Innovative modular greening system for modern buildings

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Abstract. For the sustainable development of the cities and auspicious environment for the life of future generations and the health of residents of the metropolis, it is very important to have not only comfortable housing, but also a healthy environment inside and outside it, and for this it is not at all necessary to live in rural areas. Today life in the city goes by at a very fast pace among the modern buildings. These are indispensable spaces for the life of every citizen, however, for the functioning and proper operation of the entire system of the human, it is necessary not only to move, but also to breathe the clear air. This is possible due to the plants in the urban environment, which are very few, and often the gas content and harmful impurities, together with CO2, exceed the maximum regulatory values in the air. The plants help to reduce them, and thus create a green environment for the population. Innovative modular greening systems for the roofs and facades of modern buildings, developed by the authors, possesses high manufacturability in comparison with competitors and help to the environment in general, which contributes to improving the health and longevity of people.

1. Introduction
With buildings consuming between 30% and 40% of all primary energy, it is no surprise that more building owners and investors today are looking to green or energy efficient construction, as well as sustainable development policies. There is growing evidence around the world that green buildings provide multiple benefits, according to the World Council for Green Building. These buildings are among the most successful vehicles for achieving various global goals, such as tackling climate change, creating healthy and prosperous societies, and accelerating sustainable development. What we do requires us to promote these benefits and encourage a growing evidence base to prove them. The benefits of green buildings can be divided into three categories: social, economic and environmental.

According to the United Nations Environment Program (UNEP), the construction industry has the greatest potential to reduce greenhouse gas emissions compared to other major emission sources. UNEP is also assessing this potential to reduce emissions of up to 84 gigatonnes of CO2 by 2050 through direct investment in innovative building technologies, taking into account categories such as energy efficiency, fuel conversion and renewable energy [1]. The study of buildings found that green buildings that are LEED certified in the US and other countries use 25% less energy and 11% less water than non-green buildings. In terms of economic benefits, the European Commission estimates that global energy conservation initiatives could save an additional € 280-410 billion in energy cost savings (nearly double America's annual electricity consumption). The green sector of the economy is becoming more and more voluminous. In the US alone, Bloomberg estimates it at $ 1.3 trillion, and it
is only growing. At a building level, building owners say that green buildings help achieve a 7% improvement in asset value compared to conventional buildings, whether they are new or renovated.

In addition to environmental and economic benefits, green construction has social benefits as well. According to a Harvard Research, Workers in green, well ventilated workplaces show an improvement in cognitive scores of 101%. Another research finds that improved indoor air quality (low CO2 and pollutant concentrations and high rates of ventilation) can result in performance improvements of up to 8%.

In view of these and other similar benefits of green construction and green buildings, we have offering a new green roof and green wall modular technology for private, commercial, public and government buildings. Innovative energy-efficient construction technology such as green roof and wall solutions can bring great value to the environment and help to mitigate the heat island effect.

2. Methodology

2.1. Development of greening systems in the international Building Codes

Green urbanism has own specific features when installing green covering systems on the buildings, taking into account various parameters in complex of technological processes. When installing greening systems on the walls and rooftops of the modern buildings, it must be taken into account the local regulations and the international high-level principle-based standards, developed in collaboration with Building Codes. Today, there are three known and most demanded methods at the international level that are used to assess the rating of a green building: BREEAM, presented by the Bre Global Institute, LEED, created by the American Council for Green Building and the German DGNB standard. At the same time, we will analyze the current studies of green building evaluation system implementation and international standards for green roof and vertical greening systems [2-6].

One of the first normative documents is the German standard «Planning, implementation and maintenance of green roof space» (FLL), published in 1990, developed by the Research society for greener and landscape development in Bonn (Germany) [7]. Recommendations include green roof types, different types of vegetation, engineering requirements, detailed green roof installation processes, and roof repair and maintenance. For predicting the loads on the green roof we consider German standard DIN EN 1991 «Einwirkungen auf tragwerke teil 1-1: wichten, eigengewicht und nutzlasten im hochbau, teil 1-3: schneelasten, teil 1-4: windlasten» and American standard ASTM E 2397/E2397M: 2019 «Standard practice for determination of dead loads and live loads associated with vegetative (green) roof systems» [8,17].

Greennig systems on the facades create a protection, improvement in air quality, well-being space, favorable microclimate and attractive look to a building. The vertical greening systems are provided by several international Building Codes: Growing Green Guide, Green roofs and walls RICS professional guidance, Australia (Australian standards) [21-23], the UK Guide to Green Walls (standard of United Kingdom) [24].

2.2 Analysis of labor intensity of green roof systems installation

To study the greening system for modern buildings, it is important to use in the investigation a systematic approach, evaluation and development strategies for multi-variable structures in the construction [9-16, 18-20]. The analysis carried out shows the following options for the construction of green roof systems were chosen:

- roof without greening systems (the traditional type);
- roof with continuous greening systems (non-modular type);
- roof with modular greening systems (modules with a diameter of 0.5 m - option 3, figure 1).

Green roof modular covering system, designed by authors, comprises a series of modular pots, installed side-by-side in an adjacent manner. The system consists of the modules, pierced with calibrated holes connected by a plurality of detachable interlocking apparatus that are easy to assemble.
and disassemble, supported integrated energy collecting and converting devices such as solar panels, LED-lights, micro wind turbines and irrigation system that includes drip watering tubes and sprinklers.

**Figure 1.** The greening system on the roof of modern buildings developed by the authors

Analysis of the indicators of the labor intensity of the device of the various types of the greening systems showed, that total labor intensity of device of the traditional type is compiled 98.4 labor-hours (100%), total labor intensity of device of the all-over covering systems with greening structures (non-modular type) is compiled 107.9 labor-hours (110%), total labor intensity of device of the modular greening systems for covering is compiled 79.3 labor-hours (81%), of this amount labor intensity of device of the multilayer structures is 50.2 labor-hours, that is less by 48% than labor intensity of device of the multilayer structures of the all-over covering systems (Figure 2).

**Figure 2.** The analysis of the indicators of the labor intensity of the roof installation

By varying the design of certain layers of a multi-layer structure when constructing modular systems, we achieve a reduction in the total labor intensity of the device of greening systems by 19-25%.

There are generally two types of greening systems on the wall: soil-less green walls and modular greening systems (modular green walls). Soil-less green walls (living walls, green facades, bio walls or vertical vegetation) are designed to mimic the growing conditions found where green walls occur in nature. Modular green walls use pockets of plants and climbing plants and media (soil) in prefabricated modules to produce a green wall. Modular systems are implemented in the several forms: trays, vessels, pots, half-pots, panels, usually composed of several interlocked elements, made
of lightweight materials as eco-plastic, polypropylene, HDPE (high-density polyethylene) or metal sheets (figures 3,4).

![Figure 3. The greening system on the wall of Simferopol airport](image)

3. Results
Author’s concept of innovative greening system on the walls considers the integration of planting systems and «continuous» forms of modules (figure 4), with increasing the functional potential of the greening system to building users.

![Figure 4. The 3D view of the unit and wall panel of the innovative modular greening system](image)
The lightweight and unique configuration that increases the portability of the green roof and green wall modules and make it easy to assemble, place and disassemble the system. The loads on roof with continuous greening systems and the loads on the roof with modular greening systems were calculated (table 1).

**Table 1. The load assessment of roof with greening systems**

| Load type                                              | $\rho$, t/m³ | Normative value of the load, Ln, kPa | $\gamma f^*$ | Calculated value of the load of the roof with continuous greening systems, Lc, kPa | Calculated value of the load of the roof with modular greening systems, Lc, kPa |
|--------------------------------------------------------|--------------|-------------------------------------|--------------|---------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| 1a. Soil, $\delta = 0.1$ m                             | 1.2          | 1.6                                 | 1.3          | 2.08                                                                            | -                                                                               |
| 1b. Modules with wet soil, $\delta = 0.4$ m            | 0.6          | 0.6                                 | 1.2          | -                                                                                | 0.72                                                                            |
| 2a. Drainage profiled membrane, $\delta = 0.008$ m    | 0.55         | -                                   | 1.2          | 1.8                                                                              |                                                                                |
| 2b. Drainage grid                                     | 1.5          | 1.5                                 | 1.2          |                                                                                | 1.8                                                                              |
| 3. Insulation-mineral wool slabs, $\delta = 0.1$ m     | 0.035        | 0.15                                | 1.3          | 0.195                                                                            |                                                                                |
| 4. Geotextile - 2 layers                              | 150          | -                                   | 1.2          | -                                                                                |                                                                                |
| 5a. Bitumen-polymer roll waterproofing - 2 layers     | 1.4          | -                                   | 1.3          | -                                                                                |                                                                                |
| 5b. Waterproofing                                     | -            | 1.3                                 | -            | -                                                                                |                                                                                |
| Primer                                                | 0.88         | -                                   | 1.3          | -                                                                                |                                                                                |
| 6a. Reinforced cement-sand screed, $\delta = 30$ mm ($\gamma = 18$ kN/m³) | 0.54         | 0.54                                | 1.3          | 0.7                                                                              |                                                                                |
| 6b. Adjusting supports                                | -            | 1.2                                 | -            | -                                                                                |                                                                                |
| Expanded clay gravel                                  | 0.4          | 0.23                                | 1.3          | 0.3                                                                              |                                                                                |
| Base covering, $\delta = 220$ mm                      | 2.5          | 3.4                                 | 1.1          | 3.74                                                                             | 3.74                                                                             |
| Summary:                                              |              |                                     |              | 7.015                                                                             | 6.26                                                                             |

*Load safety factor: a factor that takes into account, under normal operating conditions of structures, the possible deviation of loads in an unfavorable (higher or lower) direction from the standard values

Thus, the total load of modular greening systems is almost 10% less than the total load of continuous greening systems. Modular greening systems are lightweight structures, therefore they are best used on green roofs and walls.

**4. Conclusions**

The urbanized areas have a higher need to improve urban conditions for the inhabitants of the metropolis and improve the environment for the inhabitants of wildlife. Builders are increasingly using
green roof because they are getting rental premiums. They are given tax credits, storm-water fee credits, rebates, and construction grants as a significant portion of green infrastructure costs. In spite of these known systems, there is a need for improved modular green roof system and method for covering roofs and other surfaces. The system, created by authors, is designed in a modular manner. Ergonomic design is provided with the installation in various types such as green and blue roofs and using the system as a vertical greening system by construction of multilevel modular pot system. In conjunction with elements of decorative design such as fountains, statues, urban furniture, modular green roof system creates an extraordinarily aesthetic design that allows the project designer to exercise complete freedom of expression. The lightweight and unique configuration increases the portability of the modular elements, making it easy to assemble, place and disassemble the system: the total load of modular greening systems is almost 10% less than the total load of continuous greening systems. Thus, green buildings can help to minimize operating costs by saving on energy, improving occupant productivity, enhance asset value and profits, and improve lifecycle economic performance.

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