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# Typology of vertical greenery system

## Authors:



Sandra Čekić, MArch.  
University of Belgrade, Serbia  
Faculty of Architecture  
[s.cekic.phd@edu.arh.bg.ac.rs](mailto:s.cekic.phd@edu.arh.bg.ac.rs)  
Corresponding author



Assist.Prof. Tanja Trkulja, PhD. Arch.  
University of Banja Luka, Bosnia and Herzegovina  
Faculty of Architecture, Civil Engineering and  
Geodesy  
[tanja.trkulja@aggf.unibl.org](mailto:tanja.trkulja@aggf.unibl.org)



Prof. Ljiljana Došenović, PhD. Arch.  
University of Banja Luka, Bosnia and Herzegovina  
Faculty of Forestry  
[ljiljana.dosenovic@sf.unibl.org](mailto:ljiljana.dosenovic@sf.unibl.org)

Subject review

[Sandra Čekić, Tanja Trkulja, Ljiljana Došenović](#)

## Typology of vertical greenery system

The vertical greenery system (VGS) has drawn a considerable attention over the past decades as a strategical element of urban landscape. Implementation of this system contributes to the achievement of a harmonious relationship between the built and natural environment, as well as to the abatement of pollution and improvement of the quality of environment. This paper presents study of typology of a vertical greenery system, and propose typical models formed according to a previously derived classification system.

### Key words:

urbanization, green urban fabric, ecological quality of cities, vertical greenery system, typology

Pregledni rad

[Sandra Čekić, Tanja Trkulja, Ljiljana Došenović](#)

## Tipologija sustava vertikalnog ozelenjavanja

Sustav vertikalnog ozelenjavanja (SVO) privukao je veliku pozornost posljednjih desetljeća kao strateški element urbanog oblikovanja. Primjena ovoga sustava pridonosi postizanju skladnog odnosa između izgrađenog i prirodnog dijela okoline, smanjenju zagađenja i poboljšanju kvalitete okoliša. U radu je prikazano istraživanje tipologije sustava vertikalnog ozelenjavanja te se predlažu tipski modeli stvoreni prema prethodno izvedenom sustavu klasifikacije.

### Ključne riječi:

urbanizacija, zelena matrica, ekološka kvaliteta gradova, sustav vertikalnog ozelenjavanja, tipologija

Übersichtsarbeit

[Sandra Čekić, Tanja Trkulja, Ljiljana Došenović](#)

## Typologie vertikaler Begrünungssysteme

Das vertikale Begrünungssysteme (SVO) hat in den letzten Jahrzehnten als strategisches Element des Städtebaus große Aufmerksamkeit auf sich gezogen. Die Anwendung dieses Systems trägt dazu bei, ein harmonisches Verhältnis zwischen dem gebauten und dem natürlichen Teil der Umwelt zu erreichen, die Umweltverschmutzung zu verringern und die Qualität der Umwelt zu verbessern. Die Arbeit präsentiert eine Forschung zur Typologie des vertikalen Begrünungssystems und schlägt Standardmodelle vor, die nach dem zuvor durchgeführten Klassifizierungssystem erstellt wurden.

### Schlüsselwörter:

Urbanisierung, grüne Matrix, ökologische Qualität der Städte, vertikales Begrünungssystem, Typologie

## 1. Introduction

Due to insufficient knowledge about the concept and practical application of the modern urban design segment known as the vertical greenery system (VGS), it can be stated that the VGS is perhaps still an urban design novelty in Bosnia and Herzegovina and the wider region, even though its beginnings can be traced back to 600 BC, i.e. to one of the seven wonders of the ancient world: The Hanging Gardens of Babylon. It is known that vegetation was introduced as a significant element of the built environment in ancient Greece. This was done through planting corn and other plant species on the rooftops in honour of the god Adonis. In Roman Empire, vegetation in the form of vines served for shading, and similar use was reserved to pergolas with climbing roses, which were an indispensable element of Roman gardens. In Scandinavian countries, urban greenery started to be profusely planted in the early twentieth century on rooftops and walls of buildings for thermoregulation. These dwellings are better known as vernacular houses, primarily because of insulating features of such systems [1].

The first theories related exclusively to the term of ecology were formulated in the late 19th century, and involved a system of vertical greenery as a possible response to urbanisation effects. With the emergence of the idea of a garden city in 1898, Ebenezer Howard initiated the idea of urban planning stressing the significance of the urban green system as a strategic element in the design and planning of cities.

The idea of vertical greenery was applied in the early 20<sup>th</sup> century by architect Adolf Loos on the Scheu House (Haus Scheu) (1912–1913). He did it by introducing vegetation on the surface of the facade wall. The first green wall patent was registered in 1937 by professor Stanley Hart White from the University of Illinois under the title of Vegetation - Bearing Architectonic Structures and System [1].

The most significant step in the development of the vertical greenery system was made by Patrick Blanc, founder of vertical gardening, by presenting panels with the plant substrate and irrigation system. The introduction of the steel cable system as a substructure for green facades in 1988 enabled creation of numerous variations of types and support structures within the very VGS. In the North American market in the 1990s, a supporting substructure for green walls appeared in the form of steel cables, wire mesh, and a modular trellis panel system.

The first practical application of the trellis system was made in 1993 at the Universal City Walk in California. Only a year later the bio-wall system, based on the principle of air biofiltration, was presented as a part of the interior of the Canada Life Building in Toronto. The presence of the VGS is becoming more and more common, and Patrick Blanc's work on the hydroponic system also contributes to the improvement of the system itself, making the visual attractiveness of Blanc's vertical gardens a recognisable element of the urban matrix.

Multi-layered green facades were introduced in 2002 with the installation of a vertical green system in the MFO Park in Zürich, with over 1,300 different types of climbers on a floor plan area

of 3.500 square meters across several levels. The Bio Lung exhibition at the Aichi Expo in 2005, subsidised by the Japanese government, shows the complexity of the VGS application, as well as possible variations of different types, by presenting as many as thirty different modular types available in Japan. Commitment to research work on the VGS system was supported by the Japanese government which established in September 2008 the fund called *Introduction to Green Walls Technology, Benefits & Design*, as well as the widely recognised *Green Wall Award* for significant contribution to the VGS discipline [2].

A major step forward in the sphere of VGS implementation was made in 2009 by NParks in Singapore, which are one of the leaders in the restoration of the city's green matrix. They introduced the Skyrise Greenery concept in order to promote the VGS, and they also devised the Skyrise Greenery Incentive Scheme through which the government supports creation of a sustainable urban community through financial subsidies and tax relief incentives.

Further research work in the vertical greenery system discipline, as well as new technological achievements, have largely contributed to the development of the VGS, which to this day has been a strategic element for the design and regeneration of urban environment. One of the most prominent examples of VGS implementation as a spatial benchmark of the urban matrix is the Caixa Forum Madrid, conceived by architects Jacques Herzog and Pierre de Meuron. They had the system implemented on a wall surface of 6,500 square meters using as many as 250 different plant species. In order to improve the quality of urban space through the process of placemaking, L'Oasis d'aboukir, designed by Patrick Blanc, was installed in Paris in 2013, as a specific diagonal pattern with over 237 different plant species (Figure 1).



Figure 1. Caixa Forum Madrid and L'Oasis d'aboukir in Paris

In recent years, VGS implementation has become an increasingly topical way of restoring individual districts of cities, and as such it indisputably represents a prototype of symbiosis of natural and built environment. Practical examples of implementing VGS as an environmentally friendly model of urban renewal are on the rise in Europe and worldwide, and the use of VGS benefits from great support from the profession and the market, which are sensitive to the needs and development of the VGS, as witnessed by considerable research work in this area. The frequency of VGS implementation has contributed to the development of specialised vertical greenery

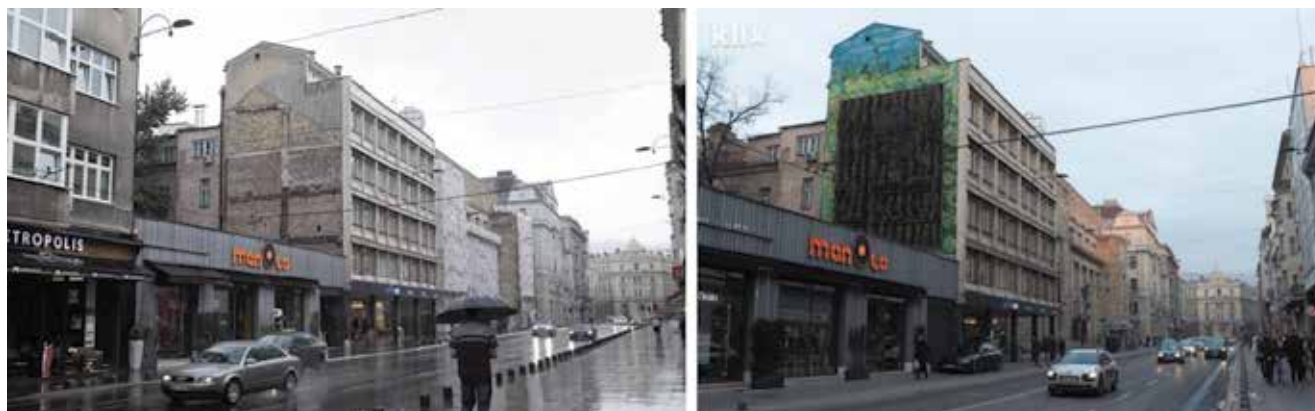


Figure 2. First green facade in B&H, before and after

structures that meet the needs of wider geographical areas, so that technological solutions often represent completely new VGS models, boasting highly advanced irrigation and maintenance systems.

However, despite an increase in practical implementation of VGS on the global scale, it is still a completely novel system in Bosnia and Herzegovina. Namely, the first green facade in B&H was installed in Sarajevo in the early 2018 on a building in Titova Street (Figure 2). However, only two months after the opening of the “first green wall which will clean the air in Sarajevo”, most of the ivy (*Hedera helix*) seedlings placed in the green wall dried up [3]. The Sarajevo Centre District authorities, which allocated KM 70,000 from their budget for this project, decided to remove it and request a refund from the NGO Opus project manager. “The expert team from KJKP Park (Cantonal Public Utility Company PARK), which performed the expertise of the green facade, determined that the ivy seedlings placed on the facade were intended for indoor use only” [4]. All of the above shows that the VGS system is novel, insufficiently known and marginally applied in B&H, and that available experts are insufficiently educated and experienced in the design and implementation of the system. This is certainly one of the reasons for its under-representation in urban scenery.

## 2. Vertical greenery system

The vertical greenery system has attracted a lot of attention in recent decades as a strategic element of urban design. Integrating vegetation into a densely built urban matrix greatly contributes to the quality of urban life by providing environmental, economic, social, spatial, and energy benefits to the community.

As a model that restores ecological quality to cities by interpolating natural structures into built-up parts of the city, the VGS directly affects the very process of urban matrix regeneration. Due to rapid urbanisation and expansion of the urban fabric, the green matrix of the city is often marginalised in the midst of market principles of construction and careless use of urban space. Environmental problems in cities occur as a result of climate change and have significant consequences on the human health and quality of life, which is significantly impaired due to omnipresence of environmental pollution.

Achieving environmental benefits through VGS implementation greatly contributes to the reduction of pollution, regulation of microclimatic conditions, and improvement of biodiversity. Therefore, the system is of great importance for the process of improving the quality of the environment, which has a direct influence on the realisation of social benefits. According to the principles of biophilia, human interaction with natural environment has a positive effect on improving people’s sense of wellbeing and health. It also reduces stress, which is the cause of many mental illnesses of modern society.

With its visual appeal, the VGS creates recognisable spatial landmarks in an already densely built urban environment, and thus positively influences realisation of numerous economic benefits. As a facade envelope with pronounced insulation characteristics that reduce heat losses, the VGS is an energy-acceptable component the application of which reduces consumption of energy required for heating or cooling, which directly contributes to economic savings. Ecological, but also economic, suitability of the VGS enables reduction of building maintenance costs while increase property value by up to 15% [5].

### 2.1. Starting points and definition of key terms

The meaning of key terms should be stated primarily in order to facilitate their understanding, as some of them are often used as synonyms, even though they have completely different meanings and represent completely different technological systems of green structures. The aim of the analysis is to explain the content of key terms in the sense of etymology and ontology. Not much has so far been said about key terminology in our theory and practice. Therefore, the need has emerged to further clarify these concepts. In order to provide a more accurate, complete and modern meaning of the VGS, it is necessary to state several of its literature definitions. In accordance with contemporary tendencies in urban practice, an attempt was made to formulate the definition in a synthetic way. We started from general definitions that are applied, and then these definitions were additionally extended and formulated, with an explanation of why specific meanings were chosen by the authors [2, 6-10].

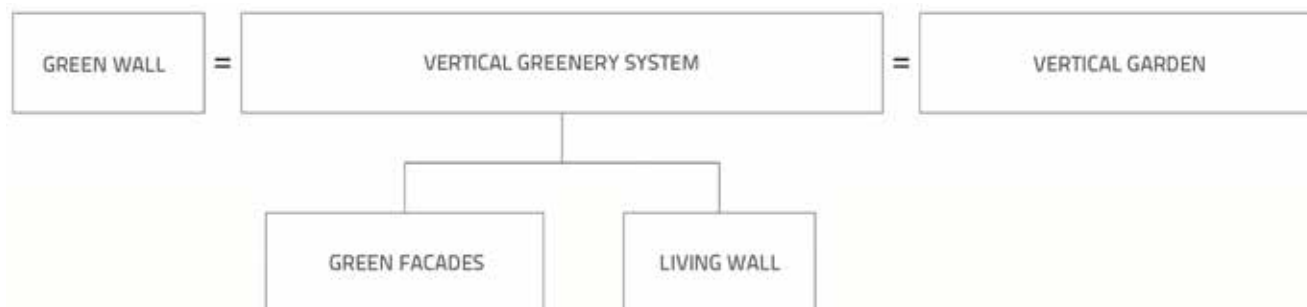


Figure 3. Synonyms for vertical greenery system

A vertical greenery system is defined in international literature by a variety of terms selected depending on individual inclination of authors and classification methods they use. The system for vertical greening of wall surfaces is often defined by names such as green wall, green facade, living wall, or vertical garden. In translation process, they are considered as synonymous, even though they are actually different types or completely new subsystems of vertical greenery (Figure 3).

Terms such as green wall, vertical garden, and vertical greenery system are synonyms that have often been used interchangeably in scientific literature. Further analysis of the interdependence of VGS terms (i.e. its synonyms) according to the bearing structure of the system and the growth mechanism of plants, the subsystems such as green facade and living wall can be defined as an established and generally accepted division. The defined subsystems represent the basic classification of vertical greenery systems with clearly defined types within each subsystem, as covered in detail by classification of VGSs (Figure 3). The term VGS is not in actual use in Bosnian, Serbian or Croatian languages. When professionally using and defining the system, the terms green wall or green facade, referring to the wall covered with vegetation, are most often used as its synonyms.

According to Tong [2], the vertical greenery system refers to any way of placing plants on a vertical surface (facade wall), regardless of the way the vegetation grows. Since it is a term that most closely encompasses an overview of the VGS and its types, it will be used as such in this paper in order to unify possible subtypes of the system. The analysis of scientific literature shows that various terms denoting the VGS system have been used as potential terms and definitions in this relatively young discipline. Chiang & Chan [6] use the term vertical greening, which encompasses greenery integrated into built city structures, including balcony gardens, terraces, and roof gardens. Cheng, Cheung & Chu [7] consider VGS as an alternative to roof greenery in the city, while Peck & Callaghan [8] as well as Bass & Baskann [9] define greenery systems as vertical gardens. Depending on particular aspects of research work, and classification systems used by individual authors [10], various definitions and various VGS terms have so far been abundantly used in literature.

The definition of VGS as a system that includes the placement and growth of plants along/on the vertical surface of the wall covers various types of vertical greenery, depending on the growth mechanism of the plant medium, substructure of the system, and benefits offered by individual types.

The term green wall denotes all forms of vegetation that cover wall surface partially or completely, depending on the type. It is divided into two main categories: green facade and living wall. As a term, green wall is equivalent to the terms *vertical garden* and *VGS* [11].

The term vertical garden refers to a vertical structure enabling spreading of vegetation greenery. This greenery can grow next to and parallel to the wall, or on the wall surface. The supporting structure can be, but does not need to be, directly linked to the facade. The term is often also used in the discipline of urban agriculture (pocket system), which often denotes a system designed for sustainable cultivation of plant species intended for human consumption [8, 9]. The term green facade refers to the vertical principle of greening the facade solely with climbing and creeping plant species, which are placed on a supporting structure (wire or mesh system) enabling the plants to grow and extend over the facade surface [12].

Living wall is a more complex type of wall greenery. It consists of a structure with a plant substrate (modular system, panel system, etc.), an irrigation system, and additional insulation layers that are placed directly onto the wall as a protective layer. Patrick Blanc defines the system as a structure of vegetation within a metal frame, with a PVC membrane layer and a plant substrate layer varying in thickness [12].

## 2.2. Typology of vertical greenery system

Due to the application of the VGS, we are faced with a number of different principles of system classification which, just like the term itself, primarily depend on the authors as well as the area of implementation. The lack of standard regulations and technical manuals for the VGS implementation has contributed to the emergence of different variations of the system during classification and definition of individual types. The wide acceptance of the VGS has resulted in the application of typology specific to certain geographical areas, depending on the authors dealing with the professional discipline of VGS. This has resulted in the existence of several different systems of classification and typology depending on the market in which VGS is implemented [2, 13-15].

U istraživačkom radu Perini i suradnika [13] sustav je vertikalnog According to research published by Katie Perini [13] the VGS is classified according to the mechanism of growth into the system of green facades and the system of living wall. Such classification has also been adopted by Perez [14] who has divided the system into extensive and intensive. Thus the system of green facades is divided into a double-skin green facade and a green curtain, with

characteristic types. According to the way of growth and choice of plant medium, Mir [15, 17] divides the system of green walls into wall vegetation, green facades, and living walls. The division of the green wall system into artificial green walls and natural green walls is characteristic for the area of Singapore and Malaysia, where Tong [2] further classifies this system according to the substrate of each model. This division has also been adopted by Wang [16].

Depending on the type, the VGS has different characteristics that bear influence on its environmental, economic, social, spatial and energy benefits. According to the analysis of scientific literature, the VGS classification is done primarily according to the aspect of system perception, that is, according to technical regulation of VGS implementation as related to the vegetation mechanism and the structure of the system itself. The presence of several distinct types on the market has enabled emergence of different system variations, primarily in relation to irrigation systems and material from which the supporting structure of the system is made.

The VGS classification used in this paper was determined after comparison of certain types, as well as after a detailed analysis of classification systems according to several authors specialising in this scientific discipline [2, 11, 13, 14, 16], mostly from the aspect of VGS benefits.

The principle of VGS classification was founded on the vegetation mechanism and on the application of appropriate types of substructure, and also on plant substrate and irrigation systems, all primarily based on the classification made by Katia Perrini (Department of Architecture, University of Genoa in Italy), taking into account all aspects that are unavoidable for achieving and meeting the utmost challenges of urban rehabilitation [13] (Figure 4).

The VGS classification scheme on which this paper is based, and the implementation models themselves, represent a personal approach of the authors in considering these universal topics. Presentation of the system by types is based on a thorough consideration of the implementation of potential types of systems, which meet by their characteristics the principle of urban renewal of green elements of the city, constituting a method for increasing

the level of greenery in the urban matrix. Accordingly, the properties of the model aimed at achieving benefits in the interior only (as well as the types having distinctly defined purpose, such as bio walls), or primarily iconic ventures in the exterior (for example, landscape walls for noise abatement and terrain stabilisation) will not be emphasized in the paper as fundamental properties. Types taken as such, with all their characteristics, are emphasized from only one of their inherent aspects, the primary goal being to satisfy the purpose for which they are installed and for which they are ultimately produced, without resorting to a fuller synthesis of characteristics from all their aspects. The VGS classification includes the types which, thanks to their characteristics, can be considered as being fully responsible for overall improvement of the quality of urban environment.

Definition of VGS subtypes according to the classification scheme (Figure 4) was performed on the basis of a typical VGS substructure and on the way in which the vegetation layer is supported. All this defines the VGS system as the system profiled on green facades and living wall systems.

### 3. Discussion

The vertical greenery system is divided into two subsystems: the green facade subsystem and the living wall subsystem (Figure 4).

In scientific literature, the green facade subsystem is often defined as a two-dimensional system involving the assembly of substructure in the form of a wire system or a mesh and modular trellis system in front of the facade wall, as a necessary supporting structure for climbing plants. For the plant medium, the green facade subsystem uses only creeping and climbing plant species (creepers and climbers) and, depending on the proximity and way of planting towards the wall surface, it is divided into direct and indirect greening [17].

The direct green system involves the planting of climbers (most often ivy species) directly next to the facade wall without installation of substructure as a support for vegetation layer. The direct greening is the oldest form of the VGS in which climbers grow directly along the wall, attaching their 'air system of roots' to the wall surface, where strong root action often causes damage to the wall structure [12, 17].

As opposed to direct greening, indirect greening system involves the use of a substructure, which means that the plants are not directly connected to the wall surface, and so any potential damage is prevented. Indirect greening supports the use of the wire and cable systems and mesh and modular trellis systems, often in combination with planters as necessary support structures that ensure greater and faster coverage of facade surfaces [12, 17].

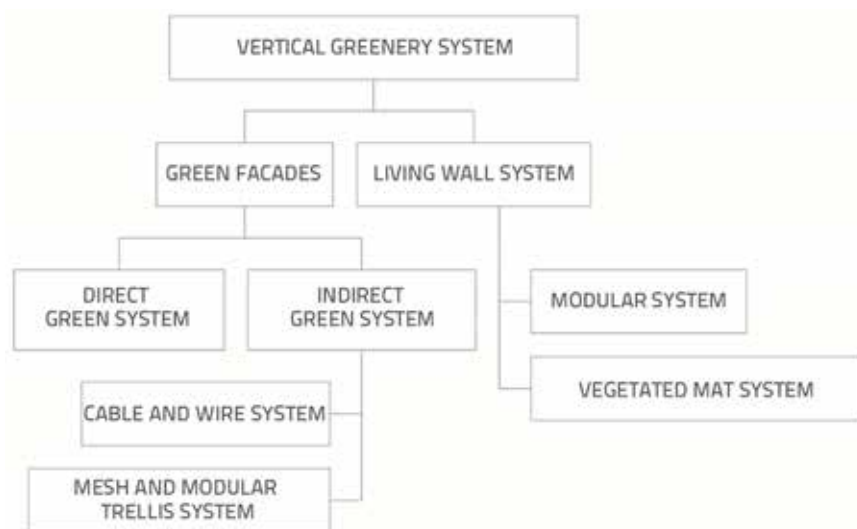


Figure 4. VGS classification, according [13]

The living wall subsystem is defined as a three-dimensional system that includes placing a vegetation layer in prepared panels and modules of different shapes, with substrate and an insulating layer of synthetic membranes, which are fixed directly to the vertical surface. Its pronounced thermal insulation properties, as well as the possibility of applying the widest range of plant species which creates, in combination of various colours and shapes, attractive design solutions, has made the system highly popular in the field of urban regeneration. However, maintenance of living walls is more demanding compared to other VGS types. This is primarily due to the

presence of irrigation system installed as an integral part of the panel, but also to frequent seasonal replacement of plant material. The market is sensitive to wide application of living wall subsystems, and offers different shapes, but also a variety of entire panel structures. Combined with the improvement and development of nutrition and irrigation systems compatible with local conditions, this situation has resulted in development of numerous specific types of subsystems. Depending on the shape and installation of vegetation layer, the living wall subsystem is divided into two basic types: modular system, which consists of vertical panels in which plant species are

Table 1. Type models of the VGS (prvi dio)











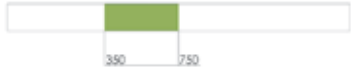
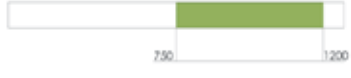
TYPE	 <p style="text-align: center;"><b>Direct system</b></p>	 <p style="text-align: center;"><b>Cable and wire system</b></p>	 <p style="text-align: center;"><b>Mesh and trellis system</b></p>
<b>Characteristics</b>	The system is known as the traditional green facade. It is the oldest form of the VGS and includes planting climbers (usually ivy) directly along the facade of the building. It only accepts climbers, which themselves are already a "substructure"	The system involves the use of steel cables (for fast-growing climbers with denser leaves) and wire cables (for slow-growing climbers due to the necessary support at closer intervals) as supporting structures necessary for the growth of climbers; the substructure is fixed with anchors in front of the building wall.	The system includes the use of mesh and trellis as supporting structures for climbers. The substructure can be made of plastic, aluminium, steel or wood. The mesh system is fixed with anchors to the wall surface, and the plant medium is planted directly into the ground, at the base of the mesh.
<b>Advantages</b>	The simplest type to apply; economically the most acceptable; easy maintenance.	Flexible system; enables wide spectrum of design possibilities; easy assembly.	Flexible system; offers interesting design solutions by combining different materials and greenery; easy assembly and disassembly.
<b>Disadvantages</b>	Uses climbers only; aggressive climbers' roots can damage the building wall structure; takes the longest to achieve full coverage; difficult removal process due to strong roots.	Only uses climbers as plant material; takes a long time to achieve full coverage.	Only uses climbers as plant material; takes a long time to achieve full coverage.
<b>Plant materials</b>	Evergreen and deciduous climbers such as <i>Hedera helix</i> , <i>Parthenocissu tricusspidata</i>	Creepers and climbers such as <i>Wisteria</i> , <i>Clematis</i>	Creepers and climbers such as <i>Wisteria</i> , <i>Clematis</i>
<b>Coverage and benefits</b>	For <i>Hedera helix</i> : full coverage in 15 years, benefits visible after 10 years	For <i>Hedera helix</i> : full coverage in 15 years, benefits visible after 10 years	For <i>Hedera helix</i> : full coverage in 15 years, benefits visible after 10 years
<b>Maintenance</b>	Easiest maintenance; plant replacement not necessary	Easy maintenance; plant replacement not necessary	Easy maintenance; plant replacement not necessary
<b>Price [€/m<sup>2</sup>]</b>	 <p>30.45</p>	 <p>40.60</p>	 <p>50.75</p>

Table 1. Type models of the VGS (drugi dio)

TYPE	 <p data-bbox="240 577 560 605"><b>Mesh and trellis system + planters</b></p>	 <p data-bbox="699 577 920 605"><b>Vegetation layer system</b></p>	 <p data-bbox="1145 577 1293 605"><b>Modular system</b></p>
<p data-bbox="147 670 166 806"><b>Characteristics</b></p>	<p data-bbox="209 670 591 806">The system includes the application of mesh and trellis in combination with planters at different levels of the facade. Plant material is planted in planters, during which irrigation must be provided.</p>	<p data-bbox="622 620 994 858">The vegetation layer system contains a plant substrate supported by two layers of synthetic fabric in the form of "pockets" which are installed in a fixed frame on the wall surface, on a previously placed waterproof membrane layer. The plant medium is planted in "pockets" and a circular irrigation system is used for maintenance.</p>	<p data-bbox="1028 633 1410 849">Uses a system of modules (square or rectangular) made of plastic or metal with a substrate in which plant material is planted. Each module uses its own substrate to suit the needs of individual plant species. The irrigation system is placed on top of the panel, and the pipes are distributed along the surface.</p>
<p data-bbox="147 886 166 978"><b>Advantages</b></p>	<p data-bbox="209 875 591 1004">Use of various types of plants, depending on arrangement of planters and the net height; possibility of wide application of the system due to better stability and faster growth</p>	<p data-bbox="622 886 994 993">Use of a wide range of plant species which, due to various combinations of colours and shapes, can create attractive spaces; pronounced thermal insulation properties</p>	<p data-bbox="1028 886 1410 993">Enables achievement of a very attractive urban space; possibility of applying the widest range of plant species; pronounced thermal insulation properties</p>
<p data-bbox="147 1037 166 1129"><b>Disadvantages</b></p>	<p data-bbox="209 1037 591 1144">Extremely rigid system; complex maintenance; necessary replacement of plant material and irrigation system after a certain period of time</p>	<p data-bbox="622 1047 994 1134">High system cost; complex maintenance and replacement of plant material; high maintenance cost</p>	<p data-bbox="1028 1047 1410 1134">The most expensive system; complex maintenance and frequent plant material replacement; high maintenance cost</p>
<p data-bbox="147 1187 166 1280"><b>Plant materials</b></p>	<p data-bbox="209 1187 591 1284">Wide range of plant species can be used, such as <i>Wisteria sp.</i>, <i>Clematis sp.</i>, <i>Ipomoea quamoclit</i>, <i>Campsis grandiflora</i>, <i>Akebia quinata</i></p>	<p data-bbox="622 1198 994 1284">Wide range of plant species can be used; includes grass species, low shrubs, ferns, exotic species...</p>	<p data-bbox="1028 1198 1410 1284">Wide range of plant species can be used, such as <i>Sedum</i>, <i>Heuchera</i>, <i>Pilea</i>, <i>Deutzia</i>, <i>Acorus</i>, <i>Euonymus</i>, <i>Asplenium</i></p>
<p data-bbox="147 1328 166 1420"><b>Coverage and benefits</b></p>	<p data-bbox="209 1360 591 1414">Full coverage after a period of 3 years; benefits visible after 3 years</p>	<p data-bbox="622 1338 994 1435">Full coverage and benefits visible from 1-2 years onwards (depending on the species and the speed of their growth) &gt; relatively quick full coverage</p>	<p data-bbox="1028 1349 1410 1425">Full coverage and benefits visible after a period of 1 year &gt; the fastest to achieve full coverage, even on largest surfaces</p>
<p data-bbox="147 1479 166 1571"><b>Maintenance</b></p>	<p data-bbox="209 1468 591 1597">Complex maintenance due to application of different plant species; up to 5 % of plant material must be replaced each year; replacement of irrigation systems every 7.5 years</p>	<p data-bbox="622 1479 994 1586">Complex maintenance system; up to 10 % of plant material must be replaced each year; replacement of irrigation systems every 7.5 years</p>	<p data-bbox="1028 1479 1410 1586">The most complex maintenance system; up to 10 % of plant material must be replaced each year; replacement of irrigation systems every 7.5 years</p>
<p data-bbox="147 1629 166 1694"><b>Price [€/m<sup>2</sup>]</b></p>	 <p data-bbox="240 1673 560 1707">100 150 400 800 MREŽA MREŽA</p>	 <p data-bbox="733 1673 883 1707">350 750</p>	 <p data-bbox="1195 1673 1376 1707">750 1200</p>

planted, and vegetated mat system, which most commonly occurs in the form of synthetic pockets. Different variations of individual types are also available on the market, which is primarily a result of applied research and technological development of the VGS itself [12]. After classification of the VGS, the process of making standard models is a synthesis of concise theoretical and practical knowledge about the system. By combining technical support to the VGS, which

is provided by selection of plant medium and support structure, it is possible to develop specific models according to previously determined VGS types. Technical characteristics of the system directly affect selection of plant material, maintenance process, and selection of an appropriate irrigation system. These form a cost estimation component, and thus represent an important element in the evaluation of economic viability [13].

Depending on the selected type model of the VGS, the time required for achieving full coverage of the system can be determined, and the corresponding benefits can be estimated, which makes certain types more acceptable for use.

Tabular presentation of type models makes it easier to see characteristics of individual types, as well as the method of system maintenance and their price range during installation, which often influences the frequency of selection (Table 1). The presented type models represent basic types of VGS, depending on the supporting structure of the system and the growth rate of plant medium. Since practical application of the VGS has increased in recent years, different variations of these types appear on the market every day. The type models included in this paper were formed according to the previously performed classification system and represent personal contribution of the authors to the study in the scientific discipline of vertical greenery systems as a topical urban regeneration model.

#### 4. Conclusion

The introduction to basic characteristics of the vertical greenery system, as well as its determination according to the terminology and linguistic approach, represent the basis for defining the VGS as a modern model of urban design, the use of which provides a variety of benefits of ecological, economic, social, spatial, and energy nature. The principle of VGS classification, as presented in this paper, is based on the analysis of the vegetation mechanism and on the way in which substructure is assembled. These two are the main criteria serving as basis for creation of the VGS type models.

The defined VGS typology, introduction to characteristics through an overview of realised benefits, and formulation of structural and design requirements, have enabled formation of type models as unique spatial-functional elements of urban design. The applied models contain an overview of advantages and disadvantages of segmental system structures, which make individual models more flexible in practical implementation (depending on the primary aspect of perception), and in definition of goals and conceptual needs of urban space. Every model is specific due to different system characteristics, such as selection of plants, system substructures, and maintenance procedures. These characteristics define the basic principle of application.

Structural requirements of the model, and design characteristics defined according to the typology, determine the way in which the system is implemented, and so they may be acceptable for

a particular location, or not compatible according to structural features. The compatibility of structural requirements, type models, and buildings on which the VGS installation is planned, is determined according to analyses defining the possibility of installing a particular type model at a given location. It is often possible to apply different type models for the same location, and in such cases the selection of adequate model is made according to the shaping and design parameters, which are considered as relevant criteria. Clearly defined characteristics of each type model indisputably determine the way in which the system will be implemented. When it comes to implementation, and in order for the system to fully meet the planned concept, it is necessary that the VGS matches local conditions, and that plant selection complies with the planned model.

The VGS implementation and achievement of environmental improvements, positively influencing the climate and other environmental problems impairing quality of life on a daily basis, enable realisation of numerous social and economic benefits. These benefits make this model of urban design an acceptable way for proper restoration of urban environment. Determination of specific character of a particular place is facilitated by recognisable visual attributes. The VGS certainly has such attributes, and it also complies with design indicators that are important for restoration of positive image of cities.

The VGS is a unique element of urban design with pronounced visual characteristics based on the multitude of colours and structure of plants. Through their diversity, these plants are principal creators of attractive and user-friendly environments. The acceptability of VGS from ecological standpoint is quite obvious as it contributes to general increase in green areas. As proper indicators of the quality of urban life, green structures contribute to the process of socialisation and activation of community life. By adding the element of visual attraction and enhanced visual appeal of the city, green structures have proven to be fundamental components in the human environment improvement process.

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