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Biodiverse green roofs in Mediterranean climate
Input and lessons learned from Germany and Switzerland

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Chiara Catalano - Doctoral Thesis

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Isn't it against all logic, if a whole urban surface
remains unused, missing the dialogue with the stars?

(Le Corbusier, 1930)

It is our duty to put nature, which we destroyed by
building the house, back on the roof.

(Friedensreich Hundertwasser, 1983)

…To the unexpected

I would have never thought to live either in Check Republic nor Switzerland or in Germany, to learn German, to drink a pint while computing in R (or at least pretending to), to meet Suspa (Jan Leps), to work with geographers, ecologists, botanists, entomologists, to enjoy vegetation science and data analysis, to swim in the lake of Zurich and in the Voidomatis river, to…Go with the flow.

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Thesis aims and chapter outline

When I started the *long and winding road* (the Beatles) of this PhD, *I found myself within a forest dark, for the straightforward pathway had been lost* (Dante, Inferno). At that time, someone asked me: "do you investigate innovative green paints?"… With these contributions, I will try to prove that green roofs can be more that green painted surfaces even in regions with Mediterranean climate: they give back what we plunder from Nature building houses (Hundertwasser, 1970) and they optimise a space that otherwise would be left alone to dialogue with the stars (Le Corbusier, 1930). Can you imagine what would happened and how powerful it would be if every flat roof of every building in our contemporary sprawling cities would have a green roof? It would be fantastic! Birds can feed and rest, other animals will nest and plants would grow, flower and perish. We would build living spaces above our houses, re-connecting the build environment with the surrounding landscape!

This thesis is based on four manuscripts (three of them published), on the awareness developed designing, building and maintaining green roofs in Switzerland and on the skills acquired during courses I attended in Germany, Czech Republic and Greece. The well-known history of green roofs, back to Babylonian hanging gardens was deliberately neglected, as such notions are widely available from several works regarding green roofs[1]. It seemed significant instead, to review some European green roofs norms in order to assess their effectiveness in supporting biodiversity and in particular in tackling the implementation of green roofs in Mediterranean climate (Chapter 1. *Some European green roof norms through the lens of biodiversity: what about the Mediterranean climate?*). The second chapter gives an introduction on the ecological role of green roofs focusing on the link between ecology and design, on the key design factors of biodiversity green roofs and on the template approach (Chapter 2. *Extensive green roofs: biodiversity at high levels*). The third chapter deepens the the plant sociology approach as a designing tool for the implementation of Mediterranean green roofs (Chapter 3. *A plant sociological approach for extensive green roofs in Mediterranean areas*). Finally, the fourth chapter presents the results of a long-term study on the vegetation dynamic of unmanaged green roofs in central Europe but also their implications for ecological design (Chapter 4. *Thirty years unmanaged green roofs: ecological research and design implications*).

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[1] Ahrendt, J. (2007). Historische Gründächer: ihr Entwicklungsgang bis zur Erfindung des Eisenbetons. Dissertation, TU Berlin. Grancharov, R. (2013). Green Roofs, History and The Present. In Global Virtual Conference Workshop (pp. 220–226).

Abstract

In the realm of the doctoral program in *technologies for sustainability and land restoration*, this thesis deepens sustainable and ecological solutions for Mediterranean environment after the German tradition and the Swiss school of green roofs for biodiversity. Specific aims were to: (1) assess the effectiveness of the existing green roofs norms in supporting biodiversity; (2) review methodologies and approaches for the implementation of biodiverse green roofs but also their application for ecological design; (3) identify habitat templates in the Mediterranean ecoregion replicable on green roofs; and (4) investigate the long term vegetation development of unmanaged green roofs in order to give ecological design guidance.

As regards the green roof norms assessment, the German guidelines were chosen for its traditional referential role, the Swiss norm for its peculiar biodiversity approach, the Italian one for affecting a territory with remarkably heterogeneous environmental conditions, stretching from Alpine to Mediterranean ecosystems. Even if the three regulations at comparison addressed to some extent biodiversity related matters, none of them focused on the peculiarities of different ecoregions in term of plant species selection and assemblage, growing medium composition (materials and granular size) and system build-ups (multi-layers and single-layer construction). It was concluded that at the current knowledge, an official and effective regulation for green roof design in Mediterranean ecoregion is still missing.

Biodiverse green roofs, being characterised by different and contiguous microhabitats (habitat mosaics or patches) can host several species with different morphological and functional traits (Brenneisen, 2003). As regards their implementation methods and approaches, the habitat template consists in choosing suitable plant species among the one living in nature under similar conditions e.g. shallow and nutrient poor substrate and drought, while the phytosociological approach applied to green roofs considers habitat analogues not only as species pools, but also as models to group plants in specific associations. It was concluded that nature conservation approaches on green roofs offer new perspectives for urban sustainability and for ecological design. However, in order to give the "naturalistic" approach a chance to develop extensively, it is necessary to act into the education and technical spheres: sensitizing the public opinion starting from the new generations (eco-litteracy) and training professionals able to conjugate scientific knowledge (analytic phase) and design (creative phase). An Eco-designer should operate considering the local climatic conditions, the potential vegetation and the interactions with neighbouring biocenosis: he/she has to be also an ecologist in order to combine the ways of nature to the ways of man.

As regards replicable habitat on green roofs in Mediterranean areas, the proposed methodology approach was based on a practical plant sociology understanding of EU Directive 92/43: a recognition of Natura 2000 habitat that could be imitated on roofs in terms of characteristic species and substrates. The results lead to three

groups: those linked to sandy substrates (psammophilous vegetation), to gravely-pebbly substrates (glareicolous vegetation) and to xeromorfic soils (garrigues and dry grasslands). Desirable plants establishment methods on green roofs should be based on diaspore hay- transfer and threshing from selected donor meadows, as it happens for grasslands restoration.

Finally, as regards the long term vegetation development over a thirty year period, results demonstrated that the main driver of the observed functional changes on undisturbed simple-intensive green roofs in temperate climate, was a shift towards relatively more thermo-xeric conditions. In terms of plant life strategies, the competitive species sown on the roof gradually gave way to stress-tolerant and ruderal species, along with a progressive increase in species with short-distance seed dispersal strategies. It is concluded that: (a) to create resilient green roofs, spontaneous colonisation should be accepted and considered as a design factor; and (b) regional plant communities could serve as a model for seed recruitment and design.

1 Some European green roof norms through the lens of biodiversity: what about the Mediterranean climate?

Abstract

Green infrastructure and in particular green roofs are crucial to meet the challenge of sustainable urbanisation fostered by the current European Research and Innovation agenda. Several guidelines were issued in the last decades in Europe for regulating design, construction and up-keep of roof greening. In particular, the actual German guidelines (FLL 2008) have been widely adopted as reference basis for green roof design and regulation worldwide, because of its exhaustiveness and proven building- and landscaping tradition. With the aim to assess the effectiveness of green roof norms in supporting plant and soil biodiversity of different ecoregions, and particularly of the Mediterranean one, the German, the Swiss and Italian regulations are screened and discussed in this paper. The German guidelines were chosen for its traditional referential role, the Swiss norm for its peculiar biodiversity approach, the Italian one for its application on a territory with remarkably heterogeneous environmental conditions, stretching from Alpine to Mediterranean ecosystems. Even if the three norms at comparison addressed to some extent biodiversity related matters, none of them focused on the peculiarities of different ecoregions in term of plant species selection and assemblage, growing medium composition (materials and granular size) and system build-ups (multi-layers and single-layer constructions). This is a crucial point for countries, like Italy, encompassing very different climatic conditions. It was concluded that at the current knowledge, an official and effective regulation for green roof design in Mediterranean ecoregion is still missing.

Keywords: green roofs, biodiversity, Mediterranean climate, norms, guidelines

1.1 Introduction

The current European Research and Innovation agenda fosters sustainable development and urbanisation by means of nature based solutions with the aim to restore degraded ecosystems, to favour climate change adaptation and mitigation, to improve risk management and resilience. Moreover, Nature-based solutions, provide at the same time *environmental, social and economic benefits* bringing nature and natural processes into the built environment (Horizon 2020 Expert group).

Green infrastructure is the network of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas (Naumann et al. 2011). In densely populated lands, the connection to this network ensures natural multiple ecosystem services including, water and air purification, landscape conservation, soil protection and space for recreation (Tzoulas et al. 2007). In built environments, constructed ecosystems such as green roofs and bioreactors are of utmost importance to ensure urban resilience (Ranalli & Lundholm 2008, Gómez-Baggethun & Barton 2013).

Green roofs can be synthetically defined as rooftops covered with growing medium, intentionally vegetated and/or spontaneously colonised (SIA 312:2013). These surfaces represent novel urban habitats fulfilling several benefits and ecosystem services: they reduce storm-water runoff, bring slowly rain-water back to its moisture cycle via evapotranspiration, increase the roof waterproof membrane lifespan, reduce the energy consumption for heating and cooling, mitigate the urban heat island effect, reduce air and sound pollution (Oberndorfer 2007).

The recognition of green roof benefits has been inferred from the synergic work of technical universities, private companies and professionals over the last century in central Europe. The need to complement scientific interest and practical issues brought to the publication, in 1990, of the first guideline on green roofs by the German Landscaping and Landscape development Research Society (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau E.V. - FLL).

The German guidelines formalised a classification of green roof types, intensive, simple-intensive and extensive (according to the vegetation forms, use and maintenance), as well as a standardised system build-up.

As regards the green roof typology:

1. Intensive green roofs can host trees, shrubs, perennials herbs and lawns on a 15-200 cm thick growing medium. They can be freely designed and developed on spatially connected areas on the same level and or at different quotes. The loading bearing structure and the total costs represent the only constrains to the design and construction possibilities. The vast species selection palette confers to intensive green roofs a comparable recreation function to that of parks and gardens on the ground but it requires also similar maintenance effort in terms of irrigation, fertilization, pruning and weeding.

2. Simple-intensive green roofs can hosts shrubs, perennial herbs and lawns on a 12–100 cm thick growing medium. The spatial design and plant species selection are comparable to those of intensive green roofs but execution, maintenance costs and total loads on the bearing structure are reduced.

3. Extensive green roofs are near-natural greened surfaces hosting mosses, succulents, forbs (including bulbs and tubers) and grasses on a 6-20 cm thick growing medium. The plants species should be local, stress tolerant, able to regenerate themselves and propagate easily. The maintenance regime is reduced to the minimum, unless of wanted pattern and specific design.

This traditional subdivision was implemented by the British code of practice (GRO 2011) with a fourth intermediate typology between simple-intensive and extensive green roofs:

4. Biodiverse green roofs aim to recreate habitats similar or even ameliorated compared to the one lost due to the construction. These roofs are sown or plug planted with autochthonous species that in turn attract specific fauna; are constructed with different substrate thickness and kind such as sand and gravel; and are supplied with specific structural elements for habitat provisioning such as trunks and boulders. This approach provide for: the spontaneous development of the vegetation, the reduction of the maintenance

effort to the minimum; and the creation of areas without vegetation to mimic brownfields (Kadas 2006, GRO 2011).

It is worth to mention that this typology was implemented for the first time in Switzerland at the beginning of this century (Brenneisen 2006, Dunnet 2015).

As regards the standardised construction build-up, from the waterproof barrier upwards, it consisted in the following functional or working layers (figure 1): anti-bonding layer, separation layer, root barrier, mechanical protection, drainage layer, filter layer, vegetation supporting layer (growing medium) and vegetation.
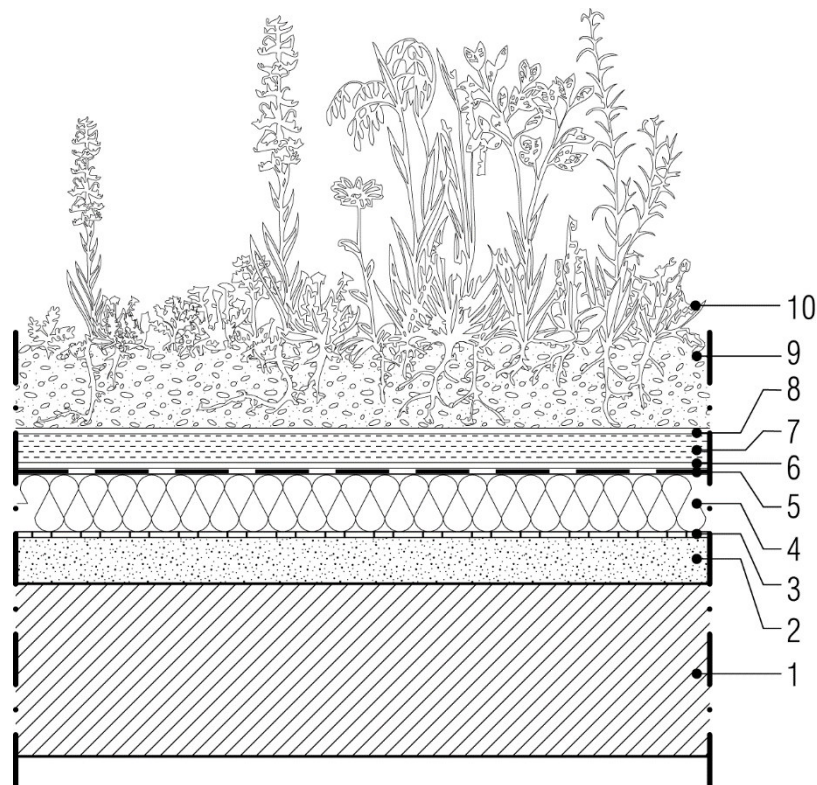
Figure 1. Extensive green roof standard technical section according to FLL guideline and UNI standard. In the drawing: 1) bearing structure, 2) draining slope, 3) vapour barrier, 4) thermic insulation, 5) waterproof membrane, 6) root barrier and mechanical protection, 7) drainage (and possible water storage), 8) filter, 9) vegetation supporting layer (and possible water storage) and 10) vegetation. The drawing was realised with Adobe illustrator CS6 and was inspired by both the technical details and the drawings as represented in the UNI and the SIA norms.

For each stratum and expected component of the roof, the norms give definite requirements and functions. The anti-bonding layer has the function to prevent the adhesion of various materials and reduce the shear stress between different layers; the separation layer to divide chemically incompatible materials; the root barrier to protect the waterproofing layer and the structure against root penetration; the mechanical protection to defend the waterproofing layer from mechanical damages (also as root barrier); the drainage layer to deliver the water in excess into the outlets for the prevention of waterlogging (also as protection of the membranes below it), but

also to increase the available space for root development; the filter layer to prevent the drainage layer to be clogged by the fine soil and substrate particles of the vegetation-supporting layer (growing medium); the growing medium to accommodate the roots of the plants. Actually, the water storage is needed when the growing medium is not able to meet the water retention demand and it can be integrated in the vegetation-supporting layer and/or in the drainage layer and/or be a separated layer. An extra water supply and irrigation system is normally installed in intensive greening and may be required also on extensive greening to support the plants in case of extreme weather conditions.

The German guidelines have been used as a reference for green roof design and for regulation worldwide because of its exhaustiveness and proven building- and landscaping tradition (Doug et al. 2005, Dvorak 2001, Abram 2006). Several national guidelines, code of practices and standards were developed after the FLL in Europe, such as the Swiss (SIA 217/2:1994), the Austrian (ONR 121131:2002) and the Italian (UNI 11235:2007) norms as well as the Dutch guideline (SBR 2006), the British code of practice (GRO 2011) and the Czech standard (SZÚZ 2016). It is worth to notice that some of the regulation were driven by ecological needs. In particular, the SIA norm followed the Federal Act on the Protection of Nature and Cultural Heritage by focusing on the ecological compensation role of green roofs (Brenneisen 2015), while the UK guideline were co-financed by the European Community LIFE+ funding program which is focused in strengthening the environmental policy across Member States (GRO 2011).

The rationale of this study was to assess the effectiveness of some European green roof norms in supporting plant and soil biodiversity in different ecoregions, with particular reference to the Mediterranean one, and to check how regulations coped with complex environmental variables and heterogeneous climatic contexts.

1.2   Materials and methods

The regulation analysed were the German "Guidelines for the Planning, Construction and Upkeep of Green-roof sites" (FLL 2008), later FLL; the Swiss "norm for roof greening" (SIA 312:2013), later SIA; and the Italian norm "criteria for design, execution, testing and maintenance of roof garden" (UNI 11235:2015), later UNI.

The FLL were chosen for their traditional referential role, the SIA for its peculiar biodiversity approach, the UNI for its application on a territory with remarkably heterogeneous environmental conditions, stretching from Alpine to fully Mediterranean ecosystems: perhaps the most environmentally complex and diverse context among the countries where currently the green roof technology is still rising.

The first German guidelines were published in 1990 by the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. – FLL (The Landscape development and Landscaping Research society) and since then further revised versions appeared in 1992, 1995, 2002 and 2008 (FLL 2008). Actually, the FLL Research Society

published the "principles of green roofing" in 1982 and revised them in 1984, prior to the publication of the effective guidelines. The FLL consisted of 16 chapters and 3 annexes regarding the planning, execution and upkeep of green roofs, roof terraces and other buildings with a growing medium up to 2 m thickness, while referred to other norms (e.g. DIN and EN standards), guidelines and code of practices for specific technical topics (e.g. structural design loads and waterproofing materials).

The Swiss norm was published by the Swiss Society of Engineers and Architects in 2013 (SIA 312:2013). The norm refers to the SIA 318 "gardening and landscaping" and substitute the SIA 271/2 "roof greening" written in 1994 and refined in 2007 (SIA 271:2007). The SIA consisted of five chapters and three annexes regarding the design and construction of roof greening while referred to other SN and SIA norms for specific technical details (e.g. draining features, top and down-soil parameters and other engineering related matters).

Table 1. Comparative table of the German (FLL 2008), Swiss (SIA 312:2013) and Italian (UNI 11235:2015) roof greening norms. The chapters were assigned to one or more competence domains among the following: design (Ds), requirements (Rq), construction (Cs), Materials (Mt), maintenance (Mn) and testing (Ts).

	FLL 2008		SIA 312:2013		UNI 11235:2015	
Chapter (n)	16		5		11	
Annex (n)	3		3		3	
Page (n)	118		24		60	
Chapter	Chapter title	Domain	Chapter title	Domain	Chapter title	Domain
0	-	-	Field of application (quoted norms and regulations)	-	-	-
1	Field of application, aim	-	Definitions	Ds	Aim and field of application	-
2	Quoted norms and other regulations	-	System design	Ds, Rq	Quoted norms	-
3	Types of Greening and vegetation forms	Ds	Calculation and dimensioning - Omitted -	-	Definitions and terms used	Ds
4	Functions and Effects	Ds	Materials	Mt, Rq	System requisites	Rq
5	Materials and construction requirements	Ds, Rq	Execution	Cs, Rq	Design instructions	Ds, Rq, Cs, Mt
6	Technical construction requirements	Ds, Rq, Cs	-		Functional schemes and systems classification	Ds, Cs
7	Greening requirements	Ds, Rq, Cs	-		Project documentation	-
8	Drainage layer	Ds, Rq, Cs	-		Materials and components requirements	Rq, Mt
9	Filter layer	Rq,Cs	-		Execution and installation instructions	Cs
10	Vegetation supporting layer (growing medium)	Ds,Rq,Cs	-		Controls	Rq
11	Seed mixtures, plants and vegetation requirements	Rq	-		Maintenance	Mn
12	Planting and sowing	Cs, Rq	-		-	
13	Maintenance regime (set-up and upkeep)	Mn	-		-	
14	Erosion protection	Rq	-		-	
15	Warranty (period of limitation of warranty claims)	-	-		-	
16	Testing	Ts	-		-	
Annex 1 or A	Indicative values for materials loads and water capacity	Ds	Structural elements to support habitat provisioning	Ds, Mt	Substrate characteristics	Ds, Rq
Annex 2 or B	Methods to investigate the growing medium and loose drainage layer on green roofs	Ts	List of the terms used	-	Vegetation forms	Ds, Mt
Annex 3 or C	Procedure to investigate the root penetration	Ts	Publications	-	Further information and testing methods	Ts

The UNI norm was issued for the first time by the Italian organisation for standardisation (UNI) in 2007 and it was revisited in 2015. The UNI consisted of 11 chapters and three annexes regarding the design, the execution, the control and the maintenance of roof greening while referred to other UNI norms for specific technical details (e.g. waterproof membrane parameters, soil and substrate improvers)

The proposed assessment was based on the evaluation of the contents affecting directly or indirectly the ecological value of green roofs. Therefore, the chapters of the regulations were grouped in one or more of the following competence domains (table 1): 1) Design (Ds), 2) Requirements (Rq), 3) Construction (Cs), 4) Materials (Mt), 5) Maintenance (Mn) and 6) Testing (Ts). The relevant details related to biotic factors were made explicit and further discussed.

1.3   Results

The regulations are structured in a way that any component designed to absolve a specific function and made with a certain material, has to fulfil given requirements, respect target values and be constructed in a well-defined manner in order to prevent failures. However, the SIA norm is more the enumeration of what needs to be planned when constructing a green roof, while it referred to other norms to define the characteristics of the functional layers (e.g. bearing capacity calculation, waterproof membrane and root barriers requirements, growing medium materials and properties).

1.3.1 Design

The three main aims and benefits recognised by the norms to green roofs are related to planning (town planning and amenities provisioning), environmental services (environmental compensation, water management and climatic mitigation) and economy (improved thermal- and acoustic insulation, increase of the building value and reduced demand on the sewage system). In particular, intensive green roofs have a recreation and aesthetic attitude similar to gardens and parks on the ground while extensive green roofs mimic dry habitats (FLL 2008) but also promote spontaneous species colonisation and development in order to build self-sustaining ecosystems (SIA 2013). Once the purpose of the green roof is defined, the factors to consider when designing it are the environmental conditions (e.g. climate, rainfall and wind) and the roof characteristics (e.g. exposition, slope, bearing structure and photovoltaic panels).

1.3.1.1   Environmental compensation value

As regards the environmental compensation value of green roofs, the SIA and the UNI norms introduced a grading system on the base of the habitat provisioning and the capability to restore the moisture cycle: "basic", "advanced" and "special" according to the SIA and A, B, C and D according to the UNI.

According to the SIA "Basic" roofs contribute almost only to the moisture cycle restoration according to their water retention capacity (table 2a). "Advanced" roofs fulfil the "basic" requirements, but are also characterised by an irregular distribution of the growing medium (figure 2) and by plant material belonging to class 1, 2 or 3 (table 2b). Optional features are the following: the use of two or three kinds of substrate with local top- or sub-soil or with local extracted materials; the use of structural elements constituting special habitats (table 3); the use of rainwater for the irrigation and the creation of temporary ponds; and the connection of the roof to the ground via green- and stone-walls.

Table 2a. Green roof classification based on the water retention capacity and the coefficient of discharge according to the SIA 312:2013 and the UNI 11235:2015 respectively.

	SIA 312:2013		UNI 11235:2015
Levels	Vegetation supporting layer thickness [mm]	Water retention capacity[1] [l/m^2]	Ψ[2]
Level 1	80-100	40-50	$\Psi > 0.45$
Level 2	100-120	50-60	$0.36 < \Psi < 0.45$
Level 3	120-150	60-75	$0.11 < \Psi < 0.35$
Level 4	150-200	75-100	$\Psi \leq 0.10$
Level 5	200-500	100-250	
Level 6	> 500	> 250	

[1]the water retention capacity is the sum of the air capacity and the plant available water.
[2]the coefficient of discharge is the ratio of the water drained volume and the rain fall volume

Table 2b. Plant material classes according to the SIA 312:2013 based on provenance of seed sources

Classes	Plant species provenance
Class 1	Seeds collected locally (from donor meadows) and transferred with hay containing seeds and/or obtained from threshed hay
Class 2	Swiss eco-types of the same biogeographic region
Class 3	Swiss eco-types of wild species without any regional specification
Class 4	Plant material with any specific characteristics

"Special" roofs fulfil both the "basic" and the "advanced" requirements, but are also supported by a detailed ecological compensation study to foster target habitat types and/or organisms.

Furthermore, the SIA norm provided suggestions to combine green roofs with solar panels by varying substrate thickness as show in figure 3. The reduction of the substrate depth in front of the panels for a width of 30 to 50 cm and the sowing of *Sedum* sp. or small growing plants will reduce the risk of shading the panels. Similarly, it is possible to increase the substrate depth on the backside of the panels where plant growth does not interfere with energy production. In this kind of roof, environmental (plant biodiversity) and economic aspects (energy production) have the same priority.
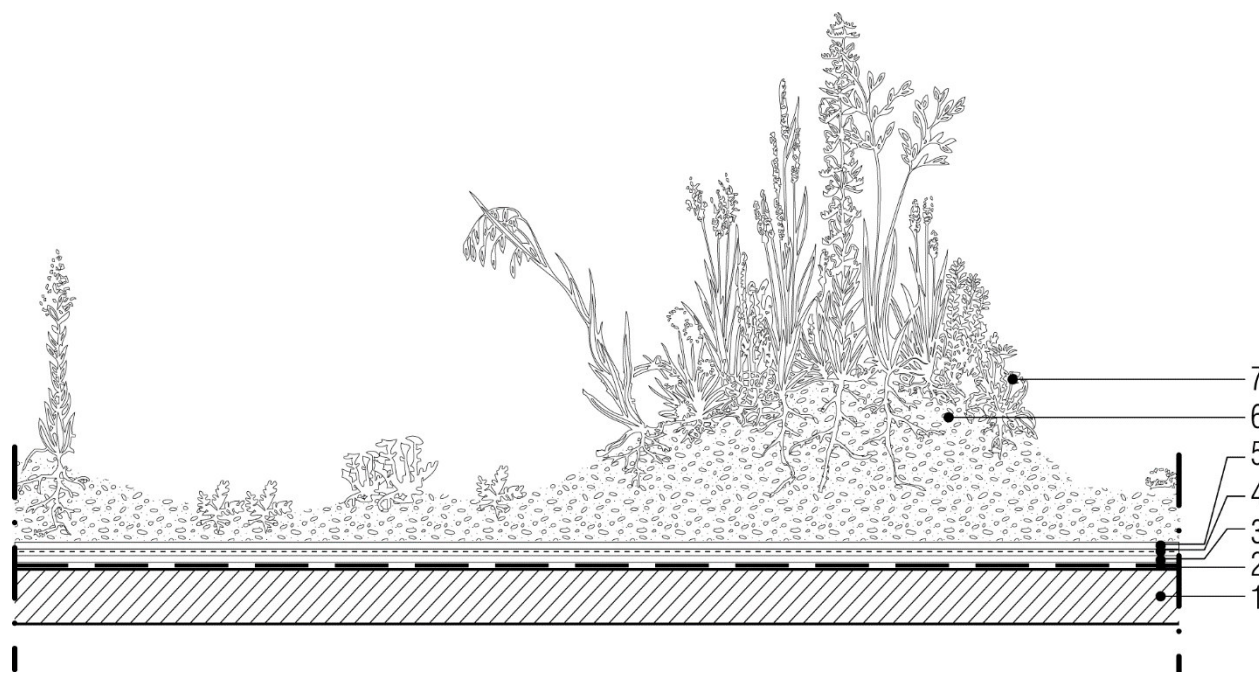
Figure 2. Example of substrate thickness variation according to SIA. In the drawing: 1) bearing structure, 2) waterproof membrane, 3) root barrier and mechanical protection, 4) drainage, 5) filter, 6) vegetation supporting layer and 7) vegetation. The drawing was realised with Adobe illustrator CS6 and was inspired by both the technical details and the drawings as represented in the UNI standard and the SIA norm.

Table 3. Structural elements to foster flora and fauna on extensive green roofs such as branch piles, roots trunks, areas with sand and alluvial sand and gravel medium, areas with boulders and no vegetation

	Branch piles	Roots-trunks	Sand	Alluvial sand and gravels	Boulders
Plants	✔	✔	✔	✔	✔
Animals					
butterflies	✔	✔			
wild bees	✔		✔	✔	
spiders	✔	✔		✔	✔
beetles	✔	✔	✔	✔	✔
grasshoppers	✔		✔	✔	✔
lizards	✔	✔	✔	✔	✔

According to the UNI, "C level" roofs are sown at least on the 1/3 of the surface, with autochthonous plant species. "B level" roofs fulfils the C level requirements but are also characterised by three vegetation forms assemblage among *Sedum* sp., small forbs, grasses, woody herbs and bushes, and by three substrate thicknesses (figure 2). "A level" roofs fulfils the B and C levels requirements but are also characterised by structures to attract and host motile animals, physical contiguity with the ground and are supplied by a detailed naturalistic study tackling ecological connectivity. Finally "D level" roofs have none of the above requisites but still an ecological mitigation value in comparison with impervious roofs.
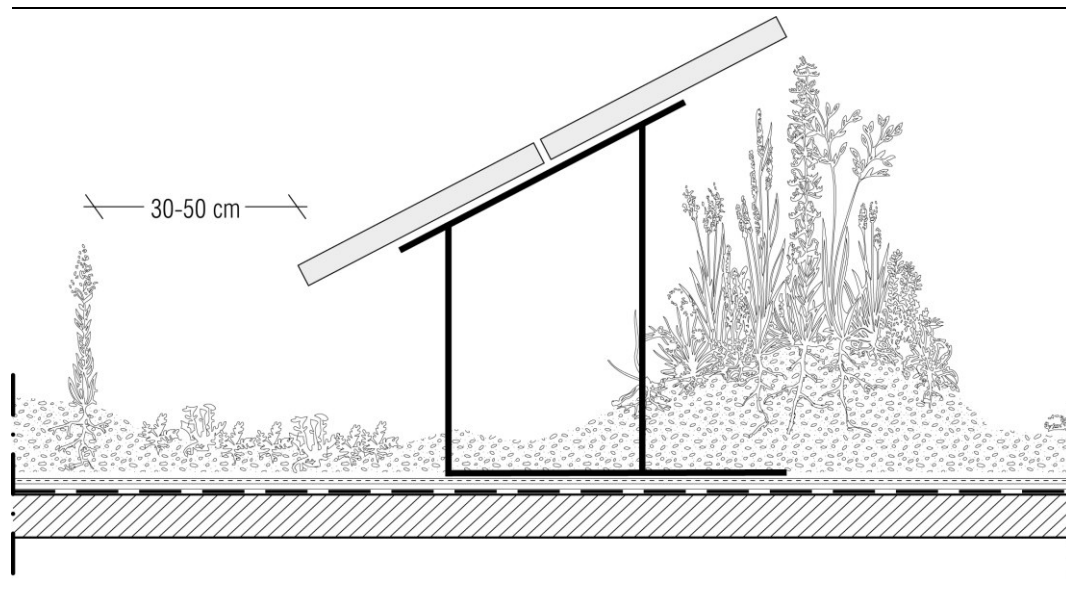
Figure 3. Integration between green roofs and photovoltaic panels. To diminish the risk of shading the panels, the substrate depth is reduced in front of the panels for a width of 30 to 50 cm and sown with *Sedum* sp. or small growing plants. Similarly, it is possible to increase the substrate depth on the backside of the panels where plant growth does not interfere with energy production. The drawing was realised with Adobe illustrator CS6 and was inspired by drawings of the SIA norm.

The UNI distinguished as well the performance of green roofs with respect to water cycles restoration into four levels on the base of the coefficient of discharge (water-drained volume on the rainfall volume) due of the overall system (table 2a). For this regards, the FLL do not use grades but considered the annual water retention as the ratio between the annual water run-off volume and the annual rain volume.

1.3.1.2 *Plant species selection and growing medium*

As it is mentioned by all three norms, the plant species should be selected according to the following criteria: abiotic factors (e.g. regional and local climate, including rainfall pattern), building and construction type (e.g. slope, aspect or orientation, sun/shade, wind flow), and plant physiological features (e.g. sensitivity to pollutants, prolonged drought and high evapotranspiration rates). Finally, the surrounding vegetation must be considered as it may affect future species pool, but also the trees growing around the building that shading the roof will influence the species composition.

Among the abiotic factors influencing plant species selection, the growing medium thickness is particularly relevant as it is shown in figure 4 (FLL), figure 5 (SIA) and figure 6 (UNI). The tables and the drawings describe in fact, the relationship between growing vegetation forms (e.g. herbs, grass) and different thicknesses. For example, according to the FLL (figure 4) in the case of extensive green roofs (4-20 cm) in a 4-8 cm thickness can grow an assemblage of mosses and *Sedum* sp., while in 6-10 cm *Sedum* sp., mosses and forbs. According to the SIA, the variation of substrate thickness on the same roof is recommended to promote biodiversity (as it

is required in the "advanced" level of the environmental compensation scale as shown in figure 2). In fact, with the intention of building a mosaic of different habitats, it would be possible to recreate rocky steppes, flower meadows, lawns and hedgerows (figure 5). According to the UNI, the substrate thickness-vegetation relationship is expressed in terms of minimum thickness required for a certain growth form: for example, 8 cm for *Sedum* sp. and 10 cm for small perennial herbs (figure 6).

Vegetation supporting course thickness [cm]		4	6	8	10	12	15	18	20	25	30	35	40	45	50	60	70	80	90	100	125	150	200
Extensive greening	Mosses-Sedum																						
	Sedum-mosses-forbs																						
	Sedum-forbs-grasses																						
	Grass and forbs																						
Simple intensive greening	Grass and few forbs																						
	Perennial forbs-shrubs																						
	Shrubs-sub-shrubs																						
	Shrubs																						
Intensive greening	Lawn																						
	Small perennial forbs-shrubs																						
	Medium perennial forbs-shrubs																						
	Tall perennial forbs-bushes																						
	Big bushes and small trees																						
	Medium and tall trees																						
	Big trees																						

Figure 4. Substrate thickness-vegetation forms relationship scheme according to the German norm (FLL 2008). Its validity is restricted to temperate climates and depends on the vegetation needs and requirements, the properties of the materials used for the working courses, the slope, the aspect (north and south facing slopes), the regional and the local microclimatic condition. Thickness is meant after subsidence.

1.3.2 Requirements

The two working layers effecting the overall ecological value of the roof in term of plant growth and water management are the draining and the vegetation supporting layers. For these layers the norms provided the correspondent hydraulic and horticultural properties (table 4).

1.3.2.1 Vegetation supporting layer, drainage and water storage

The drainage layer has the main function to take the water away as fast as possible but also to increase the available space for root development. The main properties of the drainage layer are the granulometric particle distribution, the water permeability, the water retention and the maximum run-off that is the volume of water cleared via the drainage course expressed in l/(s m).

Growth form on extensive green roofs			
Appearance/ Phenotype	Rocky steppes (sparse vegetation)	Flower meadow (medium coverage)	Flower meadow with an increase of grass species (dense vegetation)	Flower meadow with grasses and perennials forbs (dense vegetation)
Substrate height after compaction	≥ 8 cm	≥ 10 cm	≥ 12 cm	≥ 15 cm
Vegetation form	Sedum sp., mosses and some forbs	Sedum sp., forbs and some grasses	Forbs and grasses	Grasses and some forbs

Figure 5a. Substrate thickness-vegetation forms relationship scheme for extensive green roofs according to the Swiss standards (SIA 312:2013). Thickness is meant after subsidence.

Growth form on extensive green roofs			
Appearance/ Phenotype	Meadows, lawns, perennials and reptant woody species	Perennials and woody species of medium height	Tall woody species
Substrate height after compaction	12-30 cm	30-50 cm	≥ 50 cm
Vegetation form	Grasses, Perennials, small woody species	Perennials, small woody species	Small and big woody species

Figure 5b. Substrate thickness-vegetation forms relationship scheme for intensive green roofs according to the Swiss standards (SIA 312:2013). Thickness is meant after subsidence.

The growing medium, while performing certain hydraulic properties, has to possess the physical, chemical and biological requisites necessary for plant growth. In fact, the distinguishing parameters are the organic matter

content, the water retention capacity, the nutrient content, pH and of course the granulometric particle distribution or texture (figure 7).

Figure 6. Substrate thickness-vegetation forms relationship scheme according to the Italian norm (UNI 11235:2015). Thickness is meant after subsidence.

Vegetation supporting course thickness [cm]	8	10	15	20	30	50	80	100
Sedum	■							
Small perennial forbs		■						
Big perennial forbs, small shrubs			■					
Lawn			■					
Small shrubs				■				
Big shrubs and small trees					■			
Trees III (4<h <10 m)						■		
Trees II (10<h <16 m)							■	
Trees I (h>16 m)								■

In the UNI, the water storage is treated as a separate layer while in the SIA and the FLL, both the drainage and the vegetation supporting layers absolve the function to store water. To manage the effect on the plant growth and the hydraulic performance, the UNI requires the calculation of the following parameters: 1) the maximum water retention (MT) at pF 0.7 (–0.005 MPa), 2) the water content at the wilting point (PA) at pF 4.2 (–1.5 MPa) and 3) the intermediate water content (CI) at pF 2.0 (-0.01 MPa). The first is used to estimate the plant available water (ATD) as the difference between MT and PA; while the second to compute the water content at decreasing potential (APD) as the difference between CI and PA. The water retained by the system must be comprised between CI and the PA so to stimulate the plants to adopt water saving and drought tolerance strategies. This concept leads to the efficiency ratio (EF) obtained dividing APD by ATD. The ratio varies between 0 and 1 meaning that the higher the values the more efficient is the system (since the plant available water is comprised between CI and PA).

1.3.2.2   Irrigation

Beside the water retained by the substrate and the drainage, both the UNI and the FLL suggested to install an irrigation system for intensive greening but also on extensive greening to support the plants with supplemental irrigation in case of extreme weather conditions.

Table 4. Parameters for drainage and vegetation supporting layer for intensive and extensive greening according to the FLL 2008 and the UNI 11235:2015.

Main requirements	Growing medium		Drainage
	UNI	FLL	FLL
Apparent dry density [g/cm³ or kg/m³]	✓	✓	✓
Apparent density at maximum water capacity [g/cm³ or kg/m³]	✓	✓	✓
Granulometric distribution (figure 5) [%]	✓	✓	✓
Organic matter content [g/l]	✓	✓	-
Nutrient content/ soluble elements (N, P_2O_5, K_2O, Mg) [mg/l]	✓	✓	-
Water permeability [mm/s]	✓	✓	✓
Maximum water retention (at pF 0.7) [Vol.-%]	✓	✓	✓
Plant available water (range pF 0.7 – pF 4.2) [1] [Vol.-%]	✓	-	-
Water retention curve (at pF 0.7; 1.0; 2.0; 2.7; 3.4; 4.0; 4.2) [2] [Vol.-%]	✓	-	-
Maximum run-off [l/(s m)]	-	-	✓
Total pore volume [Vol.-%]	✓	✓	✓
Air volume at maximum water capacity [Vol.-%]	-	✓	-
Air volume at pF 1.8 [Vol.-%]	-	✓	-
Air volume at pF 1.0 [Vol.-%]	✓	-	-
pH	✓	✓	✓
Electric conductibility [mS/m]	✓	-	-
Cation exchange [meq/100 g]	✓	-	-
Salt content [g/l]	-	✓	✓
Effect on plants germination [%]	✓	✓	-
Foreign substances [% or cm²/l]	-	✓	-

1. The plant available water (ATD) is the difference between the maximum water retained by the growing medium at pF 0.7 (MT) and the wilting point at pF 4.2 (PA). The latter is the water retained by the porous materials of the growing medium but not available to the plants.
2. Water contained in the growing medium at pF 2.0 represent the intermediate water content (CI) which is the water retained by the porous materials of the growing medium.

1.3.2.3   Plant material

According to the FLL, seed mixtures must be certified while native species must have a nursery provenance. This is valid also for shoots, perennials, bulbous and woody species, turfs and vegetated mats. In this regards, both the SIA and the UNI did not mention such requirements.

1.3.3 Construction

1.3.3.1   Working layers

The FLL suggested two standard build-ups consisting of several layers performing a specific function (multi-layers construction) or one single layer fulfilling almost all the functions (single layer construction). The UNI norm discarded the multi-layers solution due to its presumed instability in a long-term perspective while the SIA norm did not go in such details.
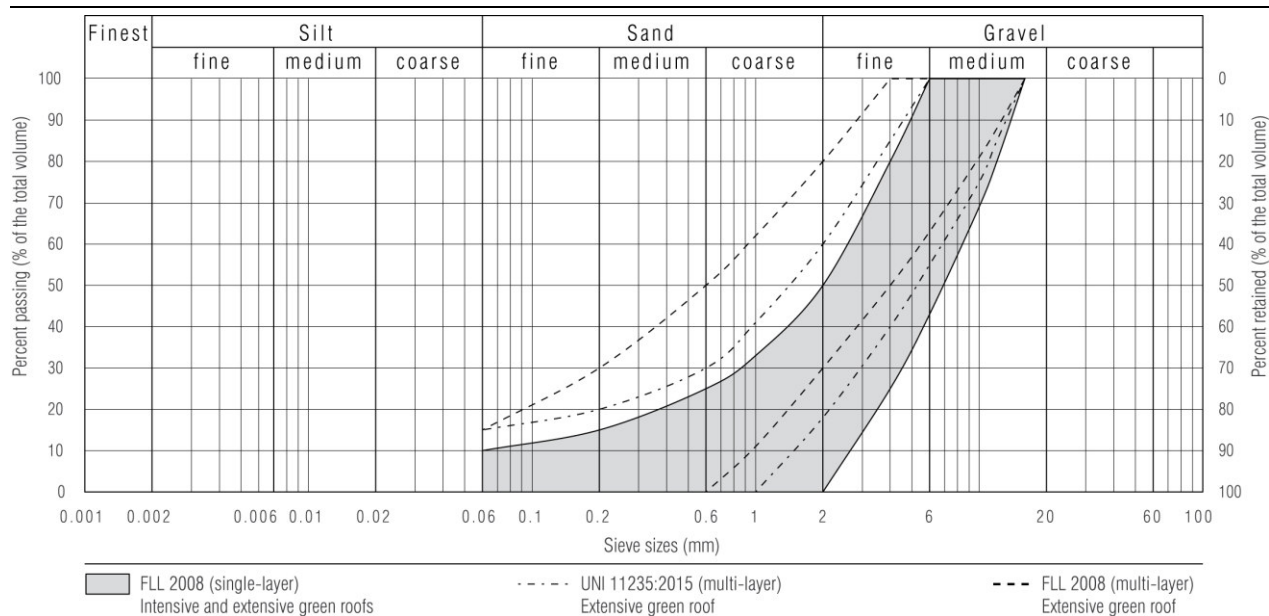
Figure 7. Granulometric distribution range of green roof substrate according to the FLL 2008 and the UNI 11235:2015. The curves shows the range for single layer extensive and intensive green roofs and for multi-layer extensive green roofs according to the FLL 2008; and for multi-layer extensive green roof according to the UNI 11253:2015 standards. On the x-axis the diameter of the particles is expressed in mm; on the y left-axis the grains passing through in % m/m, on the y right-axis the grains retained in % m/m

1.3.3.2   Plants establishment methods

As regards plant establishment methods, the guideline and the norms suggested dry seeding and wet seeding, spreading plant parts, laying vegetated mats, laying turfs and planting. The SIA introduced the hay transfer technique (known also as mulch technique) i.e. plant material with seeds coming from a selected donor meadow from the same biogeographic region (table 2b, class 1). The plant material should be exposed on the roof in spring or in autumn.

1.3.4   Materials

1.3.4.1   Drainage- and vegetation supporting layer

As regards the formation of drainage layer, both the FLL and the UNI listed the following materials: aggregates (e.g. gravel, lava and pumice, broken and unbroken expanded clay and slate), loose recycled materials (e.g. crushed bricks), drainage matting (e.g. non-woven fabric, plastic and fibre woven matting), drainage boards (e.g. foamed pellets and shaped plastic boards) and drainage-substrate boards (modified foams).

As regards the formation of the growing medium, the FLL listed loose materials (improved top soil or down-soil and mineral mixtures with or without organic compounds) substrate boards (foam and mineral fibres), water retention fibres (fleece, mats and boards) and finally vegetation matting with mineral/organic loose compounds in permanent or biodegradable carriers.

The UNI and the SIA referred as well to natural soils, amending materials and substrates (mineral- and recycled materials based growing media) but did not specify the materials composing them.

1.3.5 Maintenance

The classification of green roofs is also based on the maintenance effort. In particular, the UNI introduced a further classification according to the maintenance regime measured in minutes per square meter a year. In this classification there are extensive green roof with very low maintenance (<2 min/m^2/year), extensive green roof with low maintenance (<4 min/m^2/year), intensive green roof with reduced maintenance (<8 min/m^2/year), intensive green roof with medium maintenance (<15 min/m^2/year) and intensive green roof with high maintenance (>15 min/m^2/year). It is worth to mention that according to the FLL, the maintenance reflects the aim for which the roof was built. In fact, the aesthetical approach prevails on intensive and simple-intensive green roofs, while the ecological approach on extensive ones since the latter are characterised by a natural appearance driven by vegetation dynamics.

1.4 Discussions

Simple-intensive and extensive green roofs may have a higher ecological value than intensive greenings as they are eventually not subjected to aesthetic judgments, require less maintenance, solicit to a lesser extent the bearing structure and, consequently, are cheaper and easier to execute and to apply on a larger scale. With this regard, the SIA dedicated a subchapter to ecological compensation that include measures to foster biodiversity by design, such as the use of local plants species and of different substrate depths.

In general, while considering the environmental conditions, the regulations advised the use of *plant growth* morphological strategy (e.g. small succulents, bushes, trees) and *life forms* in the guidelines for plant species selection and for substrate depth determination (figure 4, 5 and 6). Actually, figure 5a is also an ecological succession scheme showing how the vegetation on the roof is expected to evolve in e.g. 30 years. The SIA therefore, considered green roofs as dynamic ecosystems where spontaneous colonisation should be consequently accepted.

Life forms classification considers the position of the perennating tissues (e.g. buds) in relationship to the ground and the strategy to survive the unfavourable season i.e. cold winter and dry/hot summer (Cornelissen 2013). To this regards, the UNI norm referred to: 1) therophytes (annuals surviving the adverse season in form of seeds); 2) hemicryptophytes (biennials and perennials with buds positioned close to the ground) e.g. grasses and rosette forming herbs; 3) geophytes (buds below the ground) e.g. bulbs, tubers and rhizomes developing species. The plants belonging to the mentioned categories are favoured because they develop scarce above- and belowground biomass, have good propagation capacity and are stress resistant.

However, the regulations did not suggest any specific life-form assemblage neither in relationship to the provisioning of ecosystem services (regulating, supporting, cultural, provisioning and regulating) nor to different ecoregions. To this respect, it has been suggested that life-form diversity *per se* cannot guarantee the best green roof performance in term of ecosystem services e.g. regulation of climate and water management, support to flora and fauna, provision of edible plants and aesthetic valuable plants; however, assemblage of succulents, grasses and tall forbs seams to optimise them (Lundholm et al. 2010). Additionally, plant traits selection should be driven by the most limiting factor, for instance in Mediterranean climate, drought tolerance traits (e.g. CAM metabolism, small leaf area, low leaf dry mass, stress-tolerance) should be favoured to screen plants among the regional species pools. For the same reason in cooler and humid climates, tolerance to low temperatures and humid condition should be the main screening factors (Van Mechelen et al. 2014).

Clearly, substrate depths strongly influence species diversity shaping the functional and taxonomical composition of plant communities that in turn affect the benefits provided. In fact, species-rich assemblage have higher functional diversity that in turn corresponds to higher ecosystem services (Madre et al. 2014, Van Mechelen et al. 2015). For example, higher depths determine a better water retention management while plants are crucial for the mitigation of the urban heat island effect thanks to evapotranspiration and shading (Monterusso et al. 2004).

Together with substrate depths, also substrate type with peculiar chemical and physical characteristics affect the vegetation composition. The FLL and the UNI considered this by suggesting different grain size distribution ranges (texture) for multi- and single layer intensive and extensive green roofs. It has to be mentioned that the UNI considered the single layer build-up unreliable to assure a long-term functioning while for the SIA this issue was not relevant at all. Moreover, the texture affects the porosity, the water holding- and field capacity, the hydraulic conductivity, the nutrients availability and compaction in time (figure 7). As regards the chemical characteristics, the regulations advice maximum and minimum contents/values for the organic matter, nutrients (N, P_2O_5, K_2O and Mg), pH and cation exchange (table 4). In fact, soil fertility (especially nitrogen and phosphorous content) strongly influences species richness, composition and functional diversity: poor nutrient soils generally determine higher plant diversity while the addition of nitrogen often favour alien and perennial species (Wilson & Tilman 2002).

In particular, Bretzel et al. (2009, 2016) investigating the relationship between native herbaceous species (able to survive in unproductive soil) and soil characteristics, found that seedling emergence was influenced by soil texture and structure while plant growth, biomass, flowering time, numbers and duration was effected by fertility (especially carbon and nitrogen contents).

Therefore, the compensation value of green roofs is not intrinsic in the use of wild and native species *per se,* but it is crucial to determine the conditions suitable for their establishment prior to the installation. However, the UNI and FLL did not mention plant-soil relationships and biogeographic diversifications at all, while the SIA stated the crucial importance of biogeography and plant species needs to implement the ecological compensation value. However, which plant needs and how the substrate should vary accordingly remained unclear.

Together with productivity, disturbance (e.g. burning, grazing, tillage) influences species richness and composition as well, for example grazing in productive soils has a positive effect on biodiversity, whereas in poor nutrient soil negative. Finally, the combination of disturbance and fertilisation normally exacerbate the rapid colonisation of alien and invasive species but also of annual species to the detriment of perennials (Wilson & Tilman 2002). With this regard, green roofs may be relatively undisturbed artificial habitats where native flora and fauna can establish. In fact, maintenance activities mainly aims to control the presence of unwonted species by mowing and weeding. With this respect, the FLL and the SIA mentioned the reduction of maintenance regimes to enhance the natural aspect and environmental compensation role of extensive green roofs. In fact, the cutting intensity can affect species richness and community assemblage, for example in temperate climate, the optimum between biomass and species richness can be obtained with one or two cuts per year (Bretzel et al. 2016).

As regards the materials used for the formation of growing media, the UNI remained vague about the most suitable materials with the exception of "substrates", top- and down (amended) soils. It is worth to mention that the previous version of the UNI (UNI 11235:2007) clearly discouraged the use of natural soils as "rarely fulfilling the requisites to assure a correct functioning of the green roof". In the contrary, the UNI referred to commercial substrates as "normally used" by practitioners and firms as "fulfilling the specific functions". This negative connotation of natural soils to be used for green roofs in favour of commercial substrates, evolved in the last version of the norm: substrates are now considered as a "possible choice" and not as the advised (exclusive) solution (in line with the German and the Swiss norms).

Other remarkable aspects to highlight are the seed provenance and plant establishment methods. At the state of the art, for the Italian and the German norms, seeds and plants provenance should be certified while greening methods are common to gardening practices such as sowing, plug planting and laying pre-vegetated mats. The Swiss norm, instead, suggested for the first time the use of land restoration methods such as hay transfer and seed collection from donor meadows. This revealed the ecological predominance on the technical understanding of roof greening, thus enlarging the "technical target" with ecologists and naturalists besides agronomists, landscape architects, engineers and companies to whom the German and Italian norms referred as well (Brenneisen 2015).

Finally, with reference to green infrastructures and the provisioning of ecosystem services, the missing information regarding genotypes in such constructions causes an issue of uncertainty: since not all plant species are equal, which vegetation assemblage is more effective in providing which ecosystem service? Actually, the green infrastructure term is nowadays used too generically since urban planners neglect the complexity of green spaces and the peculiar plant community populating them. This is particularly true for green roofs as their ecosystem services are related to human needs that go beyond the aesthetical appeal e.g. regulation of air temperature, atmospheric pollution and storm water run-off and amelioration of the thermal building insulation (Cameron & Blanusa 2016).

1.5   Conclusions

Likewise "languages are the best mirror of people soul" (*Die Sprachen sind der bester Spiegel des Geistes*, G. W. Leibniz), norms and guidelines content may reflect the national industrial interest but also research innovations. However, norms alone could not have boost green roofs technology without public direct or indirect incentives campaigns and local building regulations. The most famous examples in this sense came again from German speaking countries: Germany (e.g. Stuttgart), Switzerland (e.g. Basel) and Austria (e.g. Linz) (Abram 2006). On the contrary, in Italy the normative effort overwhelmed the incentive one by issuing a second revised norm, a guideline for the implementation of green roof ecological value (ISPRA 2010), while only few municipalities significantly promoted green roofs implementation (e.g. Bolzano, Trieste, Firenze). Probably this was due to the roofing experience developed in the north-eastern part of the country (e.g. the self-governing Bolzano/Bozen province) in turn influenced by the German-Swiss tradition (Abram 2006, ISPRA 2010).

Even if the three regulations at comparison addressed to some extent biodiversity related matters, none of them focused on the peculiarities of different ecoregions in term of plant species selection and assemblage, growing medium composition (materials and granular size) and system build-up (multi-layers and single-layer construction). This is a crucial point for countries, like Italy, encompassing very different climatic conditions. With this regard, it has been suggested that guidelines instead of going after national political divisions, they should follow climatic conditions in order to develop regionally based standards (Dvorak 2011). With that, the adoption of single layered build-ups together with the multi-layered ones would significantly reduce the total costs, thus pulling down one of the main limiting factor to the spread of roof greening technology.

Finally, if green roofs will be executed for environmental compensation reasons, ecological aspects should have a relevance comparable to aesthetic and technical ones. Luckily, the rising biophilic approach (Ignatieva & Ahrné, 2013) such as the use of wild plants for landscaping, is smoothing technical constraints: from merely building and roofing techniques, green roofs are starting to be considered real ecosystems (Sutton 2015). This is particularly true in Mediterranean regions where the biodiversity approach in roof greening seems to drive the

research as shown by the interest of naturalists, scientists and eco-designers. However, an official and effective guideline for Mediterranean ecoregions does not yet occur. Therefore, future research should investigate substrates from local materials, soil-amended growing media and build-up systems suitable to host Mediterranean biocenosis.

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## 2 Extensive green roofs: biodiversity at high levels

[Translated into English from Catalano, C., Brenneisen, S., Baumann, N. & Guarino, R. (2016). I tetti verdi di tipo estensivo: biodiversità ad alta quota. Reticula, 12, 1-10. The manuscript was completed with supplementary pictures]

Abstract

Cities are defined as heterotrophic systems (Odum, 1983) as they depend mainly on external resources and cause habitat loss and fragmentation. Green roofs represents a fundamental means of ecological compensation within the built environment, i.e. in highly altered and disturbed places by humans. In particular, green roofs for biodiversity (or biodiverse green roofs), being characterised by different but contiguous microhabitat (habitat mosaics or patches), can host several species with different morphological and functional traits (Brenneisen, 2003). The method known as the habitat template consists of choosing suitable plant species for green roofs from among the one that live in nature under similar conditions e.g. shallow and nutrient poor substrate, drought (Lundholm, 2006). The phytosociological approach applied to green roofs considers habitat analogues not only as species pools, but also as models to group plants in specific associations (Catalano et al. 2013).

Key words: Green roofs, habitat template, phytosociological method, ecological networks

2.1 Ecology and landscape planning: the need for a common language
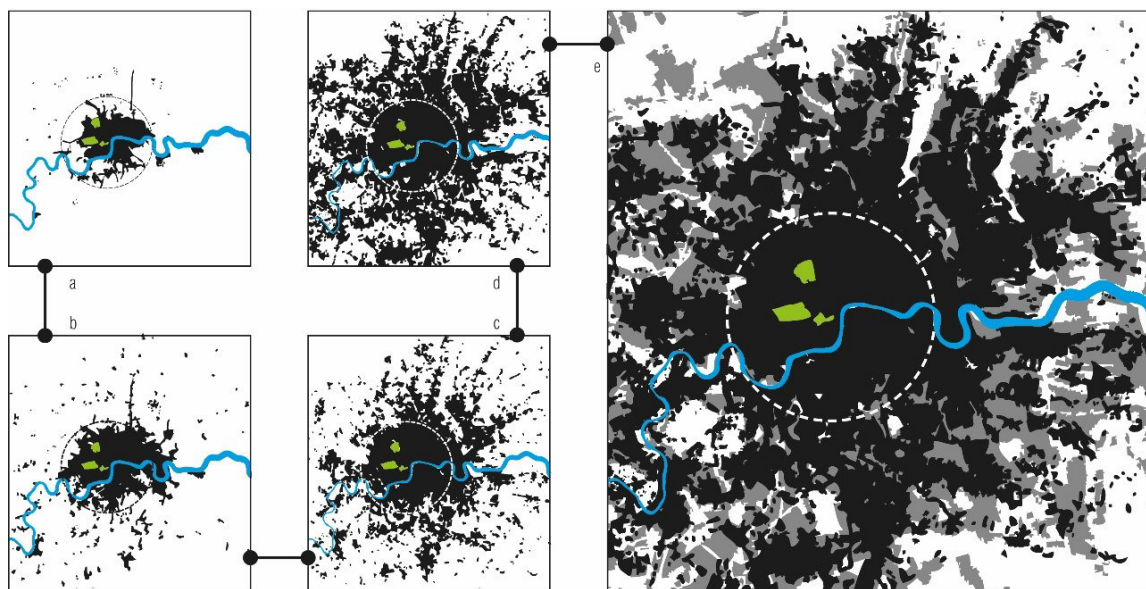
Figure 1. London urban sprawl from the 1814 to the 1978. The maps show the scattered decentralization of the city in the (a) 1840, (b) 1880, (c) 1914, (d) 1929 and (e) 1978. In green Hyde Park and Regent Park (two of the royal parks in London), in blue the Thames. The dashed circle encompasses the perimeter of the city of London in 1840.

Before the end of the Second World War, despite the attention was focused on the contemporary human tragedy rather than on sustainability and environmental protection, Saarinen (1943) wrote:

The city is an open book in which to read aims and ambitions. When it is built in a disorderly manner and the inhabitants are indifferent to its appearance, they automatically reveals this attitude.

The Finnish architect and urban planner described in a metaphor what we would nowadays call Urban sprawl (figure 1). In the same years the German botanist Kreh (1945) published Pflanzenwelt unserer Kiesdächer (the plant world of our gravel roofs), where he described the plant communities that colonised the coat of sand and gravel protecting the waterproof membrane of some roofs in Stuttgart. Similar studies followed in the 60s, the 80s and at the beginning of 2000 in Germany, Switzerland and Italy, respectively by Bornkamm (1961), Thommen (1986) and Martini et al. (2004).

Common issues were related to the uprising awareness of the big failure to design and build sustainable and resilient cities with respect to natural cycles and equilibrium. However, cities in their turn were still able to host an unexpected biodiversity and characteristic plant communities (from Linnaeus on, certain specific plant names - tectorum, murorum, muralis, urbicum – confirmed the historical and not casual occurrence of such species in urban habitat).

In the 70s, similar thoughts took the Scottish landscape architect Jan McHarg, the author of Design with Nature (McHarg, 1969), to advocated the use of ecology as the basis for design. Ideas that were brought eventually into the new graduate program in landscape architecture and regional planning he began at the University of Pennsylvania. Similarly, the landscape ecologist Konrad Buchwald introduced the scientific base of landscape ecology into landscape management and planning at the institute of landscape care and nature protection of the University of Hannover (Buchwald & Engelhart, 1968).

The work done by McHarg and Buchwald continues to influence architects, landscape architects and ecologists. Contemporary examples of extraordinary synergy among ecology and design disciplines are expressed by the work of Ken Yeang and Vittorio Ingegnoli both architects and ecologists. The first focused on eco-design that is the connection between biodiversity, ecology and architectural forms and functions (Yeang, 2006), the second focused on the responsibility of men (ecologists) for habitat health and ecosystems functioning (Ingegnoli, 2011).

The peculiar ecology of cities was clear enough already from the study of the pioneer communities spontaneously colonising ruins, walls, pavements and gravel flat roofs. These were species mostly occurring in anthropic degraded and highly disturbed habitats: the so called "ruderal communities". Urban ecology, with

studies on climate, soil, water, organisms and biotopes, was formalised as an independent discipline from landscape ecology only in the 70s despite the existing studies done since more than a century (Sukopp, 2002, Barker 1997).

Urban planning and urban ecology are still two distinct disciplines and there is an urgent need to establish a common language between social and natural sciences (Steiner, 2008) in order to attain an holistic approach in designing sustainable cities (Niemelä, 1999).

> *There is a need of a common language, a common method among all those concerned about social equity and ecological parity. This method must be able to transcend disciplinary territorialism and be applicable to all level of government* (Steiner 2008. The Living Landscape, p. 9)

2.2 Habitat fragmentation and ecological networks: towards a model of bio-permeable city

Cities were compared by Odum (1983) to heterotrophic organisms which grows upon resources (energy and goods often not renewable) produced far beyond its physical boundaries thanks to integrated transporting systems, industrial development and modern technologies (figure 2). In this development process, cities release into the environment heat and pollution, alter biogeochemical cycles while causing habitat loss and fragmentation (Fischer & Lindenmayer, 2007).
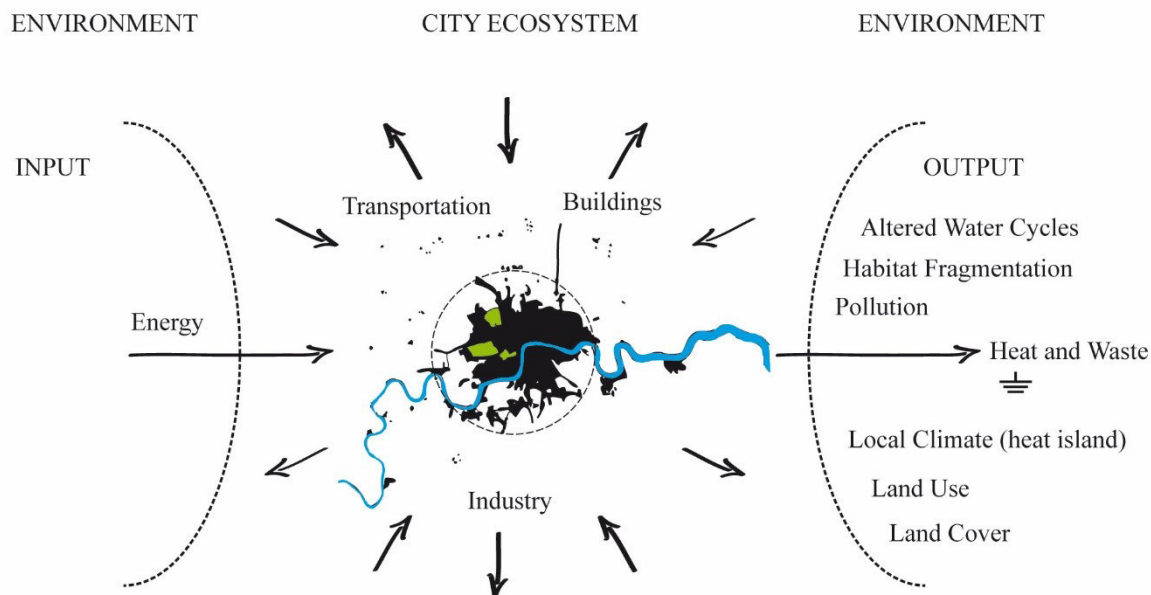
Figure 2. The city as an incomplete heterotrophic organism *sensu* Odum (1983). The city depends on large areas outside of the urban physical boundaries, requires a high input energy level e.g. fuel, food, fibre, water, and raw materials, and returns the output of chemical origin materials, heat, waste, etc.

However, man-made habitats and in particular urban environments, offers constant adaptation opportunities for several living forms, plants and animals coming from different biogeographic regions that in turn used humans as their dispersal vectors (anthropocorous species). Moreover, urban environments are characterised by high habitat patchiness and diversity with respect to the surrounding cultivated lands and may host species of conservation interest (Kowarik, 2011). This suggest that if cities would be designed and transformed to favour biodiversity and resilience, they could have an active role in nature conservation measures and in fostering ecosystem services upon which our life on earth depends.

Landscape architect Gille Clement, author of "Third Landscape" (2005), suggested the refuge role of the "landscape fragments" within the "built environment" (e.g. railway lines and dismissed industrial areas, green roofs) according to density: in urban cores, fragments are smaller and closer, in the outskirts bigger but more distant to each other. The equilibrium between the centrifugal energy of the expanding built environment and the centripetal energy of nature recolonization of empty niches, determines the resilience of urban environments.

Saarinen (1943) anticipating the organic and systemic understanding of cities as done by Odum (1983) built a metaphor between cells, organisms and cities. As the cells of one organism are distinct but correlated in the function and in turn the organism is unique but in relationship with other organic forms (form-manifestation), cities at the same way, have to be planned and built according to the principles of expression and correlation to attain a superior organic order.

The ideas of Saarinen and Odum are extremely up-to-date with respect to what has been done recently to integrate anthropic habitats to cultural landscapes and protected areas (Rete Natura 2000) with the aim to find an optimum compromise between human activities and ecosystem conservation. In fact, the challenges of landscape planning of the smart lands are centred on ecological corridors, stepping stones, ecological network and green infrastructure. The effectiveness of these instruments is related to the bio-permeability of built environments. The latter will be higher the more green public spaces (garden, parks and intensive green roofs, etc.), not accessible green spaces (extensive green roofs on apartment buildings and warehouses), residuals and peripheral areas (greened tunnels, bridges, railways, brownfields), will be realised or restored with reference to the potential vegetation, the floristic, the pedological and climatic context (Ercole et al., 2010).

> […] *the present and future methods [of town building] must be based on entirely new premises. And these new premises can and must be found only in and through the existing difficulties* (Saarinen 1943, The city, p 143).

2.3   Ecological tools: green roofs for biodiversity

Green infrastructure constitute a fertile ground for the interaction between ecology and design through experimentation: they are crucial to attain a sustainable urban development integrating landscape ecology and planning at different levels and scales.

> *Green infrastructure is* […] *an interconnected network of waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resources and contribute to the health and quality of life* […] (Benedict e McMahon, 2006, p.3).

Green roofs represents a powerful mean of environmental compensation and mitigation within urban cores where high density and disturbance constrains other living forms and inhibit natural dynamics. Extensive green roofs are greened rooftops generally not accessible and requiring low maintenance, with a substrate varying between 8 and 15 cm (FLL 2008) doomed to be colonised by the vegetation of the *Sedo-Scleranthetea* in Northern Italy and of the *Thero-Brachypodietea* in the south. From the ecological viewpoint, green roofs can act as stepping-stones through built environments for specific and targeted biocenosis, becoming an integral part of a greater ecological network (Catalano et al., 2013).

Green roofs for biodiversity originated in Switzerland thanks to the work of the geographer Stephan Brenneisen (Dunnett 2015) actually leading the urban ecology research group of the Zurich University of Applied Science (ZHAW). Initially, the specific aim was to create artificial habitats on roofs able to host invertebrate communities of riverbanks and floodplains of the Rhine River (Brenneisen, 2003). Brenneisen's activity was facilitated by a funding campaign (ca. 20.– CHF/m^2) to promote the construction of green roofs initiated by the Basel municipality between 1995-1996 for a total of 13 million Swiss francs (Brenneisen, 2010).

It is worth to mention that in Switzerland at the beginning of the 30s, Le Corbusier (1927) made green roofs sacred to generations of architects as he included them in the 5 points for a new architecture: they protect the waterproof \membrane and the structure while maximising the use of the space (figure 3). Extending the concept from architecture to town planning, supposing that all the flat roofs were green, they could compensate the construction of a whole city:

> […] *généraliser le cas* [green roofs], *c'est récupere la totale superfie d'une ville*
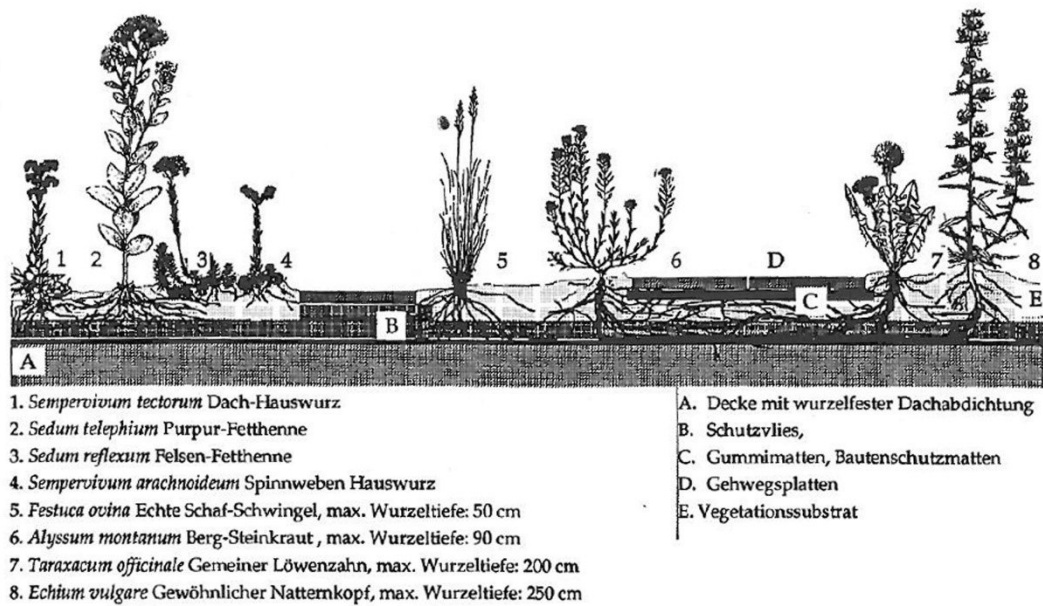>
> (Le Corbusier, 1927, p. 86).

Figure 3. Detail of a constructive section of a green roof (Riedmiller, J. 1994).

In 2002 the city of Basel introduced in the building regulation that every new flat roof had to be greened and that in case of areas bigger than 500 m^2 the system had to be optimised for biodiversity (e.g. different substrate kind and thickness, use of top soil, use of regional seed mixture). With that, the first campaign was followed by a second one between 2005 and 2007 (ca. 40.- CHF/m^2) oriented to sustain retrofitting of existing grey roofs. The final result of the two campaigns was the construction of more than 600 000 m^2 of green infrastructure: the 23% of all the existing flat roofs were extensive- (1711) and intensive (218) green roofs.

The fundamental design criterion for the construction of green roofs for biodiversity, consisted in creating micro-mosaic of different contiguous habitats capable to host different biological forms of plants and animals. In fact, the studies of Bornkamm (1961) in Germany and of Thommen in Switzerland (1983) showed how plant species establishment and succession was affected by the substrate kind and thickness, climatic conditions and of course time (succession). For instance, on the traditional roofs constructed in Germany at the beginning of the 19th century and characterised by a coat of sand and gravel protecting the waterproof membrane of tar and carton from fire hazards and weathering, the first stadium (couple of years) was dominated by commensal species (e.g. *Panico-Galinsogetum*). Temporary meadows species (e.g. *Lolio-Plantaginetum*) follow in about 10 years; *Poa compressa* meadow species (*Poetum anceptis-compressae*) follow in about 30 years in shaded areas, while mosses and Crassulaceae species (e.g. *Sedo-Sempervivetum ceratodontetosum purpurei*) in shallow substrate and fully exposed areas.

Figure 4. a) Substrates of different thickness (6, 12, 20 cm) used to accommodate different biotic communities on the roof of the Cantonal Hospital in Basel (Klinikum II). Design Stephan Brenneisen, University of Applied Sciences Zurich (ZHAW). b) Klinikum II roof from a bird's-eye view perspective (photo Stephan Brenneisen).
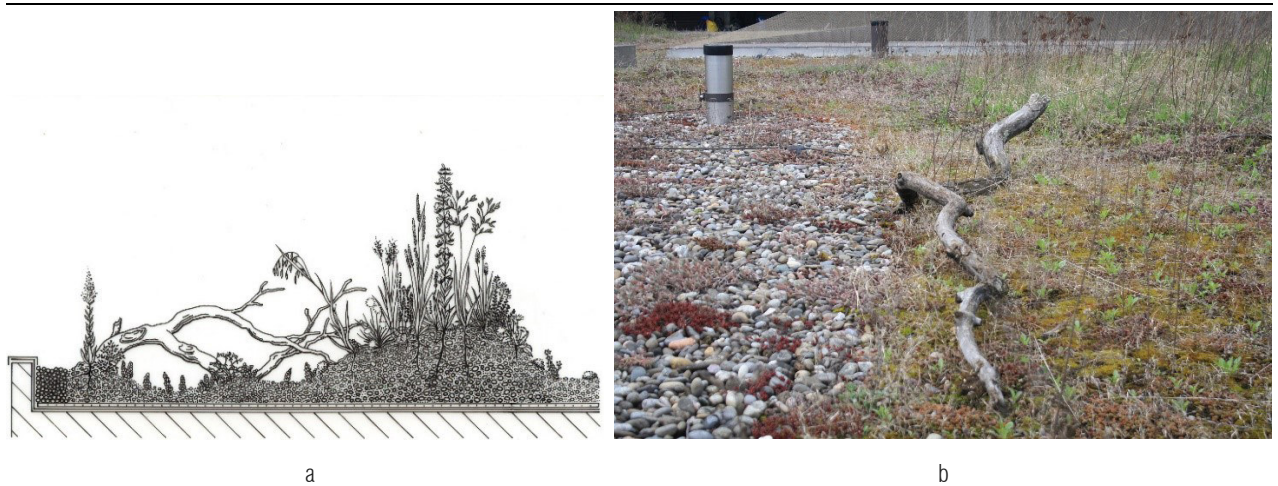
Figure 5. a) Graphical representation of the typical additional characteristics of biodiverse green roofs e.g. variable thickness of the substrate, rocks, logs, branches, etc. (Design, Zurich University of Applied Sciences - ZHAW). b) Detail of the Basel Cantonal Hospital green roof (Klinikum II). Transition between different micro-habitats (photo Chiara Catalano).

Keys designing features distinguishing the green roofs for biodiversity from extensive green roofs, can be synthesised in (Brenneisen, 2006, Baumann 2006):

1. Spatial heterogeneity:

a. Variable substrate thickness (**figure 4a**). In temperate climates 8-10 cm of substrate can host *Crassulaceae* species (e.g. *Sedum* sp.), mosses and few grasses and depths greater than 10 cm can host also forbs, in particular in 12 cm of substrate forbs and grasses out compete the *Crassulaceae* species allowing the establishment of a balanced mixture of forbs and grasses meadow. In thickness greater than 15 cm,

grasses predominate. Shallow substrates and low vegetation cover favour predatory insects of xeric habitats.

b. Different kind of substrate (**figure 4b**). Generally the substrate used for extensive green roofs is constituted by commercial mixture of light aggregates in different granulometry (recycled materials like crushed-

bricks and ceramics, volcanic materials like lava beams, pumice and zeolite, expanded aggregate like clay and slate) and organic material (peat, sterile compost, etc.). To sustain a bigger floristic diversity and host specific animal species, it is possible to use other coarse aggregate like silica sand, clay, silt, slate, pebbles and top soil (paying attention to avoid contaminated soils or containing exotic invasive species in the seed bank). Areas with solely sandy gravel favour thermophilous insects.

Figure 6. *Drosera rotundifolia*. Green roof of the Cantonal Hospital in St. Gallen (photo Stephan Brenneisen).
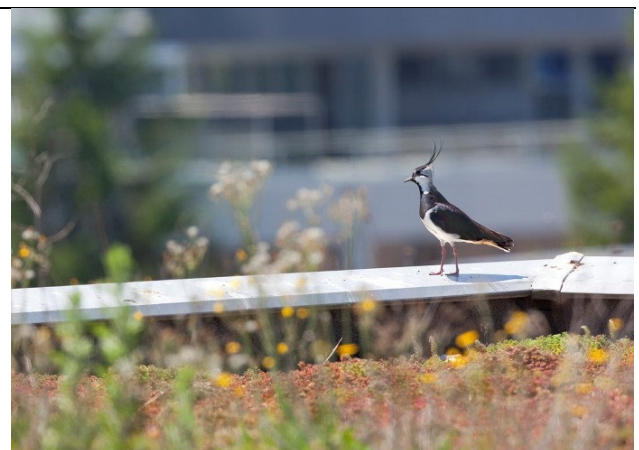
| a | b |

Figure 7. a) Lapwing chick (*Vanellus vanellus*) on a green roof in Gossau (ZH) (photo Claudio Lotti). b) Lapwing adult (*Vanellus vanellus*) on a green roof in Gossau (ZH) (photo Nathalie Baumann).

c. Extra design features (**figure 5 a,b**). Stones, trunks, brunches constitute a shelter against weathering for micro fauna as they effect micro-climatic conditions. Temporary ponds offer water source for insects and birds and favour the establishment of ephemeral biocenosis of wet areas (*Isoeto-Nanojuncetea*, **fig. 6**).

Moreover, ground nesting birds relay on green roofs to nest due to the scarcity of proper habitats on the ground because of land use change in favour of agricultural fields (**figure 7 a,b**).

2. Use of autochthonous plant species. The use of species belonging to regional species pool guarantee resilience to the artificial ecosystem as these species are already adapted to local conditions. In this way green roofs can be part of the greater ecologic network as they can host metapolulations of targeted species that otherwise would not survive in urban environments. Moreover, nurseries would be encouraged to produce seeds and plants of native species.

3. Low maintenance and disturbance. It is know from applied ecology that to a moderate disturbance correspond higher biodiversity. For this reason, green roofs for biodiversity do not need maintenance if not the annual cut in case of established grasslands or the eradication of little phanerofites (shrubs and trees). However, the low maintenance regime requested from the biotic and abiotic parts of the system, should not influence the periodical check-up of the technical and structural part.

2.4   Extensive green roofs: stepping stones for habitat of Community interest.

The interest of ecologists for urban habitats and of the applied research for green roofs was crucial to determine a comprehensive evaluation of their ecosystem services (Oberndorfer 2007) but also their consideration as habitat within the urban ecosystem (Sutton 2015). This arising awareness affected the designing phase especially the plant species selection for extensive- and simple-intensive green roofs (10-20 cm of substrate thickness). In fact, both typologies are not specifically meant to be accessible and therefore do not have to satisfy any specific aesthetical need and appreciation (Dunnett 2009) as it happens for roof gardens or intensive green roofs (50-100 cm thickness).

The species able to survive on green roofs are the one that in nature live in similar conditions: shallow and nutrient poor substrates, wind and sun exposure, high evapotranspiration and prolungated drought period. The approach to use natural habitat like limestones pavements, dry meadows, cliffs and stone outcrops as models for species selection is known as habitat template or habitat analogue (Lundholm 2006, Lundholm e Richardson 2010). This approach came across particular success in USA and in the Mediterranean regions of Europe (Catalano et. al. 2013; Van Mechelen et al. 2013) that is in geographical areas where green roof technology do not have an old and consolidated tradition like in central Europe. In Italy in fact, research is predominant and homogeneously distributed along the national boundaries (Palermo, Catania, Messina, Cosenza, Roma, Pisa, Firenze, Perugia, Bologna, Genova, Milano, Padua, Bolzano, Trieste) in comparison to the production which mostly concentrated in the north east part of the country (Venetia, Bolzano and Trieste).

In France, Van Mechelen et al. (2013) determined a pool of 142 species adapted to grow on green roofs in Mediterranean climate adopting the habitat template approach for the regions Languedoc-Roussillon and Provence-Alpes-Côte d'Azur. Plant species were obtained from vegetation relevès in open vegetated areas with shallow soils and limestones pavements but also from published phytosociological relevès of the selected areas. The results were refined according to specific functional traits (Raunkiaer life forms, Grimes's plant strategies - CSR) obtaining a list with several hemicryptophytes (perennial plants with overwintering buds at soil level) and few therophytes (annual plants that overwinter as seeds). According to the selected habitats the four clusters were 1) garrigue vegetation of limestone pavements rich in annual species with mosaic of other biological forms; 2) basophilic vegetation rich in therophytes with mosses and lichens; 3) mesophilic calcareous grassland with few therophytes and geophytes (perennials herbs with underground buds); 4) mesophilous and xerophilous garrigue and dry grasslands with very fiew therophytes. Species with roots deeper than 20 cm were excluded from the initial dataset. The latter could be reconsidered as species on green roofs develop differently than on the ground e.g. dwarf species, bigger root area, plagiotropic behaviour due to the shallow substrate and the constrain of the root barrier membrane.

In Italy, Caneva et al. (2013) obtained a list of 138 Mediterranean species capable to cope with green roof condition by comparing the list of species tested and published in literature and species selected using the habitat template approach. The latter list of species was obtained using the following filters: phytosociological relevès, habitat analogues to green roofs (rocks, walls, screes, retro-dunes, perennial steppe meadows and synanthropic habitats) (Blasi et al. 2011), chorology, biological forms and physiological characteristics (Landolt and Ellenberg indexes) for the Italian flora (Burba et al. 1992, Pignatti et al. 2005, Guarino et al. 2010, 2012). Unjustified excluded species were the annual and biennial species (therophyte and short cycle hemicriptophytes) that constitute actually a distinguish characteristic of Medieterranean landscapes. Moreover, a comprehensive species list for all the Mediterranean basin is not suitable to be used as a guideline for local seed mixture.

The phytosociological approach (Braun-Blanquet 1932) was proposed in Sicily as a specific case of habitat template (Catalano et al. 2013) where analogous habitat are considered as a model in order to recreate the specific plant consortia. The phytogeographyc approach was brought to landscape architecture from Jacobous P. Thijsse in the Netherland (Woudstra 2004): the planting and design according to species provenance and the characteristic assemblage as occurred spontaneously in nature (Van Laren 1929, Thijsse 1934). Probably is not just a casualty that Reinhold Tüxen from the neighbouring Lower Saxony emphasised the utility of the phytosociological method for ecological planning (Tüxen 1939, Kniese 1942).

To implement the ecological value of green roofs, habitat analogues could be selected among the one of Community Interest (Habitat Directive 92/43/CEE, Annex I) fostering the connectivity among those habitat as it

is advisable in the Directive document itself (Biondi et al 2012). The key role of green roof for habitat connectivity within the built environment was proved in Zurich for the arthropod communities with different mobility (*Carabidae, Araneae, Curculionidae* and *Apidae*) (Braaker et al. 2014).

The habitat of the Directive 92/43/CEE (Biondi et al. 2009) replicable on green roofs are those related to: 1) sandy substrate (psammophilous vegetation of sea dunes of the Mediterranean costs); 2) substrate with gravel, pebbles and sand (scree and cliff vegetation); and 3) xeric substrates (garrigue and dry grasslands) (Catalano et al. 2013).
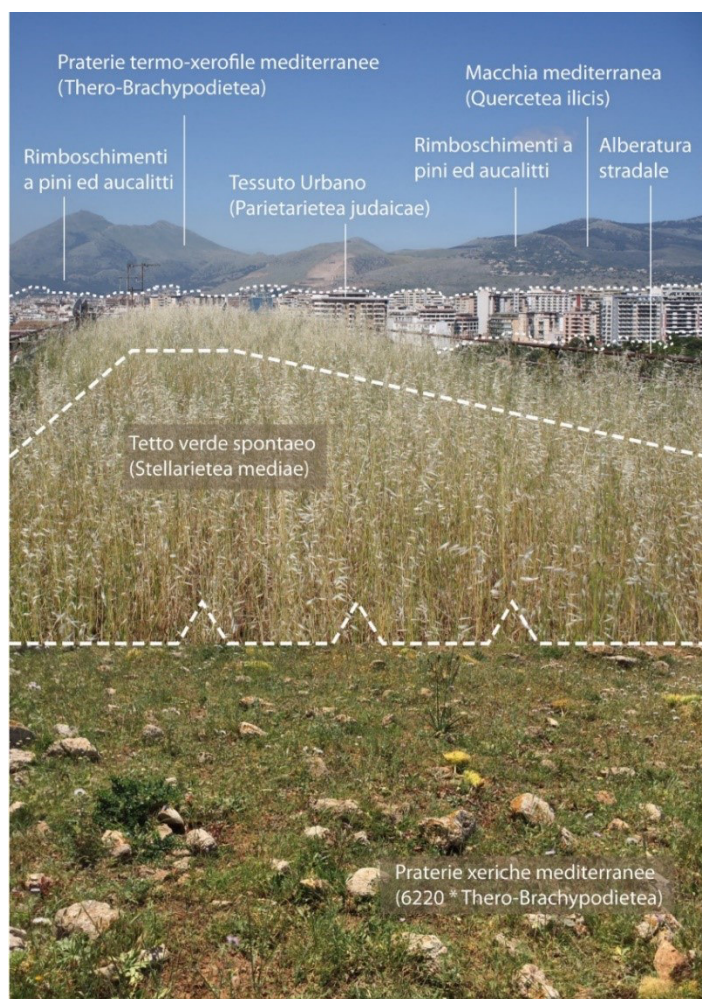
Figure 9. The phytosociological approach. Photomontage with actual habitats (spontaneous green roof in Palermo) and reference habitat (6220* Thero-Brachypodietea in Cornino Capo, Trapani). Photo Chiara Catalano.

1. To the first group belong the habitats of the sea dunes of the Mediterranean costs: the *Crucianellion marittimae* fix beach dunes (2210), the *Malcolmietalia* dune grasslands (2230), the *Brachypodietalia* dune grasslands with annuals (2240) and the *Cisto-Lavanduletalia* dune with sclerophilous vegetation (2260). In this case, the gradient corresponding to primary succession of the vegetation, from the shoreline to the retro-dune (Acosta et al. 2007), could be replicated on green roofs by choosing sandy substrate with different thickness. This will allow the creation of spatial heterogeneity mimicking the dune communities: therophytes will dominate on the very shallow substrate areas (2230), therophytes and hemicriptophytes on intermediate thickness (2240, 2210) and hemicriptophyte and camephytes (small bushes with buds at less than 30 cm from the ground) (2210, 2260) on small higher hills.

2. To the second group belong: the low formation of *Euphorbia* close to cliffs (5320); the vegetation of the Thermo-Mediterranean and pre-desertic scrub (5330); the western Mediterranean and thermophilous scree (8130); and the calcareous rocky slopes with chasmophytic vegetation (8210). This will allow the creation of

rock gardens-like roofs where dense and patchy vegetation flourishes among coarse gravels and pebbles of different size.

3. To the third group belong the vegetation of the pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea* (6220*) of semi-natural dry grasslands. This kind of vegetation is characterised by the presence of hemicriptophyte, camephyte and therophyte and it could be easily and well reproducible on green roofs. A preliminary study at issue was run on a green roof realised at the beginning of the '90 with Mediterranean red soil in Palermo (fig. 9). To verify the compatibility between the host- (the roof) and the donor (dry grassland of the 6220*) habitat, 16 substrate cores were analysed (5 on the roofs, 4 on natural areas in Palermo, 4 in natural areas in Trapani and 3 in the neighbouring agricultural field). Of the 15 chemical and biochemical parameter measured (e.g. Carbonio Organico Totale (TOC); Azoto Totale (TN); Conduttività Elettrica (EC); pH; Capacità di Scambio Cationico (CSC), etc.) none of them showed a significant difference assessing the suitability of a 25 years old soil-based green roof substrate to host semi-natural mediterranean dry grassland communities (Catalano et al. 2015).

| a | b |

Figure 10. a) Summer yellowish vegetation on the green roof of the of the Ottawa war museum. b) Wheat Field with Cypresses by Vincent van Gogh (1889).

2.5   Conclusions

Nature conservation on green roofs offer new perspectives to urban sustainability: green roofs for biodiversity constitute rooms for Nature above our houses. To camouflage the vegetated rooftops into the landscape, the design and the maintenance regime have to take into account spontaneous colonisation, communities succession, natural cycles and the decay of the vegetation from green to brown and yellow (fig.10).

However, in order to give the "naturalistic" approach a chance to develop it is necessary to act into the education and technical spheres: sensitizing the public opinion starting from the new generations (eco-litteracy) and training professionals able to conjugate scientific knowledge (analytic phase) with design (creative phase) (Stokman, A., & von Haaren, 2012). Landscape architects have to be able to express the genius loci and to shift the traditional anthropocentric way of design which satisfy only human-needs (aestethical) and sensitivity (emotion connected to the individual knowledge) towards an ecologic, systemic and *ecocentric* approach (Austin 2014). An Eco-designer should operate considering the local climatic conditions, the potential vegetation and the interaction with neighbouring biocenosis: he/she has to be also an ecologist in order to combine the ways of nature to the ways of man.

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3   A plant sociological approach for extensive green roofs in Mediterranean areas

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Abstract

Extensive Green roofs can be an important mean for environmental mitigation if designed according to the principles of restoration ecology. Moreover, if optimally executed, properly managed and of sufficient extension, they could be assimilated to meta-populations of natural habitats, worth to be included in the biodiversity monitoring network. The best example supporting this hypothesis is the Lake water plant Moos in Wollishofen (Zurich, Switzerland) where, on three 100 years old units of extensive green roofs, occur most of the typical flora of *Mesobromion*, including high density of some endangered orchid species. With this work, we propose a methodology approach for green roofs in Mediterranean areas, based on a practical plant sociology understanding of EU Directive 92/43: a recognition of Natura 2000 habitat that could be imitated on roofs in terms of characteristic species and substrates. Our results lead to three category groups: those linked to sandy substrates (psammophilous vegetation), to gravely-pebbly substrates (glareicolous vegetation) and to xeromorfic soils (garrigues and dry grasslands). According to the last theories and practical application for grasslands restoration, we suggest a method applied and studied in Switzerland for green roofs based on diaspore hay transfer from a donor meadow, in order to obtain the highest plant species richness and diversity.

Keywords: Extensive green roofs, plant sociology, habitat replication, biodiversity assessment, Natura 2000, hay transfer.

3.1   Introduction

The Mediterranean climate is characterized by dry, sunny summers and mild, rainy winters which are imposing to the vegetation two critical periods: summer drought and winter cold that, above 500 m, can be rather intense (Mitrakos, 1980). The environmental conditions on the roofs are even more critical, because of the shallow substrates, the daily temperature fluctuations and intense evaporation, with an increased tendency to dehydration. Moreover, green roofs are exposed to all the features typical of the urban ecosystem, such as the heat island effect, pollution and particulate, nitrogen and nutrients upload from human activities (Bettez & Groffman, 2013) including the abundance of synanthropic and invasive neophytes.

In this work we present a methodological approach for roof greening in Mediterranean regions, bases on the mutual relationship between the vegetation and the edaphic-climatic conditions, studied by the plant sociological science to describe the natural vegetation in terms of species assemblages, spatial and ecological range,

endogenous variability and dynamics (Braun-Blanquet, 1964). We believe that getting inspired by the plant communities existing in nature, may be a fundamental mean in the functional design of the green roof system. The approach of restoration ecology will give new perspectives regarding the spatial importance and impact, beside the traditional gardening approach of establishing vegetation on extensive green roofs which often includes the use of non-native plant species, often invasive, that may cause problems threatening native ecosystems. In fact, variables such as size, substrate depth, type and composition, micro-habitats patchwork and species diversity and interaction (endogenous variability) together with micro-climate influence, local disturbing factors and/or proximity to natural habitats (exogenous variability), can affect species richness, composition and succession in this built environment (Kadas, 2002; Gedge, 2002; Brenneisen, 2003; Dunnett 2006; Bass & Currie 2010).

An astonishing example of what kind of plant communities can establish - showing the potential conservation value of extensive green roofs - is the Lake Water Plant Moos in Wollishofen (Zurich, Switzerland) (Brenneisen 2006, Landolt 2001) (figure 1). Landolt (2001) found 175 plant species, including nine orchids species and many other endangered or rare in the eastern Swiss Plateau. Most impressive are the ca. 30'000 individuals of *Anacamptis morio* a species otherwise extinct in the surroundings of Zurich (Schnurrenberger & Spühler 2010). Moreover, the vegetation on Lake water plant Moos reflect the species richness of agricultural land at the beginning of the 20th century.

Figure 1. Lake Water Plant Moos in Wollishofen (Zurich, Switzerland) after the annual mowing. The meadow is cut in stripes to allow animals to find refuge and late flowering plant to disperse their seeds (photo Chiara Catalano)

Besides of being widely used to describe the natural vegetation throughout Europe, the Braun-Blanquet's plant sociological approach has been used to analyse and describe the spontaneous vegetation that colonized some roofs in the historical centres of many central European towns, with particular reference to those built at the beginning of 1900 (Sukopp et al. 1990, 1995; Thommen 1988). Typically, those roofs adopted a sandy-gravel layer as a protection for the waterproof membrane that enhanced the vegetation to permanently establish, due also to the accumulation of dung and nitrates over time (e.g. seagull colonies and city pollution). These phytosociological investigations highlighted an abundant vegetation ascribed to the class *Sedo-Sclerantetea*, whose chief species are featuring several habitat types targeted in the EU Directive 92/43 for the conservation of the most relevant European biotopes (Natura 2000 framework). In particular, the habitat codes 2330, 8230 and 8240 have many similarities with the natural vegetation colonizing the central European ancient roofs. This demonstrates that a well designed extensive green roof, besides of enhancing the aesthetical value and environmental performance of a building, could also play an active role against habitat loss, being a potentially undisturbed areas where also endangered species could find their habitat or, at least, a stepping stone within the urban environment. For instance, the rare *Sideritis montana* has its only stand within the Region of Friuli Venezia Giulia in the town of Trieste, on the gravel roofs of Liberty-style buildings (Martini et al. 2004).

According to the results of these investigations, we identified some habitats mentioned in the EU Directive 92/43/EEC that could be potentially imitated on roofs in terms of characteristic species and substrates (natural top soil, sandy gravel and loamy sand substrates) in Mediterranean basin. Beside of the theoretical interest of our experimental design, it may represent an useful approach for the promotion and proper use of eco-building techniques.

3.2   Methodology

Habitat selection

Basing on the available plant sociological literature, a first screening was done on all habitats belonging to the Natura 2000 network known for the Mediterranean region. A reference list of the consulted literature is available at the following website: http://vnr.unipg.it/habitat/index.jsp.

In order to select the most suitable habitats for extensive green roofs, the following criteria were considered: species composition, vegetation structure, ecological conditions and distribution range. On the base of the Raunkier's classification of plant life forms (Box, 1987), preference was given to the vegetation types linked to the habitats characterized by the prevalence of pioneer, drought tolerant therophytes, hemicryptophytes and small chamaephytes, dwelling poorly developed soils and eroded slopes.

Habitats having a species poor and scattered vegetation were excluded, as well as those characterized by a limited distribution range in the Mediterranean Region. The remaining habitats were grouped into three categories: those linked to sandy substrates (psammophilous vegetation), to gravely-pebbly substrates (glareicolous vegetation) and to xeromorfic soils (garrigues and dry grasslands).

Biodiversity assessment

Even if the approach to biodiversity assessment on extensive green roofs is classically based on the evaluation of species richness (Coffman & Waite, 2011) included non-native species (Hui & Chan, 2011) or presence-absence of Red List animal species (Brenneisen, 2006), we esteem that the similarity, and therefore the compatibility, with natural biotopes should be focused on the vegetation cover, coherently with the current trends in ecological research. In particular, a plot-based approach enable to evaluate a number of additional parameters, which are much more informative than species checklists (Box & Fujiwara, 2011) based on the assumption that a given fauna can always be associated to well defined vegetation units. Indeed, it has been widely demonstrated in ecological research, that the occurrence of motile organisms in a given site, does not necessarily imply their stable presence, which instead is related to the attitude of the system vegetation-soil, to fulfil the behavioural traits of the inhabiting fauna.

An highly standardized method widely used for the biodiversity assessment and monitoring of herbaceo-chamaephytic natural vegetation was proposed by Dengler (2009) and it is based on a nested-plot sampling sized 0.0001 m², 0.001 m², 0.01 m², 0.1 m², 1 m², 10 m², 100 m². All areas below 100 m² are replicated twice within the largest plot. Besides of the species list in incremental surfaces, the following parameters are recorded in every 10 m² plot: percentage cover value of all occurring plant species; structural data (height and cover of vegetation layers); GPS coordinates (latitude, longitude, altitude); relief (inclination, aspect, relief position, microtopography); land use; soil depth, stone cover, litter and a mixed soil sample for the analysis of basic chemico-physical parameters (Corg, nutrients, pH, carbonate, conductivity, loss on ignition, soil texture).

By using replicated smaller subplots, the approach does not only provide mean richness values, but also information on their variability, such as diversity indices, accounting for the varying performance of different species. Another parameter that can be easily obtained is the characterization of the species-area relationship and its variation over time, if the sampling is replicated yearly. Further, the frequency distributions of species at different spatial scales provide meaningful diversity information (Allers & Dengler, 2007) and the sampling approach with several replicates of all smaller plot sizes distributed within the largest plot allows a sound assessment of spatial heterogeneity of floristic, structural and abiotic parameters (Dengler, 2009).

The Dengler's approach can be easily applied to the biodiversity assessment on green roofs, to analyse the similarity ratio with comparable vegetation types in natural biotopes and its eventual variability over time.

3.3 Results

According to our screening, the list of Natura 2000 sites that could be imitated on Mediterranean roofs, in terms of characteristic species and substrates (loamy-sandy substrates, sandy gravel and natural top soil) is reported below, with short references to the construction techniques. Further details on such issue are reported in the discussion paragraph. In the following comments, bioclimatic units refer to Rivas-Martínez (1994,1996); plant sociological units refer to the European syntaxonomical checklist (Rodwell et al., 2002).

1. Psammophilous vegetation (Habitats 2210 Crucianellion maritimae, 2230 Malcolmietalia dune grasslands, 2240 Brachypodietalia dune grasslands with annuals, 2260 Cisto-Lavanduletalia dune sclerophyllous scrubs)

Coastal dune system are characterized by strong environmental gradients, which determine the coexistence of different vegetation types in relatively small areas (Frederiksen et al., 2006). One of the most outstanding features of these habitats is an high ecological diversity in terms of environmental heterogeneity and variability of species composition (Van der Maarel 2003; Martínez et al. 2004). In dune ecosystems, the most obvious gradient associated with vegetation diversity is related to primary succession with the earliest stages along the shoreline and more developed vegetation types landwards (Acosta et al. 2007; Doody 2008). This shoreline–inland gradient is influenced by a set of ecological factors such as wind, waves, salt concentration, dryness and grain size of sand (Boyce 1954; Rozema et al. 1985; Hesp 1991) resulting in characteristic zonation of species assemblages and vegetation types (Barbour 1992; Davy & Figueroa, 1993).

This allow a great versatility to design green roofs with sandy substrate, that, according to granulometry and see side distance, could recreate combinations of both annual and perennial species. In fact, different condition can be recreated by varying the substrate thickness with reference to habitats 2210 and 2260 for higher depths (10 -16 cm) and habitats 2220 and 2230 for lower ones (6-10 cm). Moreover, the vegetation of the latter habitats is dominated by annual plants and therefore is suitable to be mowed in order to get seed and mulching materials that, due to its fast decomposition, is a good initial biomass source. Instead, to get seeds from characteristic species from habitats 2210 and 2260, which are dominated by hemicryptophites and chamaephytes respectively, manual collection should be preferred. In this case the mulching material could be represented by alfalfa hay (Medicago sativa L.), which is mowed in flowering time and therefore doesn't contain seed that could compete with the sowed species, compromising the integrity of the system.

In Mediterranean areas, coastal littoral has been strongly damaged due to high urbanization rate (urban sprawl) and tourist infrastructure. Green roofs (recommended on existing buildings) with the previously mentioned communities could contribute to the protection of endangered species and habitats.

2.   Glareicolous vegetation (3250 Constantly flowing Mediterranean rivers with *Glaucium flavum*, 5320 Low formations of Euphorbia close to cliffs, 8130 Western Mediterranean and thermophilous scree)

Mixed perennial and annual vegetation, growing on lithoclastic incoherent substrates, where the pedogenetic processes are hampered by a periodical supply of clasts. These habitats are represented by riverbeds and talus slopes covered with pebbles, stones and gravel. In the Mediterranean region, the vegetation at issue refers mainly to the plant communities ascribed to the class *Scrophulario-Helichrysetea italici* (Brullo et al. 1998). They are dominated by pioneer hemicryptophytes and chamaephytes forming an open patchwork, whose interstitial space is occupied by annual species that dry up at the beginning of the summer drought, leaving behind a rich soil seed bank that ensures their persistence across the dry season.

The ecological gradients associated with vegetation diversity are driven primarily by the elevation, granulometry, chemical properties of the substrata together with water availability and periodical floods. In particular, the most suitable plant communities for green roofs belong to the following two alliances: *Linarion purpureae* and *Euphorbion rigidae*, the former including the vegetation of scree and talus slopes from the meso- to the oromediterranean bioclimates; the latter including the vegetation of gravelly riverbeds in the thermo-mesomediterranean bioclimates. The interstitial annual vegetation belongs to the classes *Tuberarietea guttatae* and *Stipo-Trachynietea distachyae* on acidic or neutral alkaline soils, respectively.

The vegetation units characterizing the habitat 5320 are suitable for application on coastal areas, on roofs slightly influence by the marine areosol, while those of the habitat 8130 can be considered only in mountain areas (supra- and oromediterranean bioclimates).

As in the previous case, there is plenty of possibilities to design highly diverse vegetation covers through the variation of depth and granulometry of the adopted substrata. On wide surfaces these variations will increase the patchiness and the chromatic-textural variance of the roof. The seeds of annual plants can be obtained through the mowing while those of perennial ones have to be collected manually.

3.   Garrigues and dry grasslands (5330 Thermo-Mediterranean and pre-desert scrub, 5420 *Sarcopoterium spinosum* phryganas, 6220* Pseudo-steppe with grasses and annuals of the *Thero-Brachypodietea*)

The considered habitat units include a variety of xerothermophilous garrigues and dry grasslands growing on oligotrophic soils throughout the Mediterranean region, from the thermo- to the supramediterranean bioclimate, from coastal to inland areas within markedly edapho-xeric conditions (Biondi et al, 2012). This vegetation is

mainly secondary, linked to degradation processes of woodlands due to the human influence (fire, overgrazing, deforestation). In particular, fire has been traditionally used in the Mediterranean area to create rangelands since prehistoric times. The species diversity in these habitats is constrained within certain limits of predictability by the spatial heterogeneity, periodical disturbance and stochasticity that is the basis for understanding the coexistence, in the same plots, of annual and perennial species (Guarino, 2006; Guarino & Ilardi, 2009). Typically, the Mediterranean dry grasslands consist of a mosaic, formed by more or less dense tussocks of perennial grasses with interstitial spaces occupied by annual grasses. The density of perennial vs. annual species is greatly influenced, as well, by disturbance and soil compaction: an excessive grazing pressure during the rainy season compacts the soil near the surface, which reduces infiltration, percolation, and water holding capacity, and concentrates roots near the surface (Menke 1989). Soil compaction also impedes root elongation, placing deep rooted species, such as the perennial bunchgrasses, at a disadvantage during seedling establishment. Seeds of annuals germinate faster and earlier and the roots develop faster than those of the seedlings of perennial grasses. Differences in germination date and early seedling vigour may determine the competitive ability of one functional group (Joffre 1990, Garnier 1992).

As far as perennial plants are concerned, the ratio between grasses and dwarf-shrubs is often influenced by the structure and texture of substrata, with grasses dominating on relatively more nutrient-rich carbonatic or marly soils and dwarf-shrubs on acidic or leached substrata (Guarino et al., 2006). In particular, most of the Mediterranean thermo-xerophilous dwarf-shrubs display several symbioses with fungi and bacteria, in order to increase the efficiency of nutrient-uptake (Kummerow, 1981; Puppi & Tartaglini, 1991)

Due to the strong relationship between human disturbance and the vegetation units at issue, the optimal way to collect seeds material is hay transfer from a donor meadow to the roof combined with manual collection of the seeds of shrub species. Copying the habitat and varying the thickness and the quantity of organic matter of the substrate, the characteristic patchiness of colours and textures of ephemeral and perennial species would be easily recreated.

3.4 Discussion

The methodology of hay transfer, as an alternative restoration method, is a technique developed since the last decade, based on the application of fresh mowing from areas with similar habitat conditions, which may be paired to topsoil removal (Kirmer & Mann, 2001; Patzelt et al. 2001; Hölzel & Otte 2003). Moreover, studies showed successful results in terms of plant species richness, number of target plant species and Red List plant species, both in a short- and long-term analysis, for the re-establishment of species rich grasslands (Kiehl & Wagner, 2006).

Figure 2. Hay transfer method (known also as mulching technique) applied on the green roof of Technopark in Zurich. a) roof (sandy-gravel substrate with scarce vegetation) prior to the intervention, b) laying of ca. 2 cm commercial garden substrate and fresh hay collected in September from the Zurich Lake water plant green roof in Wollishofen, c) result of the installation after a year, d) laying of ca 2 cm commercial garden substrate and sowing of seeds from threshed hay collected from July to September from the Zurich Lake water plant green roof in Wollishofen), e) result of the installation after a year

Applying diaspores with plant material (hay) has the advantage of having large plant species pools that normally are not commercially available with particular reference to rare species; of serving and maintaining the

genetic material; of protecting seeds from extreme micro-climate conditions, specially on bare soils; of being a cheaper practical application in comparison with direct seed sowing.

a

b

c

d

e

Figure 3. Seeds obtained from donor meadow hay. a) Collection from donor meadow, b) drying of the hay and collection of the seeds from the ground, c) sieving of the final material containing seeds and fine hay to remove bigger leaves and stems, d, e) material germination tests in trays.

This technique, indeed, has been applied to improve Natura 2000 poor mesophilus species-rich grasslands (Buchwald et al., 2007) and in general to restore grassland biodiversity in combination with the sowing of structuring species (Coiffait-Gombault et al., 2011; Pèter Török et al. 2012).

In Switzerland, the Green Roof team from the Zürcher Hochschule für Angewandte Wissenschaften (ZHAW – University of Applied Science) utilize for roof greening selected seed-mixture (UFA certified seeds) together with hay from close protected areas and/or from Lake water plant Moos in Wollishofen (Zurich). This suggest that green roofs themselves could represent also an alternative seed source. In fact, the team is running an experiment on hay transfer and seed collection from the aforesaid roof in Wollishofen (Zurich) (figure 2) and from donor meadows in Reinach (Basel land, Switzerland) and Lörrach (Baden-Württemberg, Germany) (figure 3).

The total plant species richness and the number of target plant species are surely affected by mowing time and frequency. In fact, the seeds obtained from one time mowing source material, contain lower number of species compared with the richness of the donor meadows, due to the early- or late- flowering species (Kiehl & Wagner, l.c.). Therefore, one of the aim of the project is to define a replicable method to gain a final greater specie richness results, due to the repeated mowing within one season. To determine the seed quantity/diversity apex and therefore the mowing frequency, that in this specific case was set weekly from July to September 2013, a preliminary vegetation analysis and a floristic list is needed. Successively, according to the theoretical anthesis diagram, it is possible to establish the maximum flowering period that involve the higher number of species and consequently the highest diaspora, generally after one month. Evaluating on site the shifting period due to yearly changing climatic conditions, it is possible to define the mowing schedule. Unfortunately, the possibility to apply fresh plant clippings is rare and therefore the hay, after harvested, is dried and stored in big bags in a ventilated, covered space. The monitoring of the achieved results will be done through plant sociological relevés that will be compared with the known genetic material source.

3.5   Conclusions

The desirable collaboration between vegetation ecologists and planners, when designing a green roof in terms of species richness, seed source and collection, will lead to a comprehensive designing approach counting on some preliminary analysis such as climatic conditions (bio-climatic regions) and vegetation potential, including endangered species and habitats. Moreover, with the adoption of the plant-sociological approach to select the species, it is reasonable to predict that living roofs without irrigation are also possible in Mediterranean areas due to an increased resiliency of the system. In fact, many Mediterranean species (xerophytes) have developed morpho-functional and physiological adaptations to survive in the arid climatic conditions: changes that affect the leaves (imbricate or often linear, with a thick, waxy cuticle, silvery colour, sunken stomata), the roots (deep rooting, hairy surface, fast development of young plants, symbiotic relationships), decreased photosynthesis,

loss of leaves in response to drought, incident solar radiation and high summer temperatures (Davis & Richardson, 1995). Furthermore, the Mediterranean regions have a unique floristic richness, with over 24,000 species of plants of which 35% are endemic (hot spots) and many of them linked to the Mediterranean basin.

As last, but not less important, people should be aware that those roofs would change colour and appearance during the year, following nature cycles, seasonality and respecting the genus loci. This has to be considered as an assumption that would need public effort: if roofs of public buildings would be greened following this approach (best practices), imitating and blending with the surrounding, citizens would start to perceive green differently and in line with the main principle of sustainability to design with nature.

Acknowledgement

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4　Thirty years unmanaged green roofs: ecological research and design implications

Abstract

The variations in species composition and assemblage of unmanaged simple-intensive green roofs in Hannover, Germany, were investigated over a thirty year period, in order to assess the persistence of the initial seed mixture and to evaluate floristic changes. The roofs were greened in 1985 with soil-based turf rolls sown with a mixture of five grasses (Festuca rubra, F. ovina, Agrostis capillaris, Lolium perenne and Poa pratensis). Three sets of 120 phytosociological relevés, sampled in 1987, 1999 and 2014, have been compared to assess: (1) nestedness vs. spatial turnover, (2) functional diversity and (3) the importance of vegetation dynamics on green roof performance and design. Results demonstrated that from 1987 to 1999 the species diversity increased and the species turnover prevailed over nestedness, due to the progressive niche occupation by new species. In contrast, from 1999 to 2014 species diversity remained steady, suggesting that nestedness prevailed over species turnover. The main driver of the observed functional changes was a shift towards relatively more thermo-xeric conditions. In terms of plant life strategies, the competitive species sown on the roof gradually gave way to stress-tolerant and ruderal species, along with a progressive increase in species with short-distance seed dispersal strategies. It is concluded that: (a) to create resilient green roofs, spontaneous colonisation should be accepted and considered as a design factor; and (b) regional plant communities could serve as a model for seed recruitment and installations.

4.1　Introduction

Urban sustainability is one of the urgent challenges of the 21st century (Wu, 2014), since more than 50 % of the world's population live in urban areas, and this figure is estimated to reach 66 % by 2050 (UNDESA, 2014). Continuously spreading cities and the growth of intensive agriculture are the major causes of habitat loss and fragmentation worldwide (Grimm et al., 2008). However urban green spaces can play a key role in biodiversity conservation (Goddard et al., 2010) and enhance urban ecosystem resilience (Colding, 2007). In particular, green roofs can partially compensate for the loss of green areas by replacing impervious surfaces, contributing to an increase in urban biodiversity (Brenneisen, 2003, 2006). In fact, by replicating specific habitat features and conditions, these artificial biotopes can host native flora and fauna in relatively undisturbed stands where plants, insects and birds can become established (Köhler, 2006; Kadas, 2006; Baumann, 2006).

The first known study of the biotic colonisation of green roofs dates back to 1940, when Kreh (1945) listed the plant species colonising some tar-paper-gravel roofs in Stuttgart, Germany. This roofing technique was

developed at the beginning of 19th century in Silesia and consisted of a combination of tar and four layers of paper covered by a mixture of gravel and sand (Köhler & Poll, 2010). In Kreh's study (1945), species were categorised according to the following functional group: bryophytes, CAM (Crassulacean Acid Metabolism) species and therophytes, substrate depth preferences (5 to 20 cm), pollination and dispersal strategies.

Modern green roofs can be classified as intensive, extensive and simple-intensive (German guidelines; FLL, 2008). Extensive green roofs consist of a shallow substrate ranging from 6 to 15 cm, planted or sown with drought tolerant plant species, and require low maintenance; intensive green roofs consist of a > 20 cm thick substrate (normally top-soil), planted with woody and/or herbaceous species, and generally require irrigation and high maintenance; and simple-intensive green roofs can be seen as an intermediate roof type, consisting of 15-20 cm thick substrate (including top-soil), hosting perennial grasses and tall herbaceous species, and require medium maintenance.

Several studies of spontaneously colonised tar-paper-gravel, simple-intensive as well as extensive green roofs in central Europe, have described the recurrent plant communities thriving on different depths and kinds of substrate (Darius & Drepper, 1984; Thommen, 1986; Borchardt, 1994). These studies found that on 5-8 cm gravel roofs, stress tolerant species (Sedo-Scleranthetea) are enhanced while greater depths favoured ruderal species (Artemisietea vulgaris and/or Stellarietea mediae) and competitive species (Molinio-Arrhenatheretea and Festuco Brometea) (Bornkamm, 1961; Bossler & Suszka, 1988). Moreover, humus accumulation, nutrient supply and water holding capacity were identified as the main environmental drivers for plant establishment and community dynamics over time.

Recently, plant functional traits including Grime's CSR strategies (Grime, 1974, 2001) and life forms, have been used to predict green roof ecosystem services and identify suitable plant species (Nagase and Dunnett, 2010; Lundholm et al., 2010; Van Mechelen et al., 2014).

Despite the importance of long-term data in providing adequate planning recommendations (Rowe et al. 2012), only few studies have examined green roof dynamics for more than a decade (Krüger, 1999; Köhler, 2006; Köhler & Poll, 2010). Köhler & Poll (2010) assessed the effects of growing media on the vegetation quality and species richness of roofs in Berlin over a time span ranging from 13 to 48 years. Krüger (1999, 2001) instead focused on the changes in species composition over 12 years on the roofs of an eco-settlement in Hannover previously investigated by Ackermann & Vahle (1987).

The present study revisited the research site investigated by Ackermann & Vahle (1987) and Krüger (1999, 2001) to examine the composition of the plant community over a thirty year period. Where the main goal of previous studies was the phytosociological description of the vegetation, with the recognition of different facies

(characterized by the dominance of a given species) and typologies, the current study focuses on whole roof communities.

We hypothesised that species composition and assemblage on unmanaged green roofs would have changed over the course of thirty years. Specific aims were: (1) to assess if such changes were due to nestedness (species loss) or to turnover (species replacement), (2) to determine changes in species and functional diversity over time and (3) to assess the importance of vegetation dynamics on green roof performance and design.

4.2   Materials and methods

Study area
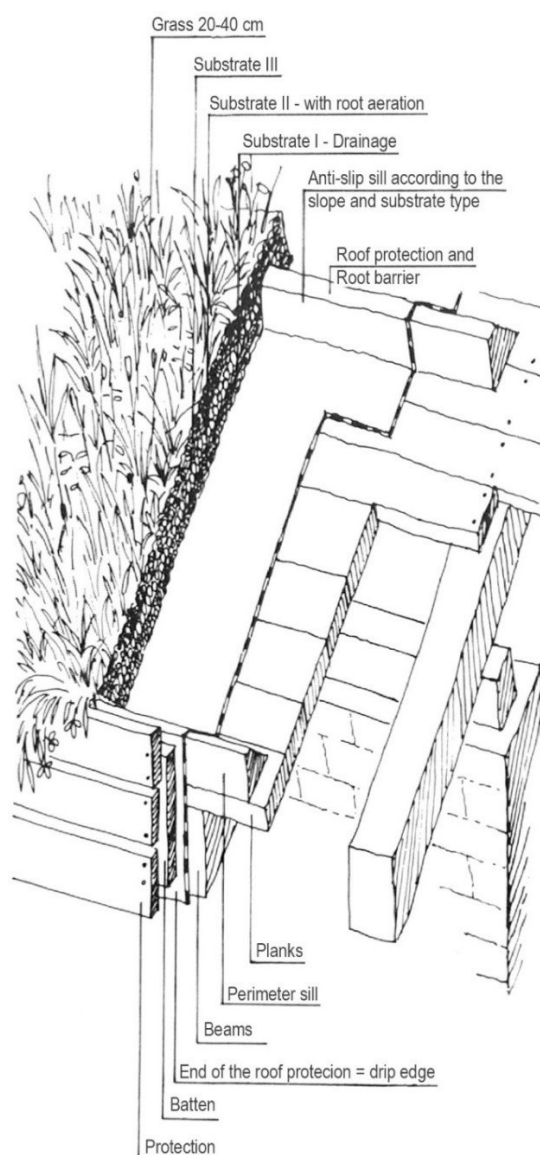
Figure 1. Detailed sketch of System Minke used in investigated roofs (after Minke & Witter, 1983, p. 42, modified).

The study area consisted of 15 simple-intensive green roofs of the Waldorf School in the eco-settlement "Laher Wiesen" in Hannover (Germany, 52°22'N, 9°43'E; 55 m a.s.l.), built between 1983 and 1985 on land formerly cultivated for rye, 9 km away from the city centre. The area lies north of the city park Eilenriede, near Laher Wald, at the southern edge of the Bothfeld district. Along the northern side, the eco-settlement is adjacent to farmland, whereas the other sides neighbour the city conurbation.

The local climate, according to the Köppen-Geiger classification, is warm-temperate, fully humid (Kottek et al., 2006). The roofs of the eco-settlement were designed by Boockhoof & Rentrop architects and by the landscape architect Gustav Störzer on the basis of the Grassdach-System-Minke roofing technique (fig. 1) (Minke & Witter, 1983; Minke 2000). This technology was conceived for sloped roofs (5-25°) and consists of a wooden structure sealed with a root resistant, waterproof PVC membrane and a mixture of local topsoil and light aggregates overlapped by a readymade turf carpet (Rollrasen). The investigated roofs had an inclination of 25°, and were elevated 4 to 7 m from the ground.

Although differences in exposure and shade cast by trees could have locally influenced the roof vegetation, the effect of these variables were not investigated in the current study since we were interested in temporal changes in species composition, rather than in spatial variation. The substrate consisted of a mixture of topsoil/expanded clay (liapor) in a 1:1 ratio, 8 cm thick, plus another 8 cm in a 2:1 ratio. The turf rolls were prepared next to the settlement on plastic films to prevent root penetration into the ground. Ten centimetres of topsoil was sown with commercial seeds of Festuca rubra (50%), Festuca ovina (25%); Agrostis capillaris (5%); Lolium perenne (5%); Poa pratensis (15%) and installed on the roofs after 6 months. Our investigation focussed on the roofs of the Waldorf School (fig. 2), since they were left to the natural succession, in contrast to the rest of the settlement, where turfs were periodically irrigated, fertilised and mown as was originally intended (Krüger 1999, 2001). Since their installation, the roofs of the Waldorf School have been surveyed twice: in 1987 (Ackermann & Vahle, 1987) and in 1999 (Krüger, 1999), allowing the presented long-term vegetation study and a realistic performance assessment.

Figure 2. Location of the 64 relevés sampled in 2014.

Vegetation data

A database of 138 species x 120 phytosociological relevés was created using TURBOVEG software (Hennekens & Schaminée, 2001), 33 of which were sampled between July and November 1987 (Ackermann & Vahle, 1987), 23 between May and June 1999 (Krüger, 1999), 64 between June and July 2014. In all cases, plot size ranged from 1 to 4 m2. All relevés were sampled following the phytosociological method of the Zürich-Montpellier School (Braun-Blanquet, 1964). In addition to the species list and their respective cover values, each relevé included the following attributes: exposure, slope, total cover of grass and cryptogramic layer. Taxonomical nomenclature was standardised using The Plant List (http://www.theplantlist.org/, accessed in November 2014). All the relevés were georeferenced via the Google Maps interface of the TURBOVEG software and then exported in Quantum GIS vers. 1.8.0-Lisboa (fig. 2).

Species traits

In order to analyse the vegetation data, 32 plant species traits were considered, grouped into the following categorical (c) or ordinal (o) functional units: (1c) cholorogy, (2c) life form, (3c) seed dispersal strategy, (4c) life strategies (5o) Ellenberg indicator values (EIVs) (6c) hemeroby, and (7o) urbanity. Species traits were taken from the BIOFLOR web database (http://www2.ufz.de/biolflor/index.jsp, accessed in November 2014; Klotz et al. 2002) and from the archives of the Digital Flora of Italy (Guarino et al., 2010). In particular, each of the surveyed species was assigned:

1. (1_c) one of the following seven chorologic units: Boreal, Atlantic, Central-European, Eurasiatic, Cosmopolitan (including sub-cosmopolitan), Eurimediterranean (including paleotropical, eumediterranean, mediterranean-turanian) and Exotic, drawn from Guarino et al. (2010);

2. (2_c) one of the following five life forms, according to the Raunkiaer's classification (Cornelissen et al., 2003; Harrison et al., 2010): chamaephyte, hemicryptophyte, phanerophyte, geophyte and therophyte, drawn from Guarino et al., (2010);

3. (3_c) one of the following five seed dispersal strategies: anemochory, autochory, barochory, zoochory (including epizoochory, endozoochory and myrmecochory), drawn from Guarino et al., (2010);

4. (4_c) one of the following three life strategies (Grime, 1974, 2001; Frank & Klotz, 1990): Competitor, Ruderal and Stress-tolerant, drawn from BIOLFLOR (Klotz et al., 2002);

5. (5_o) one of the following EIVs, based on Ellenberg et al. (1992): light (L), temperature (T), continentality (C), soil moisture (F), soil reaction (R), soil nitrogen (N), drawn from BIOLFLOR (Klotz et al., 2002);

6. (6_c) one of the following five hemeroby degrees (Hill et al., 2002; Walz & Stein, 2014): oligohemerobic, mesohemerobic, β-euhemerobic, α-euhemerobic, polyhemerobic, drawn from BIOLFLOR (Klotz et al., 2002);

7. (7_o) an urbanity value (U), expressing the species' affinity to urban environments on a scale from 1 to 5: from urbanophobic (1) to urbanophilic (5), drawn from BIOLFLOR (Klotz et al., 2002).

Substrate chemical analyses

In July 2014, fourteen representative plots (in terms of exposure, orientation and thickness) were selected. In each plot, three replicates of substrate cores were sampled to assess their chemical properties. Substrate samples were air dried and then sieved at 2 mm. Total organic carbon (TOC) and total nitrogen (TN) were determined on pulverised substrate samples by the Walkley– Black dichromate oxidation method (Nelson & Sommers, 1996) and by Kjeldahl digestion (Bremmer, 1996), respectively. Soil reaction was measured in distilled water using a soil/solution ratio of 1:2.5 (w/v) and a glass membrane electrode. Chemical properties in 1985 (LUFA, 1985) were compared with those from 2014 using paired t-tests.

Species change

To compare species composition and relative abundance over time, the whole data set was imported into JUICE software (Tichý, 2002) and relevés were grouped according to the year: 1987 (group 1), 1999 (group 2) and 2014 (group 3). Based on presence/absence data and down-weighting of rare species, a non-metric multidimensional scaling (NMDS) ordination of the species composition of the three groups was performed using R software (version 2.9.0; R Development Core Team 2009). Since NMDS is a measure of dissimilarity based on a monotonic transformation where the rank order and the distances between points of the original correlation matrix are preserved in the ordination (Austin, 1976; Kenkel & Orlóci, 1986; Whittaker, 1987), it represents an ideal tool to assess the spatial turnover. In order to measure the percentage differences between the considered groups, the Mann-Whitney U similarity was measured on presence/absence data. In this specific case, the presence/absence method was adopted instead of the square root data transformation to discard the influence of the species percentage cover. The total number of species (species pool) per group (year of survey) was calculated together with the average species richness per plot and the species pool sizes were compared by means of accumulation curves. Moreover, to visualise how the species-richness varied across increasing number of plots, a sample-based rarefaction curve was computed (Colwell et al., 2004; Jiménez-Alfaro et al., 2012). Relative frequency (RF) of diagnostic species ($\Phi > 0.20$; Chytrý et al., 2002), was calculated on a 0 to 1 scale, as a factor of a given species occurrence (N) on the total number of relevés for each group. Sørensen index was calculated to determine the β-diversity, using presence/absence data and bootstrap procedure with 500 iterations.

Functional diversity

To assess the shift in mean species trait values and their dissimilarity, a community-weighted mean (CWM) of each trait was calculated using FunctDiv (Lepš et al., 2006). CWM values are weighted by the relative abundance of species (Garnier et al., 2004). Species with mixed strategies and/or hemeroby (see tab. S1 for details) were assigned multiple traits. The obtained values for each group were organised in a traits/plot matrix, and a non-parametric Wilcoxon test was used to evaluate the differences between the years 1987-2014, 1987-1999 and 1999-2014 (pairwise comparison). The analysis was performed in SPSS software 22.0.

4.3   Results

Species change
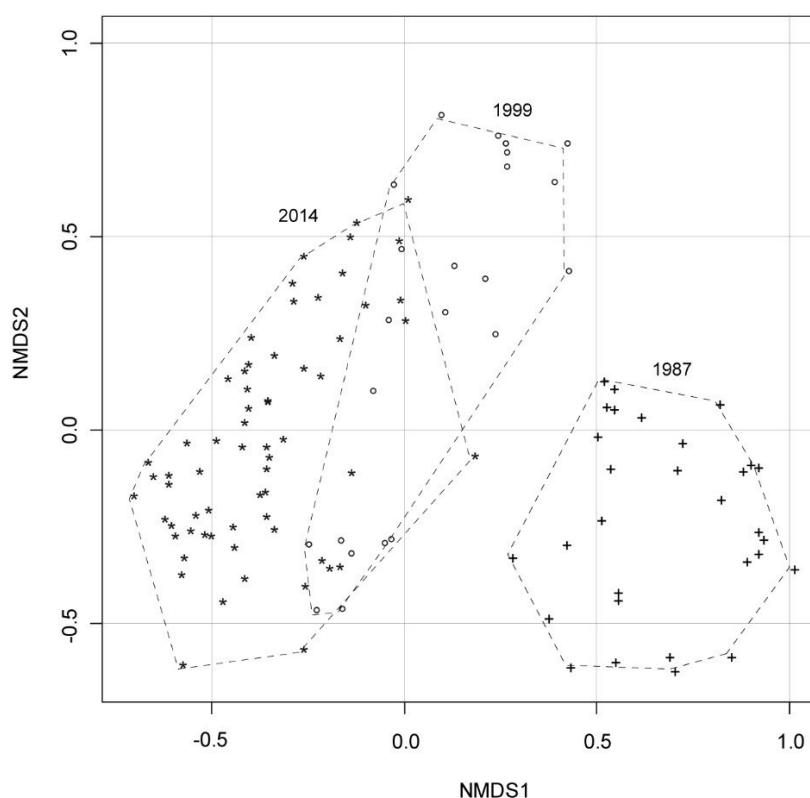
Figure 3. NMDS ordination of group 1 (1987, +), group 2 (1999, ○) and group 3 (2014,*). Dashed lines envelope the three sampling periods.

There were clear differences in species composition between the three survey years (fig.3), particularly between the years 1987-2014, with a Mann-Whitney U percentage difference of 76.32% (z-statistics 44.9, p <0.001). The lowest difference was detected between the years 1999-2014 (Mann-Whitney U: percentage difference 36.59%, z-statistics 18.94, p <0.001) and intermediate values were obtained between the years 1987-1999 (Mann-Whitney U: percentage difference 68.82%, z-statistics 23.38, p<0.001).

The total species richness increased from 1987 to 2014, with more species detected in 2014 (N=80 in 64 relevés), than in 1999 (N=70 in 23 relevés) and 1987 (N=67 in 33 relevés). Although the sampling effort differed between the three survey years, the rarefaction curve (fig.4), showed that the cumulative number of vascular plants at the 23rd relevé was higher in the 1999 group, with 70 estimated species, followed by the 1987 group, with 61 species, and by the 2014 group, with 58 species. The mean species richness per plot (α diversity) decreased from 1987 (14.1±9.1) to 2014 (10.8±3.7), reaching the maximum in 1999 (14.3±5.8). Furthermore, in 2014 the highest value of exclusive species was recorded, with 37 (26.8%) species, whereas 21 (15.2%) and 27 (19.5%) exclusive species

were recorded in 1999 and 1987, respectively. Only 23 (16.6%) species were in common among all three years, while 14 (10.1%) species were in common between the years 1999-2014; 11 (7.9%) between the years 1987-1999 and only 5 (3.6%) between the years 1987-2014. The β diversity, instead, increased from 1987 (0.49±0.03) to 1999 (0.63±0.03) and then it remained constant until 2014 (0.65±0.02).

Concerning the relative frequency (RF) of the diagnostic species, 10 of them were in common in all three groups; 15 were exclusively found in 1987, 9 in 1999 and 12 in 2014 (tab. 1).
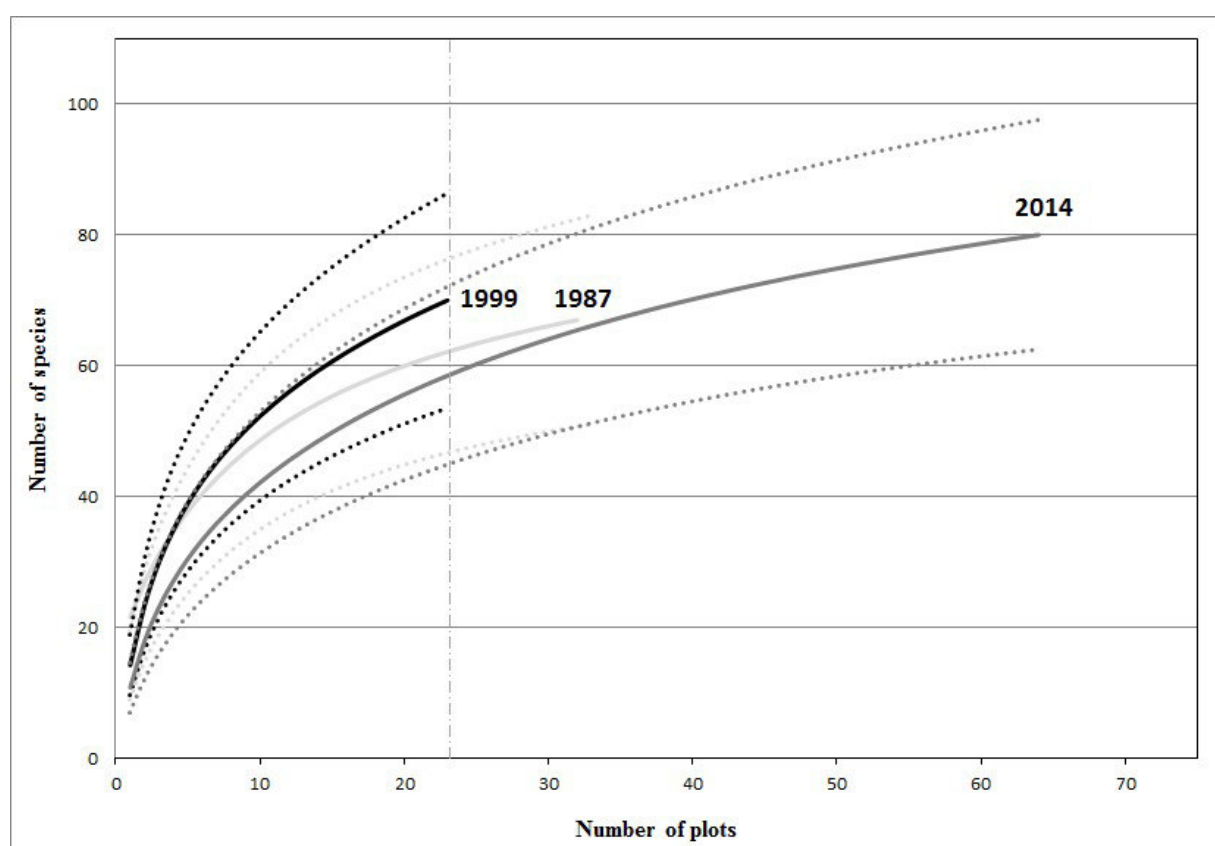
Figure 4. Rarefaction curves showing the cumulative number of vascular plants with increasing the number of plots sampled on the grass roofs in 1987, 1999 and 2014 (differentiated in grey scale). Solid lines show the estimated species-richness, dotted lines show their 95 % confidence intervals and the dot-dashed line cuts the curves at the same sampling effort.

Functional diversity

A pairwise comparison of functional diversity between years found that for most of traits there were differences over time. Out of 32 traits, 23 traits differed significantly between the years 1987-2014, 18 between the years 1987-1999 and 14 between the years 1999-2014 (tab. 2).

Between the years 1987-2014, the following traits displayed a significant variation: Boreal and Central-European species decreased while Exotic, Eurimediterranean and Eurasiatic species increased. The distribution frequency of all life forms changed: hemicryptophytes and geophytes decreased whereas chamephytes,

Table 1. Total number of occurrences (N) and relative frequency (RF) of the species with φ > 20 in the data sets of 1987 (33 relevés), 1999 (23 relevés) and 2014 (64 relevés). Species are arranged according to their relative frequency.

Species	1987		1999		2014	
	N	RF	N	RF	N	RF
Poa pratensis	31	0.9	4	0.2	0	0
Lolium perenne	26	0.8	3	0.1	0	0
Elymus repens	26	0.8	0	0	0	0
Festuca ovina	24	0.7	13	0.6	4	0.1
Conyza canadensis	24	0.7	7	0.3	11	0.2
Taraxacum officinale	23	0.7	0	0	0	0
Senecio vulgaris	22	0.7	8	0.3	0	0
Vicia sepium	17	0.5	3	0.1	1	0
Trifolium repens	13	0.4	0	0	0	0
Viola tricolor	11	0.3	0	0	0	0
Capsella bursa-pastoris	7	0.2	8	0.3	1	0
Anthoxanthum aristatum	7	0.2	6	0.3	0	0
Fallopia convolvulus	7	0.2	0	0	0	0
Epilobium adenocaulon	7	0.2	0	0	0	0
Arabidopsis thaliana	6	0.2	16	0.7	0	0
Aphanes arvensis	6	0.2	2	0.1	0	0
Myosotis arvensis	6	0.2	1	0	3	0
Acer platanoides	6	0.2	0	0	4	0.1
Matricaria perforata	6	0.2	0	0	0	0
Hypochaeris radicata	4	0.1	11	0.5	10	0.2
Vulpia myuros	4	0.1	8	0.3	11	0.2
Crepis capillaris	4	0.1	6	0.3	29	0.5
Cyanus segetum	4	0.1	0	0	1	0
Geranium pusillum	3	0.1	12	0.5	41	0.6
Betula pubescens	3	0.1	0	0	0	0
Poa annua	3	0.1	0	0	0	0
Polygonum aviculare	3	0.1	0	0	0	0
Trifolium pratense	3	0.1	0	0	0	0
Solidago canadensis	2	0.1	0	0	0	0
Cirsium arvense	2	0.1	0	0	0	0
Scleranthus annuus s. polycarpos	2	0.1	0	0	0	0
Aira caryophyllea	2	0.1	0	0	0	0
Holcus lanatus	1	0	4	0.2	3	0
Viola arvensis	0	0	13	0.6	18	0.3
Cerastium semidecandrum	0	0	12	0.5	2	0
Erodium cicutarium	0	0	11	0.5	4	0.1
Vicia sativa	0	0	10	0.4	37	0.6
Trifolium arvense	0	0	10	0.4	27	0.4
Cardamine hirsuta	0	0	9	0.4	0	0
Erophila verna	0	0	8	0.3	0	0
Trifolium campestre	0	0	5	0.2	0	0
Epilobium ciliatum	0	0	4	0.2	0	0
Chamomilla recutita	0	0	4	0.2	0	0
Cerastium glomeratum	0	0	4	0.2	0	0
Arrhenatherum elatius	0	0	3	0.1	28	0.4
Bromus sterilis	0	0	2	0.1	27	0.4
Hieracium pilosella	0	0	2	0.1	0	0
Myosotis stricta	0	0	2	0.1	0	0
Acer pseudoplatanus	0	0	2	0.1	0	0
Plantago lanceolata	0	0	1	0	30	0.5
Erigeron annuus	0	0	0	0	21	0.3
Verbascum thapsus	0	0	0	0	21	0.3
Bromus tectorum	0	0	0	0	18	0.3
Hypericum perforatum	0	0	0	0	16	0.3
Sedum rupestre	0	0	0	0	15	0.2
Oenothera biennis	0	0	0	0	9	0.1
Quercus petraea	0	0	0	0	7	0.1
Prunus spinosa	0	0	0	0	7	0.1
Geranium molle	0	0	0	0	5	0.1
Daucus carota	0	0	0	0	5	0.1
Fraxinus excelsior	0	0	0	0	5	0.1
Geranium purpureum	0	0	0	0	5	0.1

phanerophytes and therophyte increased. All the seed dispersal strategies changed significantly: anemochore species decreased while autochore, barochore and zoochore species increased. ElVs varied significantly, with the exception of R and N: in particular, C, M, and T decreased, while L increased. As regards life strategies, competitor species decreased significantly, while ruderal species increased. Hemeroby values showed that α-euhemerobic decreased while β-euhemerobic and oligohemerobic species increased.

Considering the significant variations observed between the years 1987–1999, Boreal species decreased while Eurasiatic and Eurimediterranean species increased. Life forms varied as well: hemicryptophytes and geophytes decreased while therophytes increased. As regards the seed dispersal strategies, anemochory decreased whereas barochory and zoochory increased. The following ElVs decreased: C, M, R, N. Competitor species decreased while ruderal and stress tolerant ones

increased. Oligohemerobic species increased and urbanity decreased.

The significant variations observed between the years 1999-2014 indicated a decline of Boreal, Central-European and Cosmopolitan species, while Eurasiatic, Eurimediterranean and Exotic increased. Concerning the life form, only phanerophytes and chamephytes increased significantly. As regards the seed dispersal strategies, anemochore and zoochore species decreased while autochore and barochore species increased. As regards ElVs, only R increased. Life strategies and hemeroby did not show any significant variation, while urbanity displayed a slightly significant increase.

Substrate parameters

The chemical properties of the substrate sampled in 1985 were 36 g kg-1 total organic carbon (TOC), 2.6 g kg-1 total nitrogen (TN) and 4.5 pH, whereas those determined on substrates sampled in 2014 were (means $\pm$ standard deviation) 31.0$\pm$3.0 g kg-1 of total organic carbon, 1.7$\pm$0.2 g kg-1 of total nitrogen and pH of 5.4$\pm$0.5. The absence of significant shifts in chemical properties between 1985 and 2014 was congruent with the absence of significant variation of the edaphic ElVs (N, R) between 1987 and 2014 (tab. 2). Unfortunately, no chemical data of the substrate are available for the year 1999 when, according to the ElVs, a slight acidification of the substrate could have occurred.

4.4 Discussion

The hypothesis that species composition and assemblage changed during 30 years was confirmed by the estimation of species pools, α- (species richness per plot) and β-diversity (species diversity within group) and diagnostic species per group. These changes were due both to spatial turnover (species replacement) and nestedness of assemblage (species loss) (Wright & Reeves, 1992; Ulrich et al., 2009). Since in the first decade (1987-1999) the species richness per plot and the species diversity per group increased, species turnover was more important than species loss, due to the progressive occupation of empty niches. In contrast, during the years 1999-2014 species richness per plot decreased and species diversity per group remained steady, revealing that nestedness prevailed on turnover. Our results showed that only few of the species included in the initial seed mixture were able to establish themselves permanently.

The CWM values of the considered plant traits are useful descriptors of the roof ecosystem dynamics (Garnier et al., 2004). Since ecosystem functioning is influenced more by the functional diversity than by the species richness (Díaz et al., 2007), and the functional diversity significantly changed between our three survey years, we expect that stability, productivity, nutrient balance and resilience of the green roofs also changed over the last 30 years (Mason et al., 2003). The main driver of these changes was a shift towards relatively more thermo-xeric conditions, revealed not only by the significant increase of Eurimediterranean and Eurasiatic species but also by

the decrease of hemicryptophytes in favour of therophytes and, consequently, by the significant variation of the EIVs related to temperature and edaphic humidity.

Table 2. CWM values, mean and standard deviation for each trait of the three vegetation groups. Statistic value (W) and p-value are obtained with a non-parametric Wilcoxon test. Values are arranged according to the significance values for the years 1987-2014.

	Traits	1987	1999	2014	1987 vs 1999 (W-p value)	1999 vs 2014 (W -p value)	1987 vs 2014 (W -p value)
1	Biogeography						
	Boreal	0.46±0.29	0.06±0.06	0.02±0.05	-3.893***	-2.575*	-4.994***
	Eurasiatic	0.026±0.018	0.19±0.18	0.36±0.27	-3.771***	-3.193**	-4.976***
	Eurimediterranean	0.0008±0.002	0.016±0.04	0.08±0.16	-2.197*	-2.501*	-4.229***
	Central European	0.06±0.13	0.07±0.13	0.001±0.007	-0.821	-3.109**	-3.861***
	Exotic	0.0006±0.002	0.0006±0.003	0.022±0.06	0	-2.386*	-2.983**
	Cosmopolitan	0.44±0.26	0.60±0.23	0.49±0.27	-1.277	-2.250*	-0.317
	Atlantic	0.003±0.006	0.042±0.16	0.01±0.06	-1.512	-1.354	-1.4
2	Life forms						
	Geophyte	0.041±0.08	0.001±0.006	0.006±0.05	-3.621***	-0.447	-4.432***
	Therophyte	0.12±0.13	0.43±0.30	0.45±0.28	-2.919**	-0.091	-4.412***
	Hemicryptophyte	0.82±0.14	0.55±0.30	0.46±0.29	-2.615**	-0.79	-4.172***
	Phanerophyte	0.003±0.006	0.003±0.006	0.029±0.091	-0.034	-2.479*	-3.128**
	Chamephyte	0	0.001±0.005	0.04±0.14	-1	-2.028*	-2.201*
3	Seed dispersal						
	Anemochory	0.92±0.09	0.69±0.22	0.43±0.30	-3.254**	-3.406***	-5.011***
	Autochory	0.03±0.046	0.13±0.233	0.33±0.28	-1.055	-3.011**	-4.994***
	Barochory	0.02±0.039	0.07±0.05	0.17±0.21	-2.554*	-2.585**	-4.448***
	Zoochory	0.014±0.02	0.048±0.034	0.044±0.12	-2.706**	-1.931*	-2.166*
4	Ellenberg indicators						
	Light	6.65±0.95	6.91±1.12	7.39±0.60	-1.003	-1.216	-3.403***
	Temperature	5.86±0.16	5.78±0.25	5.79±0.19	-1.791	-0.904	-2.044*
	Continentality	4.32±0.43	3.65±0.31	3.73±0.30	-3.772***	-1.126	-4.46***
	Moisture	4.69±0.27	4.47±0.37	4.14±0.65	-2.312*	-1.312	-4.012***
	Soil Reaction	5.57±0.65	5.06±0.60	5.73±0.85	-2.494*	-3.558***	-1.019
	Nutrients	5.05±0.44	4.43±0.58	4.64±0.87	-3.042**	-1.825	-1.287
5	Life strategy						
	Competitor	0.83±0.13	0.56±0.29	0.57±0.25	-2.798**	-1.338	-3.546***
	Ruderal	0.13±0.1	0.347±0.23	0.29±0.2	-2.919**	-1.094	-3.493***
	Stress-tolerant	0.036±0.037	0.09±0.08	0.12±0.16	-2.311*	-1.034	-0.973
6	Hemeroby						
	oligohemerobic	0.05±0.07	0.11±0.08	0.11±0.11	-2.646**	-0.608	-2.842**
	α-euhemerobic	0.45±0.18	0.44±0.27	0.33±0.22	-0.608	-1.368	-2.546*
	β-euhemerobic	0.18±0.078	0.20±0.1	0.24±0.12	-0.608	-1.307	-2.403*
	polyhemerobic	0.03±0.02	0.028±0.02	0.052±0.089	-0.243	-0.568	-0.475
	mesohemerobic	0.27±0.12	0.21±0.12	0.24±0.12	-0.912	-0.76	-0.687
7	Ubanity						
	Urbanity	2.83±0.16	2.46±0.40	2.56±0.34	-2.919**	-2.281*	-1.527

With regard to plant dispersal, two years after the construction of the roof (1987) anemochory dominated. This means that the competitive species that were originally sown decreased gradually, leaving space and resources to the ruderal ones. This may be a result of the ability of wind-dispersed ruderal species to colonise empty niches, which progressively became available (Grime, 2001). A greater number of ruderal species was recorded in 1999 (tab. 2) after which, stress-tolerant ones gained space, and were at their most common in 2014. Along with that, the progressive increase in barochory and autochory illustrated a shift in the succession towards short-distance dispersal species. Furthermore, the establishment of ant colonies probably affected the vegetation dynamics (Guarino et al., 2005) as the observed increased incidence of zoochorous (myrmecochorous) species in 1999-2014 would suggest.

Unexpectedly, zoochory and hemerochory played a more important role than wind which may be related to the habitat filtering as provided by settlements. In fact, dispersal by man and animals may express species-specific preferences i.e. animals may prefer locations with already established biocenosis (fertile surfaces) rather than roads or pavements (sealed surfaces). Wind, instead, is normally channelled along streets, buildings and in general sealed surfaces increasing the probability that anemochorous species will land on unfertile grounds (Knapp et al., 2008).

As a matter of fact, green roofs can serve not only as extra fertile surfaces (not sealed) where plant species can grow in urban environments, but also as places where they may thrive and build a viable population.

There remain other factors that could have affected community dynamics: (a) the influence of the seed bank persisting in the substrate, which contained a relevant percentage of local topsoil, (b) the possible influence of random human visits (e.g for maintenance purposes) which may have accidentally introduced seeds from neighbouring areas, and (c) the effect of climate change on the observed shifts in life strategy. Indeed, since the edaphic conditions remained almost steady over the thirty year period and the selected roofs were not maintained, environmental factors might have been the most influential. Throughout the last century, Central Europe has experienced a remarkable increase in mean temperatures and the last decade in particular (2005-2014) was the warmest on record (EEA, 2015). In Germany specifically, there has been a strong increase in air temperature and between 1988-2000, almost all years had warmer annual means than the average (Chmielewski et al., 2004). This trend has been even more substantial in urban agglomerations due to the heat-island effect which favours the establishment of xeric species coming from warmer regions (Sukopp & Wurzel, 2003).

Moreover the turf-roll construction and the inclination of the roofs was responsible for certain abiotic conditions. The greening took place on the ground and after six months, the grown grass-mats were installed on the sloped roofs. This resulted in the change of several growing conditions such as moisture (from damp, due to the effect of the plastic film used to prevent the root penetration into the soil, to drained, due to the roof slope

and used substrate mixture) and exposure as the roofs were facing north, south, east and west. Moreover, the inclination caused a slight shift of the substrate and thus an alteration of the initial homogeneous thickness: on the ridge, the substrate varied from 5-10 cm whereas the depth at the gutter ranged from 20-25 cm. These effects became visible after several years: the survey conducted in 1987 still reflected the initial conditions, while in 1999 and 2014 the decline of competitor species in favour of ruderal and stress tolerant species became evident.

4.5   Conclusions

Species composition and assemblage changed dramatically over 30 years: from five species sown in 1985, over 10 times more species were recorded in 1987 (67), in 1999 (70) and in 2014 (80), with only 23 of them in common across the whole data set. This suggests that tailored seed mixtures rarely possess the ability to create stable communities without high maintenance (irrigation, fertilisation and weeding). Therefore, if the aim is to develop resilient plant communities on green roofs, spontaneous colonisation should be accepted and considered as a design factor.

We believe that screening regional flora, the recurrent combinations of plant species could serve as a model for seed recruitment and installation on green roofs (Catalano et al., 2013). In fact, plants thriving in similar conditions to those of the roofs but not belonging to the regional nor to the local species pool (sensu Zobel et al. 1998) can become successfully established but may fail to enhance habitat connectivity in urban areas.

From a monitoring perspective, plant functional traits prove to be a good means to assess and interpret species change over time. With reference to CSR strategies, the most successful plants in our study were the stress-tolerant species (which have the capacity to maximise limited resources) followed by the ruderal species (which have the capacity to maximise resources in disturbed conditions). These species were better adapted to green roof conditions and outcompeted the sown ones.

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