Basic Methodology in Construction of Vertical Gardening of a Building

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Abstract. The research covers basic procedure of the formation of a model of vertical gardening of buildings within the concept of landscape gardening, ecology of vertical gardening, green construction technologies and measures to improve the energy performance of buildings. The “objective tree” is set; it determines the current trends of development of green panes. The content of the landscape-ecological "green constructor" of plant selection is set, in order to ensure the comfort of the living environment, the formation of the biodiversity of the urbanized environment, and the resolution of the socio-ecological problems of the city and agricultural issues. For the first time, a selection procedure for vertical gardening is offered. Architectural and landscape solutions for improving the environment with green panes in the city of Volgograd are presented. The work uses multivariate landscape-ecological analysis; simulation method and experimental design of a green pane in in the city of Volgograd. The developed methodology of landscape-ecological construction of green panes allows using these ideas in domestic and foreign construction in similar environmental conditions. New landscape solutions are presented. They increase the potential of energy-saving technologies of buildings in the formation of vertical gardening, including issues of improving comfort, health and safety of people.

1 Introduction

Considerable experience has been gained in the world practice of engineering, construction and operation of buildings in the direction of Energy Performance of Buildings using elements of architectural planting.

The use of landscape solutions for vertical gardening of buildings’ panes attracts interest, because it can reduce energy costs and improve the environment. For regions with a sharply arid climate, including the city of Volgograd, the aim to improve environment is becoming an important energy-saving measure, where green construction takes an active role. Techniques for vertical gardening of panes (shading, wall cooling) are directed to creating favorable living conditions for citizens, and can be significantly increased by a reasonable plant selection.

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1.1 Research objectives

Research objective is to determine regional features of landscape-ecological solutions for the construction of living walls in the concept of vertical gardening

Research tasks:

- analysis of the features of landscape construction of vertical gardening of buildings;
- selection of plant species for the construction of the living walls of buildings and the allocation of areas of impact on the urban environment as exemplified by the city of Volgograd;
- development of the principles of landscape construction in the field of vertical gardening of the city and drawing up a model of landscape-ecological construction of vertical gardening of the city;
- implementation of experimental developments on the design of vertical gardening exemplified by the buildings in the city Volgograd.

1.2 Practical and theoretical foundation of research

The research of the general and complex problems of the formation of the green concept of the city, development of vertical gardening systems (VGS) is based on scientific research from the different perspectives. In this paper, the architectural planting is considered as the basis for sustainable development of the city. The authors recognize the concept of architectural planting or sustainable architecture as the style of buildings constructed in accordance with the principles of environmental protection. Scientists note that architectural planting seeks to minimize the amount of resources consumed during the construction and operation of a building. Living wall techniques can become a part of a sustainable city strategy, and green vertical surfaces bring significant environmental, social and economic benefits to urban areas [1, 2].

The issues related to the application of energy-saving technologies and methods for improving the energy efficiency of buildings attract attention when using landscape solutions (vertical gardening of the southern panes of buildings and landscaping of roofs), which can reduce energy costs [3]. Vertical gardening is considered here as a passive tool for energy saving of a building. The aspects that should be taken into account when working with VGS (classification systems, various working mechanisms, green storm infrastructure) are being clarified [4]. The examples of design proposals for energy saving due to landscaping cladding, green spaces and for historic buildings are made [5, 6].

The study of an important aspect of vertical gardening, aimed at overcoming the hot conditions in the room during the day (temperature control, the amount of heat transfer in the building), forms important group of scientific publications [7]. These include the results of experiments proving that the decrease in temperature of a building with a green pane system is higher than that of a building without a green pane system [8].

The assessment of the acoustic characteristics of green panes and their effect on the propagation of noise over long distances also deserves consideration. The mentioned property is checked in different building conditions (dense buildings, open streets) with different noise sources [9, 10].

It is necessary to remember about the aesthetic effect of vertical gardening on city landscapes [11]. The improvement of urban design was facilitated by the spread of vegetation on the external street walls, which significantly increased the visual effect of the area [12]. Attractive places for walking and cycling, building plots with hybrid architecture, and memorable public spaces (bays and city center) appear [13-15].

The considered researches show the environmental and microclimatic benefits of integrating vegetation into architecture. The use of plants in vertical gardening is important to maintain a comfortable urban environment. However, the possibilities of vertical gardening systems for the modernization of buildings are still underexplored, especially the environmental and aesthetic selection of plants typical for the region of construction.

2 Materials and Methods

2.1 Creation of the “objective tree” for the vertical gardening

The theoretical part of the research is to develop the tasks of landscape-ecological approach of designing a model of the vertical greening plane, to define the concept of comfortable landscaped environment when choosing the types of formation of vertical gardening of the panes of the building and the selection of dendrological content in plants for landscaping.
Firstly, the environmental problems of high-rise construction (consumption of excess amount of energy, expulsion of vehicles attracted by a high-level object, collection and disposition of garbage, negative hydraulic impact, artificial lighting at night, influence on changing climatic conditions, shading of a large area, influence on the person, change of the wind conditions, negative influence of panes on birds) were analyzed and the property package which are neutralized by vertical gardening is defined.
Further research actions were aimed at solving the problems of development of the “objective tree”, required for the formation of a comfortable environment in the implementation of landscape-ecological properties of vertical gardening: improvement of the microclimate, high cumulative capacity of rain water; reducing the effect of island heat accumulation; energy efficiency due to isolation against wind, thermal insulation or cooling effect during evaporation; noise absorption; improved air quality (some plants may partially catch fine dust); optical valorization of unattractive panes and walls; contribution to stress reduction; protection against graffiti; creation of life space for fauna and flora, and etc.
The discovered objectives and tasks allow us to determine the whole range of measures for the formation of comfort of the environment using various technologies of vertical gardening, Fig.1.

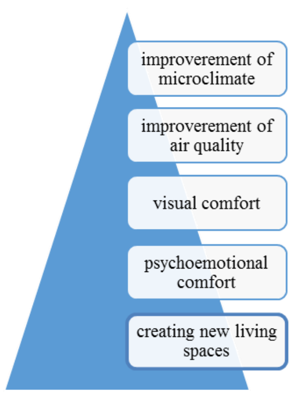


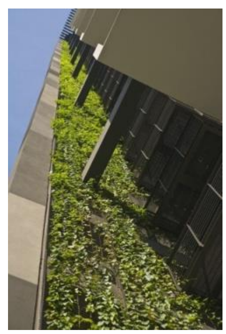
Fig. 1. The “objective tree” for development of the vertical gardening of the buildings

2.2 Choosing a vertical gardening system

The choice of a vertical gardening system in construction depends on a group of citywide factors, environmental factors and a group of factors for a particular object [16]. Shading by plants reduces the temperature gradient on the inner and external surfaces of building envelopes. Therefore, the thermal conductivity of structures and air infiltration inside the premises are reduced, which ensures a decrease in the electric energy consumption of the building [17, 18].

In modern cities, vertical gardening is widely applicable both for the panes of low-rise and medium-rise buildings, as well as for high-rise buildings and structures and their internal spaces – atriums. Landscaping techniques for the walls of buildings and structures may vary - complete, partial and accent wall coating. The choice of techniques depends on the project challenge, architectural design of the building and the environmental conditions of the territory. For the arrangement of vertical gardening, various design and technology solutions of building panes are used (Table 1).

Table 1. Design and technology solutions of building panes for vertical gardening [16]

Name of design and technology solution	Description of design and technology solution
Sand-cement frame to hold the soil: Landscaping adjoins the surface of the wall at a short distance. Plants are attached to the frame (trellis) attached to the wall at a short distance.	
The supporting structure with a metal lattice: A system of metal mesh is a tightly wreathen mesh of aluminum or lightweight steel cables attached to the pane with buckles. Plants usually grow from special modules located along the entire wall height. The system of cables and ropes consists of flexible vertically stretched elements. For example: Pasona Headquarters in Tokio; School of the Arts in Singapore; Helios Residences in Singapore; Newton Suites in Singapore	 Newton Suites in Singapore http://zvt.abok.ru/articles/351/Ozelenenie_kak_instrument_ekologicheskih_reshenii
The supporting structure is a system of cables and ropes; stiff, fixed system: A rigid system is a hedge structure that can be either flat or volumetric. Due to its spatial rigidity, it holds due to wall fasteners or columns, and also without any vertical support members.	 Consorico project in Santiago

	http://zvt.abok.ru/articles/351/Ozelenenie_kak_instrument_ekologicheskih_reshenii
System with mid-mounted felt pockets - living wall: Option 1. Herbaceous plants are used for its arrangement. In order to protect the filling structures against moisture, they are covered with a moisture protective membrane. The irrigation system can be equipped with rain sensors. The roots of plants are located in felt pockets filled with nutrient content. Option 2. Fabric (cloth) surface secured with a rigidly installed lining. Previously grown plants are installed in pockets, in a layer of fabric (felt). In such a system, the use of a substrate is not provided - all nutrients are received by the roots with water from irrigation channels installed under a layer of fabric (felt). For example: Trio Apartments in Sydney; Athenaeum Hotel in London; B3 Hotel Virrey in Bogota.	 Athenaeum Hotel in London http://zvt.abok.ru/articles/351/Ozelenenie_kak_instrument_ekologicheskih_reshenii  B3 Hotel Virrey in Bogota http://zvt.abok.ru/articles/351/Ozelenenie_kak_instrument_ekologicheskih_reshenii
Modular system of plastic containers: A modular system of lean square-cut mostly plastic containers, filled with a nutritional content. Such a system is attached to a rising wall or stands unobstructed, resting only on the ground surface. Containers are made of light metal or plastic. It can be boxes or wire cells. In some cases, the containers are divided into smaller cells located at an angle to the back surface of the container. Plants are grown directly in these modules, filled with soil, inorganic nutrient content or native fibers.	 One PNC Plaza in Pittsburgh http://zvt.abok.ru/articles/351/Ozelenenie_kak_instrument_ekologicheskih_reshenii

For example: One PNC Plaza in Pittsburgh	

In order to adopt an optimal design solution, the analytical system analysis method - the hierarchy analysis method is used. This method was applied by the author in a scientific work [18], devoted to the study of the influence of traffic noise on the formation of an acoustic medium in the intersections' zone, in particular, the development of a structural model based on a method that allows one to evaluate a group of factors that affect the sound level, adopt adequate decisions on the selection of major factors.

This method consists in decomposing the problem into simpler components and then processing the sequence of judgments of the decision maker (DM) based on pairwise comparisons. As a result, we have a description of the intensity of elements interaction in the hierarchy, then judgments are expressed numerically. This method includes procedures for synthesizing multiple judgments, obtaining priority criteria and finding alternative solutions. At the first stage we identify the most important issues of the problem, at the second - the best way to verify observations, test and evaluate the elements, the next stage is to develop a way to apply the solution and evaluate its quality. The use of a mathematical model allows us to evaluate the results of decision-making and their consequences. The process of finding the optimal solution is carried out according to a hierarchical principle: the results obtained at one of the levels are used as input for another level. The hierarchy analysis method systematizes the process of solving such a multi-stage problem [18, 19].

The basis for process modeling are the principles of identity and decomposition, the principles of discrimination, comparative judgment and synthesis [19]:

Stage 1 - the goal which determines the problem is formulated;

Stage 2 - the criteria are determined by which the optimal solution of the problem is selected;

Stage 3 - generation of alternatives: a certain set of alternatives (objects) to be selected for subsequent evaluation.

After decomposition, the problem of choice is divided into three hierarchical levels. A hierarchy is considered complete if each element of a given level functions as a criterion for all elements of a lower level [18, 19]. After a hierarchical description of the problem in the form of a structural diagram, the priority values of the criteria are established, and each of the alternatives is evaluated taking into account all the criteria. Variants of structural and technological solutions for vertical gardening were selected as objects for analysis. A hierarchical representation of the assessment model of a group of factors is built from the top (the goal is set from a management point of view), through intermediate levels to the lowest level, which is a list of alternatives - options for structural and technological solutions for vertical gardening. The model has created a complete dynamic hierarchy in which each element of a given level functions as a criterion for all elements of a lower level (Figure 2).

In order to implement the principles of discrimination and comparative judgments, task elements are compared in pairs using a comparison matrix. For subjective pairwise comparisons, a classic scale of comparative importance is used [18].

The next step in the implementation of the methodology is the synthesis of local priority vectors. From a group of matrices of paired comparisons, a set of local priorities is formed that express the relative influence of many elements on each element adjacent to the top level. Using well-known methods of analytical planning, it is possible to obtain a column of relative values (or eigenvectors of priorities) of each system criterion in relation to all other criteria [18]. The last stage of the analysis is the application of the synthesis of integrated priority vectors. Local priority vectors are multiplied by the priorities of the corresponding criterion at a higher level and are summed for each element in accordance with the criteria that this element affects. This procedure provides with an element global priority vector.

3 Experiment

3.1 Climatic features of the Volgograd territories potential

Territory of the Volgograd region belongs to a place unique in its climatic conditions. There are small land areas on the globe with a similar climatic situation. These territories lie in a zone of sharply continental climate and are characterized by harsh environmental conditions (winds bring dust storms, the absolute maximum temperature reaches +50 ° C with extreme air dryness): Mongolia - Ulegei, China - Yinchuan and Argentina - San Carlos de Barilogue.

By the significant amount of heat and light, Volgograd is on a par with subtropical cities. The sun is hidden by clouds no more than 80 days a year. An analysis of the temperature-humidity situation of the urban environment of Volgograd shows that on the streets the air temperature is between +35 and +45 °C, that is, 75% higher than the optimum temperature required for plant development; relative humidity decreases to 8–11% (for the midland this value is 50–80%). Asphalt pavement heats up to + 60 °C and higher, and the temperature of the earth at a depth of 15 cm on a hot day exceeds + 30 °C.

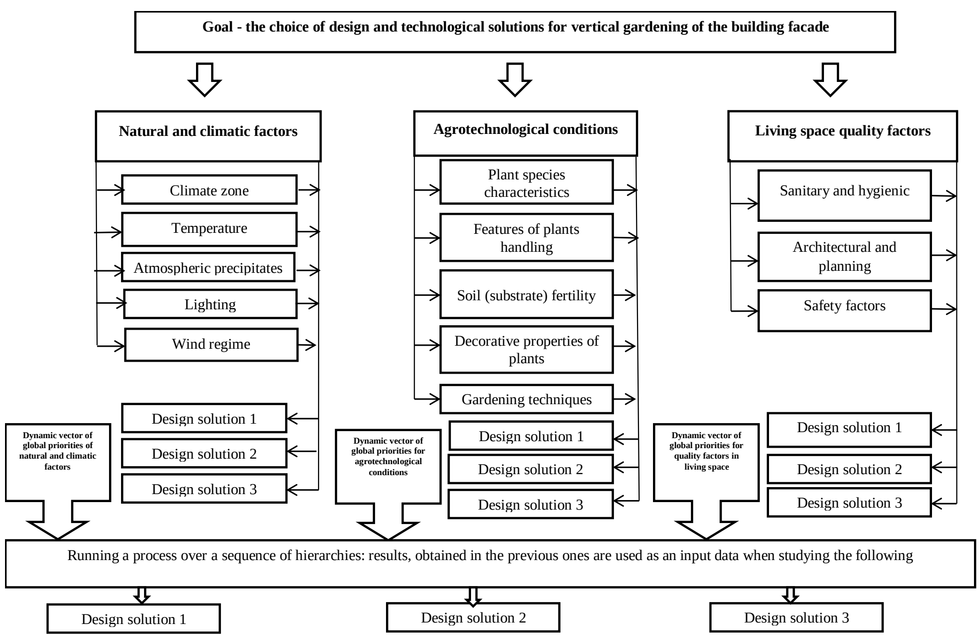


Fig. 2. Structural model for selecting a design and technological solution for vertical landscaping of the building surface

In Volgograd, dry winds and dust storms (from 50 to 55 days) with a wind speed of 14 m/s are usually observed in the summer-spring season, while comfortable conditions, as is commonly known, are at 2-6 m/s. In addition to hot air currents, the wind carries sand and “coating dust”, polluting urban spaces and sharply restricting visibility. Climatic conditions of Volgograd and the region differ by low relative humidity, strong winds and dust storms, adverse physical properties of soils. All this creates great difficulties in the selection of species for vertical gardening and their cultivation.

3.2 Features of vegetation development (vines and dwarf shrubs and trees)

In addition to negative climatic conditions, two more groups of negative factors affect the vegetation of Volgograd. A common set of “urban” influences is a complex factor. For Volgograd, they are: anthropogenic changes in the soil, gas contamination and dustiness of the air, a variable temperature regime (due to the diversified industrial transport infrastructure). They all lead to a premature death of plants. So the life expectancy of trees on the streets is reduced by 3-5 times compared to the natural forest (dying off occurs at the age of 20-30 years - the period of time of the most decorative and gardening effect).
Regional features of the formation of plantations in Volgograd and the region include: intensive development at a young age, after 3-8 years, plant growth slows down. Many species have a decorative view in 3-5 years; low stemming of tree species, shrubs grow up to 3-4 meters in height; sustainability of male planting (poplar, ash-leaved maple, green ash, Amur velvet, sea buckthorn).

4. Results

Design task has been considered and solved for the urban territory of Volgograd as part of the solution to the problem of vertical gardening of building facades in the context of reconstruction of buildings and providing comfortable living conditions.

As a result of field surveys, observations and mathematical calculations, quantitative and qualitative estimates of the parameters of each group of factors are obtained. The obtained hierarchical model includes three levels, each of which is divided into sub-levels (Fig. 2). A dynamic hierarchy is created in the model in which each element of a given level functions as a criterion for all elements of a lower level. As a result of the analysis, 16 matrices of judgments were obtained, in which the degree of influence of the components of the group of factors — natural and climatic, agrotechnological and safety factors — was assessed: at the sub-level 2.1 - 5, the criterion for assessing natural and climatic factors; at a sub-level 2.2 - 5 criteria for assessing agrotechnological factors; at sub-level 2.3 - 3 criteria for assessing safety factors and 3 types of design and technological solutions, which were compared in pairs according to each of the criteria. The correctness of the obtained characteristics, as well as the quality of the reasoning, their logical completeness are estimated by the value of the conformity index (CI) [18], the characteristic of the reasoning matrix Lmax and the conformity ratio (CR) which value does not exceed 10% of the CI [18, 19]. Vectors of integrated priorities for environmental, climatic, agrotechnological and safety factors, calculated for each of the 3 types of design solutions, were the data for compiling matrices of significance pair relationships according to criteria of a group of factors at levels 2 and 3 of the hierarchy. Vector processing was carried out in Microsoft Excel, which allowed us to rank the objects under study (Table 2).

Table 2. Integral indicator of the influence of a group of factors on the choice of a design and technological solution for vertical gardening of the facade at the stage of its reconstruction

Bike lane objects	Assessment of a group of factors that influence the choice of design and technological solutions

	Integrated priorities	Rank
Design and technological solution 1	0,654	1
Design and technological solution 2	0,112	3
Design and technological solution 3	0,234	2

An assessment of the factors showed that the optimal design and technological solution for vertical gardening is design and technological solution 1 (rank 1), a group of natural and climatic, agrotechnological factors have the greatest influence on the choice of design solution, Figure 2. The optimal option is a bearing support with a metal grid - a system of metal mesh - a closely interwoven mesh of aluminum or light steel cables, attached to the facade using brackets.

Selection of vegetation for vertical gardening was carried out using the "green constructor" system, including the names of spaces that meet environmental, aesthetic and dendrological requirements (drought-resistant, beautifully flowering, with high phytoncide properties, effectively reducing noise levels, resistant to smoke and gas), used in the formation of a greened wall. Principles of plant selection: growth rate, unpretentiousness, drought and smoke resistance, winter hardiness, light regime and the ability to survive the conditions of the city.

In vertical gardening, vines are widely used: Aristolochia durior and Aristolochia manshuriensis, Celastrus orbiculatus, Celastrus flagellaris lucensis lucensis, Lonicera caprifolium and others. These are mainly vines 7-10 m long with dense foliage, large leaves. Plants with the highest number of points were determined for the vertical composition of gardening of the library building in Volgograd, Table 3.

Table 3. Plants for vertical gardening of a building in Volgograd

Plant	Area, m^2	Quantity, pcs.
Bergenia crassifolia	1,0	20
Berberis thunbergii	2,0	20
Ajuga reptans	5,0	100
Lamium	17,7	155
Juniperus sabina	10,7	43
Festuca gautieri	6,7	200
Artemisia austriaca	9,1	230
Sedum acre Aureum	2,5	200

Sedum caucasicum	7,6	230
Sedum spurium	2,5	80
Sedum morganianum	7,6	230
Amabile Plenum	45,0	900
Spiraea japonica	4,0	20
Stachys byzantina	14,7	300
Thymus serpyllum	2,5	80
Ajuga reptans	3,36	70

Slowly growing plants have their final, dense appearance only after months and do not require much time to care. The main species are: Amabile Plenum, Stachys byzantina, Lamium, Ajuga reptans, Festuca gautieri, Artemisia austriaca, Sedum acre Aureum, Sedum caucasicum, Sedum morganianum, which occupy up to 90% of the gardening area of the building facade. The color accents are Berberis thunbergii, the harmonious additional color spots: Bergenia crassifolia, Thymus serpyllum, Ajuga reptans, Sedum spurium, etc., bushes Spiraea japonica and Juniperus sabina are located at the base of the vertical composition, Fig. 3.

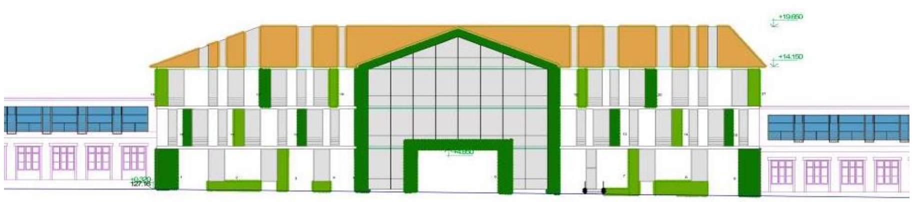


Fig. 3. Gardening of the openwork type facade

Conclusions:

1. The design of city facades gardening is aimed at improving the living conditions, human health and the restoration of the ecological landscape;

2. The landscape and ecological designer of plant breeds selection has improved the use of the advantages of vertical gardening, aimed at creating a comfortable urban microclimate, biodiversity and achieving energy efficiency of buildings;

3. The proposed method for assessing a group of factors is universal and easily applicable in practice; it can be the basis for preliminary selection of factors and determination of mathematical dependencies. The study has continued to address the issues of designing vertical gardening, focusing on the integrated use of various structural and technological solutions for vertical gardening and assessing the degree of safety for human health of living conditions and stay in buildings and structures;

4. Experimental design was supported by the developed model of landscape and ecological construction of vertical gardening, where the structure of the vertical distribution of tree

species is an important factor influencing external shading and evaporation, as well as the comfort of the internal environment.

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