# New urbanstyle technology – modular green roof and wall system

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***Abstract***

**In this paper, we describe the most innovative environmental projects and modular green technology as a key element of our urban spaces and the lungs of the cities. The decision to completely eliminate carbon fuels and reduce environmental pollution, make urban style more sustainable and friendly to the environment is reflected in the use of modular design and technological solutions for the building facades and roofs. A comprehensive analysis of the presented green systems allows to identify their shortcomings and show the advantages of modern modular greening technology using devices that integrate and convert solar and wind energy such as solar panels, micro wind turbines and modern automatic irrigation system. Ergonomic design is provided with the installation in various roof configurations and types such as green and blue roofs and using the system as a vertical gardening by construction of multilevel modular pot system. Another motivating factor will be the deeper appreciation of Green Environmental Protection and the relentless efforts of many governments to this end.**

***Keywords:*** *Green building, green roof technology, manufacturability, sustainable development, urban health*

## I. INTRODUCTION

The relevance in this work is determined by the fact that at present new construction technologies are being formed with integrated greening systems on the roofs and facades of buildings in order to create a comfortable and healthy urban environment for future generations. Nowadays in many countries, environmental policy is aimed at getting rid of excess carbon footprint and making the urban spaces environmentally friendly for a favorable living environment for its citizens. The greening of roofs and walls of buildings is a necessary element of sustainable ecological development of modern cities. «Clean air and a livable climate are inalienable human rights and solving this crisis is not a question of politics, it is a question of our own survival. This is the most urgent of times, and the most urgent of messages», Leonardo DiCaprio, United Nations Messenger of Peace for Climate, said it on the United Nations Climate Summit in 2014, and we have to influence it as soon as possible [1].

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## II. GREEN ROOFS AND PV TECHNOLOGY

The combination of green roof and PV technology can be beneficial and provide several advantages. It is well known that an increase in PV cells' temperature adversely affects the conversion efficiency, limiting the ability of a PV module (figure 1) to produce energy in favorable conditions, such as with high level of solar irradiation [2], [3].

*Figure 1. Integration of PV panels on the green roof.*

Vegetation and substrate on a green roof are responsible for the evapotranspiration effect, that is believed to reduce the air and system temperature converting solar radiation into latent heat released in the atmosphere, producing consequently savings in terms of cooling energy need [4]. Furthermore, the green roof reduces the surface temperature, with consequent cooler near-surface air temperature, thus providing enhanced conditions for PV operation and production.

The recent research has analyzed the combination of these two technologies in order to assess the cost-effectiveness as well as the environmental benefits [5]. The experimental evaluation of Photovoltaic (PV) – green roofs under Mediterranean climate summer conditions was performed in [6] selecting two autochthonous plants, (Gazania rigens and Sedum clavatum) and a PV-gravel configuration as the reference roof. The results revealed that the green roof caused a positive effect leading to the improvement of PV electrical performance, with maximum power output increase for PV-gazania and PV-sedum of 1.29% and 3.33%, respectively, when compared to a PV-gravel roof. A study [7] evaluated the overall profit considering the energy generated and saved thanks to the installation of PV and green roofs considering also climate uncertainties with a two-stage stochastic programming mode. With a 20-year time span, more consistent with PV and green roof lifespan, the results showed the importance of the integration of PV-GR for efficiency increase as it can significantly change the optimal solutions and that the model is highly sensitive to GR parameters that must be properly calibrated. The effect of different roofing technologies was explored in [8], where it was found that a white-PV roof can reduce the total flux by 55%, whereas a green-PV roof reach a total flux reduction of about 42%, both compared to a traditional black roof. The relationship between ambient temperature and PV output by comparing the performance of green roof–PV and black roof–PV systems considering a one-year field experiments was investigated in [9]. The results revealed that the green roof was expected to increase the PV power generation by 0.9% under high temperature scenario, for the climate conditions of Pittsburgh.

It is important evaluate the performance of the various plant layers which enhance the PV-green roof integration in order to maximize the power output [10] and therefore there is a need to select the best vegetation according to climate conditions of the specific locality. It was highlighted that the integration of a PV on a green roof can affect the plant development and community [11]. The main effect of the PV is the shade provided by the modules. Shade can be useful to developing plants in dry environments because of the increased moisture while it appears unnecessary in moist environments.

Since extensive green roofs in Mediterranean climates generally lose moisture quickly following the end of seasonal precipitation, PV would be expected to contribute to higher moisture levels on the green roof, and thus benefit plants. Several studies that have examined the effects of shade on multiple species found that only some of them responded positively [12], [13]. Shade heterogeneity can allow competing species to coexist [14]. Since shade and its effects benefit some species, but are detrimental to other species, a green roof with PV, where there is a heterogeneous environment with different levels of shade, would be expected to produce a diverse plant community [11].

A more interesting and appealing solution that allows to exploit even better the characteristic of the green roof is the use of Bi-facial PV modules. The use of conventional photovoltaic system often installed with low-tilt angles, prominently in South, South-East or South-west directions, and the close placements of modules to each other, in order to optimize the available space, can results in an almost coverage of the roof surface, completely shading the vegetation. Or, if PV panels are installed at a low height from the roof plane, the plants growing in between the modules can generate undesirable shading of the collector surface with the risk to reduce the annual energy yield. So, in such cases, it becomes important a frequent maintenance procedure, that can be however, complicated by dense PV system layouts.

In order to overcome these limitation vertically mounted bifacial modules were proposed [15]. They tested a standard green roof substrate with a standard mixture of green-leaved plants and a recycled green roof substrate with silver-leaved plants to achieve a higher albedo. Despite the East-West orientation, the bifacial modules were able to achieved a specific yield close to typical values of south-facing systems in the same region. It was also shown that plants with silvery leaves improve the system yield compared higher resilience of the plants that provides a more stable albedo.

The PV-green roof is believed to be a promising technology to enhance the PV output on a building scale. However, there are several challenges for combining the two technologies together which obstacle its application. Challenges relating to green roofs include high investment costs, a lack of sustainable materials, and the difficulty of real-life applications in larger projects [5]. Most importantly the biggest challenge for the PV-green roof application is the limited availability of case studies and experimental data making it difficult to draw robust conclusion on the feasibility of such integration.

## III. GREEN ROOF INSTALLATION PROCESS

When installing green roofs, we took into account:

- the load that the structure of this roof can withstand; taking it into account, the type of green spaces is selected;

- the volume of the soil layer required to accommodate plant roots;

- the required amount of moisture to provide plants with water; the need for drainage to remove excess moisture, gets operational coverage during precipitation or watering plants;

- the need to protect structural elements from root penetration;

- the possibility of arranging energy converting systems such as PV modules, wind turbines and others.

At the same time, we were analyzed the continuous and modular device of greening systems:

- continuous green roof with devices for independent irrigation - variant 1(Figure 2);

- modular green roof system with the cells - variant 2 (Figure 3);

- modular green roof system, designed by authors - variant 3 (Figure 4).

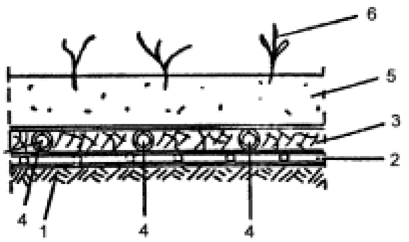

*Figure 2. Continuous green roof with devices for independent irrigation: 1 - Concrete vault; 2 - Sealing (sealing) gasket; 3 - a layer of fiberglass; 4 - Flexible tube; 5 - Root checkmate; 6 - Vegetation layer.*

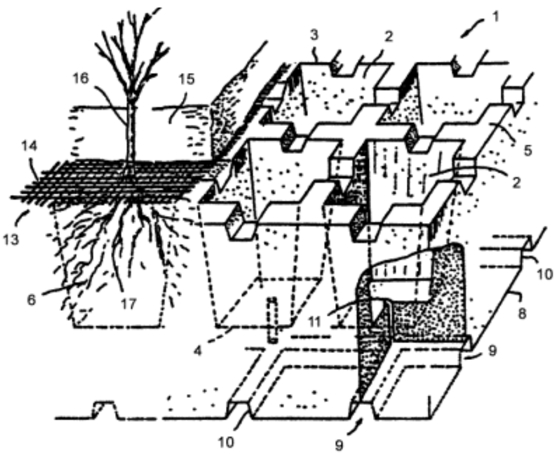

*Figure 3. Modular green roof system with the cells: 1 – support; 2 – cell; 3 – upper part; 4 – bottom; 5 – cruciform connection element; 6 – organic base; 7 – base coating; 8 – water isolation layer; 9 – openings in water isolation layer; 10 – edge on water isolation layer; 11 – narrow opening; 12, 13 – layers of textile material; 14 – grating; 15 – soil layer; 16 – plants; 17 – roots.*

Based on these considerations, we carried out an analysis of various constructive and technological solutions for green roofs, consisting of the following elements: type of the fastening system and convenience of installation and use (Table 1).

**Table 1. The comparative analysis of the green roof systems.**

| No | Description of the green roof systems | Type of the fastening system | Convenience of installation and use |
|---|---|---|---|
| 1 | The system provides for a device for independent irrigation, which is located between the waterproofing and the vegetation layer and consists of a canvas and irrigation channels carried out in the canvas or under it. | The fastening system is complex enough to maintain during operation. | The system uses a lightweight independent irrigation system, which allows for ease of installation. |
| 2 | The modular green roof system, consists of the cells, which are preferably identical and symmetrical. Each cell is open in its upper part and closed in the lower part by the bottom, which has narrow openings for removing excess water supplied to the panel. The cells are filled with an organic base for feeding the roots of plants planted in a soil layer. The upper part of the panel is insulated from the ground with a layer of textile material. | The system contains a support made of plastic with a low specific weight. This support is a structure that forms a large number of separate cells located side by side. | Installation takes place in several stages, the duration of installation process is longer. |
| 3 | The modular green roof system, designed by authors consists of the modules with the ability to integrate devices that convert solar and wind energy. | Simple fastening system, consisting of reinforcing elements with a double-headed arrow, can be easy applied to the building structure. | Installed modules are adapted to be gripped by a person's hand, which allows a person to fast move the module by himself. |

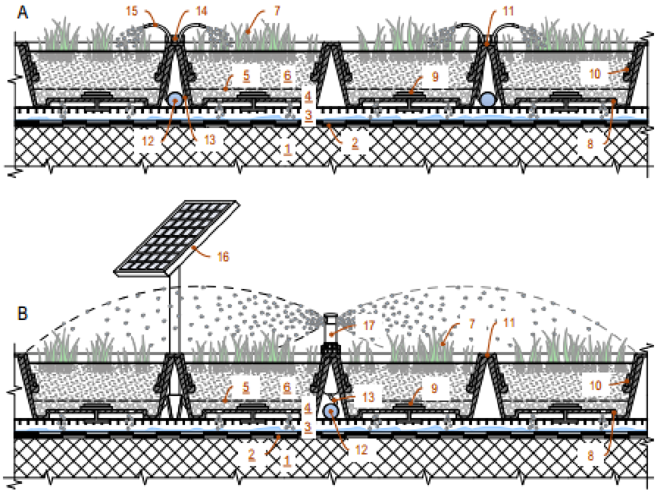

*Figure 4. Modular green roof system with the cells: 1 – base coating; 2 – water isolation layer; 3 - grating; 4 – water flow; 5 – drainage layer; 6 - soil layer; 7 – plants; 8 – module; 9 – fastener; 10 – rim; 11 – interlocking apparatus; 12 – hose; 13 – water delivery tubes; 14 – perforated cup; 15 – drip watering tube; 16 – PV module; 17 – sprinkler.*

We had evaluated manufacturability of these structural and technological solutions (STS) [16]. Calculation of the coefficient of manufacturability of the device of continuous green roof with devices for independent irrigation $K_{t\,gr}^{1}$ showed that this STS is acceptable:

$$K_{t\,gr}^{1} = \frac{Qgr\ k}{Qml\ i + Qgr\ k} = 0{,}16 - (0{,}1 \ldots 0{,}2).$$

Calculation of the coefficient of manufacturability of the device modular green roof systems $K_{t\,gr}^{2}$ and $K_{t\,gr}^{3}$ showed that these STS are rational:

$$K_{t\,gr}^{2} = \frac{Qgr\ k}{Qml\ i + Qgr\ k} = 0{,}04 < 0{,}1.$$

$$K_{t\,gr}^{3} = \frac{Qgr\ k}{Qml\ i + Qgr\ k} = 0{,}03 < 0{,}1.$$

The most expedient is the solution of the green roof device using modular structures, since with an increase in the complexity of the roof, the total labor intensity of work on the installation of such coatings will be minimal when comparing various options for the device of roofing.

## IV. APPLICATION OF INNOVATION GREEN WALL SYSTEM

The great interest is the innovative projects of urban green schools that are being built in San-Francisco and educate children according to a special ecological Curriculum based on the Waldorf pedagogical system. The mission of such green schools is to develop a person who independently chooses paths through life and have imagination, a sense of justice and a sense of responsibility on which the essence of education is based. Green building with a vegetation cover to place of classrooms and the farm where students teach both traditional subjects and acquire behavioral skills, take care of environment, growing zucchini, cabbage, onions and other herbs and vegetables. The unique design is being developed by SWA Landscape, who designed an effective green roof for the building of the California Academy of Sciences in the Golden Gate Park. This building is a tool for teaching in complete harmony with nature. The construction of green rooftops of the building cladding absorbs water, provides thermal insulation and provides a natural habitat for pollinating insects (Figure 5).

*Figure 5. Design project of green school in San-Francisco.*

Innovative technology for covering of the school buildings and facilities with modular green wall systems is proposed by authors (Figures 6, 7).

*Figure 6. The modular green wall system in school buildings and facilities.*

*Figure 7. The modular green wall system, designed by authors.*

The advantages of the system, designed by the authors, emphasizes its unique qualities such as wavy-continued design, pre-vegetated green wall modules, which may be transported to the building, where modules may be arranged in a grid-like fashion to cover one or more walls of the dwelling house or business center. In this manner, the pre-vegetated green wall may be installed in a relatively short period of time.

Many researchers are developing new solutions and researching existing technologies for greening urban areas, the attitudes regarding their application and assessments of manufacturability remains open [17-21].

## V. RESULTS

New urbanstyle technology – modular green roof and wall system is developed for use in residential and public buildings. The diversity and multiplicity of modular green system, designed by authors with different configurations and sizes of modules allows to use greening structures in buildings of various functional purposes, including school and preschool education, considering geographic zone and climate characteristics. And it shows interest in installation of this biggest variants of green roofs and walls, their ergonomic design and industrial applicability. It is also important to note that this system, developed by the authors, allows you to integrate devices such as solar panels, micro wind turbines and modern automatic irrigation system, the system also provides trays for filling with water (see Figure 8).

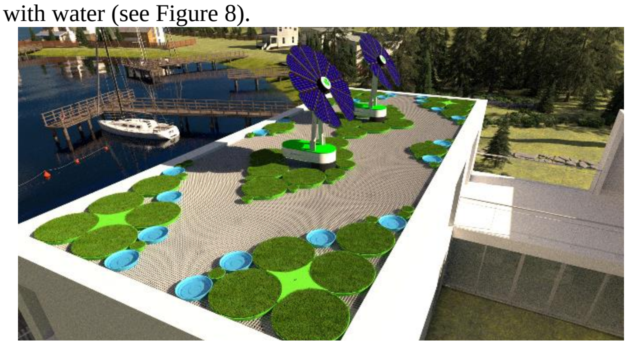

*Figure 8. The modular green and blue roof system, designed by authors.*

## VI. CONCLUSIONS

In this study, we compared the continuous and modular structural and technological solutions of the device green covering systems and concluded that the modular green system is the most applicable since their manufacturability is higher than their counterparts. Assessment was carried out with the method calculation of the coefficient of manufacturability of the device green roof systems.

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