located at a convenient visual distance; hence, following them should be clear for longer routes. This also supports the findings by Vega and Küffer (2021) that small spots of greenery designed in a complex network could have a significant impact as an open green space.As determined in field analyses, three construction methods were examined based on different surface types, such as walls, which are typical for creating vertical gardens, less conventional column designs and free-standing green structures. We are presenting three case study model designs herein, which could be applicable in various situations.

3.1 Vertical gardens on walls

In this case, a 9-story building on Dunajská Street was chosen. It is located in the middle of one of the city centre squares, and its architecture is incompatible with the surrounding buildings. This location has long been problematic since its architecture and infrastructure are deteriorating. However, it has great potential to become one of the main hubs for social life. The building selected has two sides wholly covered in advertisements (Fig. 6), so it is ideal for creating a green wall, making it aesthetically and environmentally beneficial (Fig. 5).



Fig. 5 *Visualization of living wall (Zaťovičová, 2019)*



Fig. 6 *Current state of the facade with navigational arrow (Zaťovičová, 2019)*

We have chosen a textile pocket system (Fig. 7), which is lightweight and simple to assemble. It gives plants enough space for rooting through and, thanks to multi-level irrigation, all the plants have an equal water supply. This technology can be used on facades of any scale. The construction has a 30 m height and 11 m width and is at a 130 mm distance from the façade, which prevents leakage from irrigation onto the wall; it further creates an air membrane that also serves as a thermal insulation layer. This type of vertical garden consists of a metal support frame mounted on a wall. Thick PVC hydrophobic foil is connected to the back of the frame. Water mixed with fertiliser is delivered to the plants via drip irrigation installed on the frame throughout the textile pocket system. Excess water is collected by drainage at the foot of the wall and recirculated back into the irrigation system. The whole system is automated and controlled by a unit at the base of the construction.

The selection of suitable plant species will ensure that the idea of the navigation arrow will be clearly recognisable throughout the year (Fig. 8). *Sedum Spurium 'Purpur winter'* is hardy and does not require much care. It has red leaves that preserve the navigational function in the winter. At the same time, other species are designed to bloom gradually to attract pollinators from March to October, and always in the shape of a navigation arrow. *Hosta 'Stifry', Brunnera macrophylla 'Alexander's great',* and *Carex caryophyllea 'The Beatles'*, were selected as filler species around the arrow. They have decorative leaves and inconspicuous flowers.

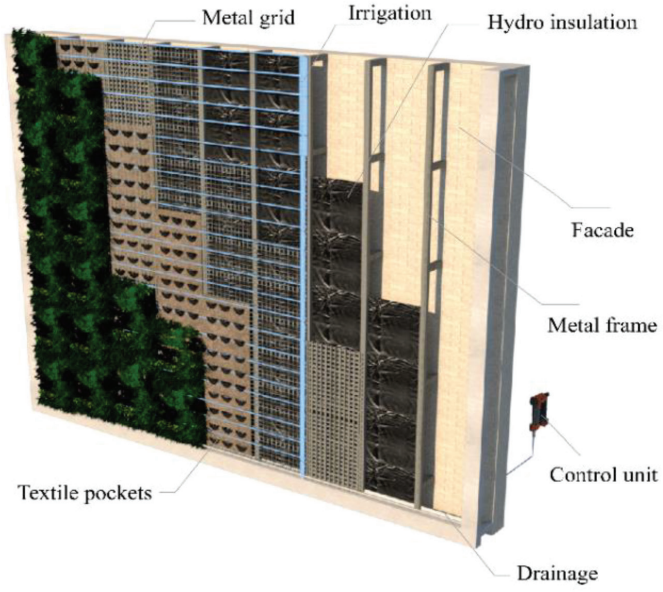


Fig. 7 *Textile pocket system layers (Zaťovičová, 2019)*

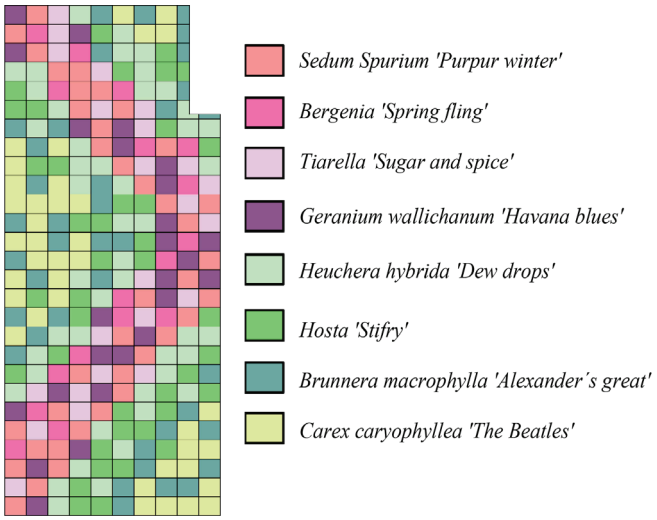


Fig. 8 *Planting plan (Zaťovičová, 2019)*



Fig. 9 *Current state of the overpass (Zaťovičová, 2019)*



Fig. 10 *Visualization of the overpass (Zaťovičová, 2019)*

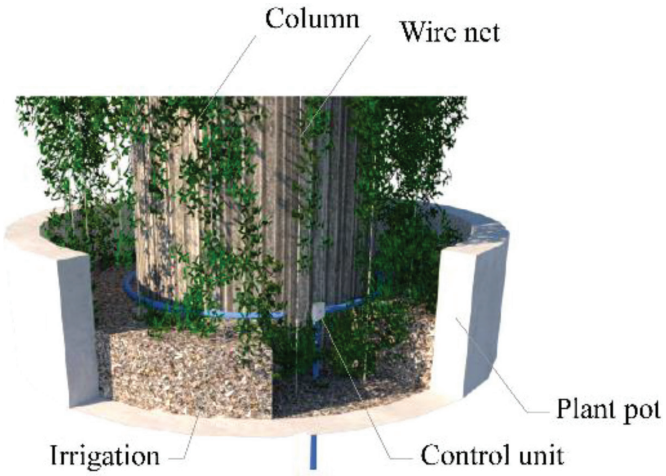


Fig. 11 *Column structure layers (Zaťovičová, 2019)*

3.2 Vertical gardens on columns

For this type of construction, the pedestrian overpass on Pražská Street was selected. It is a rigid concrete structure with no design value, and is located near the train station (Fig. 9). It connects several public transport stops, making it one of the first sights for visitors coming by train. The vertical garden offers a relatively quick and simple solution for increasing its aesthetic value and improving the area's microclimate (Fig. 10).

We created a simple construction (Fig. 11) consisting of a steel wire net mounted onto columns and pots located at the foot of the columns. The irrigation system is connected to the public water supply, thereby providing the required amount of water directly to the roots in the pot. The structure has a 7.2 m height, while the column perimeter is 800 mm. The designed pots have a height of 400 mm and a width of 300 mm, thereby providing enough space for a root system. We selected *Hedera helix*, which is hardy and tolerant of urban conditions. It grows relatively quickly, so it can provide the desired effect in a short time. Studies suggest that it can attract pollinators (Ivan *et al.*, 2022). The wire system provides support, mainly in the initial stages of growth. Over time, plants will be able to climb on horizontal parts of the overpass, thus enhancing its aesthetic and microclimatic value.

3.3 Free-standing vertical garden structure

Vertical gardens can also be made as free-standing structures when constructing them on more traditional surfaces is not available. They offer a less space-demanding alternative to conventional parks and give a free hand for creating various designs, shapes, and sizes. We chose a paved area on the Rázus embank-ment (Fig. 12) near a coffee house and former port of the Propeler boat. It is a Modernist architectural landmark of Bratislava created by the notable Slovak architect Emil Belluš. Despite its recent renovation and high-profile location on the city centre promenade, it does not attract many visitors. One of the reasons might be its large, paved surroundings without any greenery or shade, which suffers from significant overheating in the summer. Considering the historical importance of the area as a Propeler steamboat port, we designed a structure inspired by the shape of this boat (Figs. 13, 14, 16), which represents a symbolic gateway to the historical city centre from the other side of the river Danube (Fig. 15), as it used to be in the past. The metal structure comprises three columns at a 3 m distance apart on each side. Its lightweight design does not interfere with any architecture and views of the historical city centre and lets the vegetation stand out. Each side has a different height of the columns, i.e., 5.5 m and 7.5 m. The column located in the middle represents the steamboat chimney and is 12.5 m high. These vertical structures are connected with steel wire, enabling climber plants to grow horizontally, too. This will, over time, create the desired shade. There are pots at the foot of each column with dimensions of 110 x 110 cm; their height will allow people to sit on their edges. The whole structure has a 10 m width and a 20 m length. Fast-growing *Hedera helix* will achieve the desired effect in a relatively short time. The idea of navigating to the city centre will be preserved by *Parthenocissus quinquefolia,* which will grow on a horizontal wire arrow.



Fig. 12 *Current state of the location (Zaťovičová, 2019)*



Fig. 13 *Visualization (Zaťovičová, 2019)*



Fig. 14 *The first Propeler steamboat (https://sk.pinterest.com/pin/537124693037095777/)*

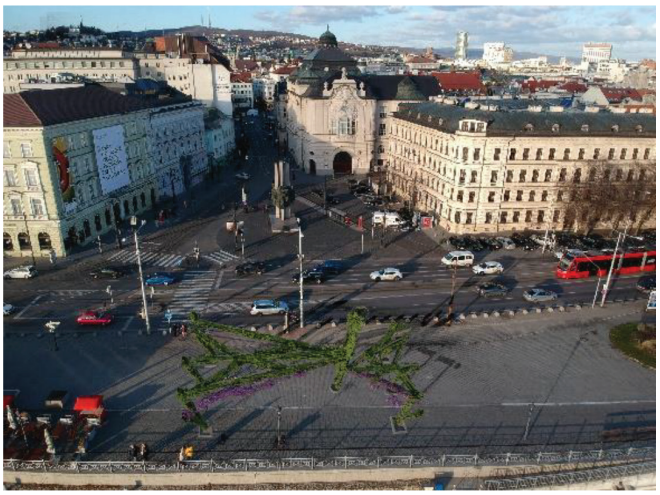


Fig. 15 *Aerial view (Zaťovičová,2019)*



Fig. 16 *Visualisation of the structure (Zaťovičová,2019)*

4 CONCLUSION

Intensive urban development and global warming are rapidly becoming major issues, and it is thus becoming more necessary to emphasise the importance of urban greenery. This article proposes various options for vertical garden creations in different situations. Vertical gardens offer a broad palette of construction methods for different surfaces at various price ranges. They present an alternative solution for supporting biodiversity and mitigation of the overheating of such urban areas where that is not possible by creating new horizontal green areas. They can transform these measures to vertical dimensions while effectively utilising bare surfaces prone to overheating that would otherwise be unused. They do not take up valuable land space and can be relatively quickly and easily constructed on existing structures, thereby offering positive microclimatic, economic, and aesthetical values.

This article proposes a practical application of green structures with additional design value using the example of the Old Town district of Bratislava. We examined all the potentially suitable surfaces and created a network of the maximal usage of these spaces by proposing a complex and systematic look at the absence of vegetation in the city centre. We have also presented the idea of using these structures as a navigational system since they are often located on important routes connecting transport hubs with the city centre. Specific types of constructions on facades, columns, and free-standing structures in the most exposed parts of the area were described in the case study examples.

Vertical gardens offer plenty of benefits regarding the microclimate and positive effects on the human psyche and energy efficiency of buildings. Their implementation in Bratislava's urban environment and globally is still relatively rare, making them worthwhile sights for visitors and residents. However, it is essential to consider these structures not only as aesthetic elements but also as relatively simple solutions to mitigate the overheating of facades and bring natural elements to areas where the surroundings do not allow for a conventional approach.

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REFERENCES

Balany, F. et al (2020) *Green Infrastructure as an Urban Heat Island Mitigation Strategy - A Review*. Water, 12(12).

Baran, Y. B. and Gultekin, A. (2017) *Green Wall Systems: A Literature Review*, Springer, Cham.

Berardi, U.- GhaffarianHoseini, A. - GhaffarianHoseini, A. (2014) *State-of-the-art analysis of the environmental benefits of green roofs.* Applied Energy, Vol. 115, pp. 411-428.

Brković Dodig, M. - Auer, T. - Radić, M. (2019) *Green Facades and Living Walls—A Review Establishing the Classification of Construction Types and Mapping the Benefits.* Sustainability, 23 Aug., p. 5.

Coma, J. et al (2017) *Vertical greenery systems for energy savings in buildings: A comparative study between green walls and green facades.* Building and Environment, Vol. 111, pp. 228-237.

Daemei, A. B. - Azmoodeh, M. - Zamani, Z. - Khotbehsara, E. M. (2018) *Experimental and simulation studies on the thermal behavior of vertical greenery system for temperature mitigation in urban spaces.* Journal of Building Engineering, Vol. 20, pp. 277-284.

de Munck, C. et al (2013) *How much can air conditioning increase air temperatures for a city like Paris, France?* International Journal of Climatology, Jan., 33(1), pp. 210-227.

Dunnett, N. and Kinsbury, N. (2008) Planting green roofs and living walls.

Elgizawy, E. M. (2016) *The Effect of Green Facades in Landscape Ecology.* Procedia Environmental Sciences, Vol. 34, pp. 119-130.

Emilsson, T. - Czemiel Berndtsson, J. - J.E, M. (2007) *Effect of Using Conventional and Controlled Release Fertiliser on Nutrient Runoff from Various Vegetated Roof Systems.* Ecological Engineering, 29(3), pp. 260-271.

Eumorfopoulou, E. A. and Kontoleon, K. J. (2009) *Experimental approach to the contribution of plant-covered walls to the thermal behaviour of building envelopes.* Building and Environment, 44(5), pp. 1024-1038.

Francis, A. R. and Lorimer, J. (2011) *Urban reconciliation ecology: The potential of living roofs and walls.* Journal of Environmental Management, Vol. 92, pp. 1429-1437.

Ghaitidak, D. and Yadav, K., (2013) *Characteristics and treatment of greywater—a review.* Environmental Science and Pollution Research, Volume 20, pp. 2795-2809.

Hadba, L. M. P. and. S. L. T. (2017) *Green walls: an efficient solution for hygrothermal, noise and air pollution control in the buildings.* Living and Sustainability: An Environmental Critique of Design and Building Practices, Locally and Globally.

Hoelscher, M. T. - Nehls, T. - Jänicke, B. - Wessolek, G. (2016) *Quantifying cooling effects of facade greening: Shading, transpiration and insulation.* Energy and Buildings, Vol. 114, pp. 283-290.

Holec, J. (2018) *Surface temperature data.* Bratislava, Slovak Hydrometeorological Institute.

Jialin, T. (2013). *Living Wall: Jungle to Concrete.* Hong Kong, China: Design Media Publishing Ltd.

Kuhn, M. E. and Bass, B. (1999) *Benefits, Barriers and Opportunities for Green Roof and Vertical Garden Technology Diffusion,* Canada

Liberalesso, T. - Cruz, C. O. - Silva, C. M. - Manso, M. (2020) *Green infrastructure and public policies: An international review of green roofs and green walls incentives.* Land Use Policy, July, Vol. 96.

Loh, S. (2008) *Living Walls-A Way to Green the Built Environment.* Environment Design Guide, pp. 1-7.

Majorošová, M. - Mazancová, E. (2020) *Stimulation Surfaces in Urban Places.* Slovak Journal of Civil Engineering, 28.4: 45-51.

Manso, M. and Casto-Gomez, J. ***(2015)*** *Green wall systems: a review of their characteristics.* Renewable and Sustainable Energy Reviews, Vol. 41, pp. 861-873.

Manso, M. - Teotónio, I. - Matos Silva, C. - Cruz, C. O. (2021) *Green roof and green wall benefits and costs: A review of the quantitative evidence.* Renewable and Sustainable Energy Reviews, Vol. 135.

Mir, M. A. (2011) *Green facades and building structures,* Delft, The Netherlands

North American Wetland Engineering (1998). *Ecology, Construction, and Benefits*. ReNature, 18 May.

Oquendo-Di Cosola, V. - Olivieri, F. and Ruiz-García, L. (2022) *A systematic review of the impact of green walls on urban comfort: temperature reduction and noise attenuation.* Renewable and Sustainable Energy Reviews, Vol. 162, p. 112463.

Ottelé, M. *et al.* **(2011)** *Comparative life cycle analysis for green facades and living wall systems.* Energy and Buildings, Vol. 12, pp. 3419-3429.

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

Pérez, G. - Coma, J. - Sol, S. and Cabeza, L. F. (2017*) Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect.* Applied Energy, pp. 424-437.

Perez, G. and Perini, K. (2018) *Nature Based Strategies for Urban and Building Sustainability*. Oxford: Butterworth-Heinemann.

Pérez-Urrestarazu, L. - Fernández-Canero, R. - Franco-Salas, A. - Egea, G. (2016) Vert*ical Greening Systems and Sustainable Cities.* Journal of Urban Technology.

Perini, K. - Ottelé, M. - Haas, E. M. - Raiteri, R. (2011) *Greening the building envelope, façade greening and living wall systems.* Open Journal of Ecology, pp. 1-8.

Prodanovic, V. *et al.* **(2017)** *Green walls for greywater reuse: Understanding the role of media on pollutant removal.* Ecological Engineering, Vol. 102, pp. 625-635.

Qin, X. - Wu, X. - Chiev, Y. M. - Li, Y. (2012) *A green roof test bed for stormwater management and reduction of urban heat island effect in Singapore.* Brit J Environ Clim Change, 2(4), pp. 410-420.

Ruiz-Valero, L. - Arranz, B. - Faxas-Guzmán, J. - Flores-Sasso, V. - Medina-Lagrange, O. - Ferreira, J. (2023). *Monitoring of a Living Wall System in Santo Domingo, Dominican Republic, as a Strategy to Reduce the Urban Heat Island.* Buildings, 13(5), 1222.

Sarkar, A. N. (2018) *Selection of Plants for Vertical Gardening and Green Roof Farming.* International Research Journal of Plant and Crop Sciences, 4(3), pp. 132-153.

Shafiee, E. - Faizi, M. - Yazdanfar, S. A. - Khanmohammadi, M. A. (2020) *Assessment of the effect of living wall systems on the improvement of the urban heat island phenomenon.* Building and Environment, Vol. 181, p. 106923.

Sheweka, S. and Magdy, A. N. (2011) *The living walls as an approach for a healthy urban environment. Energy Procedia,* pp. 592-599.

Stemberg, T. - Viles, H. - Carthersides, A. - Edwards, M. (2010) *Dust particulate absorption by Ivy (Hedera Helix L.) on historic walls in urban environments.* Science of the Total Environment, pp. 162-168.

Susca, T. - Zanghirella, F. - Colasuonno, L. - Del Fatto, V. (2022) *Effect of green wall installation on urban heat island and building energy use: A climate-informed systematic literature review.* Renewable and Sustainable Energy Reviews, Vol. 159, p. 112100.

Susorova, I., Azimi, P. - Stephens, B. (2014) *The effects of climbing vegetation on the local microclimate, thermal performance, and air infiltration of four building facade orientations.* Building and Environment, Vol. 76, pp. 113-124.

Taleghani, M. (2018) *Outdoor thermal comfort by different heat mitigation strategies - A review.* Renewable and Sustainable Energy Reviews, Vol. 81, pp. 2011-2018.

Timur, O. B. - Karaca, E. (2013) *Vertical Gardens.* Advances in Landscape Architecture. pp. 587-622.

Vox, G., Blanco, I. - Schettini, E. (2018) *Green facades to control wall surface temperature in buildings.* Building and Environment, Vol. 129, pp. 154-166.