Urban Ecosyst
DOI 10.1007/s11252-016-0578-5

Towards a comprehensive green infrastructure typology: a systematic review of approaches, methods and typologies

Carlos Bartesaghi Koc[1] · Paul Osmond[1] · Alan Peters[2]

Abstract There is no consensus on a comprehensive classification for green infrastructure (GI). This is a consequence of the diversity of disciplines, application contexts, methods, terminologies, purposes and valuation criteria for which a GI typology is required. The aim of this systematic literature review is to evaluate the existing evidence on how GI is being categorised and characterised worldwide. We reviewed a total of 85 studies from 15 countries that were analysed for contextual trends, methods, parameters and typologies. Results show that relevant literature lacks a common terminology and that a universal typology for all scenarios is impractical. Analysis reveals that GI can be organised into four main GI categories: (a) tree canopy, (b) green open spaces, (c) green roofs and (d) vertical greenery systems (facades/walls). Green open spaces and tree canopy attracted the attention of researchers due to their complexity, variability and important roles in GI planning. Evidence suggests that a ternary approach in terms of the functional (purpose, use, services), structural (morphology) and configurational (spatial arrangements) attributes of GI should be applied for a more comprehensive classification. Although this approximation is inherently generic, since it can be used across different research disciplines, it is also sufficiently specific to be implemented for individual scopes, scenarios and settings. Further research is needed to develop a typology capable of responding to particular research aims and performance analyses based upon the findings discussed in this paper.

Keywords Urban greening · Classification schemes · Typologies · Systematic review · Ecosystem services · Spatial scales

Introduction

Researchers have defined green infrastructure (GI) as the interconnected network of natural and semi-natural elements capable of providing multiple functions and ecosystem services (ESS), encompassing positive ecological, economic and social benefits for humans and other species (Benedict and McMahon 2002, 2006; Ely and Pitman 2014; Jacobs et al. 2014; Naumann et al. 2011; Williamson 2003). Many studies concentrate on defining GI, though as an emerging and evolving concept, this is influenced by particular approaches and scopes. Conversely, studies focusing on GI classification are more scarce. The definition, identification, characterisation and classification of GI has become a necessity for researchers, practitioners and governments to be able to benchmark and assess existing conditions, allocate different initiatives and propose future development scenarios (Jacobs et al. 2014; Naumann et al. 2011). Existing classification systems offer limited insights on the identification and categorisation of GI across different urban settings, and are inadequate to support planning perspectives (Young et al. 2014).

✉ Carlos Bartesaghi Koc
c.bartesaghikoc@unsw.edu.au

Paul Osmond
p.osmond@unsw.edu.au

Alan Peters
alan.peters@unsw.edu.au

[1] Faculty of Built Environment - UNSW; Cooperative Research Centre for Low Carbon Living (CRC-LCL), Sydney, Australia

[2] Faculty of Built Environment - UNSW, Sydney, Australia

Published online: 09 July 2016

This represents a significant research gap, in terms of both theory and practice.

This review responds to this gap by addressing the following questions: (a) what is the geographic location of the key literature dealing with the classification of GI; (b) what are the different methods, principles, approaches and parameters employed for cataloguing GI; (d) which high level categories can GI be classified into; (e) which typologies and terminology can be assigned to each category; and (f) how can this knowledge be translated into a conceptual framework to inform a more comprehensive typology in the future?. To answer these questions, this paper integrates evidence from across a broad range of literature by reviewing 85 studies in three languages. The aim of this systematic literature review is to synthesise and evaluate the existing evidence on how GI is being categorised and characterised worldwide. Our analysis is intended to provide the conceptual framework for a more comprehensive classification scheme in the future.

Review methodology

We used a systematic literature review for the formulation of this paper (Khan et al. 2003; Pickering and Byrne 2013; Pullin and Stewart 2006). This differs from the classic meta-analysis since it analyses geographic, methodological and theoretical trends and patterns in the literature (Pickering and Byrne 2013; Rupprecht et al. 2015).

Search & selection criteria

For this review, we systematically searched two major databases (Google scholar, and Scopus) and printed material. The number of documents identifying different types of GI is extensive; hence, we did not pretend to synthesise exhaustively all available documentation, but to review the most cited and representative publications. To be included in this review, research papers had to meet the following selection criteria:

a) Articles considered any of the following classification aspects: ecosystems services (ESS), multi-functionality, morphological and structural attributes, land-use and land covers.
b) The literature belonged to any of the following fields: urban planning and design, landscape architecture, street design, urban forestry, remote sensing and land surveying, geography and urban climatology/meteorology.
c) The literature studied, described or discerned an identifiable GI typology.
d) Documents were in English, Spanish and German. One limitation is the exclusion of other languages which could potentially bias interpretation of the findings.

The context and the main authors' affiliations were used to determine the geographical origin of studies.

Content analysis

Interpretation of the findings was based on: (a) type of publication (Table 1), (b) differing terminology (Table 2), (c) geographic location of studies under each GI category (Table 3), (d) classification approaches and parameters (Table 4 and 5), and (d) typologies identified per GI category (Table 6, 7, 8, 9 and 10).

Review of studies

We identified a total of 100 potential articles that distinguished at least one type of GI, but only 85 met the final selection criteria. The review was organised in three parts: (a) Geographical implications and contextual response; (b) Classification approaches, parameters and research methods; and (c) Typologies and spatial scales identified per category.

Analysis of geographical context

Geographical context includes biophysical settings, institutional research interests, geopolitical conditions and country-based GI planning strategies. Table 1 presents the number and type of publications grouped according to their geographic location. The review included publications from 15 countries and/or territories, split fairly evenly between peer reviewed and grey literature. The largest contribution was from the UK ($n=24$), followed by other European countries ($n=20$), especially Germany ($n=7$) and Spain ($n=4$), together representing more than half of the reviewed literature ($n=45$). The remaining 50 % of articles came from the USA and Canada ($n=18$) and Australasia ($n=14$) with fewer from Asian countries ($n=8$). These figures demonstrate a strong geographic bias and a greater interest from European countries in the characterisation and classification of GI (Davis 2010; Mazza et al. 2011; Mell 2014; Naumann et al. 2011).

The majority of studies came from peer-reviewed publications (52 %) with the exception of the UK, where the discussion on GI has been led by grey literature such as government reports and technical papers. The Planning Policy Guidance Note 17 (PPG17) produced by the Urban Green Spaces Taskforce (Office of the Deputy Prime Minister 2002a, b), has served as a guideline and benchmark for most reports produced across the UK since 2002.

The process of identifying and characterising the different assets or components of GI largely depended on the terminology and definitions employed by each study. In a preliminary analysis we detected overlapping

Table 1 Number and type of articles per geographic location

Type of publication	UK	Rest of Europe[a]	USA & Canada[b]	Australasia [c]	Asia[d]	Number of papers	Percent of papers
Journal	7	12	11	6	7	**44**	**50.5**
Report/Guidelines	14	4	1	8	–	**27**	**31.8**
Book/Chapter	2	2	5	–	1	**9**	**11.8**
Thesis	1	1	1	–	–	**3**	**3.5**
Conference	–	2	–	–	–	**2**	**2.4**
Number of papers	**24**	**21**	**18**	**14**	**8**	**85**	**100.0**
Percent of papers	**28.2**	**24.7**	**21.2**	**16.5**	**9.4**	**100.0**	

Values in bold represent totals

Number of studies per country

[a] Germany ($n = 7$), Spain ($n = 4$), European Union-EU ($n = 3$), The Netherlands ($n = 2$), Austria ($n = 1$), Denmark ($n = 1$), Greece ($n = 1$), Italy ($n = 1$)

[b] USA ($n = 13$), Canada ($n = 5$)

[c] Australia ($n = 12$), New Zealand ($n = 2$)

[d] Hong Kong ($n = 3$), China ($n = 3$), Singapore ($n = 2$)

terminology, which was catalogued in high level themes (Table 2). This demonstrates that the majority of green assets can be grouped in the following main categories: (a) tree canopy (TC), (b) green open spaces (GOS), (c) green roofs (GR) and (d) vertical greenery systems (VGS) (green walls/facades). The number and origin of studies concentrated in each category are summarised in Table 3.

Analysis of methods, approaches and parameters

Literature review (89 %), case studies (52 %) and remote sensing (including land surveying) (37 %) were the most common methods employed to identify and classify GI. Evidence suggests that GI can be classified according to three main principles: (1) the *functional*, (2) the *structural*

Table 2 Different terminology associated with main categories of green infrastructure

Tree canopy (TC)	Green open spaces (GOS)	Green roofs (GR)	Vertical greenery systems (VGS)
Green canopy	Green belts	Eco-roofs	Bio-walls
Green streets	Green corridors	Green rooftops	Green façades
Green alleys	Green covers	Living roofs	Green walls
[Street] Trees	Greenspaces	Rooftop gardens	Living walls
Shrubs, shrubbery	Greenways		Vertical landscaping
Tree cover	[Vegetated] Ground covers		Vertical vegetation
Urban forestry	Ground surfaces		
Urban tree canopy	Land covers		
Woodland	[Public] [Urban] open spaces		
[Forest]land	Urban land		
	[Urban] vegetation structures		
	Vegetative covers		

Based on: Abunnasr (2013); Ahern (1995); Arlt et al. (2005), Bowler et al. (2010a, b), Brady et al. (1979); Byrne and Sipe (2010); DTLR (2002); Dunnett et al. (2002); English Nature (2003); Foster et al. (2011); Francis and Lorimer (2011); Hunter et al. (2012); Jacobs et al. (2014), Jim (1989, 2015), Jim and Chen (2003); Landscape Institute (2009); Lehmann et al. (2014); Mathey et al. (2011); Mathey et al. (2010); Norton et al. (2015); Norton et al. (2013); Oberndorfer et al. (2007); Ochoa (1999), ODPM (2002a, b), OEH (2015); Oke et al. (1989); Ottelé et al. (2011); Pauleit and Duhme (2000); Pauleit et al. (2003); Pérez et al. (2014); Peters et al. (2011); Stewart and Oke (2012); Susorova (2015); Tooke et al. (2009); VEAC (2011); Wong (2011); Wong and Chen (2010); Woolley (2006)

Table 3 Number and origin of studies mentioning different green infrastructure categories

GI category	UK	Rest of Europe	USA & Canada	Australasia	Asia	Number of papers	Percent of papers *
GOS	22	13	13	10	5	**63**	**74.1**
TC	13	10	13	7	4	**47**	**55.3**
GR	7	3	5	7	1	**23**	**27.1**
VGS	2	8	3	7	4	**24**	**28.2**
OC	1	–	–	1	–	**2**	**2.4**

TC tree canopy, *GOS* green open spaces, *GR* green roofs (GR), *VGS* vertical greenery systems, *OC* other classification

* Percentage calculated from 85 articles

Values in bold represent totals

(morphology) and (3) the *configurational* (spatial arrangements), in accordance with the tripartite approaches proposed by Ahern (1995, 2007) and Mell (2008, 2010), and the spatial scales defined by Oke et al. (1989) and Oke (2006). We have sought to identify the main principle applied by each study; however, in some cases classifications were underpinned by more than one principle. Additionally, we identified different approaches, theoretical concepts and classification parameters that depended on the types of GI under investigation (Table 4 and 5).

Functional-configurational classification

Green infrastructure has been mostly classified from a *functional-configurational* perspective. The 'multi-functional network and connectivity' has been widely accepted as a classification approach, encompassing land-use types, purpose, connectivity, hierarchy (spatial scale), spatial configuration, catchment, accessibility, values and significance (ecological, cultural, social, political and economic), location and distribution of functions. Table 4 organises the studies that employed functional and configurational principles to classify GI by summarising their classification approaches, parameters, and research methods.

The 'accessible natural greenspace standard model' (ANGSt) proposed by English Nature (2003) has incorporated accessibility, structural complexity and intensity of use as classification parameters based on the principle of greenspace continuity and the gradual progression from grey (artificial) to green (natural) infrastructure. Additionally, this model highlights the capacity of different spatial configurations to support the physical and ecological processes provided by GI (Pauleit et al. 2003).

The criteria defined by the urban green space taskforce (UGST) (DTLR 2002) and the 'PPG17 guidelines' (ODPM 2002a, b) have largely influenced approaches and classifications across the UK. This key literature drew on stakeholder forums and remote sensing to propose a need-based approach for auditing green spaces, providing the groundwork for most of the later publications. For instance, Gill et al. (2007) updated the PPG17 typology including urban morphology types (UMT) for the spatial integration of natural processes and human activities. Similarly, the Mersey Forest approach (Landscape Institute 2009; TMF 2010, 2011), and the East Midlands scoping study (EMDA 2010; TEP 2005) utilised the PPG17 to propose a mapping framework to audit GI for planning development purposes.

Mell (2008, 2010) proposed a tripartite approach to classify GI in terms of form, function and context following Ahern (1995) greenways classification system. Mell's work highlighted the role of GI beyond land-use types, addressing this problematic both theoretically and practically by considering the aspects of connectivity, accessibility and multi-functionality (Mell 2010). On the other hand, Young et al. (2014) proposed a very distinctive categorisation that focuses on the social and ecological aspects of GI. Both studies attempted to reconcile different overarching classification approaches such as hierarchy (Ahern 1995; Dunnett et al. 2002), ecological values (Davies et al. 2006), human health (Tzoulas et al. 2007); and valuation of ESS (Dobbs et al. 2011; European Environment Agency 2011; de Groot et al. 2002; Millennium Ecosystem Assessment 2005).

'Hierarchy and significance' is another concept linked to the principle of multi-functionality that was pioneered by Ahern (1995). The primary focus of this approach is the importance of landscape contexts and goals across different spatial scales. The hierarchy approach, introduced in the UK by the London Planning Advisory Committee (LPAC) (Llewelyn-Davies Planning 1992), has been adopted by a considerable number of studies for the stratified classification of green open spaces at national, regional, metropolitan and local levels (Byrne and Sipe 2010; CBC 2008; CCC 2010; Dunnett et al. 2002; TSG 2008; VEAC 2011; Wong 2011).

Supporting the *functional* classification principle, the concept of ecosystem services (ESS) has been employed to differentiate distinctive delivery capacities of GI among the high level ESS themes of supporting, providing, regulating, and cultural (Mazza et al. 2011; MEA 2005). Among these categories, the climate-regulating services have captured the attention of climate change

Table 4 List of methods, approaches and parameters used by studies under 'functional-configurational' classifications

Citation	Research methods	GI Categories	Classification approaches	Classification parameters
Abunnasr (2013) [a]	LR	TC, GOS, GR, VGS	- Network approach - Multi-functionality - Landscape ecology	1. Size 2. Location & catchment 3. Scale & hierarchy
Ahern (1995)	LR, CS	GOS	- Hierarchy & significance - Multi-functionality	4. Spatial configuration & complexity
Ahern (2007)	LR	GOS	- Multi-functional network - Patch-Corridor-Matrix	5. Land-use types 6. Purpose
Aldous (2014)	LR, GIS, CS	GOS	- Multi-functionality	7. Significance
Bell et al. (2007) [b]	LR, RM	GOS	- Multi-functionality - Value of public space	8. Accessibility & ownership 9. Management & maintenance
Bowler et al. (2010b)	LR	TC, GOS, GR	- Climate regulating ESS	10. Intensity of intervention/use
Byrne and Sipe (2010)	LR	GOS	- Hierarchy & significance - Multi-functionality	11. Functions & values: a. Socio-cultural
CBC (2008) [b]	LR, GIS, APS	GOS	- Hierarchy & significance - Multi-functionality	b. Economic c. Environmental
CCC (2010)	LR, CS	GOS	- Hierarchy & significance - Multi-functionality	d. Political 12. Ecosystem services:
Cooper (2010) [b]	CS, NA, GIS, SF	TC, GOS	- ESS - Network analysis (Green grid)	a. Provisioning b. Regulating
Davis (2010)	LR, GIS, CS	TC, GOS	- ESS - Connectivity	- Shading (LAI) - Evapotranspiration
Davies et al. (2006)	LR, SF	TC, GOS, GR	- Multi-functionality	- Wind modification
DEFRA (2008) [b]	LR, CS	TC, GOS	- ESS - Green grid concept	- Water supply - Thermal properties
DTLR (2002) [b]	LR	GOS	- Multi-functionality - Need-based approach	- Plant support - Surface properties
Dunnett et al. (2002)	LR, CS, SI	TC, GOS	- Hierarchy - Multi-functionality	- Anthropogenic heat - Type of vegetation
Ely and Pitman (2014)	LR	TC, GOS, GR, VGS	- ESS - Water sensitive urban design	c. Cultural d. Supporting
EMDA (2010) [b]	LR, CS	TC, GOS	- Multi-functional network	
English (2003) [b]	LR, APS, CS	GOS	- Accessible Natural greenspace standard (ANGSt) model - Multi-functionality	
Foster et al. (2011)	LR, CS	TC/GR	- ESS - Low impact development	
Gill et al. (2007)	LR, GIS, CS	GOS	- Multi-functional network - ESS - Urban morphology types	
Hunter et al. (2012)	LR	TC, GR, VGS	- Climate regulating ESS - Hierarchy	
Jim and Chen (2003)	LR, CS	TC, GOS	- Multi-functional network - Landscape ecology	
Keeley (2011)	LR	GOS, GR	- Climate regulating ESS - Green area ratio	
Landscape Institute (2009) [b]	LR, CS	TC, GOS, GR, VGS	- Multi-functional network - ESS	
Llewelyn-Davies (2000)	LR	TC, GOS	- Hierarchy & significance - Multi-functionality	
Li et al. (2005)	LR, GIS, CS	TC, GOS, GR, VGS	- Multi-functional network - ESS - Landscape ecology	
Mazza et al. (2011) [c]	LR, CS	TC, GOS	- ESS - Multi-functional network	
Mell (2010) [d]	LR, SI	Other	- Multi-functionality	
Naumann et al. (2011)[c]	LR, CS	TC, GOS	- ESS - Ecosystem habitats	

Table 4 (continued)

Citation	Research methods	GI Categories	Classification approaches	Classification parameters
Norton et al. (2013, 2015)	LR, GIS	TC, GOS, GR, VGS	- Climate regulating ESS	
ODPM (2002a, b) (PPG17)	LR	GOS	- Multi-functionality - Need-based approach	
OEH (2015)	LR	TC, GOS, GR, VGS	- Climate regulating ESS - Urban green cover	
Panduro and Veie (2013) [e]	LR, GIS, CS	GOS	- Hedonic Valuation Model - ESS	
Pauleit et al. (2003) [f]	LR, GIS, SI	GOS	- Multi-functional network - ANGSt model	
Rupprecht et al. (2015)	LR	TC, GOS, GR, VGS	- ESS - Biodiversity	
Schilling and Logan (2008)	LR	TC, GOS, GR	- Multi-functionality	
Sheate et al. (2012) [b]	LR, NA, GIS	TC, GOS	- ESS - Network analysis	
TEP (2005) [b]	LR, GIS, SF	TC, GOS	- Multi-functionality	
TMF (2010) [b]	LR, CS	TC, GOS, GR	- Multi-functionality	
TMF (2011) [b]	LR, GIS	TC, GOS, GR	- Multi-functionality	
TSG (2008)	LR	GOS	- Hierarchy & significance - Multi-functionality	
VEAC (2011)	LR	GOS	- Hierarchy	
Wang (2001)	LR	GOS	- Multi-functionality	
Wong (2011) [g]	LR, GIS, CS	GOS	- Multi-functional network	
Wong and Chen (2010)	LR, GIS, CS	TC, GOS, GR, VGS	- Climate regulating ESS	
Woolley (2006)	LR, CS	TC, GOS, GR	- Hierarchy - Value of space (home range concept)	
Young et al. (2014)	LR, CS	Other	- Multi-functionality (Triple-Bottom-Line)	

APS Aerial & photographic survey, *CS* Case study, *GIS* Geographic information systems, *LR* Literature review, *NA* Network analysis, *RM* Research mapping, *SF* Stakeholders forum, *SI* Survey & interviews, *ESS* Ecosystem Services, *TC* Tree canopy, *GOS* Green open spaces, *GR* Green roofs, *VGS* Vertical Greenery Systems

[a] Typology after Gill et al. (2007) and Ahern (2007)

[b] Classification based on ODPM (2002b) (PPG17)

[c] Classification based on Davis (2010)

[d] Typology based on Ahern (1995)

[e] Typology after Bell et al. (2007)

[f] Evaluates English Nature (2003) approach

[g] Urban space typology based on Woolley (2006)

researchers (Bowler et al. 2010b; Hunter et al. 2012; Norton et al. 2013, 2015; Wong and Chen 2010). For instance, Bowler et al. (2010b) used an ESS approach to undertake a systematic review of the potential cooling effects of three types of GI: parks, trees/forests and green roofs. Studies conducted in Australia, identified evapotranspiration, albedo, shading and wind flow as key parameters for classification (Coutts et al. 2012, 2015; Hunter et al. 2012; Norton et al. 2013, 2015).

Returning to ESS as a functional approach, some authors have emphasised the classification of land-uses (Cooper 2010; DEFRA 2008; Ely and Pitman 2014; Panduro and Veie 2013; Sheate et al. 2012), often using remote sensing to inform the spatial distribution of ESS. Reports from the European Union have similarly focused on the use of spatial planning and mapping tools to guide design interventions (Davis et al. 2015; Mazza et al. 2011; Naumann et al. 2011). In contrast to the holistic overview of ESS proposed by European research, studies from other countries have concentrated on particular services. For instance, Foster et al. (2011) appealed to the low impact development (LID) concept in the USA. In Australia, Ely and Pitman (2014) and Coutts et al. (2012) described the environmental potentialities of GI appealing to water sensitive urban design (WSUD), while the New South Wales Office of Environment and Heritage (OEH 2015)

Table 5 List of methods, approaches and parameters used by studies under 'structural-configurational' classifications

Citation	Research methods	GI Categories	Classification approaches	Classification parameters
Anderson et al. (1976)	LR, GIS, CS	TC, GOS	- Land use/land cover (LULC)	1. LULC types 2. Spatial scale 3. Urban morphology types 4. Vegetation attributes: a. Foliage geometry & shape b. Foliage contiguity & distribution c. Foliage density (LAI, NDVI) dimensions / volume d. Foliage type (deciduous, evergreen) e. Extension & orientation f. Segment attributes of trees g. Derived fractions of vegetation h. Thermal properties of plants 3. Surface properties: a. Biological b. Physical & thermal c. Structural 4. Supporting structure attributes (only for green roofs and vertical greenery systems): a. Construction material b. Installation c. Location & orientation d. Operation & maintenance e. Intensity of use f. Accessibility
Arlt et al. (2005)	LR, GIS, CS	TC	- Vegetation structure - Urban biotopes & land-use	
Brady et al. (1979) [b]	LR, CS	TC, GOS	- LULC - Urban ecosystem types	
Cadenasso et al. (2007, 2013)	LR, GIS, CS	TC, GOS	- LULC	
Di Gregorio and Jansen (1998)	LR	TC, GOS	- LULC - Hierarchy	
Dunnett and Kingsbury (2004)	LR, CS	GR, VGS	- Morphological attributes	
Francis and Lorimer (2011)	LR	GR, VGS	- Morphological attributes - Urban reconciliation ecology	
Höfle and Hollaus (2010)	GIS, CS	TC	- Vegetation edge-based segmentation	
Hunter et al. (2014)	LR	VGS	- Morphological attributes - Climate regulating ESS	
Jacobs et al. (2014)	GIS, ITM	TC, GOS	- Vegetation cover attributes - Multi-functionality	
Jim (1989)	GIS, APS	TC	- Morphological attributes - Spatial configuration	
Jim (2015)	LR	VGS	- Morphological attributes	
Kontoleon and Eumorfopoulou (2010)	LR	VGS	- Morphological attributes	
La Rosa and Privitera (2013)	LR, CS, GIS	TC, GOS	- LULC	
Lehmann et al. (2014) [a]	LR, GIS, CS	TC, GOS	- Urban vegetation structure types (UVST) - Urban biotopes - Climate regulating ESS	
Liu and Yang (2013) [b]	GIS, CS	TC, GOS	- LULC	
Mathey et al. (2011) [a]	LR, GIS, CS	TC, GOS	- Urban vegetation structure types (UVST)	
Mathey et al. (2010) [a]	LR	TC, GOS	- Urban biotopes - Climate regulating ESS	
Oberndorfer et al. (2007)	LR	GR	- Morphological attributes - Provisioning ESS	
Ochoa (1999)	LR, CS	TC, GOS	- Morphological attributes	
Oke et al. (1989)	LR	TC, GOS	- Climate regulating ESS	
Ottelé et al. (2011)	LCA, CS	VGS	- Morphological attributes - Life cycle analysis (LCA)	
Pauleit and Duhme (2000)	GIS, CS	TC, GOS	- LULC	
Pérez et al. (2011a, b, 2014)	LR, CS	VGS	- Morphological attributes	
Perini et al. (2011)	LR, CS	VGS	- Morphological attributes - Climate regulating ESS	
Peters et al. (2011)	GIS, CS	TC, GOS	- LULC - Climate regulating ESS	
Stewart and Oke (2012)	LR, GIS	TC, GOS	- LULC - Local climate zones (LCZ)	
Susorova (2015)	LR	VGS	- Morphological attributes - ESS	
Tooke et al. (2009)	GIS, CS	TC, GOS	- Morphological attributes	
Williams et al. (2010)	LR,CS	GR	- Morphological attributes	

Table 5 (continued)

Citation	Research methods	GI Categories	Classification approaches	Classification parameters
Wilmers (1988)	GIS, APS	TC, GOS	- LULC - Morphological attributes	
Wong et al. (2010)	LR, CS	VGS	- Morphological attributes	
Zhou et al. (2014)	LR, GIS, CS	TC, GOS	- LULC	

APS Aerial & photographic survey, *CS* Case study, *GIS* Geographic information systems, *ITM* i-Tree mapping, *LCA* Life cycle analysis, *LR* Literature review, *ESS* Ecosystem Services, *TC* Tree canopy, *GOS* Green open space, *GR* Green roofs, *VGS* Vertical Greenery Systems

[a] Approach based on Arlt et al. (2005) vegetation structures classification

[b] Classification based on Anderson et al. (1976)

addressed GI from an environmental point of view and Rupprecht et al. (2015) considered biodiversity implications.

Structural-configurational classification

The identification and study of the *structural* characteristics of vegetation has been another important principle underpinning classifications; nevertheless, this research found that in some cases a functional approach was additionally included to achieve more comprehensive and explanatory typologies. Table 5 organises the studies that employed the structural and configurational principles to classify GI by summarising their classification approaches, parameters, and research methods.

It has been acknowledged the tremendous importance of spatial configurations for understanding the heterogeneity of GI, and for discovering how different patterns and physical interactions shape a multi-functional network (Hawken et al. 2014). The identification of the physical and formal attributes of GI was the primary focus of research concerning tree canopy, green roofs and vertical greenery systems, whereas land and vegetation cover classifications served for inventorying tree canopy and green open spaces.

In relation to green open spaces and tree canopy, a classification scheme of major land-use/land cover types for remote sensing studies in conservation and ecology was initially introduced by Anderson et al. (1976), adopted by Brady et al. (1979) and modified and expanded by Liu and Yang (2013). This classification was initially aimed at studies on natural resource management at very coarse levels. Anderson et al. (1976) scheme has become almost a standard for the industry, being adopted by multiple schemes such as the National Land Cover Characterisation (NLCC) (United States Geological Survey 2003), the Multi-resolution Land Characteristics (MRLC) [United States Geological Survey (USGS) (1992)], and the global land-cover classification [Food and Agriculture Organisation (FAO) (Di Gregorio and Jansen 1998)] (Cadenasso et al. 2007, 2013; Di Gregorio and Jansen 1998).

The classification scheme called HERCULES (High Ecological Resolution Classification for Urban Landscapes and Environmental Systems) also relies on land classification, although it separates function (land-use) and structure (land-cover), and entirely focuses on the latter (Cadenasso et al. 2007, 2013; Zhou et al. 2014; Zhou and Troy 2009). This scheme acknowledges the heterogeneity of urban landscapes by proposing the combination of three sets of elements: buildings, surfaces and vegetation, distinguished in terms of form, amount and organisation. In contrast to Anderson and related schemes, the HERCULES classification can be applied at medium scales in varied urban contexts (Cadenasso et al. 2013; Zhou and Troy 2009).

To amend the deficiencies of urban-rural classifications, and in similar way to the HERCULES approach, Stewart and Oke (2012) proposed 'local climate zones' (LCZ) as a scheme combining different surface properties, urban morphologies and human activities. The LCZ characterisation provides a series of standardised land cover types that can be recombined into subclasses, facilitating the investigation of vegetation in particular conditions. Similarly, other studies have used the physical properties of canopy and surface covers as parameters to compare green and non-green open spaces and to differentiate pervious and impervious surfaces (Jacobs et al. 2014; La Rosa and Privitera 2013; Liu and Yang 2013; Pauleit and Duhme 2000; Peters et al. 2011; Wilmers 1988).

In Germany, an approach initially proposed by Arlt et al. (2005) incorporating the urban biotope theory and vegetation structures has served as the basis for subsequent studies investigating the correlation between tree-derived attributes (i.e. volume, size, geometry and height), surface permeability and air temperature differences (Lehmann et al. 2014; Mathey et al. 2010, 2011). All these parameters interact with existing building structures and land uses to create particular 'urban vegetation structure types' (UVST). Similarly, Ochoa (1999) has proposed the study of ground cover characteristics along with the spatial configuration, orientation, geometry and

Table 6 List of tree canopy typologies identified by studies

Citation	Spatial scale	Tree canopy typologies
Abunnasr (2013)	Me, Lo	1. Street trees / green streets / green alleys / road trees / urban tree canopy
Anderson et al. (1976)	Me	2. Street greenways / greenbelts
Bowler et al. (2010b)	Lo, Mi	3. Street verges / hedges / hedgerows
Cadenasso et al. (2007, 2013)	Me, Lo, Mi	4. Shrubs / scrub / bushes
Cooper (2010)	Me, Lo	5. Urban forestry / forest / community forests / forestland / forest reserves
Davies et al. (2006)	Me, Lo, Mi	6. Woodlands / community woodlands
DEFRA (2008)	Me, Lo	7. Parkland trees
Dunnett et al. (2002)	Me, Lo	
Ely and Pitman (2014)	Lo, Mi	
EMDA (2010)	Me, Lo	
Foster et al. (2011)	Lo	
Hunter et al. (2012)	Lo, Mi	
Jacobs et al. (2014)	Me	
Jim and Chen (2003)	Me, Lo	
Landscape Institute (2009)	Me, Lo	
Li et al. (2005)	Me, Lo	
Llewelyn-Davies (2000)	Me, Lo	
Mazza et al. (2011)	Me	
Naumann et al. (2011)	Me	
Norton et al. (2013, 2015)	Me, Lo, Mi	
OEH (2015)	Lo, Mi	
Oke et al. (1989)	Me, Lo, Mi	
Pauleit and Duhme (2000)	Me, Lo	
Rupprecht et al. (2015)	Lo, Mi	
Schilling and Logan (2008)	Me, Lo	
Sheate et al. (2012)	Me, Lo	
TEP (2005)	Me, Lo	
TMF (2010, 2011)	Me	
Wilmers (1988)	Me, Lo	
Woolley (2006)	Me, Lo, Mi	
Wong and Chen (2010)	Lo, Mi	
Zhou et al. (2014)	Me, Lo, Mi	
Arlt et al. (2005)	Me, Lo	1. Trees (tall vegetation):
Höfle and Hollaus (2010)	Lo	a. Isolated / scattered / sparse / detached / semi-detached
Jim (1989)	Lo, Mi	b. Linear / in rows / aligned / connected
Lehmann (2014)	Me, Lo	c. Dense clusters (high density)
Mathey et al. (2010, 2011)	Me, Lo	d. Grouped (medium and low density)
Ochoa (1999)	Mi	e. Geometry (ovoid, cylindrical, conical, conical inverted, spherical)
Stewart and Oke (2012)	Me, Lo	2. Shrubs, bushes (medium vegetation)
		3. Turf, lawn, meadow (low vegetation)
Arlt et al. (2005)	Me, Lo	1. Evergreen trees / forest
Dunnett et al. (2002)	Me, Lo	2. Deciduous trees / forest
Liu and Yang (2013)	Me	3. Mixed trees / forest
Ochoa (1999)	Mi	4. Vegetated wetland
Peters et al. (2011)	Me, Lo	
Tooke et al. (2009)	Lo	

Spatial scales: *Me* Meso, *Lo* local, *Mi* Micro type of vegetation to identify the capacities of GI for controlling urban microclimate conditions.

To classify tree canopy structures, Höfle and Hollaus (2010), Jim (1989) and Tooke et al. (2009) have used remote-sensing approaches such as decision tree classification (spectral mixture analysis) and vegetation edge-based segmentation to discriminate green elements independently from the functions and services provided. Their main focus was the technical and descriptive study of spatial configurations, patterns of distribution and deciduous-evergreen differentiation.

The classification approaches of green roofs and vertical greenery systems were more straightforward in comparison to other categories due to their structural simplicity. Studies have primarily divided green roofs into intensive and extensive, depending on substrate depths, roof dimension and intensity of use. In comparison, vertical greenery systems have been differentiated according to the location of greening (rooted on the ground or rooted on the wall), the characteristics of the supporting structures and the level of maintenance (Jim 2015; Susorova 2015). Besides structural attributes, Ottelé et al. (2011) incorporated life cycle analysis (LCA) for a comparative study of the functionality of green facades and living walls. Mostly, green roofs and vertical greenery system typologies have supported studies concerning building energy performance, stormwater benefits, and microclimatic effects at fine scales.

Analysis of categories and typologies

Tree canopy

The classification of tree canopy has depended on (a) the functional aspects referring to extension, location, hierarchy, land-use and purpose; (b) the structural characteristics such as size, geometry, type of foliage; and (c) the spatial arrangements (isolated, dense, and aligned) of vegetation elements. The differentiation of the tree canopy typologies has also depended on the geographic context, within or without the urban boundary, and more importantly, the spatial scale of observation. For instance, at regional scale tree canopy can be considered as forestland while at precinct scale can be referred to as street trees. This situation has caused the double counting and/or overlapping of typologies across scales. Three scales –micro, local and meso– have been defined and widely accepted for the classification of tree canopy in terms of its micrometeorological implications, scales that can also be applied for other types of studies (Hunter et al. 2012; Norton et al. 2013, 2015; Oke 2006, 2009; Oke et al. 1989). Table 6 offers a list of typologies identified in the literature and the corresponding spatial scales.

Green open spaces

Green open spaces have attracted the most research attention due to their importance for defining planning strategies and interventions. Their classification has depended on (a) the spatial scale (hierarchy), dimension and location of spaces (urban core versus periphery); (b) their primary purposes (land-uses/land-covers) and intensities of use; (c) accessibility and ownership (private versus public); and (d) Biophysical surface characteristics (permeability, amount of vegetation cover, thermal attributes). Table 7 lists the different green open space typologies identified by studies at different spatial scales.

The major differentiation of green open spaces has emerged from the rural–urban dichotomy (criticised by Stewart and Oke 2012), the identification of land-use types and the different scales of approximation. Green open spaces have primarily been distinguished into those within urban cores and those beyond the urban periphery, both studied at local and meso scales (Abunnasr 2013; Landscape Institute 2009; Woolley 2006). Ahern (2007) has classified greenspaces according to their spatial dimension into urban patches, corridors and matrix; meanwhile Davis (2010) has appealed to conservationist approaches, identifying spaces in terms of their connectivity and biodiversity restoration capacities (Mazza et al. 2011; Naumann et al. 2011).

In the UK, the PPG17 guidelines have listed 17 distinctive types of greenspaces predominantly focused on land uses for the implementation of planning policies and the delivery of government objectives (ODPM 2002a, b). The majority of subsequent studies have based their own typologies on this list, and whether adopting, extending or modifying it, this has facilitated the identification of needs and opportunities to broaden the community benefits of GI (Cooper 2010; DEFRA 2008; EMDA 2010; Sheate et al. 2012; TMF 2010). Likewise, the work of Gill et al. (2007) and TEP (2005) applied PPG17 categories to develop a more complete terminology on green open spaces for North West England (Landscape Institute 2009).

The intensity of use and level of human intervention has served to discriminate natural and designed greenspaces (English Nature 2003; Lehmann et al. 2014; Mathey et al. 2010, 2011; Pauleit et al. 2003). Typologies derived from this approximation have resulted from land-cover classifications which have mainly distinguished between hard and soft landscapes (pervious and impervious surfaces) (Keeley 2011; Norton et al. 2013; Ochoa 1999; OEH 2015; Peters et al. 2011; Wilmers 1988).

Likewise, some studies have acknowledged the heterogeneity and complexity of built environments by incorporating a mix of biotic, semi-natural and man-made elements to characterise open spaces as an amalgam of uses, urban biotopes and vegetation features (Anderson et al. 1976; Brady et al. 1979; Cadenasso et al. 2007; La Rosa and Privitera 2013; Lehmann et al. 2014; Mathey et al. 2010, 2011; Stewart and Oke 2012;

Table 7 List of green open spaces typologies identified by studies

Citation	Spatial scale	Green open spaces typologies
Abunnasr (2013) Ahern (1995, 2007) Aldous (2014) Anderson et al. (1976) Bell et al. (2007) Bowler et al. (2010b) Byrne and Sipe (2010) CBC (2008) CCC (2010) Cooper (2010) Davies et al. (2006) DEFRA (2008) DTLR (2002) Dunnett et al. (2002) Ely and Pitman (2014) EMDA (2010) Gill et al. (2007) Jim and Chen (2003) Landscape Institute (2009) La Rosa and Privitera (2013) Li et al. (2005) Llewelyn-Davies (2000) ODPM (2002a, b) Pauleit and Duhme (2000) Panduro and Veie (2013) Rupprecht et al. (2015) Schilling and Logan (2008) Sheate et al. (2012) TEP (2005) TMF (2010, 2011) TSG (2008) VEAC (2011) Wang (2001) Wong (2011) Wong and Chen (2010) Woolley (2006)	Me, Lo Me Me Me Me Lo, Mi Me, Lo Me, Lo Me, Lo Me, Lo Me, Lo, Mi Me, Lo Me, Lo Me, Lo Me, Lo Me, Lo Me Me, Lo Me, Lo Me Me, Lo Me, Lo Me. Lo Me, Lo Me, Lo Lo, Mi Me, Lo Me, Lo Me, Lo Me Me, Lo Me, Lo Me, Lo Me Lo, Mi Me, Lo	I. According to the purpose: 1. Parks and gardens: country, urban and local parks, public & private gardens, courtyards 2. Natural & semi-natural green spaces: woodlands, forests, reserves, heathlands, grassland, meadow, conservation land 3. Greenways, green corridors, ecological buffers, green streets/alleys, green wedges, cycle paths, pedestrian trails, routes. 4. Wetlands: marshlands, intertidal mudflats. 5. Brownfield land: quarries, wastelands, landfills, vacant and derelict land 6. Amenity green spaces: recreation grounds, sport fields/facilities, golf courses, playgrounds, racecourses, 7. Community green spaces: allotments, community gardens, orchards 8. Waterbodies and waterside areas: coasts, beaches, seafronts, rivers, canals, ponds, lakes, estuaries, swales, ditches 9. Green links, utility areas: roads, rails, power lines, drainage-ways, transport corridors 10. Agricultural land, farms, ranches 11. Landscaped and incidental areas 12. Churchyards, cemeteries, burial grounds 13. Institutional grounds 14. Civic spaces: squares, plazas, malls, foyers 15. Built-up areas residential land, multistorey buildings, mixed uses, construction sites II. According to the scale and location: 1. Urban periphery a. National-regional • Patches, corridors, matrixes 2. Urban cores a. City-district b. Neighbourhood c. Local / parcel III. According to accessibility/ownership: 1. Unrestricted 2. Limited 3. Not accessible
Brady et al. (1979)	Me	1. Cliff/organic detritus 2. Derelict/weedy grasslands 3. Derelict savannah 4. Mowed grassland 5. Urban savannah 6. Abiotic/weedy complex 7. Urban/forest plantation 8. Rail-highway/grassland 9. Remnant ecosystem/natural island 10. Remnant ecosystem/agricultural island 11. Lake-stream/aquatic complex 12. Dump/organic detritus
Cadenasso et al. (2007, 2013) Di Gregorio and Jansen (1998)	Me, Lo, Mi Me	According to surface characteristics: 1. Pervious surfaces (permeable)

Table 7 (continued)

Citation	Spatial scale	Green open spaces typologies
English Nature (2003) Jacobs et al. (2014) Keeley (2011) Liu and Yang (2013) Norton et al. (2013, 2015) Ochoa (1999) OEH (2015) Pauleit et al. (2003) Peters et al. (2011) Stewart and Oke (2012) Tooke et al. (2009) Wilmers (1988) Zhou et al. (2014)	Me Me, Lo Me Me, Lo Me, Lo, Mi Mi Lo, Mi Me, Lo Me, Lo Me, Lo Me Me, Lo Me, Lo, Mi	a. Irrigated green space b. Non-irrigated green space c. Vegetated surfaces (grasslands, pasture, crops, forests, fields, greenspaces) d. Non-vegetated / bare soils / sands / snow e. Porous pavements f. Rain-gardens / biofilters / bioswales 2. Impervious surfaces (impermeable) a. Reflective pavements / hard surfaces b. Bare rocks 3. Water bodies a. Vegetated wetlands / wet grounds b. Open water / lakes / rivers
Davis (2010) Mazza et al. (2011) Naumann et al. (2011)	Me Me Me	1. Protected areas 2. Restoration ones 3. Sustainable use areas 4. Green urban and peri-urban features 5. Natural connectivity features 6. Artificial connectivity features 7. Multifunctional zones
Lehmann et al. (2014) Mathey et al. (2010, 2011)	Me, Lo Me, Lo	13 main categories and 57 urban vegetation structure types (UVSTs): 1. Residential sites, mixed-use sites as well as industrial, commercial and specialized sites 2. Transport facilities and infrastructure 3. Green spaces 4. Urban wastelands 5. Landfills and quarries 6. Agricultural sites 7. Grassland 8. Trees, shrubs and bushes 9. Woodland 10. Near-natural wetlands 11. Waterside zones 12. Arid grasslands, heathlands 13. Open sites

Spatial scales: *Me* Meso, *Lo* local, *Mi* Micro

Zhou et al. 2014). Accessibility and ownership have also been applied to discriminate and audit different types of open spaces (CBC 2008; TSG 2008).

Green roofs

Green roofs have been relatively simple to characterise despite the overlapping terminology used by different authors (i.e. eco-roofs, green rooftops, living roofs and rooftop gardens) (See Table 2). Table 8 summarises different studies organised in sub-groups depending on the typologies that were identified at different spatial scales. The characterisation of typologies depended mainly on spatial extension, dimensions, substrate thickness, intensity of use, level of maintenance and vegetation size (Dunnett and Kingsbury 2004; Francis and Lorimer 2011; Oberndorfer et al. 2007; OEH 2015; Williams et al. 2010).

Intensive and extensive roofs are the two main types recognised by most authors. Intensive roofs have deeper substrates and consequently more capacity to sustain larger plant species than extensive roofs; and their use depends on this differentiation (Francis and Lorimer 2011; OEH 2015). Some studies have also considered brown roofs (gravel substrates), blue roofs (water harvesters) and cool roofs (light coloured roofs) as types within this category (Dunnett and Kingsbury 2004; Francis and Lorimer 2011; OEH 2015). Dunnett and Kingsbury (2004) have additionally identified a third typology, the 'semi-extensive roofs' (also called semi-intensive), which combines the characteristics of intensive and extensive roofs, requiring occasional irrigation and moderate maintenance levels.

Vertical greenery systems

Key aspects for the classification of vertical greenery system typologies are the structural characteristics of supporting systems, the selection and types of plants and the level of maintenance required (Jim 2015; Susorova 2015). From a functional perspective, most vertical greenery systems studies relate to their climatic effects and indoor or outdoor thermal performance benefits at micro scales.

Vertical greenery systems have been mainly divided into two types as summarised in Table 9; 'green facades' and 'living walls'. The term 'green facades' refers to vegetation rooted on the ground, that make use of either the wall itself for climbing (traditional direct systems) or independent supporting systems such as trellis, wires, cables or meshes (double-skin indirect system) affixed to walls. Conversely, 'Living walls' have been made of felt, geotextile, pots, panels or boxes where pre-cultivated vegetation has been planted and subsequently suspended and fixed to a larger vertical structure; hence, plants are not in contact with the ground. Living walls demand more complex construction and imply higher installation and maintenance costs in comparison to green facades (Dunnett and Kingsbury 2004; Francis and Lorimer 2011; Hunter et al. 2012; Kontoleon and Eumorfopoulou 2010; Ottelé et al. 2011; Pérez et al. 2014; Perini et al. 2011; Susorova 2015; Wong et al. 2010; Wong and Chen 2010). Jim (2015) has proposed a more comprehensive typology based on a triple-criteria scheme: (a)

Table 8 List of green roof typologies identified by studies

Citation	Spatial scale	Green roofs typologies
Abunnasr (2013)	Lo	1. Green roofs
Bowler et al. (2010b)	Lo, Mi	
Davies et al. (2006)	Lo, Mi	
Ely and Pitman (2014)	Lo, Mi	
Keeley (2011)	Lo	
Landscape Institute (2009)	Lo	
Mazza et al. (2011)	Me	
Naumann et al. (2011)	Me	
Schilling and Logan (2008)	Lo	
TMF (2010, 2011)	Lo	
Woolley (2006)	Lo, Mi	
Dunnett and Kingsbury (2004)	Mi	1. Green roofs
Foster et al. (2011)	Lo	a. Intensive green roofs
Francis and Lorimer (2011)	Mi	b. Extensive green roofs
Hunter et al. (2012)	Lo, Mi	• Complete
Norton et al. (2013, 2015)	Mi	• Modular
Oberndorfer et al. (2007)	Mi	• Pre-cultivated vegetation blanket
OEH (2015)	Lo, Mi	c. Semi-extensive
Williams et al. (2010)	Mi	2. Living roofs
Wong and Chen (2010)	Lo, Mi	a. Intensive green roofs
		b. Extensive green roofs
		3. Brown roofs
		4. Eco-roofs
		5. Cool roofs
		a. White roofs
		b. Cool coloured roofs
		c. Blue roofs

Spatial scales: *Me* Meso, *Lo* local, *Mi* Micro

Table 9 List of vertical greenery systems typologies identified by studies

Citation	Spatial scale	Vertical greenery systems typologies	
Abunnasr (2013)	Lo	1. Green facades	
Dunnett and Kingsbury (2004)	Mi	(rooted on ground / base – extensive)	
Ely and Pitman (2014)	Lo, Mi	a. Traditional direct system (self-climbing)	
Francis and Lorimer (2011)	Mi	b. b. Double-skin indirect systems	
Hunter et al. (2012, 2014)	Mi	• Cable and wire net system	
Kontoleon and Eumorfopoulou (2010)	Mi	• Trellis and container system	
Landscape Institute (2009)	Lo	• Modular trellis panels	
Li et al. (2005)	Lo	• Mesh	
Mazza et al. (2011)	Lo	2. Green walls / living walls	
Naumann et al. (2011)	Lo	(rooted on wall– intensive)	
Norton et al. (2013, 2015)	Mi	a. Felt/Mat System (geo-textiles)	
OEH (2015)	Mi	b. Modular panel system	
Ottelé et al. (2011)	Mi	c. Flowerpots (planter boxes)	
Pérez et al. (2011a, b, 2014)	Mi	d. Hydroponic systems	
Perini et al. (2011)	Mi	3. Bio-walls (indoor)	
Susorova (2015)	Mi		
Wong et al. (2010)	Mi		
Wong and Chen (2010)	Mi		
Jim (2015)	Mi	1. Climber green walls	
		a. Wall-toe-substrate	b. Training-system
		• In-ground (wall-toe)	• Veneer (appressed)
		• Hanging planter-single	• Netting (web)
		• Ground planter	• Trellis (mesh)
		• Hanging planter-serial	• Wirerope (cable)
		2. Herb-shrub green walls	
		a. Substrate-system	b. Elevated-substrate
		• Box (pot)	• Containerized soil
		• Tray (panel)	• Mineral-wool slab
		• Bag (pocket)	• Containerized mix
		• Absorbent-layer	• Geotextile-fabric felt

Spatial scales: *Me* Meso, *Lo* local, *Mi* Micro

Plant growth-forms, (b) The supporting systems and (c) the substrate systems (on ground and elevated) along with wall design factors. The final typology consisted of 24 possible permutations, used for informing designers and researchers about the variations, potentials, and limitations of VGS (Jim 2015).

Other classifications

Mell (2010) and Young et al. (2014) proposed comprehensive classification frameworks instead of focusing on identifying discreet elements and specific typologies (Table 10). Both studies addressed a knowledge gap in terms of understanding the different factors and possibilities of cataloguing GI not only relying on land uses and purposes, but also opportunities for intervention (Young et al. 2014), different research aims, and planning scenarios (Mell 2010). Mell (2010) has thoroughly analysed Ahern (1995) scale-goal-context approach to propose a refined typology where ecological, economic and social aspects have been translated into 'form', 'function' and 'context' (Table 10). 'Form' refers to the physical characteristics of vegetation elements, 'function' to the processes and services provided, and 'context' to the different influences on urban landscapes. Young et al. (2014) classification considers the ecological, political and economic triggers for GI intended to distinguish intervention opportunities based on social and ecological systems.

Discussion

This systematic literature review has evaluated the evidence on how GI elements are being classified worldwide to distil the most relevant approaches and clarify existing typologies.

Table 10 List of other types of classification of green infrastructure

Citation	Spatial scale	Other classification typologies
Mell (2010)	Me	A typology classification based on vegetation's 1. Form: a. Ecological element (physical space, connectivity, elements) b. Economic (costs of a space, design) c, Social & cultural (users of a space, aesthetics of a space, motivations) 2. Function: a. Ecological element (biodiversity, conservation) b. Economic (industry, business, regeneration) c. Social & cultural (education, recreation, health) 3. Context: a. Ecological element (biodiversity, supporting networks, ecological mobility) b. Economic (costs of a space, economic development, sustainability) c. Social & cultural (location, facilitations, motivations, perceptions)
Young et al. (2014)	Me	1. Social system: a. Setting: type of social system b. Drivers (social components driving GI) c. Social production units • GI production units • GI social configuration of labour d. External relationships • Upstream relationship • Downstream relationship 2. Ecological system: a. Setting: type of ecological system b. Drivers (ecological components driving GI) c. Cultivated ecosystems • GI subparts • System • Ecosystems connection/relation d. External relationships (impact on ESS).

Spatial scales: *Me* Meso, *Lo* local, *Mi* Micro

Our intention is to provide the conceptual framework for a more comprehensive classification scheme that could inform the auditing, mapping and assessment of GI in the future.

Geographical context has played an important role on classifying GI and has depended on: (a) the site-related conditions, (b) research objectives, and (c) the country-based geopolitical conditions and regulations (Mell 2010). This suggests that it is impractical to propose universal and unique classification typologies that can serve for all research purposes and settings and that there is a regional bias to particular locations where the classification of GI has concentrated the attention of experts.

The literature has been largely dominated by the UK and European countries, primarily led by government reports and guidelines. Green open spaces and tree canopy attracted more the attention in European countries where planning strategies are well-established and intervention priorities have focused on the provision of large greenways, corridors and networks at city and regional level. Studies from Germany have slightly differentiated from the rest by combining the principle of urban biotopes with the structural characteristics of vegetation. Conversely, Asian countries have demonstrated a particular interest in green roofs and vertical greenery systems that represent the most suitable solutions in context of high-density and land scarcity. In Australia, classifications have been triggered by the necessity of prioritising GI to respond to the urban heat island (UHI) phenomenon, while literature from North America has been more focused on biodiversity conservation and water management implications of GI, through the notion of low impact development (LID).

The main methods used to characterise GI were literature reviews, remote sensing and case studies. However, GIS-based tools have not been extensively explored; signifying a great opportunity for a more accurate and time-saving visualisation and analysis of highly complex and heterogeneous settings. The available evidence suggests the classification of GI can be done according to the (a) *functional* (services); (b) *structural* (form/morphology); and (c) *configurational* (spatial interrelationships) attributes of vegetation.

Whereas the classification of greenspaces has been strongly linked to land-uses, purposes, functions, hierarchy and connectivity, the categorisation of trees, green roofs and vertical greenery systems has been mainly addressed from physical and morphological perspectives. Classifications that solely relied on land-uses and accessibility (public/private differentiation) were constrained in representing the ecological processes of GI (i.e. carbon sequestration and thermal regulation). This is because GI functionality does not only depend on purpose, but most importantly on the physical attributes and spatial interrelationships between vegetation assets (Ahern 2007; Cadenasso et al. 2007, 2013; English Nature 2003; Hawken et al. 2014; Jacobs et al. 2014; Pauleit et al. 2003; Peters et al. 2011; Stewart and Oke 2012; Tooke et al. 2009; Wilmers 1988). Hence, we recommend that a comprehensive classification scheme should consider this ternary set of principles in line with Ahern (1995, 2007) and Mell (2008, 2010) approaches.

In England, the PPG17 guidelines (ODPM 2002a, b) and the criteria defined by the urban green space taskforce (DTLR 2002) have become standards for most subsequent studies, illustrating the strong influence of government planning policies on the identification, characterisation and deliverability of GI. The value of these documents lies in their broad applicability and flexibility across different geographical settings, ownerships and delivery purposes within the UK (Sheate et al. 2012; Tzoulas et al. 2007). However, these schemes should be adopted with caution since they are extremely contextualised to particular land-use types that reduce its applicability in other geo-political contexts and research scopes.

The hierarchical characterisation introduced by the London Planning Advisory Committee (LPAC) (Llewelyn-Davies Planning 1992) has been adopted by a myriad of studies (Byrne and Sipe 2010; CBC 2008; CCC 2010; Dunnett et al. 2002; TSG 2008; VEAC 2011; Wong 2011). Also, it has had great acceptance among local governments and authorities because audit and strategic planning of GI can be easily assigned to specific jurisdictions (Woolley 2006). This stratified subdivision has the capacity to aggregate or disaggregate categories depending on the level of detail required; nonetheless, there is always the possibility of double counting or overlapping types across scales (Dunnett et al. 2002).

The complexity of the built environment has precluded the definition of precise boundaries between the natural and the artificial world. Consequently, there is still no consensus of what can or cannot be considered GI, which may prove detrimental to understand the discernibility of features (Mell 2010). To address this limitation, the ‘accessible natural greenspace standard model’ (English Nature 2003) proposed the integration of green and grey infrastructure. Critically discussed by Pauleit et al. (2003), this model illustrates the difficulties that arise when attempting to reconcile two dichotomous points of view: the conservation of nature and the public use of greenspaces. Nonetheless, its merit consist of conceiving GI functionality as a continuum phenomenon in accordance with Ahern (2007) and Davies et al. (2006) perspectives.

Originally introduced by Anderson et al. (1976), the classification of land-use and land covers (LULC) has been an influential approach dominating the characterisation of greenspaces and trees (Brady et al. 1979; Jacobs et al. 2014; La Rosa and Privitera 2013; Liu et al. 2013; Pauleit and Duhme 2000; Peters et al. 2011). In some cases, greenspaces have included built-up areas (homes, buildings), derelict land, brownfield land and utilities (i.e. roads, power lines) as an effort to integrate engineered and natural elements in a more comprehensive manner (Anderson et al. 1976; Pauleit and Duhme 2000). However, green roofs and vertical greenery systems were completely excluded from LULC types. Extensively criticised by Cadenasso et al. (2013) and Cadenasso et al. (2007), Anderson and related approaches have proved to be more suitable for studies at coarse scales since they remain inadequate to capture urban heterogeneity at fine scales. Cadenasso et al. (2007) have also noted that LULC types combine socio-economic functions and purposes (land-uses) with the physical structures of landscapes (land-covers), having left aside the ecological functioning of GI.

Classification systems such as the LCZ (Stewart and Oke 2012), HERCULES (Cadenasso et al. 2007) and UVST (Lehmann et al. 2014) have integrated man-made structures, vegetation features, human activities, and surface properties in different amounts and spatial arrangements. Despite their broad applicability and versatility across different urban settings, these schemes were primarily aimed for city and district levels (medium scales) with relatively homogeneous characteristics. Thus, future research should target their application in more heterogeneous conditions and finer scales.

Both, Mell (2008, 2010) and Young et al. (2014) proposed very distinctive classifications based on the political, socio-economic and ecological values of GI. These schemes have not listed a set of identifiable features or spaces, but instead proposed overarching frameworks and principles that other typologies can draw on. Both have demonstrated to be highly applicable for the strategic planning of GI.

Analysis has shown that most of studies have grouped GI assets in four high level categories of (a) tree canopy; (B) green open spaces; (c) green roofs; and (d) vertical greenery systems. Figure 1 depicts these major categories in terms of functionality, morphology, spatial scale and configuration. This is intended to clarify and simplify the identification of GI features and to graphically summarise the most important findings of this review. The terminology derived from each category has been varied and overlapping, hindering the classification task. Among these groups tree canopy and green open spaces have attracted more attention and have been more difficult to catalogue due to their inherent complexity. In contrast, engineered vegetation such as green roofs and vertical greenery systems have been classified more straightforwardly.

The scope and scale of analysis are crucial when identifying the contribution of different typologies in either urban or natural landscapes. For instance, tree canopy and green open spaces have been studied from regional to street canyon levels, while green roofs and vertical greenery systems have concentrated on the street canyon and building scales (Fig. 1). The discernibility of typologies has been mostly influenced by scale; indeed, we observed that in some cases GI features were classified into more than one category. For instance, whereas large clusters of trees at mesoscale were described as woodland, linear plantations of trees constituted alleys at microscale (Cadenasso et al. 2007, 2013; Oke et al. 1989; Stewart and Oke 2009). In summary, the coarser the scale the more generalised and difficult is to discern individual elements and their spatial arrangements. Thus, neglecting or underestimating the influence or hierarchy and scale could lead to an erroneous characterisation of GI (Lehmann et al. 2014; Oke et al. 1989; Stewart and Oke 2009). This confirms the necessity of developing a multi-scale and multi-purpose typology suitable for varied contexts, locations and research purposes.

A number of researchers consider blue roofs, brown roofs and cool roofs as additional typologies within the 'green roof' category. On one hand, they are capable of providing certain ESS and functions such as climate regulation, while on the other hand their biological content or capacity to sustain complex forms of life is considerably smaller compared to other types of green roofs and GI. We consider that their inclusion or exclusion will depend on the particular scope and intention of the particular research.

Conclusions

A more comprehensive classification of the biotic and abiotic elements forming GI is crucial for the identification of needs, the assessment of conditions and implementation of planning and design interventions. This review has investigated how different authors have identified, described and catalogued GI elements worldwide. Present evidence confirms that a universal set of typologies cannot be proposed for all scenarios; however, most studies have grouped GI assets into four high level categories. We suggest that further research should be conducted as to how these categories can be disaggregated and adapted to support specific research goals.

A significant amount of overlapping terminology has created ambiguity and loss of clarity when cataloguing GI. Defining clear boundaries between the natural and the built world is difficult, a gap in knowledge that responds to contrasting views on what constitutes GI and if typologies should be studied individually or holistically. Further studies should consider the green-to-grey spectrum, the spatial dimensions and the research context to propose more standardised classification schemes tailored according to particular needs and purposes.

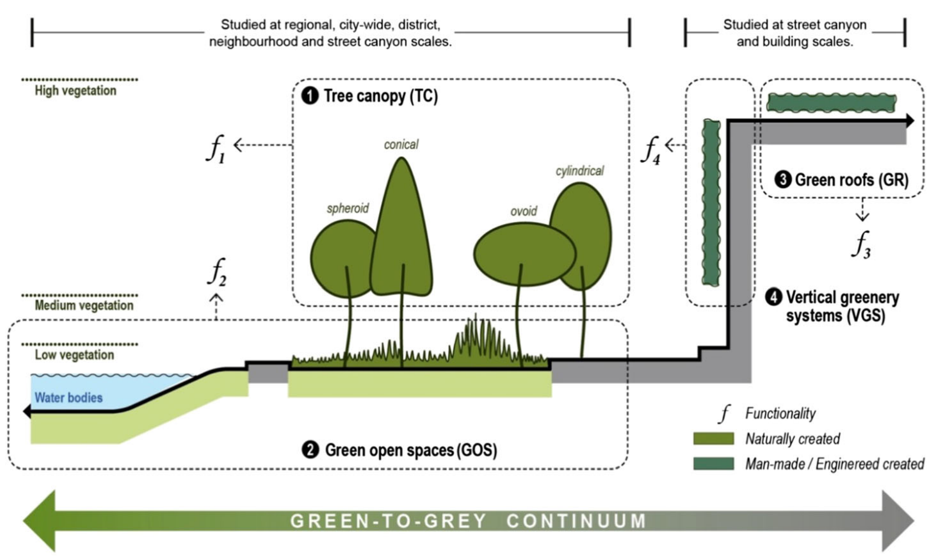

Fig. 1 Spatial conception for the identification of main GI categories in a green-to-grey spectrum considering the functional, structural and configurational attributes of GI

It was observed that GI has been closely linked to land uses although these are not directly related to the functional performance of vegetation. We strongly suggest future investigations consider a ternary classification approach based on the capacities to provide ESS (functional principle), the morphological attributes (structural principle) and the way elements organise and relate to each other (configurational principle). Spatial scale is another important factor influencing the discernibility of vegetation since at large scales the differentiation of features is hampered by the lack of detail, leading to the homogenisation and generalisation. Investigations should contemplate the heterogeneity of GI according to their scale of study; consequently we recommend remote sensing methods as a time-effective solution to map and evaluate highly complex and diverse geographic settings.

Most studies have emphasised comparison between tree canopy and green open spaces versus green roofs and vertical greenery systems, because the latter are engineered features with less natural complexity and variability, and because they are partially segregated from larger GI networks. We suggest that future research should concentrate on how to integrate green roofs and vertical greenery systems into natural systems/networks in a more holistic manner. Finally, we recognise that a universal typology of GI is unrealistic and that the present findings and conclusions remain provisional and require further discussion. As part of ongoing research, it is our intention to take on this task and develop a multi-purpose and multi-scale classification of GI that could be validated in practice.

Acknowledgments This paper is part of an ongoing research conducted at the Australian Graduate School of Urbanism, University of New South Wales (UNSW-Australia) and the Node of Excellence – Cooperative Research Centre for Low Carbon Living (CRC-LCL). This research is possible thanks to the financial support of the Graduate Research School –UNSW (University International Postgraduate Award - UIPA) and the CRC for Low Carbon Living (Top-up scholarship). The authors sincerely thank the anonymous reviewers for their valuable suggestions and comments that contributed to improve the quality of the manuscript.

References

Abunnasr YF (2013) Climate change adaptation: a green infrastructure planning framework for resilient urban regions (PhD). University of Massachusetts Amherst

Ahern J (1995) Greenways as a planning strategy. Landsc Urban Plan 33(1-3):131–155. doi:10.1016/0169-2046(95)02039-V

Ahern J (2007) Green infrastructure for cities: the spatial dimension. In: Novotny V, Brown P (eds) Cities of the future: towards integrated sustainable water and landscape management. IWA Publishing, London

Aldous DE (2014) Australia's national classification system for green open space. Australas Parks Leis 16(2):30–33

Anderson JR, Hardy EE, Roach JT, Witmer RE (1976) A land use and land cover classification system for use with remote sensor data: geological survey professional paper 964

Arlt G, Hennersdorf J, Lehmann I, Thinh NX (eds) (2005) IÖR-Schriften. Auswirkungen städtischer Nutzungsstrukturen auf Grünflächen und Grünvolumen. Impact of city's structures of land use on green spaces and green volume, 47th edn. Dresden

Bell S, Montarzino A, Travlou P (2007) Mapping research priorities for green and public urban space in the UK. Urban For Urban Green 6(2):103–115. doi:10.1016/j.ufug.2007.03.005

Benedict MA, McMahon ET (2002) Green infrastructure: smart conservation for the 21st century

Benedict MA, McMahon ET (2006) Green infrastructure: linking landscapes and communities. Island Press

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS (2010a) How effective is 'greening' of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the 'urban heat island effect'?: CEE review 08-004 (SR41). Environmental evidence

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS (2010a) Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landsc Urban Plan 97(3):147–155

Brady RF, Tobias T, Eagles PF, Ohrner R, Micak J, Veale B, Dorney RS (1979) A typology for the urban ecosystem and its relationship to larger biogeographical landscape units. Urban Ecol 4(1):11–28. doi:10.1016/0304-4009(79)90020-2

Byrne J, Sipe N (2010) Green and open space planning for urban consolidation - a review of the literature and best practice (No. 11). Brisbane

Cadenasso ML, Pickett S, Schwarz K (2007) Spatial heterogeneity in urban ecosystems:: reconceptualizing land cover and a framework for classification. Front Ecol Environ 5(2):80–88

Cadenasso ML, Pickett STA, McGrath B, Marshall V (2013) Ecological heterogeneity in urban ecosystems: reconceptualized land cover models as a bridge to urban design. In: Pickett S, Cadenasso ML, McGrath B (eds) Resilience in ecology and urban design. Linking theory and practice for sustainable cities. Springer, New York

Cheltenham Borough Council (CBC) (2008) Green space audit-final report. Worcestershire, UK

Christchurch City Council (CCC) (2010) Public open space strategy 2010-2040. New Zealand

Cooper LM (2010) Network analysis in CEA, ecosystem services assessment and green space planning. Impact Assess Proj Apprais 28(4): 269–278. doi:10.3152/146155110X12838715793048

Coutts AM, Tapper NJ, Beringer J, Loughnan M, Demuzere M (2012) Watering our cities: the capacity for water sensitive urban design to support urban cooling and improve human thermal comfort in the Australian context. Prog Phys Geogr 37(1):2–28. doi:10.1177/0309133312461032

Coutts AM, White EC, Tapper NJ, Beringer J, Livesley SJ (2015) Temperature and human thermal comfort effects of street trees across three contrasting street canyon environments. Theor Appl Climatol. doi:10.1007/s00704-015-1409-y

Davies C, MacFarlane R, McGloin, C, Roe M (2006) Green infrastructure planning guide. North-East community forests, Durham, Marea Britanie. Retrieved from https://www.scribd.com/doc/55042694/Green-Infrastructure-Guide-Project-Davies-Et-Al-2006. Accessed Monday, March 30, 2015

Davis M (2010) Green infrastructure In-Depht case analysis.: theme 7: mapping for planning. Task 4.1: In-depth case analysis – green infrastructure implementation and efficiency – ENV.B.2./SER/2010/0059

Davis M, Ramírez F, Vallejo AL (2015) Vertical gardens as swamp coolers. Proc Eng 118:145–159. doi:10.1016/j.proeng.2015.08.413

de Groot RS, Wilson MA, Boumans RMJ (2002) A typology for the classification, description and valuation of ecosystem functions, goods and

services. Ecol Econ 41(3):393–408. doi:10.1016/S0921-8009(02)00089-7
DEFRA (2008) Case study to develop tools and methodologies to deliver an ecosystem-based approach - Thames gateway green grids. Research Project Final Report. UK
Department for Transport, Local Government and the Regions (DTLR) (2002) Green spaces, better places: final report of the urban green spaces taskforce. London
Di Gregorio A, Jansen LJM (eds) (1998) Land Cover Classification System (LCCS): classification concepts and user manual. Food and Agriculture Organization (FAO), Rome
Dobbs C, Escobedo FJ, Zipperer WC (2011) A framework for developing urban forest ecosystem services and goods indicators. Landsc Urban Plan 99(3–4):196–206. doi:10.1016/j.landurbplan.2010.11.004
Dunnett N, Kingsbury N (2004) Planting green roofs and living walls. Timber Press, Portland
Dunnett N, Swanwick C, Woolley H (2002) Improving urban parks, play areas, and open space.: urban research report. London
East Midlands Development Agency (EMDA) (2010) A guide and toolkit. Green Infrastructure.: playind an important role in achieving sustainable economic growth. Nottingham
Ely M, Pitman S (2014) Green Infrastructure: LIFE support for human habitats. The compelling evidence for incorporating nature into urban environments: Green Infrastructure Evidence Base 2014. Green Infrastructure Project, Botanic Gardens of South Australia. South Australia
English Nature (2003) Providing accessible natural greenspaces in towns and cities: a practical guide to assessing the resources and implementing local standards for provision. UK
European Environment Agency (EEA) (2011) Green infrastructure and territorial cohesion.: the concept of green infrastructure and its integration into policies using monitoring systems. EEA Technical report No. 18/2011
Foster J, Lowe A. Winkelman S (2011) The value of green infrastructure for urban climate adaptation
Francis RA, Lorimer J (2011) Urban reconciliation ecology: the potential of living roofs and walls. J Environ Manag 92(6):1429–1437. doi:10.1016/j.jenvman.2011.01.012
Gill S, Handley J, Ennos A, Pauleit S (2007) Adapting cities for climate change: the role of the green infrastructure. Built Environment 33(1):115–133
Hawken S, Metternicht G, Chang C, Liew S, Gupta A (eds) (2014) Remote sensing of urban ecological infrastructure in Desakota environments: A review of current approaches. : 35th Asian conference on remote sensing (ACRS 2014)
Höfle B, Hollaus M (2010) Urban vegetation detection using high density full-waveform Airborne Lidar Data -: combination of object-based image and point cloud analysis, XXXVIII, Part 7B, 281–286
Hunter A, Livesley SJ, Williams NSG (2012) Literature review. Responding to the urban heat island: a review of the potential of green infrastructure. Report funded by the Victorian Centre for Climate Change Adaptation (VCCCAR). Melbourne, Australia
Hunter AM, Williams NS, Rayner JP, Aye L, Hes D, Livesley SJ (2014) Quantifying the thermal performance of green façades: a critical review. Ecol Eng 63:102–113. doi:10.1016/j.ecoleng.2013.12.021
Jacobs B, Mikhailovich N, Delaney C (2014) Benchmarking Australia's urban tree canopy: an i-Tree assessment.: Final Report. Prepared for Horticulture Australia Limited. Sydney
Jim CY (1989) Tree-canopy characteristics and urban development in Hong Kong. Geogr Rev 79(2):210–225
Jim CY (2015) Greenwall classification and critical design-management assessments. Ecol Eng 77:348–362. doi:10.1016/j.ecoleng.2015.01.021
Jim C, Chen SS (2003) Comprehensive greenspace planning based on landscape ecology principles in compact Nanjing city, China. Landsc Urban Plan 65(3):95–116. doi:10.1016/S0169-2046(02)00244-X
Keeley M (2011) The green area ratio: an urban site sustainability metric. J Environ Plan Manag 54(7):937–958. doi:10.1080/09640568.2010.547681
Khan KS, Kunz R, Kleijnen J, Antes G (2003) Systematic reviews to support evidence-based medicine. Royal Society of Medicine Press Ltd., London
Kontoleon KJ, Eumorfopoulou EA (2010) The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. Build Environ 45(5):1287–1303. doi:10.1016/j.buildenv.2009.11.013
La Rosa D, Privitera R (2013) Characterization of non-urbanized areas for land-use planning of agricultural and green infrastructure in urban contexts. Landsc Urban Plan 109(1):94–106. doi:10.1016/j.landurbplan.2012.05.012
Landscape Institute (2009) Green Infrastructure connected and multifunctional landscapes.: Position Statement
Lehmann S (2014) Low carbon districts: mitigating the urban heat island with green roof infrastructure. City Cult Soc 5(1):1–8. doi:10.1016/j.ccs.2014.02.002
Lehmann I, Mathey J, Rößler S, Bräuer A, Goldberg V (2014) Urban vegetation structure types as a methodological approach for identifying ecosystem services – Application to the analysis of micro-climatic effects. Ecol Indic 42:58–72. doi:10.1016/j.ecolind.2014.02.036
Li F, Wang R, Paulussen J, Liu X (2005) Comprehensive concept planning of urban greening based on ecological principles: a case study in Beijing, China. Landsc Urban Plan 72(4):325–336. doi:10.1016/j.landurbplan.2004.04.002
Liu T, Yang X (2013) Mapping vegetation in an urban area with stratified classification and multiple endmember spectral mixture analysis. Remote Sens Environ 133:251–264. doi:10.1016/j.rse.2013.02.020
Liu K, Gao W, Gu X, Gao Z (eds) (2013) The relation between the urban heat island effect and the underlying surface LUCC of meteorological stations. Source of the Document Proceedings of SPIE - The International Society for Optical Engineering 8869 - 88690R
Llewelyn-Davies (2000) Urban design compendium 1. English Partnerships & The Housing Corporation, London
Llewelyn-Davies Planning (1992) Open space planning in London. The Committee, London (UK)
Mathey J, Rößler S, Lehmann I, Bräuer A (2010). Urban green spaces: potentials and constraints for urban adaptation to climate change. Resilient Cities, Local Sustainability Volume 1, 2011, pp 479–485, Volume 1, 479
Mathey J, Rößler S, Lehmann I, Bräuer A, Goldberg V, Kurbjuhn C, Westbeld A (eds) (2011) Naturschutz und Biologische Vielfalt Vol. 111. Noch wärmer, noch trockener? Stadtnatur und Freiraumstrukturenim Klimawandel.: Even warmer, even drier? Urban nature and green spacedevelopment under climate change. Bundesamt für Naturschutz (Bfn. Ed.), Bonn-Bad Godesberg
Mazza L, Bennett G, Nocker L, de Gantioler S, Losarcos L, Margerison C, van Diggelen R (2011) Green infrastructure implementation and efficiency: final report for the European commission, DG environment on contract ENV.B.2/SER/2010/0059. Institute for European Environmental Policy, Brussels and London
Mell IC (2008) Green infrastructure: concepts and planning. FORUM E journal - Newcastle University (8) 69–80
Mell IC (2010) Green infrastructure: concepts, perceptions and its use in spatial planning (PhD). Newcastle University, UK
Mell IC (2014) Aligning fragmented planning structures through a green infrastructure approach to urban development in the UK and USA. Urban For Urban Green 13(4):612–620. doi:10.1016/j.ufug.2014.07.007
Millennium Ecosystem Assessment (MEA) (2005) Ecosystems and human well-being: synthesis. Island Press, Washington, DC, **Friday, June 12, 2015**
Naumann S, Davis M, Kaphengst T, Pieterse M, Rayment M (2011) Design, implementation and cost elements of green infrastructure projects.: final report to the European Commission, DG Environment. Contract no. 070307/2010/577182/ETU/F.1

Norton B, Coutts A, Livesley S, Williams N (2013) Technical report. Decision principles for the selection and placement of Green infrastructure: technical report

Norton BA, Coutts AM, Livesley SJ, Harris RJ, Hunter AM, Williams NS (2015) Planning for cooler cities: a framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. Landsc Urban Plan 134:127–138. doi:10.1016/j.landurbplan.2014.10.018

Oberndorfer E, Lundholm J, Bass B, Coffman RR, Doshi H, Dunnett N, Rowe B (2007) Green roofs as urban ecosystems: ecological structures, functions, and services. Bioscience 57(10)

Ochoa JM (1999) La vegetacion como instrumento para el control microclimatico (PhD). Universitat Politecnica de Catalunya, Barcelona

Office of Environment and Heritage (OEH) (2015) Urban green cover. Technical guidelines

Office of the Deputy Prime Minister. (2002a) Assessing needs and opportunities a companion guide to PPG17

Office of the Deputy Prime Minister (2002b) Planning policy guidance 17: planning for open space, sport and recreation

Oke TR (2006) Towards better scientific communication in urban climate. Theor Appl Climatol 84(1–3):179–190. doi:10.1007/s00704-005-0153-0

Oke TR (ed) (2009) The need to establish protocols in urban heat island work. 8th symposium on urban environments

Oke TR, Crowther JM, McNaughton KG, Monteith JL, Gardiner B (1989) The micrometeorology of the urban forest. Philos Trans R Soc Lond B 324:335–349, **Tuesday, August 25, 2015**

Ottelé M, Perini K, Fraaij A, Haas EM, Raiteri R (2011) Comparative life cycle analysis for green façades and living wall systems. Energy Build 43(12):3419–3429. doi:10.1016/j.enbuild.2011.09.010

Panduro TE, Veie KL (2013) Classification and valuation of urban green spaces—A hedonic house price valuation. Landsc Urban Plan 120: 119–128. doi:10.1016/j.landurbplan.2013.08.009

Pauleit S, Duhme F (2000) Assessing the environmental performance of land cover types for urban planning. Landsc Urban Plan 52(1):1–20. doi:10.1016/S0169-2046(00)00109-2

Pauleit S, Slinn P, Handley J, Lindley S (2003) Promoting the natural greenstructure of towns and cities: English nature's accessible natural greenspace standards model. Built Environ 29(2):157–170

Pérez G, Rincón L, Vila A, González JM, Cabeza LF (2011a) Behaviour of green facades in Mediterranean continental climate. Energy Convers Manag 52(4):1861–1867. doi:10.1016/j.enconman.2010.11.008

Pérez G, Rincón L, Vila A, González JM, Cabeza LF (2011b) Green vertical systems for buildings as passive systems for energy savings. Appl Energy 88(12):4854–4859. doi:10.1016/j.apenergy.2011.06.032

Pérez G, Coma J, Martorell I, Cabeza LF (2014) Vertical Greenery Systems (VGS) for energy saving in buildings: a review. Renew Sust Energ Rev 39:139–165. doi:10.1016/j.rser.2014.07.055

Perini K, Ottelé M, Fraaij A, Haas EM, Raiteri R (2011) Vertical greening systems and the effect on air flow and temperature on the building envelope. Build Environ 46(11):2287–2294. doi:10.1016/j.buildenv.2011.05.009

Peters EB., Hiller RV, McFadden JP (2011) Seasonal contributions of vegetation types to suburban evapotranspiration. J Geophys Res 116(G1). doi:10.1029/2010JG001463

Pickering C, Byrne J (2013) The benefits of publishing systematic quantitative literature reviews for PhD candidates and other early-career researchers. High Educ Res Dev 33(3):534–548. doi:10.1080/07294360.2013.841651

Pullin AS, Stewart GB (2006) Guidelines for systematic review in conservation and environmental management. Conserv Biol : J Soc Conserv Biol 20(6):1647–1656. doi:10.1111/j.1523-1739.2006.00485.x

Rupprecht CD, Byrne JA, Garden JG, Hero J-M (2015) Informal urban green space: a trilingual systematic review of its role for biodiversity and trends in the literature. Urban For Urban Green 14(4):883–908. doi:10.1016/j.ufug.2015.08.009

Schilling J, Logan J (2008) Greening the rust belt: a green infrastructure model for right sizing America's shrinking cities. J Am Plan Assoc 74(4):451–466

Sheate W, Eales R, Day E, Baker J, Murdoch A, Hill C,. . . Karpouzoglou T (2012) Spatial representation and specification of Ecosystem Services: A Methodology using land use/land cover data and stakeholder Engagement. J Environ Assess Policy Manag 14(01), 1250001. doi:10.1142/S1464333212500019

Stewart ID, Oke TR (eds) (2009) Newly developed "thermal climate zones" for defining and measuring urban heat island "magnitude" in the canopy layer. T.R. Oke Symposium & 8th Symposium on Urban Environment. USA January 11–15

Stewart ID, Oke TR (2012) Local climate zones for urban temperature studies. Bull Am Meteorol Soc 93(12):1879–1900. doi:10.1175/BAMS-D-11-00019.1

Susorova I (2015) Green facades and living walls: vertical vegetation as a construction material to reduce building cooling loads. In: Pacheco-Torgal F, Labrincha JA, Cabeza LF, Granqvist C-G (eds) Eco-efficient materials for mitigating building cooling needs: design, properties and applications. Woodhead Publishing, p 127–153. Thursday, March 31, 2016

TEP (2005) East Midlands green infrastructure scoping study. Final report: prepared for East Midlands regional assembly and partners

The Mersey Forest (2010) Liverpool green infrastructure strategy: technical document. Version 1.0. Liverpool, UK

The Mersey Forest (2011) The value of mapping green infrastructure. London

The Scottish Government (TSG) (2008) Planning advice note: PAN 65 planning and open Space. UK

Tooke TR, Coops NC, Goodwin NR, Voogt JA (2009) Extracting urban vegetation characteristics using spectral mixture analysis and decision tree classifications. Remote Sens Environ 113(2):398–407. doi:10.1016/j.rse.2008.10.005

Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kaźmierczak A, Niemela J, James P (2007) Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landsc Urban Plan 81(3):167–178. doi:10.1016/j.landurbplan.2007.02.001

United States Geological Survey (USGS) (1992) Multi-resolution land characteristics. Retrieved from http://www.mrlc.gov/. Accessed Sunday, December 20, 2015

United States Geological Survey (USGS) (2003) National land cover classification. Retrieved from http://landcover.usgs.gov/usgslandcover.php. Accessed Sunday, December 20, 2015

Victorial Environmental Assessment Council (VEAC) (2011) Metropolitan Melbourne investigation final report. East Melbourne, Vic

Wang X-J (2001) Type, quantity and layout of urban peripheral green space. J For Res 12(1):67–70

Williams N, Rayner JP, Raynor KJ (2010) Green roofs for a wide brown land: opportunities and barriers for rooftop greening in Australia. Urban For Urban Green 9(3):245–251. doi:10.1016/j.ufug.2010.01.005

Williamson KS (2003) Growing with green infrastructure

Wilmers F (1988) Green for melioration of urban climate. Energy Build 11(1–3):289–299. doi:10.1016/0378-7788(88)90045-X

Wong KK (2011) Urban open space system in northern Kowloon Peninsula: an emerging green infrastructure network in Hong Kong. Asian Geogr 27(1–2):13–28. doi:10.1080/10225706.2010.9684150

Wong N-H, Chen Y (2010) The role of urban Greenery. In: Ng E (ed) High-density cities. The Role of Urban Greenery, p 227–262

Wong N-H, Kwang Tan AY, Chen Y, Sekar K, Tan PY,. . . Wong NC (2010) Thermal evaluation of vertical greenery systems for building walls. Build Environ 45(3), 663–672. doi:10.1016/j.buildenv.2009.08.005

Woolley H (2006) Urban open spaces. Spon Press & Taylor and Francis Group, London & New York

Young R, Zanders J, Lieberknecht K, Fassman-Beck E (2014) A comprehensive typology for mainstreaming urban green infrastructure. J Hydrol 519:2571–2583. doi:10.1016/j.jhydrol.2014.05.048

Zhou W, Troy A (2009) Development of an object-based framework for classifying and inventorying human-dominated forest ecosystems. Int J Remote Sens 30(23):6343–6360. doi:10.1080/01431160902849503

Zhou W, Cadenasso M, Schwarz K, Pickett S (2014) Quantifying spatial heterogeneity in urban landscapes: integrating visual interpretation and object-based classification. Remote Sens 6(4):3369–3386. doi:10.3390/rs6043369