I/ General description and characterization of the NBS type

I.1 Definition and different variants existing

Definition

Green roofs serve several purposes for a building, such as absorbing rainwater (Simmons et al., 2008), providing insulation (Alexandri and Jones, 2008), creating a habitat for wildlife (Nagase and Tashiro-Ishii, 2018), increasing benevolence and decreasing stress of the people around the roof by providing a more aesthetically pleasing landscape (Ragheb et al., 2016), and helping to lower urban air temperatures and mitigate the heat island effect (Jin et al., 2018).

Extensive green roofs are generally made up of a very thin layer of substrate (from 8 cm to 15 cm) or other planting medium with shallow-root plants like sedum, herbs, mosses, and grasses. This solution requires a minimal maintenance and it normally is not occupied.
Often, green roofs substrate is contained by a tray system, which provides a barrier to excessive growth, protects the roof membrane, and interlocks the entire system together to prevent wind damage.

Chicago City Hall Green Roof.
Author: TonyTheTiger
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Different variants existing

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

=> Extensive vegetative cover

They consist of different superimposed layers allowing easy and quick installation of plants on a waterproof roof:

- A carpet of pre-cultivated sedums composed of different varieties of plants.
- Modular system: an irrigation mat controlled by a humidity sensor, designed to bring water when the plant needs it while limiting consumption.

- A retention layer that is used to control the inflow of water during periods of drought.
- A drainage layer, placed directly on the waterproofing of the roof, which allows to evacuating excess water and aerating the roots of plants.

The green roof unfolds like a succession of carpets
© sempergreen

=> Installation in micro-clumps

The planting of clumps or buckets on the roofs makes it possible to diversify the vegetal palette 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.

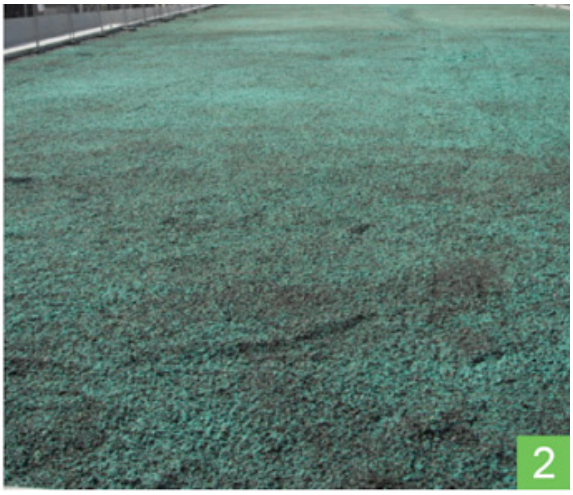
Micro-clumps used during the extensive green roof installation
© micro-mottes.fr

Plantation of micro-clumps on a green roof
© Le prieuré

=> Fragments or cutting plants

The revegetation complex with seedling fragments 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. The ultimate appearance of the project depends on good quality planting (distribution of cuttings, rolling 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 to be planted,
- Roll the surface area in order to facilitate contact



Aesthetic appearance of a green roof produced by sowing sedum cuttings. 1. Using manual sowing 2. Using gel seeding
© Vegetal I.D.

=> Pre-planted tray plants

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 is a complete extensive green roof system in a modular tray, ensuring excellent planting quality with simple installation
© Axter

I.2 Urban challenges and sub-challenges related + impacts

Main challenges and sub-challenges targeted by the NBS	02| Urban water management and quality > 02-2 Flood management 07| Public health and well-being > 07-2 Quality of life	- Reduce Storm water Runoff and Combined Sewage Overflows. The most important benefit of green roofs is that they can reduce the amount of rainfall (52% of the total rainfall) and improve the quality of storm-water runoff from a building site, depending on month and soil thickness (Mentens et al., 2006). - 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.
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	- Reduce "Urban Heat Island Effect. The natural plantings and soils in green roofs mitigate the heat island effect by better modulating local air temperature

	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	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). In addition, it can store carbon. - 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.
Possible negative effects	07| Public Health and well-being > 07-3 Health 10I People security > 10.3 Other: bad structural designs 04| Urban space management	- Plants can affect allergies - Risk of roof structure collapsing. Green roof increases structural load, so that is critical to conduct a structural investigation to determine the building's existing structural load-bearing capacity. It makes green roof **capital cost rise**. - Green roof requires routine landscape maintenance, which can vary from occasional to regular and can add a **significant ongoing cost**.

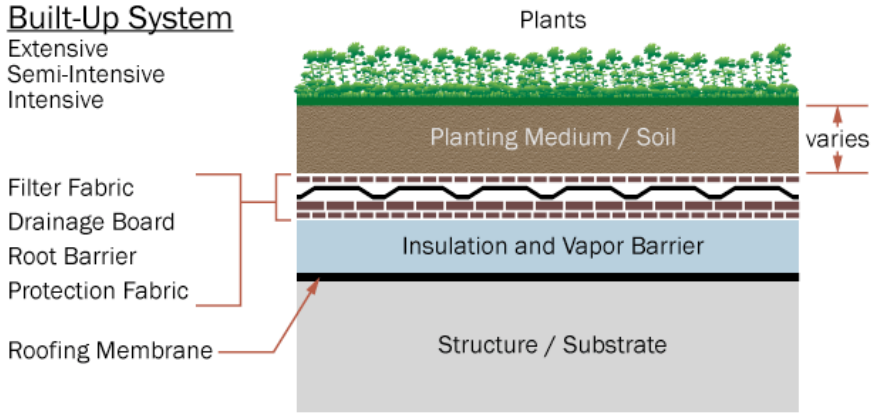
II/ More detailed information on the NBS entity

II.1 Description and implication at different spatial scales	
Scale at which the NBS is implemented	Buildings and sometimes only partially.
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. It is depending of green roof area coverage
II.2 Temporal perspective (including management issues)	
Expected time for the NBS to become fully effective after its implementation	> Tray system: immediately > Build up green roof. depends on the selected plants: · shallow-root plants like sedum, mosses, and grasses: 1 year · flowering plants, taller grasses, and small shrubs: 1 to 2 years · large shrubs and trees: 3 to 5 years
Life time	30-50 years
Sustainability and life cycle	Extensive green roof requires significant interventions to be removed. Moreover, the plants and substrate can be composting or recycling in most of the cases.
Management aspects (kind of interventions + intensity)	- nutrients - minimal maintenance, 1-2 interventions per year
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 - Experienced engineers, - Building surveyors, - Property managers
Technical stakeholders & networks	- Landscape architect, planer, designers, - Structural engineers, - Architects - Specialized green spaces management firms and gardeners.
Social aspects	-Necessity to find an agreement with all the co-owner of a building => 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.)

II.4 Design / techniques/ strategy

Knowledge and how-know involved	- On a new building or existing one, that needs a structural engineer investigation. - Selection of plant adapted to: • the local climate • Sunlight orientation and overshadowing • Wind exposure - Set up the maintenance keeping plants in the right conditions. - Maintaining services in the right conditions. Care must be taken to keep roots and leaves out of the drainage system
Materials involved	- moisture barrier (roofing membrane) - thermal insulator - waterproofing membrane (root barrier) - drainage layer - filtering layer - growing medium (substrate) - sedum plants most of the time



© Archoolbox

II.5 Legal aspects related

- 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).
- Irrigation and drainage: Water supply is usually a simple tap, but if irrigation is needed, and a hydraulic engineer is required to review how it is to be serviced and drained and it is likely need irrigation licence (2).
- Access permit to the roof (2)
- Insurance. Insurance will be required by the party maintaining the garden or produce area, as well as insurance for visitors and general public; also liability for work, health and safety legislation (2).

II.6 Funding Economical aspects

Range of cost	Green roof cost range from 25 to 75 €/m^2 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).
Origin of the funds (public, private, public-private, other)	- Private: the ownership is a private as business building, hotels, apartments - Public. The building ownership is a public owner like City councils, museums, schools, etc.

II.7 Possible combinations with other kinds of solutions (other environmental friendly solutions or conventional ones)

- It is possible de combine green roof system with conventional photovoltaic (PV) solution. 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 cooling. 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).

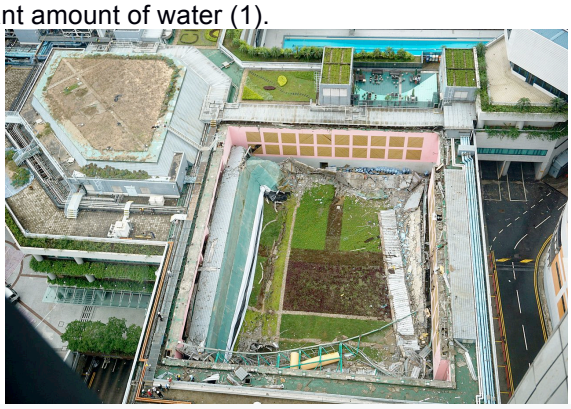
Green roof and photovoltaic combination
© 2018, International Green Roof Association

- Green roofs provide habitat to many bee species. 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).

Implementation of beehive on a green roof
© 2018 Dusty Gedge's Roofs & Rambles

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 of the green roof. Is it intended primarily to deliver environmental, cost-saving benefits? Is it expected to serve as a decorative landscape element? Is it for urban farming? To set the direction for any project, first define the purpose of the green roof, establish priorities for specific goals and align stakeholder expectations (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 and plants you can and should have (Rowe et al., 2003).
Limiting factors	- Take into account **the new structural load** when refurbishing a building: One important item to be considered is the increased structural load. The structural engineer must factor in the weight of completely saturated soil since the plantings and the soil will hold a significant amount of water (1).  City University of Hong Kong Hu Fa Kuang Sports Centre roof collapses site Author: exploringlife-CC BY-SA 4.0 - **Lifetime of the roof membrane.** Green roofs tend to improve the life of the membrane because it is completely covered by plantings and is not exposed to the sun's harsh UV rays. However, the membrane may be exposed to plant roots, animals and insects, and fertilizer chemicals. It is important that a protective barrier be used over the waterproofing membrane. - **Maintenance ongoing cost is also important to consider** that a green roof requires routine landscape maintenance, which can vary from occasional to regular and can add a significant ongoing cost. In addition, space should be allocated for storage of maintenance materials

III.2 Comparison with alternative solutions

Grey or conventional solutions counterpart	- White or cool roof: the green roof decreases the annual building needs for heating and cooling by 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)

White or light-colored roofs

© NREL/CRAIG MILLER PRODUCTIONS/DOE

- Gravel roof: The gravel in a ballasted roof helps absorb heat, 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

Gravel roof

© Anderson Roofing

Close NBS

- Other green roof types (semi-intensive and intensive green roof)
- Build or attached planter systems (including balconies)

IV/ References

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

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