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REVIEW AND COMPARISON OF DESIGN AND TECHNOLOGICAL SOLUTIONS FOR GREEN ROOFS WITH EXTENSIVE LANDSCAPING

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Key positions in the design of "green" roofs were identified, which provide advantages in the certification of buildings according to LEED standards. Modeling of organizational and technological processes for three variants of green roofs with extensive gardening was carried out

A large number of developments for green roofs are proposed in patents. A recycled green roof is proposed in patent No. 281624, MKI E 04 D 11/00, 1990 (Germany). A recycled roof provides for the use of waste, which, in combination with concrete with monofractional aggregate, forms a vegetative, filtering and protective layers, as well as a root boundary. The nutrient solution-impregnated edge mat covers the cultivated soil while reducing water pressure. The waste is placed in the form of prefabricated boxes and, after the preparation of the green roof surfaces, is covered with rolled turf. Mesh waste from textile production provides, as a filter layer, cleaning and draining of pressure water through fungicidal concrete, which dries quickly due to lateral ventilation and prevents root germination. The undulating bottom surface of the concrete compacts the fine stamping waste laid as a protective layer for the high polymer waterproofing sheets and drains the accumulated water through flat troughs that can be walked on by maintenance personnel.

The use of slag to make a drainage layer is proposed in application No. 4220334 MKI E 04 D 11/00 "Greening of flat roofs" (Germany) When landscaping flat roofs, the following layers are provided: insulating against root germination, a drainage layer, a permeable separating layer and a vegetative layer; their simplest device is provided with an increased ability to accumulate moisture. The drainage layer is made up of prepared slabs of combined slags with a specific bulk density of 80 - 120 kg/m3. The drainage layer is covered with a separating layer, which is a Specialized materials for "green" roofs are produced by many foreign companies: ZinCo (Germany), Index (Italy), Delta, Flordepot, Imperbel and TechnoNIKOL (Russia).

Roof greening systems with a minimum number of elements are of interest. Bauder companies greening of large areas with Bauder SDF mat: protective, drainage and filtering layer in one material (Figure 1) [1].

1 – landscaping; 2 – substrate - based on minerals 90% and 10% organic; 3 – protective, drainage and filter layer - Bauder SDF (polyamide drainage material - monofilament, drainage density 400 g/m^2, material of the protective and filter layers polyester, density 200 g/m^2, thickness 20 mm, total weight 600 g/m^2)

Figure 1. – Green roof construction with Bauder SDF mats [1]

It is known to cover the green roof "ZinKo" [2]. A single drainage-accumulative and protective layer is located on the entire surface of the roof. Additional structures and coatings are located and attached directly to it. Drainage is carried out along the drainage layer, so the system is not tied to internal communications. The ZinCo green roofing system consists of five main components.

Dörken GmbH & Co. KG suggests using the DELTA drainage membrane as a filter layer. DELTA-TERRAXX and DELTA-FLORAXX TOP membranes combine filtering, drainage and protective functions. As a separate filter layer, it is proposed to use non-woven thermally bonded geotextile with high tensile strength and an optimal parameter of 120-150 microns (open hole size) for simultaneous filtering and drainage functions (Figure 2) [3].

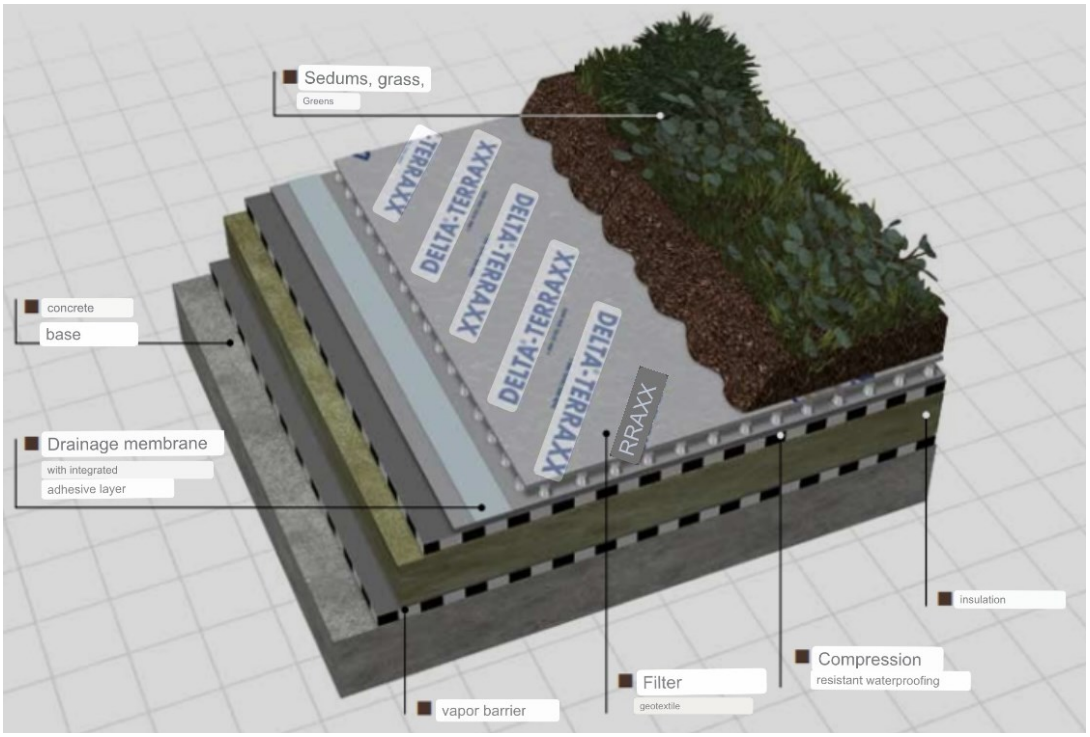
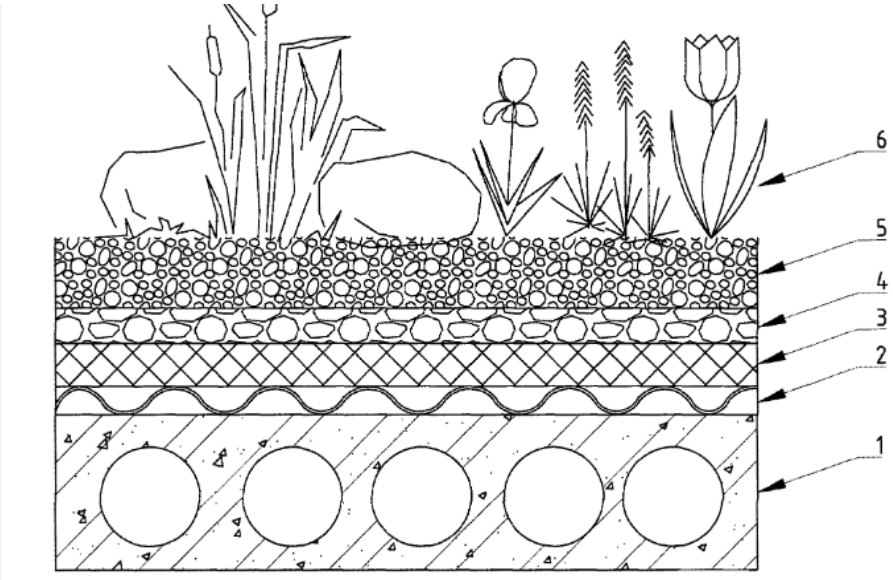


Figure 2. – DELTA-TERRAXX roof system with extensive greenery [61]

The design of the green roof (patent RU No. 163334 U1, E04D 11/00, published on 07/10/2016 [4]) includes a reinforced concrete floor slab, protective, filtering and plant layers, while ondulin is used as a protective layer, additionally includes a heat-insulating layer and a layer of fixing soil, consisting of loam, monomeric acid waste, diluted liquid glass with a density of up to 1.13 g/cm3 and a solution of calcium chloride (Figure 3).



1 – reinforced concrete slab with cement joints and bitumen coating; 2 – protective layer - ondulin; 3 – heat-insulating layer; 4 – filter layer of peat and/or gravel; 5 – fixing soil mixture, consisting of loam, monomeric acid waste, diluted liquid glass with a density of up to 1.13 g / cm^3 and calcium chloride solution; 6 – plant layer

Figure 3. – Green roof construction with soil fixing mixture

A multifunctional design that allows you to obtain economic and social benefits from its use throughout the year (pool, cafe, garden) is proposed in a patent RU № 191863 U1 E04D 11/00 [5].

The green roof structure includes a reinforced concrete floor slab, euroroofing material, consisting of a durable non-rotting base, supports made of high-strength propylene, with the possibility of increasing the support due to an additional insert of 60 mm, two layers of ondulin, in the middle - waterproofing with liquid rubber, the central part is further terraced board, along the edges - a drainage layer, soil in the form of a substrate, green flooring - green spaces (Figure 4).

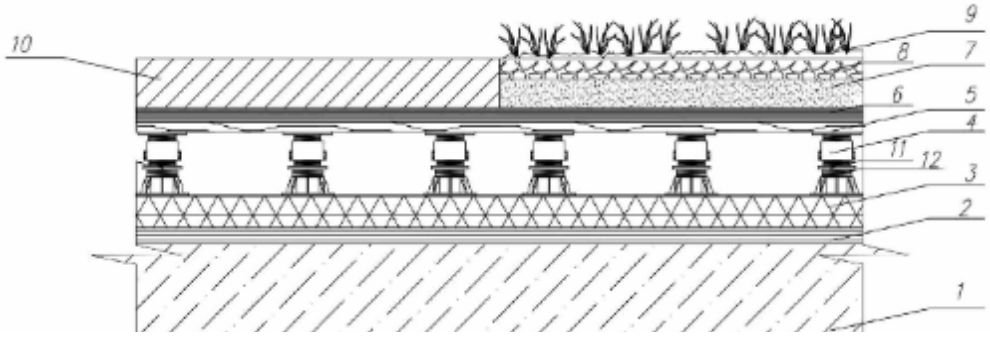


Figure 4. – Multifunctional green roof construction [5]

The design consists of two parts. The common base is a reinforced concrete floor slab 1, on which the following layers are laid: Euroruburoid HMP 2, thermal insulation ISOVER 3, adjustable supports Forest Style 4, ondulin 5, waterproofing with liquid rubber 6. Support 4 is a plate with four mounting holes for mounting, made of steel coated with anti-corrosion coating. A galvanized stud 11, 15 cm in size, with a thread to adjust the height of support 4, is welded to support 4. The position, angle of inclination of support 4 is fixed with a lock nut 12. The following layers are located above support 4: for a green roof - this is a drainage layer 7, soil 8, green spaces 9, for the roof under the pool - terrace board CM 10. The design of the green roof is arranged as follows: on a reinforced concrete floor slab 1 installed with sealing of joints with cement and coating with bitumen, KhMP 2 euro roofing material is laid, consisting of a solid non-rotting base, which provides flexibility, heat resistance and water resistance; then ISOVER 3 thermal insulation, which creates thermal protection and prevents the formation of condensate; then Forest Style 4 supports made of high-strength propylene with thermal endurance from -20C to +85C. Supports 4 are resistant to destruction by sunlight, have the possibility of increasing due to an additional insert of 60 mm, a thrust bearing diameter of 20 cm allows using on a "soft" roof and on compacted soil 8; at the edges of the drainage layer 7 ENKADRAIN PREMUIM resistant to aggressive environments, resistant to decay and fungus, provides filtration and protection of the waterproofing layer 6; two layers of ondulin 5 brand for the entire width of the roof provides strength and frost resistance, in the middle waterproofing 6 with liquid rubber is non-toxic, resistant to deformation, atmospheric and biological influences, soil 8 (substrate) is an environmentally friendly product, without chemical additives, it is hydrophobic - i.e. it easily releases accumulated moisture and nutrients to plants, it is highly resistant to decomposition, it can be used repeatedly, the CM natur 10 terrace board goes further along the central part - it is resistant to decay and damage by mold, fungi, insects, does not emit formaldehyde, phenol or other harmful substances, keeps the surface non-slippery even in the rain, along the edges of the green flooring - green spaces. Such a roofing device works as follows. Two types of coverage are combined: the first type is the side, which allows you to use the green roof all year round, and the central part - under the pool, and in winter under the cafe [6].

The installation of a green roof is a complex technological process in which the number of technological operations performed depends on the type of green roof landscaping. Green roofs are divided into roofs with mobile (container) and stationary type of greenery. Landscaped roofs with stationary landscaping, depending on the predominant type of plants used, are divided into three types:

with intensive landscaping;

with semi-intensive landscaping;

with extensive landscaping.

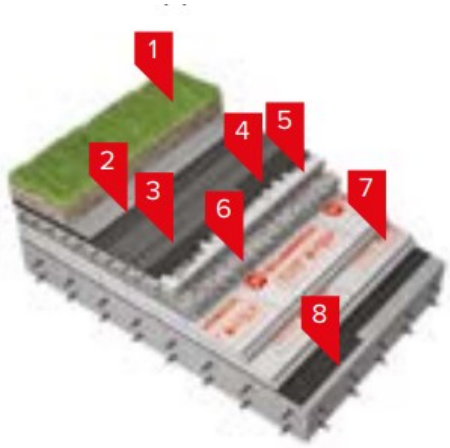
Mobile (or container) gardening of roofs is implemented by planting plants in tubs (modules, containers) with further installation on an exploited roof. Mobile green roof systems are equipped with devices for installing and fastening modules to each other - connecting elements that are constituent parts of the modules or can be separate components of the system.

Considering the organizational, technical and constructive solutions of modern green roofs, we can distinguish two main methods for their construction: the traditional method of building green roofs, which is the

process of step-by-step formation of each layer of a green roof directly on the base surface and provides for the presence of many working operations, including the installation of a vegetative layer, a substrate, as well as special layers, such as a drainage layer, a drainage-water storage layer, a waterproofing layer and etc; a method of partially enlarged assembly, implemented with a mobile (or container) roof gardening system. Thanks to the use of containers, there is a reduction in labor costs at the stage of installing a gardening system.

Modeling of organizational and technological processes was carried out for three variants of the green roof:

A) with extensive landscaping TN ROOFING STANDARD GREEN (TechnoNIKOL) (Figure 5) [7].



1 – soil with green spaces; 2 – drainage membrane PLANTER geo;
3 – waterproofing - Technoelast EPP in two layers; 4 – Bituminous primer TECHNONICOL No. 01;
5 – base under the roof - reinforced cement-sand screed; 6 – slope-forming layer - expanded clay concrete;
7 – heat-insulating layer - XPS TECHNONICOL CARBON PROF 300;
8 – vapor barrier layer – Technobarrier

Figure 5. – Green roof with fixed landscaping TN ROOFING STANDARD GREEN (TechnoNIKOL)

B) with extensive landscaping Dörken GmbH & Co. KG with a drainage membrane that combines a protective, drainage and filter layer in one material (Figure 2);

C) multifunctional roof with extensive landscaping (Figure 4).

Table 1 presents a list of technological operations for the installation of a green roof for three options. The following designations are accepted in the table: Q1A, Q2A… Q8A – labor intensity of the green roof device during technological operations 1, 2…8; A, B, C - green roof construction methods; 1, 2...8 - the number of technological operations for the installation of a green roof.

Determining the cost of 1 м^2 of a green roof according to the proposed options showed that the difference in the cost of the green roof options under consideration is due to the cost of materials and work on the installation of Forest Style adjustable supports (Figure 6) and decking (option C), the cost of drainage membranes. Option C has the highest green roof cost.

The drainage membrane with geotextile DELTA®-TERRAXX (Germany) is sold in rolls with an area of 30 m2, the cost of a roll is 57.60 Belarusian rubles (as of 11/01/2022, source: doms.by online store). The cost per square meter is $0.77. DELTA®-TERRAXX is a profiled membrane - virgin high density polyethylene with an embedded self-adhesive tape, a filter layer of thermally bonded non-woven geotextile (virgin polypropylene). Adhesive layer of modified acrylate (Figure 7, a).

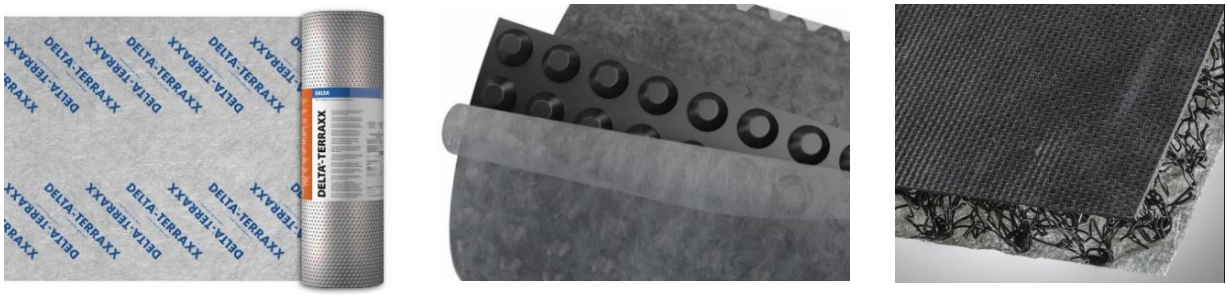
Figure 6. – The use of screw supports in the construction of green roofs TechnoNIKOL

Table 1. – The list of works for the installation of a green roof with extensive landscaping

Name of technological operations	Option A- TN ROOF STANDARD GREEN (TechnoNikol)	Option B - DELTA-TERRAXX (DELTA®System)	Option C - multifunctional green roof (patent RU No. 191863 U1 E04D 11/00)
Specific labor costs at the stage of roofing, man-hour / 100м2	46	42	55
8 Cover device for cafe, swimming pool	-	-	deck board installation
	(Q8A)	(Q8B)	(Q8C)
7 Arrangement of the landscaping system	backfilling, landscaping	backfilling, landscaping	backfilling, landscaping
	(Q7A)	(Q7B)	(Q7C)
6 Laying the drainage layer	drainage membrane PLANTER geo	drainage membrane with geotextile DELTA®-TERRAXX	drainage layer ENKADRAIN PREMIUM
	(Q6A)	(Q6B)	(Q6C)
5 Waterproofing device	waterproofing - Technoelast EPP in two layers; bituminous primer TECHNONICOL	waterproofing - TPO, PVC, EPDM membrane	waterproofing - liquid rubber Hydra between layers of Ondulin
	(Q5A)	(Q5B)	(Q5C)
4 Device cement-sand screed	reinforced cement-sand screed	-	Ondulin 2 layers
	(Q4A)	(Q4B)	(Q4C)
3 Laying the slope layer	expanded clay concrete	-	Forest Style adjustable feet
	(Q3A)	(Q3B)	(Q3C)
2 Laying the thermal insulation layer	heat-insulating layer – XPS TECHNONICOL CARBON PROF 300	slab insulation	thermal insulation ISOVER3
	(Q2A)	(Q2B)	(Q2C)
1 Laying the vapor layer	vapor barrier layer - Technobarrier	vapor barrier layer	vapor barrier layer - Eurorubu-roid HMP
	(Q1A)	(Q1B)	(Q1C)
Support structure device (Qbs)			

PLANTER Geo profiled membrane is a high-density polyethylene (HDPE) sheet with a spike height of 8.5 mm, with a layer of thermally bonded geotextile glued to it. Thanks to the protrusions on the surface of the membrane, channels are formed for the rapid removal of water. The membrane consists of two levels: geotextile collects water, and drainage channels direct it (Figure 7, b). The price per square meter is 6.7 US dollars (as of 11/01/2022, source: TechnoNikol online store shop.tn.ru).

ENKADRAIN® Premium ST is a polymeric geocomposite drainage mat consisting of two external filters made of heat-sealed non-woven material with a continuous polyester/polyamide thread inserted with a three-dimensional drainage structure with a high vacuum index of polyamide monofilaments. The three elements are connected together by a thermal seal at the points of contact (Figure 7, c). Price per square meter 9 US dollars (as of 11.01.2022) [8].



a b c

a – drainage membrane with DELTA®-TERRAXX geotextile; b – PLANTER Geo profiled membrane; c – polymeric geocomposite drainage mat ENKADRAIN® Premium ST

Figure 7. – Drainage layer materials

In the considered options, polymeric materials are used for the drainage layer, the production and processing of which cause significant harm to the environment. The use of such materials will not provide benefits for building LEED certification.

A significant contribution to the creation of a "green" building is made by the use of environmentally friendly, "green" building and finishing materials for its construction.

The considered types of green roofs are a multilayer structure. For all three types of green roofs, a characteristic feature is an increase in labor costs, construction costs, a large amount of waste during the dismantling of a green roof in case of a change in functionality. All these factors will hinder the implementation of such green roof structures in green buildings. The first direction of improving the organizational and technological solutions of green roofs for green buildings is to reduce the excessive use of plastics and artificial sponge elements (mineral wool, dense polystyrene), polystyrene or other unnecessary components on green roofs. The second direction should be to simplify the design of green roofs. Many components of green roofs provide little or no direct benefit to vegetation. However, they increase costs and reduce reuse.

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