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A revised terminology for vegetated rooftops based on function and vegetation

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Running head: A revised terminology for vegetated rooftops

Abstract

The proliferation of vegetated, or green roofs, warrant a revisit of the terminology used in order to efficiently, and without confusion, convey information among scientists, policy makers and practitioners. A Web of Science and Google Scholar search (from 1996-2018) showed a steady increase in green roof articles, reaching close to 300 per year in WOS and ca. 2500 in Google Scholar, with approximately 10 – 20%, and up to 40% of all articles using the terms extensive and/or intensive, especially in recent years. We evaluated the use of these terms, including 'green roof', and 'intensive and extensive roof', found that they are used in confusing ways, and provide compelling evidence for revising the terminology. Acknowledging that most, if not all, vegetated roofs are multifunctional, we propose a new classification system based on the roof's primary function(s) and vegetation, such as "stormwater meadow roof", "biodiversity meadow roof", "biodiversity forest roof", or even "multifunctional meadow roof". This new terminological sphere is not meant to be rigid, but should be allowed to evolve so that useful combinations survive the scrutiny of academia and practitioners, while less useful ones go extinct. A clear and standardized terminology will serve to avoid confusion, allow for generalizations and aid in the development of this rapidly-expanding field.

Keywords: extensive roof, function, green roof, intensive roof, terminology, vegetated roof, vegetation

1. Introduction

Adaptation to climate change coupled with increasing urbanization has brought building-integrated greening to the forefront. While the use of green walls is still in its infancy, rooftops that are intentionally constructed to support vegetation - commonly referred to as green roofs - are becoming a popular option to improve the urban environment, and the number of scientific and applied publications is growing rapidly (Fig. 1; see figure legend for the search criteria) (Blank et al., 2013; Li & Babcock, 2014; Vijayaraghavan, 2016). The reason for this global interest is that rooftop greening is expected to tackle a multitude of problems related to climate change, urbanization, densification and good life. Subsequently, the proliferation of vegetated rooftops lies in their potential to support biodiversity and to offer several ecosystem services such as stormwater management, thermal comfort, noise abatement and aesthetic appeal (Oberndorfer et al., 2007; Rowe & Getter, 2010; Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014; Besir & Cuce, 2018) that can improve the urban milieu in a variety of ways.

With evolving green roof research, planning, design and policies, it is essential that everyone speaks the same language, i.e., uses as efficient and standardized terminology as possible. Recently, it has been argued that the classification of various green roof types is well established and that several guidelines and standards guarantee the uniformity and quality of green roof solutions (Pérez & Coma, 2018). However, as green roof research is booming (see Fig. 1), current terminology is insufficient, and the linguistic uncertainty it creates (see Regan, Colyvan, & Burgman, 2002) leads to misunderstandings in applied fields, and to weak scientific hypotheses, poorly comparable results, and thus, overall confusion (cf. Peters, 1991).

Underdeveloped conceptualizations hinder meaningful comparisons of results as well as communication of findings to other fields; examples include the concepts of evenness (Tuomisto, 2012), resilience (Hodgson, McDonald, & Hosken, 2015; Ingrisch & Bahn, 2018; Elmqvist et al. 2019) and disturbance (Pickett, Kolasa, Armesto, & Collins, 1989; White & Jentsch, 2001), and redundant/confusing terminology in green infrastructure and urban drainage for stormwater management research (Fletcher et al., 2015; Prudencio & Null, 2018), to name a few. Efficiency and a standardized terminology has also been called for in order to avoid a redundant search for "new" knowledge that, in fact, already exists (e.g., Herrando-Pérez, Brook, & Bradshaw, 2014 for ecology). Using data available on the internet could be facilitated by unequivocal meanings for terms (cf. Madin, Bowers, Schildhauer, & Jones, 2008). Outside academia, poor conceptualizations can lead to restricted worldviews and interpretations of what is possible, thus narrowing down ideas about possible futures, while strong concepts and terms allow for efficient and focused communication and development (cf. Kull, de Sartre, & Castro-Larrañaga, 2015 for the concept of ecosystem services). In the worst-case scenario, huge investments in green infrastructure, including vegetated roofs, fail to achieve their targets due to deficient communication between science and practice, and/or between stakeholders of the planning and the construction process (Bernardi et al. 2019). This might result in, e.g., vegetated roofs that were installed for the purpose of stormwater management but do not, in reality, retain much water due to their thin substrate with low water holding capacity, and vegetation that does not efficiently use or intercept water (e.g., Farrell, Szota, Williams, & Arndt, 2013). In summary, both scientists and practitioners would greatly benefit from speaking the same language, which is greatly facilitated by clear unambiguous terminology.

Many cities or countries have established regulations that aim at increasing the share of vegetated versus other kinds of roofs (Carter & Fowler, 2008; Kazmierczak & Carter, 2010; Catalano, Laudicina, Badalucco, & Guaino, 2018). Obviously, 'one solution doesn't fit all', and the variation and combinations of green roof characteristics are expanding rapidly; for instance, various technical solutions, vegetation types and growing media mixes are used in different climatic zones (Simmons, Gardiner, Windhager, & Tinsley, 2008; Berardi et al., 2014). In order to advance our understanding and the applicability of green roof solutions, terminology should evolve to master and communicate the multitude of solutions in a comprehensible and logical way. Ideally, it should efficiently convey the main characters of different kinds of green roof systems in order to avoid misinterpretation of scientific results, and importantly, to improve precision.

In this paper we present quantitative evidence for the frequent use of the terms intensive and extensive in the 'green roof' literature, and provide qualitative evidence that these terms are used in contradictory and confusing ways. We briefly discuss the motivations for a terminological revision and the status quo of concepts and terms. Consequently, we propose a revised terminology for green roofs, based on tangible characters so that the terminology conveys the main *function* together with the main *vegetative component* of the roof. Our proposed terminology allows for easy, efficient and unbiased comparisons between studies, findings and knowledge across the globe and across disciplines, thus enhancing discussions, hypotheses and the application of knowledge. The clarification of green roof terminology will be useful in several scientific and practical fields, as green roof research, planning and design is typically and necessarily inter- and transdisciplinary (Blank et al., 2013). To summarize, the main deliverable of this work is to propose an evolving terminological sphere that embodies vegetated rooftop *function* and the *type of vegetation* present, thus moving away from a limiting duality of, for instance, intensive vs. extensive green roofs. Additionally, we discuss the possibilities to adopt and communicate this new terminology and how it might propagate through both the scientific and practitioner communities.

2. Green roofs are not always green

As discussed by Francis and Lorimer (2011), the term “green roof” can be misleading as the appearance of a “green” roof is not necessarily that of lush vegetation that is predominantly and constantly green, but depends on the design, vegetation type, seasonal variation and the establishment success of vegetation. The word “green” in green roofs is also easily linked to environmental benefits, such as energy efficiency and sustainability, while in reality such generalizations may not hold. For example, some of the common green roof materials (Bozorg-Chenani, Lehvävirta, & Häkkinen, 2015) and the possible nutrient leaching from green roofs (Berndtsson, 2010; Li & Babcock, 2014; Kuoppamäki & Lehvävirta, 2016) have negative environmental impacts and the realized environmental benefits are dependent on the functionality of individual green roof designs (Rowe, 2011; Bates, Sadler, Greswell, & Mackay, 2015). To avoid the above confusions, we will use the term *vegetated roof* throughout the rest of the manuscript.

3. The confusing terms extensive and intensive

One of the most consequential conceptualizations concerning vegetated rooftops is the dichotomy of “extensive” vs. “intensive”; ca. 10 - 20%, and up to 40% of all articles dealing with vegetated rooftops used the terms extensive and/or intensive, especially in recent years (Fig. 1; for the search criteria, see figure legend). According to Weiler and Scholz-Barth (2009), these terms are particularly used within the fabrication, supply and design industries in Europe. To further illuminate the use of these terms, as well as terms related to vegetated roofs in general, we analyzed their use in the titles and abstracts of 1973 scientific articles and reviews written between 1996 and 2018 with the VOSviewer (Van Eck & Waltman, 2010) software. This software creates a 2D bibliographic map of relations between terms in articles. Each term is placed on a cluster map and linked to other terms based on their co-occurrence in papers (see Fig. 2). In VOSviewer, a link is a connection or a relation between two items, here between co-occurring terms. The map is optimized to minimize the summed Euclidean distances between all pairs of items in the map (Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011).

Research concerning substrate and vegetation installed on rooftops is multidisciplinary (see e.g., Blank et al., 2013), and our analysis revealed that the term ‘extensive green roof’ is indeed connected to a variety of topics. It was used in 251 of the 1973 articles, and had 406 links to other terms across all clusters. In Fig. 3, links between terms that have more than 10 co-occurrences with ‘extensive green roof’ are highlighted. The term extensive green roof is drawn away from its own cluster and placed between clusters that are characterized by energy and runoff. This means that although ‘extensive green roof’ has most co-occurrences with terms like substrate, plant, and species, i.e. the green cluster, it is also used frequently with topics such as stormwater runoff and the heat island effect. The term ‘intensive green roof’ occurred in 36 articles and was not prominent enough to be incorporated into the map.

The terms extensive and intensive appeared in the literature at the end of the 1990s. Thereafter, extensive, intensive and sometimes semi-intensive or -extensive have been defined by a number of attributes. Table 1 portrays the diversity of meanings endorsed by these terms via presenting a comprehensive but not exhaustive set of examples that we found in the literature, yet sufficient to demonstrate the confusion that these terms inflict. Based on our search, the criteria for classifying roofs as extensive or intensive range from substrate depth to organic matter content, vegetation type, building type, design, roof weight, the need and type of maintenance, and use. Thus, the dichotomy of intensive vs. extensive originates from several very different perspectives making this terminology incoherent, and difficult to use in design or maintenance decisions (Weiler & Scholz-Barth, 2009). Simple intensive (FLL, 2008), semi-intensive or semi-extensive roofs are supposed to be somewhere between these two extremes (extensive vs. intensive), and it is not surprising to see major confusion in the definition and usage of these intermediate terms.

Substrate thickness is often considered a major determinant behind the extensive/intensive dichotomy, but with little agreement on the demarcation line (Table 1). For instance, Berndtsson (2010) showed an overlap in the categorizations based on substrate thickness and suggested caution when interpretations concerning roof functionality are based on this dichotomy. The vagueness of this dichotomy-based categorization becomes further amplified by the fact that substrate alone pertains to characteristics such as organic matter content, water holding capacity and the availability of nutrients, all of which lack a clear demarcation between roof types (see Table 1).

Another instance of a relative and thus weakly informative expression is that extensive roofs are lighter than the intensive type (Bianchini & Hewage, 2012b). However, in reality, the weight of a vegetated roof depends on the materials used in the substrate and other layers. Therefore, the thinnest roof may not be the lightest, or the thickest roof the heaviest, and these two criteria (weight and substrate depth) do not fully correlate to allow for a coherent distinction between roof types. Essentially, we argue that the extensive/intensive categorization is a misleading terminological artifact based on generic, assumed qualities rather than detailed definitions and data.

3.1. Extensive chaos

There are different kinds of definitions or descriptions of extensive vegetated roofs that produce a mind-boggling chaos. For example, a variety of descriptions are given for vegetation, it being either dense, low growing, drought-resistant, *Sedums* or small herbaceous species (Table 1). Expectations as regards the occurrence of spontaneously arrived vegetation are contradictory (Table 1).

Low organic matter (OM) content of the substrate has also been used as a criterion for extensive roofs (Emilsson, Berndtsson, Mattsson, & Rolf, 2007; FLL, 2008; Oberndorfer et al., 2007; Poë, Stovin, & Berretta, 2015), but this criterion varies (Table 1). Furthermore, OM content changes over time as organic matter decomposes (Nagase & Dunnett, 2011), and decreases or accumulates, thus making this criterion subject to successional change. For instance, Getter, Rowe, and Andresen (2007) found that within 5 years, OM doubled from ca. 2% to 4%.

Often other attributes are also used to characterize extensive vegetated roofs, e.g., their suitability to certain kinds of buildings or uses. One criterion is that they are designed to be virtually self-sustaining and require minimum maintenance, however, definitions regarding the level of maintenance remain mostly unquantified, relative and variable.

3.2. Intensive mess

Intensive roofs are often referred to as gardens with rich vegetation, ranging from grasses to trees (Ahiablame, Engel, & Chaubey, 2012; Bianchini & Hewage, 2012a), or are “comparable to” roof gardens (Claus & Rousseau, 2012). Minimum values given for substrate depth vary from 15 to 20 cm, or are expressed as relative (e.g. “deep”), while maximum values start at 120 cm, with some papers providing no upper limit (Table 1). Intensive roofs are considered to have a higher amount (expressed either as a percentage or g L^{-1}) of OM than extensive systems (Pérez & Coma, 2018), yet some intensive roofs have substrates being primarily mineral (Berndtsson, Bengtsson, & Jinno, 2009). Joimel et al. (2018) in turn speak about “productive green roofs” that have deeper soils (15–30 cm) with higher OM content due to the use of compost or peat, as a distinction from extensive ones with 5–15 cm thick substrates.

In their review, Ahiablame et al. (2012) showed that intensive roofs are widely used on commercial buildings, while Bianchini and Hewage (2012a) wrote that “*Intensive green roofs are designed to hold higher loads than extensive*”. Trying to understand the extensive/intensive categorization from these perspectives provides a conflict as many commercial buildings such as retail parks may have large roofs that need to be built at low cost and maintained with minimal effort. Furthermore, if “*One of the major goals of intensive green roofs is to provide an open and accessible space for users to enjoy*” (Bianchini & Hewage, 2012a), then residential, hospital, or other public buildings are equally suitable for intensive roofs as commercial buildings. Building type, thus, does not help in categorizing roofs into intensive or extensive, rather, it muddles the issue even further.

3.3. Semi-jumble

A simple-intensive, semi-intensive, semi-extensive or even 'intermediate' roof represents some characteristics of extensive and intensive roofs, or is either defined as a "middle way system" (Palla, Gnecco, & Lanza, 2010) or a combination of both extensive and intensive vegetated roof types. According to Yang, Yu, and Gong (2008), a semi-intensive green roof should have ≤ 25% of its area classified as extensive. Given the muddle in terminology regarding extensive vs. intensive vegetated roofs, creating additional categories to establish a continuum of vegetated roof types will only result in more confusion. For example, Blanusa et al. (2013) used a 20 cm substrate thickness "*…to mimic a standard semi-intensive green roof*". When referring to extensive or semi-extensive roofs in the same paper, for the first one they state that the substrate is "shallow", but do not explain at all what they mean by the latter. Thus the reader is left with vague ideas or free association with what could be meant by these, and no scientific inference is possible.

3.4. The cure

While the categorization of vegetated roofs into intensive and extensive (and their 'semi' in-betweens) is confusing and uninformative, it is also outdated. This may limit the sphere of possible solutions and leeway in planning, as people's ideas become fixed with two to three options at best (Hannigan, 1995; Dunnett, Nagase, & Hallam, 2008b; Mesimäki, Niemi, & Lehvävirta, 2015). Furthermore, information content of the words intensive and extensive is poor as they do not point out the specific features of the roof. This can lead to major misunderstandings: for instance, a vegetated roof with a substrate depth of 100-150 mm can be reported by different authors as intensive or extensive (see Berndtsson, 2010). As the number of publications on vegetated roofs is increasing steadily, it is essential to break the cycle of passing on incoherent terminology for those new to the field.

The cure would be an informative, easily understandable, immediately intuitive but logical terminology. Indeed, a terminology that is able to distinguish different kinds of vegetated roofs is urgently needed in order to allow for studying, planning and constructing them for a variety of benefits and uses (cf. Dunnett et al., 2008b). The scientific gain, per se, is obvious. A logical, and hopefully less-fallible, terminology will provide opportunities to generalize patterns and processes across studies from different parts of the world, and thus strengthen the theoretical underpinnings of the functionality of vegetated roofs, be it in terms of biodiversity, conservation, or other ecosystem services such as stormwater management, carbon sequestration, climate regulation and aesthetics. The practical advantages of having a logical and descriptive terminology stem from the various potential benefits of vegetated roofs, such as energy conservation, stormwater management, carbon sequestration, experiential or gardening and agricultural opportunities (Oberndorfer et al., 2007; Berardi et al., 2014; Collins, Kuoppamäki, Kotze, & Lü, 2017; Besir & Cuce, 2018; Mesimäki, Hauru, & Lehvävirta, 2018; see also Fig. 2).

4. Clarifying vegetated roof terminology - let's call a spade a spade

We propose a new terminology that was inspired by our involvement in the standardization of vegetated roofs in Finland (Laurila et al., 2014; RT Building Information Files) and by the well-known naming of species by Carl von Linné.

Vegetated roof terminology needs to be flexible with the possibility to evolve in line with the rich variety of possible uses (Sutton, 2015), design expectations and citizens' dreams (Mesimäki, Hauru, Kotze, & Lehvävirta, 2017). In essence, the naming of vegetated roofs should allow for new ideas and conceptualizations along with innovation. There are two important and obvious approaches to naming vegetated roofs, i.e. to convey the main *function* and the *vegetative component* of them.

Our previous work with researchers, architects, planners, decision-makers, other stakeholders (Laurila et al., 2014; RT Building Information Files) and the literature review performed here (Table 1) clearly signalled that *functionality* is a main issue in the process of planning and implementation of vegetated roofs, i.e. the primary motivation to build such roofs. Furthermore, widely cited review papers on vegetated roofs, such as those by Oberndorfer et al. (2007) and Berndtsson (2010) as well as the recent book "Green roof ecosystems" edited by Sutton (2015) all introduce vegetated roofs by emphasising their functions and benefits. These functions also mirror ecosystem services, which is a well recognised classification system for benefits provided by nature. A naming system immediately and unequivocally conveying functionality would help set targets in planning and design, develop regulation and policies, interpret research results, and in the end, even help productization of vegetated roofs for specific purposes. There are several functions that have been emphasized in the scientific literature and among practitioners (Grant & Jones, 2008; Lundholm, 2015; Sutton, 2015; Vijayaraghavan, 2016), with varying degrees of empirical evidence backing them up. In essence, all vegetated roofs are to some extent multifunctional, i.e., provide a number of ecosystem services, yet they are often built with one or two main functions in mind. Optimising for particular functions leads towards certain choices in the design, which may not be fully optimal from the perspective of other functions – in fact, Simmons et al. (2008) suggested that the design of vegetated roofs should be based on their functional goal.

Second, the main visible component of a vegetated roof is its vegetation. It is obvious and tangible, and there is a long tradition of classifying urban and rural nature based on vegetation. Furthermore, the selection of vegetation (individual plants or a particular plant community) is arguably the most essential step in the construction of vegetated roofs.

Based on these two components, we propose categorizing and naming vegetated roofs according to their ***function and vegetation***. This could result in terms like “Stormwater meadow roof”, “Biodiversity meadow roof”, “Scenic moss roof”, “Restorative forest roof” “Restorative meadow roof”, “Biodiversity chaparral roof”, “Pollinator flower roof”, “Habitat connectivity grassland roof”, or a “Multifunctional meadow roof”. We give examples of naming vegetated roofs this way from Finland in the Supplementary Material, Appendix 1, and provide a tentative list of functions associated with vegetated roofs (Supplementary Material, Table S2). Such terminology is easy to use and grasp, it will evolve according to emerging needs and solutions, and ideally, will result in the survival of the most appropriate categories based on trial-and-error. In essence, we propose an evolving terminology that will also be explicit and tangible, and thus useful for both scientific and applied purposes.

An evolving terminology will allow certain classifications to survive the scrutiny of scientists, planners and designers, while other, less useful classifications go extinct.

What we suggest here seems to be an intuitive solution given that some companies have started to promote their products in terms of vegetation and/or function, or other kinds of characterizations, such as ‘public’ or ‘light-weight’ roofs. In the future, taxonomic rules may be needed to regulate how the naming is developed and accepted. For example, to call a roof a stormwater meadow roof, a minimum water retention capacity and substrate properties could be required and a certain vegetation structure expected (e.g. type of plant species, layers and number of species). Global organizations, such as The Society for Urban Ecology (SURE), World Green Infrastructure Network (WGIN), International Association for Landscape Ecology (IALE) and The International Society of City and Regional Planners (ISOCARP), and digital platforms like ThinkNature and Oppla, could join forces to standardize the taxonomy. These organizations, in collaboration with i) scientists hosting special sessions on terminology at conferences, ii) research groups at universities and architectural schools, and iii) professional and academic periodicals can contribute to the propagation of the proposed terminology, thus promoting the development of vegetated roof research.

To summarize, we suggest an intuitive classification system for the terminological evolution of vegetated roofs, which will alleviate the terminological confusion that currently hampers the development of knowledge, policies and actions concerning vegetated roofs. As the field is growing fast, the terminology also needs to be dynamic. At the same time it needs to be specific, clear, and distinguishable, to avoid linguistic uncertainty (cf. Herrando-Pérez et al., 2014). The proposed terminology will, apart from scientific advantages, help streamline regulations across cities and countries and the design-construction process, and meet the different expectations of stakeholders (Calleja-Perucho, Mazarrón, Pou-Merina, & Cañas-Guerrero, 2015; Mesimäki et al., 2015). Ultimately, policies can be improved across regions (or be region specific, see Lambrinos, 2015), especially in the setting of targets in the face of climate change and increasingly-densified cities.

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Table 1. Examples of attributes and parameters most commonly used to describe the distinction between intensive and extensive green roofs, extracted from our data (see Fig. 1 titles and legend for the search criteria). Terms and wordings presented here are reproduced from the references to avoid biased interpretations by the authors, but have been shortened where possible without changing the meaning.

Criterion	**Extensive**	**Intensive**	**References**
Substrate depth	< 15 cm	> 15 cm	Mentens et al., 2006
	3-5 cm		Emilsson et al., 2007
	2-20 cm	20 cm or more	Oberndorfer et al., 2007
	< 4-20 cm	> 15 cm, up to > 200 cm	FLL, 2008
	50-150 mm	much deeper media	Hathaway et al., 2008
	< 15 cm	20 cm - 1.2 m, semi-intensive green roof is a mixture of extensive and intensive green roof	Yang et al., 2008
	2.5-10 cm	deep substrate	Molineux et al., 2009
	thin	deep	Berndtsson, 2010
	< 10 cm	greater than 10 cm	Rowe & Getter, 2010
	20-200 mm	more than 200 mm	Nagase & Dunnett, 2010
	about 5 cm	> 20 cm	Jim & Tsang, 2011
	< 15 cm	> 15 cm	Rowe, 2011
	relatively thin layer of soil	reasonable depth of soil	Bianchini & Hewage, 2012a
	typically 15 cm thick or less	greater than 15 cm thick	Carson et al., 2013
	less than 20 cm in depth, often between 5 and 15 cm	at least 20 cm in growth media depth	Morgan et al., 2013
	shallow (often less than 80 mm)	deep	Rumble & Gange, 2013
	less than 150 mm	more than 150 mm	Speak et al., 2013
	< 150 mm	> 200 mm	Connop et al., 2013
	median media depth 10 cm	median media depth 15 cm	Li & Babcock, 2014
	shallow growing medium	deep growing medium	Lundholm, 2015

	60-200 mm	about 150-400 mm, on underground garages > 1000 mm (semi-intensive: 120-250 mm)	Raji et al., 2015
	< 20 cm		Eksi & Rowe, 2016
	30-150 mm		Elliott et al., 2016
	less than 15 cm	20-200 cm	Vijayaraghavan, 2016
	4-15 cm	> 30 cm (semi-intensive: 12-30 cm)	Lata et al., 2018
	no more than 10 cm		Rumble & Gange, 2017
	6-20 cm	> 25 cm (semi-intensive 10-25 cm)	Pérez & Coma, 2018
Organic matter content of the substrate	up to 30%	up to 45%	Bianchini & Hewage, 2012a
	≤ 65 g/l	≤ 90 g/l	FLL, 2008
	low organic matter	low organic matter	Oberndorfer et al., 2007
	inorganic low-density material with high water-holding capacity		Emilsson et al., 2007
	2.3%	3.8% (semi-intensive)	Poë et al., 2015
Other substrate properties	high porosity	high porosity	Oberndorfer et al., 2007
	few (1.9%) fine, < 0.063 mm particles	greater (2.7%) proportion of fine particles	Poë et al., 2015
	light substrate	natural soil (semi-intensive: light substrate)	Lata et al., 2018
Vegetation	Sedum	grasses, perennial herbs and shrubs	Mentens et al., 2006
	low-growing communities of plants and mosses selected for stress-tolerance qualities (e.g. *Sedum* spp., *Sempervivum* spp.)	no restrictions other than those imposed by substrate depth, climate, building height and exposure, and irrigation facilities	Oberndorfer et al., 2007
	only a restricted range of specialized species will survive due to most extreme environmental conditions		Dunnett et al., 2008a
	types of mosses, Sedums, and other succulents with a height of 50-130 mm	larger vegetation types, such as shrubs and trees with a height of up to 5 m or higher	Hathaway et al., 2008
	planted with low height and slow growing plants	large perennial herbaceous plants and, occasionally, shrubs and small trees	Yang et al., 2008

	apparently natural vegetation… well suited to coping with extreme conditions… ability to regenerate easily… mosses, succulents, herbaceous plants and grasses and can be complimented with bulbs and tubers.	perennials, grasses, bulbs, annuals and shrubs and even an occasional tree…	FLL, 2008
	substrate-based with a vegetated layer or a Sedum mat	roof gardens supporting large trees and shrubs	Molineux et al., 2009
	small plants with full coverage of the vegetated roof at the final stage	large plants and bushes; semi-intensive or simple-intensive vegetated with lawns and ground covering plants	Berndtsson, 2010
	grasses, herbaceous plants and drought-tolerant sedums	shrubs and trees	Jim & Tsang, 2011
	typically a ‘carpet’ of plants	more deeply planted vegetation	Stovin, 2010; Stovin et al., 2012
	drought tolerant succulents such as *Sedum*	may include trees, shrubs and hardscapes	Rowe, 2011
	dense, low growing, drought-resistant	diverse population of vegetation	Ahiablame et al., 2012
	short rooting, drought resistant plants	deeper rooting plants including shrubs and trees	Carson et al., 2013
	thin layer of vegetation	heavy construction that can support small trees and shrubs	Kolokotsa et al., 2013
	moss-Sedum-herbs and grasses	lawn or perennials, shrubs and trees (semi-intensive: grass-herbs and shrubs)	Raji et al., 2015
	mainly succulent plants	unlimited choice of plants (semi-intensive: grasses or low-development shrubs)	Lata et al., 2018
	moss-Sedum-herbs and grasses	lawn or perennials, shrubs and trees	Besir & Cuce, 2018
	succulent, herbaceous and grasses	grasses, shrubs and trees	Pérez & Coma, 2018
Design and building type	single and multifamily residential building	commercial buildings	Ahiablame et al., 2012
	slope angle can be as high as 45°	slope less than 10°	Mentens et al., 2006

	- vegetation undergoes a natural process of change, including new plant species - if a particular aesthetic effect is desired, e.g. a particular pattern or planting design with flowers from herbs and succulents…	- may be laid out in swathes, at different heights or sporadically planted about the site - wide range of options for designs… can be planted in a comparable way to ground level planting	FLL, 2008
		comparable to roof garden	Claus & Rousseau, 2012
	system build-up height: 60–200 mm	system build-up height: 150-400 mm, underground garages ≥ 1000 mm	Besir & Cuce, 2018
Weight	maximum water-saturated weight of approximately 50-55 kg m^{-2}		Emilsson et al., 2007
	60-150 kg m^{-2}	180-500 kg m^{-2} (semi-intensive 120-250 kg m^{-2})	Raji et al., 2015
	50-150 kg m^{-2} at maximum water capacity	> 350 kg m^{-2} at maximum water capacity (semi-intensive 120-350 kg m^{-2})	Pérez & Coma, 2018
	60-150 kg m^{-2}	180-500 kg m^{-2}	Besir & Cuce, 2018
Maintenance	low maintenance	equivalent to parks or gardens (simple intensive: well-maintained lawns or ground cover)	Grant & Nicholson, 2003
	- most require little or no irrigation - little or no maintenance required - some weeding or mowing as necessary	- often require irrigation - same maintenance requirements as similar gardens at ground level	Oberndorfer et al., 2007
	- hardly any external input for either maintenance or development - if a particular aesthetic effect is desired, it could be necessary to fertilize certain plants - selected maintenance activities may be required	regular attention, in particular watering and fertilizing is required	FLL, 2008

	maintenance free but some fertilization recommended for commercial products	weeding, fertilizing and watering (semi-intensive require frequent maintenance including cutting, watering and fertilization)	Berndtsson, 2010
	virtually self-sustaining and require minimum maintenance	require skilled labor, irrigation and constant maintenance	Bianchini & Hewage, 2012a
	low maintenance, no irrigation	high maintenance, regular irrigation (semi-intensive: periodically maintenance and irrigation)	Raji et al., 2015
	no watering	watering (semi-intensive: watering)	Lata et al., 2018
	low; never or periodically irrigation	high; regular irrigation (semi-intensive: moderate maintenance with periodical irrigation)	Pérez & Coma, 2018
	low maintenance, no irrigation	high maintenance, regular irrigation	Besir & Cuce, 2018
Use/function	stormwater management, thermal insulation, fireproofing; generally functional rather than accessible; will need basic accessibility for maintenance	functional and aesthetic: increased living space and typically accessible; bylaw considerations	Oberndorfer et al., 2007
	not usually designed to be accessible, except for maintenance	usually accessible	Teemusk, 2009
		wide range of options for uses	FLL, 2008
	pollution abatement	frequently designed as public places	Rowe, 2011
	often installed primarily for their stormwater benefit		Harper et al., 2015
	not designed for public use but mainly developed not only for aesthetic but for ecological benefits	accessible to people, used as parks or building amenities	Bevilacqua et al., 2015
	ecological protection layer	park like garden (semi-intensive: designed green roof)	Raji et al., 2015

	only accessible for maintenance	pedestrian/recreation areas (semi-intensive: pedestrian areas but with moderate use)	Pérez & Coma, 2018

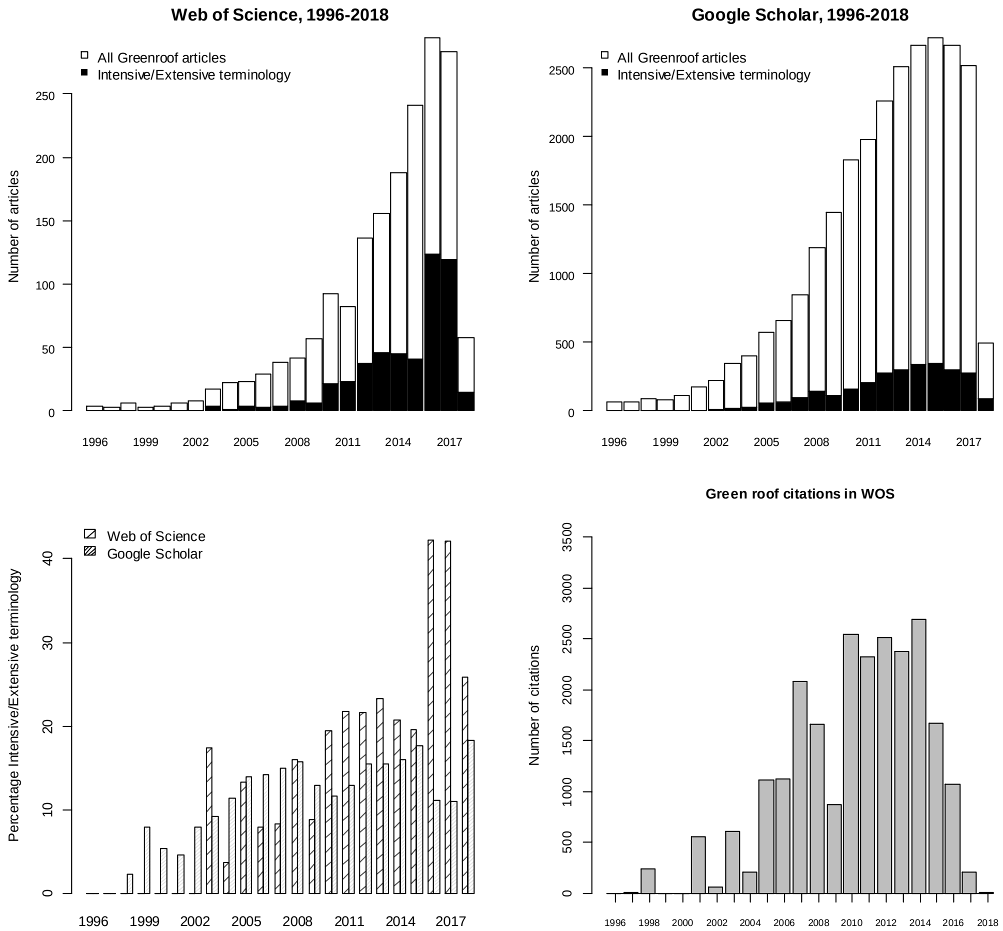


Figure 1. The number of publications (above) and citations (below) on green roofs in ISI Web of Science (Thompson Reuters) from 1996 to March 2018. We used the search sentence “green roof*” OR “vegetated roof*” OR “living roof*” OR “roof* garden*” OR “planted roof*” OR “rooftop farm*” to include terms that cover the topic. We left out terms that would have resulted in irrelevant hits, such as sky gardens (interior gardens in the top level of high buildings) and ecoroof* (low impact development), and excluded wild cards that selected irrelevant publications.

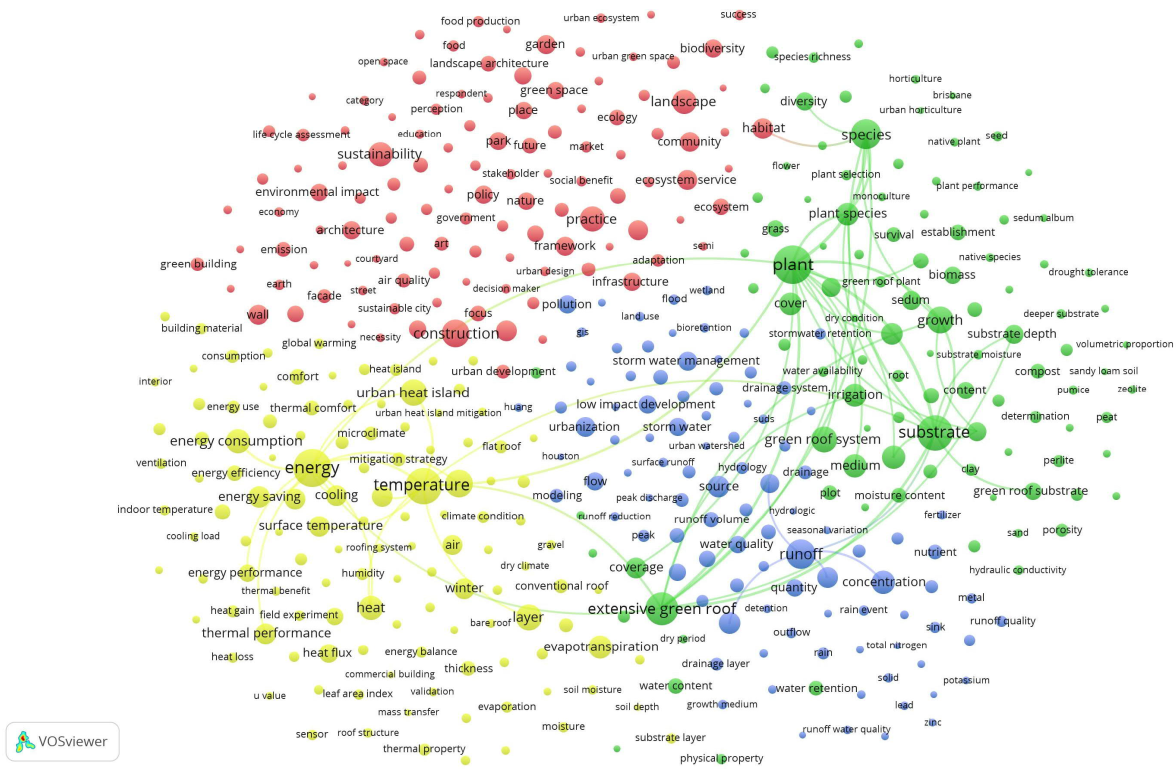


Figure 2. A two-dimensional bibliometric map of the relationship between terms listed from the titles and abstracts of scientific articles published between 1996-2018. Terms were collected from the Web of Science Core collection using the following search terms: “green roof*” OR “vegetated roof*” OR “living roof*” OR “roof* garden*” OR “planted roof*” OR “rooftop farm*”. The search was performed on 4 October 2018, resulting in 1973 articles. The map is based on WOSviewer software (Van Eck and Waltman 2010) that analyses the occurrence of terms in the title, keywords and the abstract of the papers. The size of the dots denote the frequency of occurrences of a term. The map shows four distinct clusters related to vegetated roofs; i) a red cluster, related to construction, policy and sustainability ii) a blue cluster related to run-off and stormwater management, iii) a green cluster with plant, substrate and species and iv) a yellow cluster related to energy, temperature and the heat island effect. Note that the term ‘green roof’ was removed from this analysis since it dominated the terminological sphere. Supplementary Material, Table S1 lists the merging of terms if they had the same meaning but different spelling.

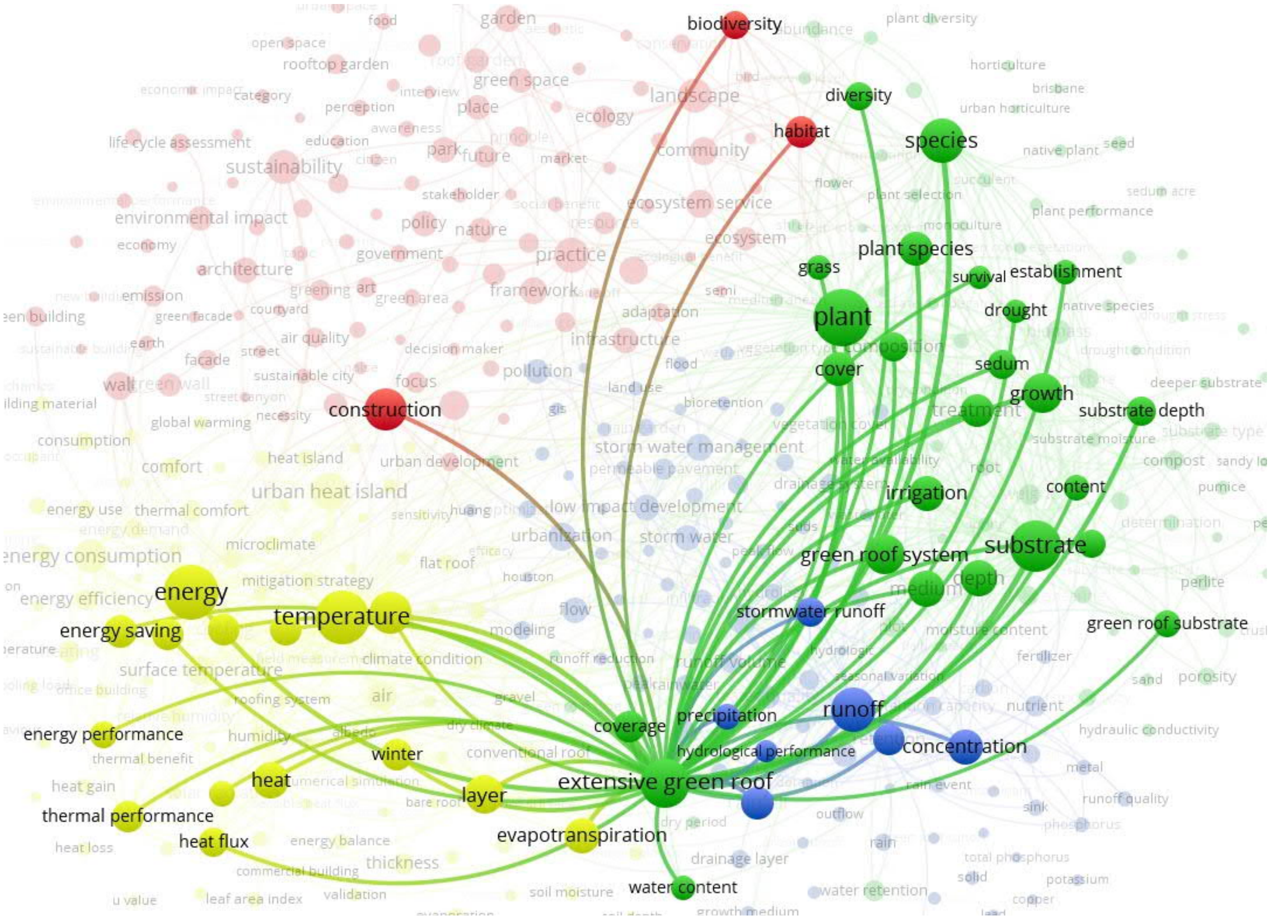


Figure 3. Highlighted links of the term extensive green roof that had a strength of more than 10 co-occurrences in a paper. In WOSviewer a link is a connection or a relation between two items, in this case co-occurrence between terms. Each link has a strength, represented by a positive numerical value: here, the number of publications in which two terms occur together. Placement of the term extensive green roof between the blue and yellow clusters also shows that these fields of study use the term often. For more details on the method, see Fig. 2 legend.

Supplementary Material, Table S1. Thesaurus file. Terms found in the VOSviewer analysis that had the same meaning but with a different spelling (see Fig. 2). Terms on the left side were replaced by terms on the right side to correct misspellings and abbreviations or to conform the spelling before the analysis.

label	**replace by**
air-quality	air quality
air-temperature	air temperature
best management practises	best management practice
best management practise	best management practice
best management practices	best management practice
best management practices (bmps)	best management practice
bmps	best management practice
bmp	best management practice
buildings	building
cities	city
climate-change	climate change
climates	climate
communities	community
cool roofs	cool roof
cost-benefit analysis	cost benefit analysis
eco-roof	eco roof
ecoroof	eco roof
ecoroofs	eco roof
ecosystems	ecosystem
ecosystem functions	ecosystem function
ecosystem services	ecosystem service
energy savings	energy saving
energy-balance	energy balance
energy-consumption	energy consumption
environments	environment
environmental impacts	environmental impact
extensive green roofs	extensive green roof
extensive green roof system	extensive green roof
gardens	garden
green buildings	green building
green facades	green facade
green roof systems	green roof system
green roofs	green roof
green-roof	green roof
gree-roofs	green roof
green roof substrates	green roof substrate
green walls	green wall
greenroof	green roof
habitats	habitat

heat-island	heat island
heat island effect	heat island
heat waves	heat wave
heavy-metals	heavy metals
hong-kong	hong kong
hydrological modelling	hydrological model
hydrologic performance	hydrological performance
impacts	impact
intensive green roofs	intensive green roof
lai	leaf area index
land-use	land use
landscapes	landscape
lca	life cycle assessment
lid	low impact development
lid practice	low impact development
life cycle assessment (lca)	life cycle assessment
life-cycle assessment	life cycle assessment
living roofs	living roof
living walls	living wall
low-impact development	low impact development
low impact development (lid)	low impact development
lysimeters	lysimeter
modelling	modeling
models	model
native plants	native plant
nature-based solutions	nature based solutions
ndvi	normalized difference vegetation index
new-york-city	new york city
new-zealand	new zealand
of-the-art	state of the art
permeable pavements	permeable pavement
pervious pavement	permeable pavement
porous pavement	permeable pavement
rain gardens	rain garden
roofs	roof
roof gardens	roof garden
rooftop gardens	roof garden
sedum spp	sedum
soils	soil
state	state of the art
stormwater	storm water
stormwater management	storm water management
storm-water management	storm water management
street canyons	street canyon
substrates	substrate
surfaces	surface
surface-temperature	surface temperature
systems	system
swmm	storm water management
temperatures	temperature

uhi	urban heat island
uhi effect	urban heat island
urban heat-island	urban heat island
urban heat island (uhi)	urban heat island
urban-environment	urban environment
vegetated roofs	vegetated roof
vegetative roofs	vegetated roof
vertical gardens	vertical garden
waste-water	waste water
waste-water treatment	waste water treatment
wastewater treatment	waste water treatment
water-quality	water quality
water-retention	water retention

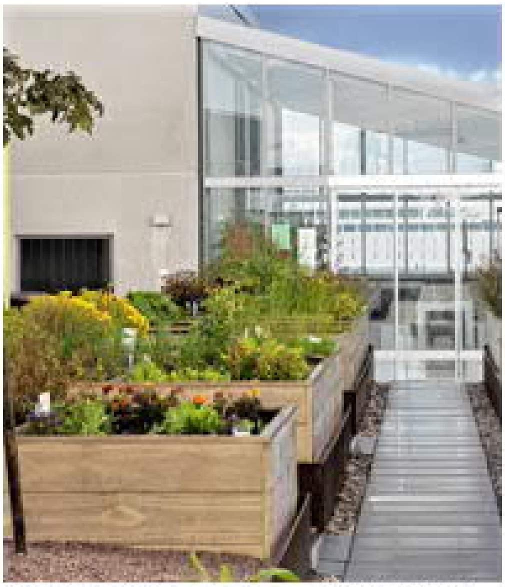
Supplementary Material, Table S2. A tentative list of functions that could be used in the naming of vegetated roof types. As the field develops, some of these terms will remain, new functions will be added, and some may go extinct.

Biodiversity
Habitat connectivity
Pollination/Pollinator
Bird nesting
Edible garden
Aesthetic
Scenic
Landscaping
Multisensory
Water retention
Cooling
Air purification
Carbon sequestration
Restorative
Silencing
Socializing

Supplementary Material, Appendix 1. Examples of the naming of vegetated roofs in Finland, using the new terminology.

Supplementary Material, Appendix 1. Examples of the naming of vegetated roofs in Finland, using the new terminology.

Biodiversity dry meadow roof (est. 2017) was designed specifically for plants and pollinators, focusing on local native plants that would provide flowers from spring to autumn. The average substrate depth is 12.5 cm, but variation is provided with reed humps below it. Stones and logs offer nesting and hiding opportunities. The roof is accessible for the residents. Photo by M. Mesimäki in 2018.



Socializing kitchen garden roof (est. 2017) in a residential block was designed specifically to offer possibilities for cooperation, parties, eating together, etc., i.e. for building social capital among residents. It was planted with edible herbs and flowers, plus bushes, climbers and trees producing berries and fruit. It also offers planter boxes where residents grow what they want. Photo by M. Mesimäki in 2018.

Scenic moss roof (est. 2015). The city of Helsinki demanded a new big sports hall to be covered by vegetation to scenically fit into a natural-like park. Moss was selected as the cover because the load support capacity of the roof was limited, and because there was an interest to test this new lightweight solution. The roof was designed using different substrate materials based on recycled or side products in different mixtures and proportions (e.g. compost, stone ash, soiled bark). The mosses clearly respond to the substrate so that the different test stripes are visible. Photo by S. Lehvävirta in 2019.

Supplementary Material, Appendix 1, continued.

Water retention calcareous meadow roof (est. 2013) to manage stormwater at a concrete factory. 8-10 cm thick alkaline substrate is made of local crushed lightweight concrete, a side product of the factory, mixed with 20% or 40% compost and 5% crushed bark. This study roof tests the capacity of a vegetated roof with high pH substrate to retain nutrients and rainwater, and to support plant and soil animal communities. This roof concept has been used in several places in Finland (ca. 1000 m^2 until 2019). Photo by S. Hallikainen in 2017.

Restorative berry bush roof (est. 2017) is a sauna terrace that is meant to become a verdant oasis that would serve as a tranquil space for relaxation during and outside sauna hours. It was established with a wide variety of bushes, dwarf shrubs, small trees and climbers that produce edible fruit or berries for the users to enjoy. The aim was to provide the feeling of a lush space, a hideaway where the visitor is embraced by vegetation. Picture from Talli architects/Pia Ilonen.

Landscaping meadow roof (est. 2008). This is an example of a roof that did not live up to expectations concerning the landscaping function because the aims were lost, confused or not communicated in the planning-construction-maintenance process. If designing with vegetation is not properly recognized as part of a roof planning-construction process, and the target vegetation and functions of the roof not communicated among the relevant stakeholders through the planning process, it may happen that the outcome does not meet any of the aims initially set for the roof, neither as for the vegetation nor the functionalities. Communication failure may also lead to a situation where the maintenance staff is unaware of how the vegetated roof should look like, and try to maintain, e.g. a meadow roof as a lawn (Mesimäki et al. 2015, Bernardi et al. 2019). More precise terminology would help the stakeholders in every phase to recognize the aims. Photo by H. Nieminen in 2014.