## I/ General description and characterization of the NBS type

### I.1 Definition and different variants existing

Green roofs serve several purposes for a building and the city, such as absorbing, storing, cleaning and supplying rainwater and mitigating risks of stormwater (Simmons et al., 2008), providing insulation and therefore saving energy for heating and cooling (Alexandri and Jones, 2008), creating a habitat for wildlife (Nagase and Tashiro-Ishii, 2018), increasing social inclusion through the creation of amenity spaces and contributing to citizens' health and wellbeing by decreasing stress, providing a more aesthetically pleasing landscape (Ragheb et al., 2016), and helping to lower urban air temperatures and mitigate the heat island effect through evapotranspiration and albedo transformation of building surfaces (Jin et al., 2018).

![Niederösterreich Haus Krems, Austria](image)

Owner: NÖ Landesimmobiliengesellschaft mbH
© Verband für Bauwerksbegrünung VfB
Extensive green roofs are standardized in over 10 European Union countries with a total built-up height of min. 8 to max. 15 cm, applicable to flat, sloped and pitched roofs. **An extensive Green Roof is meant to sustain itself as a resilient ecosystem and does not require irrigation after the establishment period.** The species composition may change over years following natural succession processes. Extensive Green Roofs are usually composed of 1.) rootproof membrane (waterproofing), 2.) protection layer 3.) storage and drainage layer (mineral or other) and 4.) a filter layer, 5.) a layer of substrate or other substitution medium and 6.) the vegetation layer consisting of shallow-root plants like succulents, herbs, mosses and grasses that can be planted, seeded or brought in as pregrown vegetation mat. The described layers can be made of different materials, it is important to select a suitable built-up for the right project site that fits local climatic conditions and plant species. Depending on the vegetation and on the location of the green roof, the layer thickness and material properties have to be considered in the planning process. It is recommended to use components that fulfill the requirements of various national standards and guidelines and may as well have a quality certification for components and built-ups as they are proven and safe and the lifetime of a greenroof is over 40 years.
standardized structure of green roofs
© GRUNSTATGRAU

- Rootproof membrane (waterproofing)
  This layer needs installing either as an additional layer on non root-proof roofs or as a fully functional single layer, forming a watertight and root-proof environment. Only components, that are proven to sustain roots according to the relevant test setups should be used, requirements for vapour and diffusion-openness have to be taken into consideration depending on the structural overall roof-built-up. Different materials are available, their ecological footprint differ (EPDM, Bitumen, etc.).

- Protection layer
  This layer protects the roof membrane against damage during the installation and use of the green roof.

- Storage and drainage layer (mineral or solid body forms)
  This layer regulates drainage and water storage, it is root-accessible for plants. It consists either of mineral (recycling) bulk materials or solid body forms (drainage mats, drainage plates, drainage elements) consisting of different materials (e.g. recycling PVC) with and without water storage function. The layer must not loose its physical properties for at least 40 years.
Filter Layer
The layer is installed between drainage layer and substrate. The fleece holds fine particles in the vegetation substrate and protects the drainage layer from silting up. This layer consists of root-permeable and water-permeable geotextiles.

layer of substrate or other substitution medium
This layer is structurally stabilised, must not loose its many physical properties (e.g. water holding capacity, air, drainage, pH, grain size distribution, etc.) for at least 40 years and has to be suitable for wide range of species. The substrate consist of mineral open-pore materials, for example: expanded clay, expanded shale, granulate made of bricks, which are mixed with a organic substances, like compost. It is important to use substrates from local sources. Extensive green roofs contain a reduced amount of organic components in comparison to intensive green roofs. Substrate substitution components (e.g. mineral wool) are available as well but their
long-time functionality has to be examined in detail. The substrate depth has to fit the envisaged vegetation. That is important especially for Solar-greenroofs where plants can share the panels.

\[\text{Extensive multi layer substrate E-Light} \]
\[\text{© Optigrün international AG} \]

- The vegetation layer
The vegetation layer can consist shallow-root plants like succulents, herbs, mosses and grasses that can be planted, seeded or brought in as pregrown vegetation mat.

\[\text{Typical succulents mix for extensive Green Roofs} \]
\[\text{© Verband für Bauwerksbegrünung VfB} \]

- Technical equipment for pitched roofs
Sloped or pitched extensive greenroofs need addition reinforced sloping structure to keep the built-up at the roof1.

About Vegetation and system built-ups

There are different kinds of production and planting methods for vegetation depending on the system approach of extensive green roofs:

- multiple layer substrate based systems
  This system is the most common and resilient against changing conditions.

- single layer substrate systems
  Only used for reduced extensive green roofs (and intensive Green Roofs of course). It is mostly used in low budget projects targeting statitical lightweight situations. Caution: this built-up system can not be installed on inverted roofs.

- all in one modular substrate systems in tray structure
  Prefabricated Systems, most commonly used in small scale Projects like Carports or Projects that have restrictive access or issues with machines. Sometimes irrigated.

- multiple layer systems with alternative substrate substitutions e.g. geotextiles and mineral wool
  This systems are mostly used in lightweight situations and have to be irrigated always.

Examples of planting methods of the vegetation layer:

Various kinds can be identified, depending of the botanical properties:

- **Seeding:**
  - dry seeding with/without glued fixing (depending on the weather and wind conditions)
  - wet seeding with/ without shoots (most common combined with glued fixing)
  - hydroseeding (including organic glue and mykhorriza starters)
  - spreading plant parts or shoots
  - hay-thresh seeding from other natural donation areas

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1 According to standards, green roofs can be installed on roofs with a slope of 1.8% (1°) to 58% (30°). Roofs with a slope more than 9% must protect the rootproof membrane and protection layer from slipping and with more than 26% the entire green roof structure must be secured.
covering:
- Pre-cultivated vegetative carrier/cover/mats (grasses, herbs, succulents) with:
- reinforcement made off netting thread mats
- straw mats with/ without coconut mats
- nonwoven mats
- geotextiles

- planting:

=> Installation in micro-plugs
The planting of plugs or larger potted plants on the roofs makes it possible to diversify the species richness of the green roof. The installation of this revegetation complex is only possible in the spring or autumn to optimize the rooting of the plants in the substrate. The vegetative cover rate reaches 80% after a period of 12 to 24 months.

Micro-clumps used during the extensive green roof installation © micro-mottes.fr

=> Spreading of Cuttings
The revegetation complex with cuttings of succulent species is particularly suitable for large-scale projects (more than 1000 m²). Easy and fast to implement, the rate of plant cover reaches 80% after a period of 18 to 36 months if the used material was enough in volume. The ultimate appearance of the project depends on good quality planting (distribution of cuttings and watering after spreading), and also on the care given to maintaining the roof during the phase when the plants are getting established. It is essential to have a water connection on the roof when spreading cuttings. In order to have optimum chance of success, a few essential steps must be taken when planting using the spreading method:

- Obtain the plant cuttings,
- Spread out the cuttings well over the whole of the surface area
- Often combined with Seeding and additional planting of bulbs

- **Extensive vegetative cover- all in one systems**
They consist of different layers in a framing structure (additional material resource effort) allowing easy and quick installation of systems on a water- and rootproof roof membrane:

- pre-cultivated vegetation (planted, seeded, Vegetation mat)
- Irrigation: in general, an extensive Green roof is not irrigated automatically. Some All-in-One Providers require the installation of an irrigation system for extensive green roofs that results in increasing maintenance and care need and cost
- A drainage and storage layer that is used to control the inflow of water during periods of drought that allows to drain the system

Sketch of a pre-fabricated green roof System without irrigation © HAAS GARTEN-, DACH- UND LANDSCHAFTSBAU

This modular system incorporates all the layers of a green roof system (drain, filter, growing medium and plants) grouped together in one unit known as a tray, module or paver © Vegetal I.D.
It is a complete extensive green roof system in a modular tray, ensuring excellent planting quality with simple installation © Axter

Installing a pre-fabricated extensive greenroof, Austria © Haas

Maintenance and Care Periods:

- Establishment period (1st vegetation period establishment maintenance) until a specific coverage is reached (60-80%)

- Development period (normally 2nd vegetation period, ends with the official acceptance of the finalization maintenance this is when the installer has delivered his duties and the roof is officially accepted by the client)

- Upkeep maintenance (regular yearly maintenance contracts)

During the two periods that covers regularly 24 months after installing, Vegetation has to be regularly controlled and maintained (Nutrition, water, taking out problematic vegetation e.g. seeds of trees or invasives), so that the target vegetation can successfully develop and the resilient ecosystem itself gets alive. Maintenance and care especially in the beginning are of utmost importance! Afterwards efforts may be reduced as the roof itself has reached a stable phase.

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<th>I I.2 Urban challenges and sub-challenges related + impacts</th>
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<td><strong>Main challenges and sub-challenges targeted by the NBS</strong></td>
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- Aesthetic and wellbeing. One benefit of green roofs that is not easily quantifiable is the aesthetic improvement that landscape provides. This is especially important where building occupants overlook lower roof areas, which are often barren planes or are full of mechanical equipment.

- Reduce “Urban Heat Island Effect. The natural plantings and soils in green roofs mitigate the heat island effect by better modulating local air temperature fluctuations by 1 to 2°C caused by radiant heating during the day (Bass et al., 2003).
- Green roof substrate can include microarthropods and microbes (Rumble et al., 2018)
- Enhancement of architectural interest and biodiversity (Castleton et al., 2010)
- The green roof substrate is able to support vegetation. In addition, it can store carbon (Bouzouidja et al., 2018)
- Green roofs can help reduce energy costs for a building by acting as another layer of insulation between the inside and outside of the roof,
- Extend roof life: actually double the life of the waterproofing material 10-20 years to 50 years as it is protected from UV and the chemical damage (Theodosiou, 2009)
- Green roofs can also help reduce sound transmission through the roof from outside the building.

| Co-benefits and challenges foreseen | 01| Climate issues  
> 01-2 Climate adaptation  
04| Biodiversity and urban space  
> 04-1 Biodiversity  
> 04-2 Urban space development and regeneration  
> 04-3 Urban space management  
5| Soil management  
> 5.1 | Soil management and quality  
06| Resource efficiency  
> 06-1 Food, energy & water  
07| Public health and well-being  
> 07-1 Acoustics |
| Possible negative effects | 07| Public Health and well-being  
> 07-3 Health  
10| People security  
> 10.3 Other: bad structural designs  
04| Urban space management |

II/ More detailed information on the NBS entity

II.1 Description and implication at different spatial scales

| Scale at which the NBS is implemented | Buildings, underground level structures and secondary traffic infrastructures and structures. |
| Impacted scales | At building scale and depending on the number of green roofs existing. At neighbourhood or city scale, the impact of green roofs is less relevant for public but relevant for tenants and investors (e.g. Energy efficiency). The impact for the city depends on the green roof area coverage and closed network. The effectiveness and impact scale depends on the density of green roof surfaces, their performance |
regarding water retention, their quality and maintenance and their ecological stepping-stones potential (Biodiversity).

## II.2 Temporal perspective (including management issues)

| Expected time for the NBS to become fully effective after its implementation | > Pregrown tray system or pregrown vegetation mat: immediately  
| > On-site installed green roof depends on the selected species, resilient built-up and proper maintenance and care during the first 2 vegetation periods:  
|  - shallow-root plants like sedum, mosses, and grasses: 1 year  
|  - flowering plants, taller grasses, and small shrubs: 1 to 2 years |
| Life time | 40-50 years, over 100 year old Green Roofs exist in Europe |
| Sustainability and lifecycle | Properly planned extensive green roofs use recycling and local materials (e.g. substrate components as crushed brick) to reach high ecological performance and contribute to local community and businesses jobs. Extensive green roof require minor interventions to be removed, pre-grown all in one systems can be removed and re-used easier. Mostly, plants and substrate can be composted or recycled or even re-used at other sites in most of the cases. |
| Management aspects (kind of interventions + intensity) | - nutrients  
|  - water on demand in the establishment period  
|  - minimal ongoing maintenance, 1-2 interventions per year (except from irrigated prefabricated extensive green roof systems that are being discussed by experts in their efficiency and life expectancy)  
|  - Maintenance effort reduction after establishment period |

## II.3 Stakeholders involved/ social aspects

| Stakeholders involved in the decision process | - Private owners, or co-owners of buildings  
|  - Municipality in case of public buildings, funds or regulations  
|  - Experienced engineers,  
|  - Building surveyors,  
|  - Property/Facility managers |
| Technical stakeholders & networks | - Landscape architects, planners, designers  
|  - Structural engineers,  
|  - Architects  
|  - Landscaping contractors  
|  - specialized green roof installers  
|  - Specialized green spaces management firms and horticulturists |
| Social aspects | - Necessity to find an agreement with all or a certain percentage (mostly 51%) of the co-owners of a building (depending on the national laws) => importance of the participatory process.  
|  - Necessity to inform about the real impacts, to reassure about widespread prejudices (risk to keep humidity across the roof, fear to introduce insects in the building, etc.), strengthen aspects as biodiversity, less cooling need and costs |

## II.4 Design / techniques/ strategy

| Knowledge and how-know involved | - Structural engineer investigation especially for refurbishment projects  
|  - Selection of target vegetation and technical built-up adapted to:  
|  - the local climatic conditions and future changes (especially water scarcity and heavy rain events)  
|  - Sunlight orientation and shading of surrounding buildings  
|  - Wind exposure  
|  - Set up the maintenance keeping plants in the right conditions, differ between establishment period and ongoing maintenance efforts.  
|  - Maintaining services in the right conditions. Care must be taken to keep roots and leaves out of the drainage outlets.  
|  - no single-layer built-up on inverted roofs!  
|  - Timber roof constructions: make sure to use right built-up (vapour diffusion) |
Materials involved

1.) rootproof membrane (waterproofing)
2.) Protection layer (geotextile)
3.) storage and drainage layer (mineral or full body systems)
4.) a filter layer (geotextile)
5.) a layer of substrate or other substitution medium
6.) the vegetation layer
7.) Safety equipment (professional use: single point fall protection or other)

II.5 Legal aspects related

- National building regulations and laws, Standards, guidelines, policies, state of the art, codes of good practise, Health and safety regulations, sustainability concerns for materials and components, biodiversity aspects - apply to national conditions
- Ownership and tenant. There is a clear difference between an owner (landlord) and a tenant (lessee). A landlord has exclusive rights to their property to use in any manner according to the planning constraints and permissions in each jurisdiction (and no third-party consent is generally required to create a green roof or wall). A tenant is bound by the terms of their lease, and a green roof or wall may be prohibited or a permissible use with consent. Consent is likely to be required from the landlord (2).
- Structural loads. Analysis by a structural engineer is required (2) especially in refurbishment projects and if the Planner/Architect does not offer this qualification.
- Drains: Water supply is usually a simple connection, hydraulic engineer/system provider required for drainage dimension calculation (2).
- Safe Access permit to the roof during installation and maintenance, if access by non-trained parties/visitors planned, if relevant insurance and national regulations reg. safety standards (2)

II.6 Funding Economical aspects

Range of cost

Green roof cost range from 25 to 75 €/m² installed depending on the distance between the structural material storage (Niu et al., 2010). In addition, Greenery systems can provide an energy saving of about 215 $ year⁻¹ depending on regional and climatic conditions (Besir and Cuce, 2018). Depending on the maintenance effort in time, the range of the maintenance cost for extensive or intensive green roofs are 45-80 €/h by skilled professionals in Europe.

Origin of the financial capacity (public, private, public-private, other)

- Private investment: the ownership is private (e.g. office/industry building, hotels, private housing)
- Public investment: the building ownership is a public owner e.g. municipalities and state (e.g. schools, public agencies, public housing, etc.)

In most EU countries, there are additional local or state funds, grants, subsidies and co-financing possibilities available for green roofs (refurbishment, new buildings)

II.7 Possible combinations with other kinds of solutions to maximize performance and target other CCA/CCM goals (e.g. mobility, energy, digitalisation, social, food security, biodiversity, etc.)

- It is possible de combine green roof system with photovoltaic (PV) and solar energy production without perforating the membranes (the extensive green roof provides the necessary load capacity to the solar installation). This solution provides structural change in available microhabitats for plant species and pollinating insects and as well birds (shady areas, areas with more/less water). A positive influence for this integration: green roof surface and soil temperatures are reduced from the shading and higher power output of PV panel is achieved from the microclimatic cooling. Of course all other benefits that derive from green roofs are as well included. For a low-rise commercial building, the results indicated that the energy consumption for air conditioning of the integrated system is slightly lower than the stand-alone system and the PV system on integrated approach generates 8.3% more electricity than the stand-a-lone option. (Hui and Chan, 2011).
Attention: a proper solution is required (minimum distance between panels and vegetation, proper water management under panels and extensive green roof built-up) to keep maintenance requirements predictable.

- Green roofs are habitats for ground nesting and other pollinating species who visit flowers (bees, butterflies, hoverflies, etc.), beetles, ants, bugs and larvae of dipteras and ladybugs (Pfoser et al., 2013).

As mentioned green roofs provide habitat to many wild bee species. Research shows, that 236 wild bee species have been identified on green roofs (Hofmann, 2017). The green roof is used as a food source and as a nesting and feeding opportunity for wild bees. For example, in New York City, U.S.A., a study of the bee diversity in urban gardens found a total of 54 species from 19 sites (Matteson et al., 2008). In Vancouver city, Canada, gardens and urban parks obtained a total of 56 bee species from 25 sites; species richness did not differ significantly among site types (Tommasi et al., 2004).

Attention: the offered habitat structure diversity of the roof is the relevant asset for its flora and fauna (see fact sheets semi-intensive roofs). Honeybees can compete and suppress wildbee species!

III/ Key elements and comparison with alternative solutions

III.1 Success and limiting factors

| Success factors | - Green Roof Goal: It is essential to start project planning with the purpose and targeted vegetation on the green roof. Is it intended primarily to deliver environmental, biodiversity, cost-saving benefits and/or stormwater management? Is it expected to serve as a decorative landscape element or does it serve as community space? To set the direction for any project, first define the purpose of the green roof, establish priorities for specific goals and align stakeholder expectations and budgets (Rugh, 2014)
| Architectural Factors: Roof structural load capacity is the most basic issue (Rowe et al., 2003) |
Location: Regional climate determines what type of green roof built-up and plants you can and should have (Rowe et al., 2003).

**Limiting factors**

- Project developers must take into account the new structural load when refurbishing a building. The structural engineer must factor in the weight of completely saturated built-up since vegetation and substrate will hold a significant amount of water and plants will as well grow (1).

- **High Quality planning and Installation.** Green roofs extend the life of the membrane for at least 10 years because it is completely covered by the green roof and is not exposed to environmental influences (e.g. uv-rays, hail, temperature amplitude). However, a tested rootproof membrane needs to be installed and the different professionals have to be managed properly during installation. Leak detection is as well possible on green roofs.

- **Professional, regular maintenance with predictable budget.** A green roof requires regular maintenance and care, which can vary from occasional to regular and can add a significant ongoing cost in case the planning and installation and maintenance contracts were not done properly.

**III.2 Comparison with conflicting solutions**

**Grey or conventional solutions counterpart**

- White or cool roof: the extensive green roof decreases the annual building needs for heating and cooling depending on it’s built-up by at least 1.2% while the white roof contributes to decrease the needs just by 0.4%. This small difference is mainly attributed to the higher insulation capacity of the green roof and the lower calculated surface temperatures on it (Santamouris, 2014) Nevertheless, a white roof does not come along with any of the green roof’s benefits and co-benefits.

![White or light-colored roofs](© NREL/CRAIG MILLER PRODUCTIONS/DOE)

- Gravel roof: the gravel in a ballasted roof helps absorb heat by reflection, preventing the sun from heating the roof materials below and making the roof more energy-efficient. In addition, gravel also protects against hail and from foot traffic during repair or maintenance work. The gravel is easy to move when conducting repairs or maintenance.

- 65 - 70% of the annual precipitation is restrained with a extensive green roofs with 10 cm substrate, a gravel roof restrains only 0 to 18% (Köhler,Kaiser,Wolff, 2018). During the growth phase, 80 - 90% of the annual precipitation is restrained with a extensive green roofs with 10 cm substrate, a gravel roof restrains only 29 % (Köhler,Kaiser,Wolff,
Nevertheless, a gravel roof does not come along with any of the green roof’s benefits and co-benefits.

- Other green roof types (semi-intensive and intensive green roof)
- Build or attached plantainer systems (including balconies) and facades (green walls).

### IV/ References

*Nota:* references presented below are often common with the whole category Vertical structures “Green walls & façades”.

#### IV.1 Scientific and more operational references (presented jointly)


### IV.2 Sources used in this factsheet


Exemplar Projects: EFB https://efb-greenroof.eu/exemplar-projects/, GSG https://gruenstattgrau.at/datenbank/?type=projekt&tax-art-der-begruenung%5B%5D=000_dachbegruenung

### V/ Author(s)

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