Science of the Total Environment 615 (2018) 1364–1378

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Assessment of urban green space structures and their quality from a multidimensional perspective

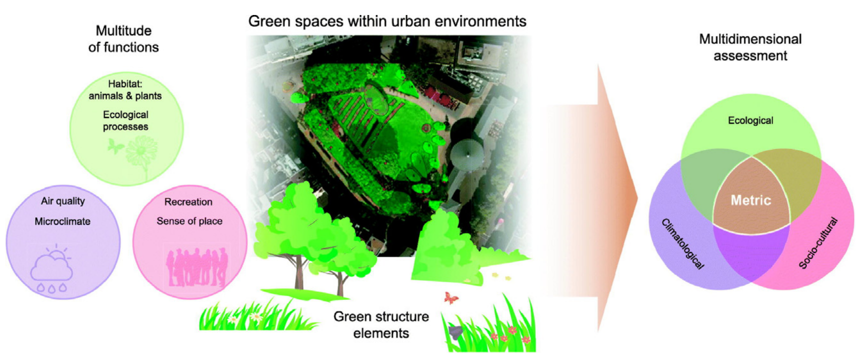
Benjamin Daniels [a,*], Barbara S. Zaunbrecher [b], Bastian Paas [c], Richard Ottermanns [a], Martina Ziefle [b], Martina Roß-Nickoll [a]

[a] Institute for Environmental Research, RWTH Aachen University, Worringerweg 1, 52074 Aachen, Germany
[b] Human-Computer Interaction Center, Chair for Communication Science, RWTH Aachen University, Campus Boulevard 57, 52074 Aachen, Germany
[c] Physical Geography and Climatology, RWTH Aachen University, Templergraben 55, 52056 Aachen, Germany

HIGHLIGHTS

- Compact green cities require multifunctional open spaces.
- Development of a multidimensional indicator set to assess urban green spaces.
- Empirical study on the perception of park structure by citizens.
- Need to differentiate artificial and natural elements in urban green spaces.
- Findings can be integrated into a higher-scale assessment and planning of cities.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 June 2017
Received in revised form 15 September 2017
Accepted 16 September 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Multidimensional assessment
Urban green spaces
Ecosystem functions and services
Public perception
Habitat structure

ABSTRACT

Facing the growing amount of people living in cities and, at the same time, the need for a compact and sustainable urban development to mitigate urban sprawl, it becomes increasingly important that green spaces in compact cities are designed to meet the various needs within an urban environment. Urban green spaces have a multitude of functions: Maintaining ecological processes and resulting services, e.g. providing habitat for animals and plants, providing a beneficial city microclimate as well as recreational space for citizens. Regarding these requirements, currently existing assessment procedures for green spaces have some major shortcomings, which are discussed in this paper.

It is argued why a more detailed spatial level as well as a distinction between natural and artificial varieties of structural elements is justified and needed and how the assessment of urban green spaces benefits from the multidimensional perspective that is applied. By analyzing a selection of structural elements from an ecological, microclimatic and social perspective, indicator values are derived and a new, holistic metrics[1] is proposed. The results of the integrated analysis led to two major findings: first, that for some elements, the evaluation differs to a great extent between the different perspectives (disciplines) and second, that natural and artificial varieties are, in most cases, evaluated considerably different from each other. The differences between the perspectives call for an integrative planning policy which acknowledges the varying contribution of a structural element to different purposes (ecological, microclimatic, social) as well as a discussion about the prioritization of those

* Corresponding author.
E-mail address: benjamin.daniels@bio5.rwth-aachen.de (B. Daniels).

[1] The term metrics is derived from the Greek word μετρικός and is used in this paper as the comprehensive compilation of a set of indicators (ecological, microclimatic, and social). Note that the three indicator values are not weighed or mathematically combined to a global indicator, but represent a space in which all parameters are used in their original way to be used for an interdisciplinary assessment of urban green spaces.

https://doi.org/10.1016/j.scitotenv.2017.09.167

purposes. The differences in the evaluation of natural vs. artificial elements verify the assumption that indicators which consider only generic elements fail to account for those refinements and are thus less suitable for planning and assessment purposes.

Implications, challenges and scenarios for the application of such a metrics are finally discussed.

1. Introduction

Rapid global development of urban systems causes need to mitigate urban sprawl by designing compact and multifunctional cities. Compact cities, in this sense, refer to urban landscapes which are densely populated and provide functions for their citizens in compact, dense areas to avoid urban sprawl. The term *compact green cities* highlights the importance of sustainable use of resources, enhancement of mobility and reduction of city-specific particulate emissions within those cities (Stevenson et al., 2016). The term *green*, however, comprises also the provision of open green spaces in a city, i.e. free spaces with a significant coverage of intended vegetation (such as public parks and recreation areas).

Green spaces play a key role in the development of compact green cities by providing a variety of ecosystem functions and services. This makes green spaces valuable from a variety of perspectives: from the microclimatic point of view, they contribute to a balanced city climate (Bowler et al., 2010) and affect the local concentrations and distribution of air pollutants such as particulate matter (Litschke and Kuttler, 2008; Janhäll, 2015), ozone and its major anthropogenic precursors, volatile organic compounds (VOCs) and oxides of nitrogen (e.g., Sillman, 2002; Calfapietra et al., 2013). From an ecological perspective, they can provide habitable space for plants and animals (Nielsen et al., 2014; Farinha-Marques et al., 2011) as a basis to maintain and preserve basic ecological properties and processes (Mace et al., 2012; Geslin et al., 2013). From a social point of view, they provide functions to city dwellers in the form of meeting points and places to relax and to recreate (Peters et al., 2010). Furthermore, it was shown that urban green spaces have a positive impact on health and wellbeing (Nielsen and Hansen, 2007; Richardson and Mitchell, 2010).

For dense cities, it is therefore of particular importance to efficiently use the few open spaces (Jim, 2004) by designing urban green spaces in terms of ecological, climatic, and social considerations at the same time (Gill et al., 2007). This will increase the multifunctionality of a site and promote sustainable urbanization which is a basic prerequisite for the concept of compact green cities (Næss, 1995).

For the design of urban green spaces according to ecological, climatic and social criteria, adequate indicators and assessment strategies are needed which reflect the multifaceted functions urban green spaces fulfill (Mörtberg et al., 2017). Up to now decision-making in practical management is mostly based on cost and aesthetic considerations (Beer et al., 2003) but less on ecological or climatic criteria.

The aims of this research are (1) to identify gaps and challenges in urban green space assessment and (2) to develop a truly quantitative methodology for multidimensional, indicator-based assessment based on structural elements in urban green spaces. Furthermore, we aim (3) to provide a sample application as a proof of concept for the developed assessment approach and (4) to discuss the implications, challenges and application contexts within future planning procedures.

With regard to these aims the resulting novelties are:

(1) A brief overview that acquires insights about current gaps and challenges in urban green space assessment. We will review the shortcomings and explain how our approach addresses these gaps.
(2) A combined methodology in which urban green spaces are assessed from three different, but very important perspectives at the same time using an integrative approach. The underlying idea of the joint approach is to treat all perspectives as equally important and to combine them within one frame of references in order to make different assessment results visible. An empirical study to assess citizens' perceptions and preferences, the multidimensional indicator set and its development are presented.
(3) A way to quantify the multidimensional benefits of urban green spaces within a novel, holistic metrics on a local small-scale level. Such an assessment has not been conducted quantitatively in the literature so far, although there might be an understanding from planners' perspective that multiple factors need to be taken into account.
(4) Knowledge about the applicability of the indicator set taking selected structural elements of urban green spaces as examples. Differences in the valuation of structural elements by various scientific perspectives are identified.

The outcome provides a common ground for specific discussion about trade-offs and synergies in planning procedures of such urban green space in the future.

1.1. Gaps and challenges in urban green space assessment

To develop livable compact and green cities, indicators are required that assess the quality of urban green spaces and serve as planning tools in the future. Based on a review of current indicators and evaluation procedures, three gaps in research and/or management procedures were identified. The first gap refers to the spatial level of current assessment indicators, the second to the unidimensionality of the assessment and the third to the generic treatment of structural elements.

1.1.1. Gap 1: spatial level of detail of urban green spaces in assessment procedures

Green space assessment, decision making and maintenance in cities and municipalities is based more and more on ecosystem services assessment approaches (Niemela et al., 2010; Hansen et al., 2015). The concept of ecosystem functions and services can help to improve existing green spaces or create new ones within a city (Konijnendijk et al., 2013). However, assessments of ecosystem services in an urban environment are mostly conducted on a landscape-level rather than on a local site-scale (Dennis and James, 2016; Haase et al., 2012). Especially with regard to the overall accepted aim to mitigate urban sprawl for economical, climatological and ecological reasons (Stone et al., 2010; Sushinsky et al., 2013; Whitmee et al., 2015), it is of particular relevance to focus on the specific, small-scale design and characteristics of the few open spaces. Therefore, a local scale perspective with high spatial resolution needs to be adopted. Because often ecological properties and processes can only be recognized and assessed on a small-scale level, it is indispensable to focus on single structural vegetative units or habitats (Lovett et al., 2005).

Urban research has been conducted on small-scale habitat structures before (e.g., Voigt et al., 2014; Lehmann et al., 2014; Byrne, 2007), considering structural diversity with regard to single functions (e.g., recreational services, microclimate effects or urban soil ecology) of green spaces. However, there is still a lack of knowledge regarding a multidimensional evaluation on this site-scale level and a test of its applicability. Therefore, the presented assessment approach of this paper aims at a local scale level.

1.1.2. Gap 2: dimensions and categories of evaluation in green space assessment - the need for a multidimensional assessment

It has been acknowledged that urban green spaces provide a variety of services to urban areas and that research on those spaces therefore requires multidimensional efforts (James et al., 2009; Luederitz et al., 2015). This is important because elements with a low ecological value might be rated high from a microclimatic or social perspective. This way, elements which would be dismissed on the basis of current indicators can thus be appropriately valued. Although the need for a multidimensional perspective is widely acknowledged and accepted (Balram and Dragićević, 2005; Borgström et al., 2006; De Ridder et al., 2004), it is still not realized in many assessment procedures. Current indicators (e.g., the percentage of green areas, percentage of sealed soil, green volume) used in the assessment of urban green spaces often imply single functions or services, and thus evaluate urban green spaces in a unidimensional manner (Grunewald and Bastian, 2015). In practice, there is still the challenge of capturing, operationalizing, and measuring functions and services from different disciplinary perspectives in a joint approach (Luederitz et al., 2015).

O'Sullivan et al. (2017) exemplify such an approach by characterizing different tree species in terms of several ecosystem services (e.g., air quality and biodiversity value). However, an aesthetic function is not covered by their approach, although including social parameters in the set of indicators can further enhance efforts of planning of urban green spaces according to public needs and wishes (Wilker et al., 2016), in the way that citizens' preferences for single structural elements are systematically assessed.

On the other hand, studies on perception of urban green spaces by citizens have already been conducted (Todorova et al., 2004; Sanesi and Chiarello, 2006; Shackleton and Blair, 2013) showing that there is conflicting evidence regarding people's attitude towards natural or artificial design, but also that the specific design of urban spaces, artificial or natural, is a pressing question. These studies, however, did not incorporate ecological and microclimatic aspects of the studied sites.

Integrating social parameters in urban green space assessments provides a way of equitable citizen participation next to, e.g., ecological considerations in urban green management. The necessity of including the social perspective in terms of citizen participation is stressed by Balram and Dragićević (2005) and provides an opportunity to address the mismatch between experts' and laypeople's perspectives on ecosystems (Garritt, 2006; Lazo et al., 1999; Bonnes et al., 2007; Hofmann et al., 2012).

These opposing preferences present a difficulty for the sustainable implementation of nature-conservation policies (Harrison et al., 1998; Bonnes et al., 2007), as policies introduced by experts may lack support by urban dwellers which are mostly laypeople. An integration of the citizen perspective is thus all the more important to design urban green spaces *with* the citizens rather than *for* them in a top-down manner (Gross, 2007; Zaunbrecher and Ziefle, 2016). By this, not only livable and socially valued urban green spaces are provided, but also the awareness of laypeople for the importance of sustainable urban green spaces in general is increased.

There is a large strand of research which connects at least two of the three parameters (ecological, microclimatic and social) in the context of urban green spaces. However, the research undertaken had another focus and aim than the indicator set which is developed and argued later in this paper.

On the one hand, there were approaches in which a social factor in the context of urban green spaces (Nielsen and Hansen, 2007; Peters et al., 2010; Sanesi and Chiarello, 2006) was combined with either a planning (Baycan-Levent and Nijkamp, 2009; Gobster et al., 2007), an ecological (Meacham et al., 2016; Arnberger and Eder, 2012) or a microclimatic perspective (Cohen et al., 2012; Mahmoud, 2011). To the best of our knowledge, in none of the papers all three parameters - social, ecological and microclimatic - have been combined, in particular not on the level of single structural elements (cf. Gap 1). In addition, most of this research takes an explanatory approach of the factors examined, investigating either the influence of urban green spaces on social parameters (urban green spaces as explanans, e.g., Hegetschweiler et al., 2017; van Herzele and Wiedemann, 2003; Mambretti et al., 2005) or on attitudes and perceptions of residents towards urban green areas (urban green spaces as explanandum, e.g., Bertram and Rehdanz, 2015; Balram and Dragićević, 2005). What is missing is a neutral metrics or methodology for planners, with which they are able to describe and evaluate a given area taking different perspectives into account, without the need of explaining the interconnection between the factors. This is the novel idea of this paper - to contribute to a metrics which allows describing urban green spaces out of the three major perspectives in an equitable way.

1.1.3. Gap 3: assessment of the ecological quality of a site (artificial vs. natural)

The current numerical assessment procedures of habitats and landscapes take different land cover types and biotopes into account in a generic manner (Biedermann et al., 2008; Burkhard et al., 2009). This means that no differentiation is made within the respective categories or elements (e.g. trees, hedges, lawns etc.) on a site-scale approach.

Recently, Mörtberg et al. (2017) conducted a study in which ecosystem services are analyzed in conjunction with accessibility and urban planning. While presenting an example for a valuable, integrated approach to ecosystem services, the specific green areas considered are not analyzed in more detail, i.e. with regard to their ecological quality.

Similarly, while in Voigt et al. (2014) a multidimensional approach to urban green spaces is taken on the level of single structural elements, these elements are not differentiated according to their quality (artificial or natural).

A classification which considers only generic elements (like "hedge" or "tree"), however, fails to account for diversity in ecosystem services provided by different instances of the same element, e.g. a near-natural and a trimmed hedge or different species of the same element (O'Sullivan et al., 2017). Furthermore, very generalized indicators provide only vague guidelines with regard to the design of urban green spaces, since they only indicate which element is referred to but not in which variety or quality this should be implemented. The distinction between natural and artificial instances is not only relevant from a planners', but also from laypeoples' perspectives (Hofmann et al., 2012; Jankovska et al., 2010; Jim and Chen, 2006; Southon et al., 2017). The innovative approach of the indicator set which is developed in this work is therefore the explicit distinction between natural and artificial instances of structural elements.

1.2. Questions addressed and logic of procedure

The review of indicators and assessments used in the context of urban green spaces has revealed three major gaps and challenges that will be addressed in this paper.

The challenge of analyses on a site-scale (see gap 1) will be addressed by a comprehensive analysis of structural elements in urban green spaces. This local site-scale approach allows evaluation of single components in a green space rather than whole landscapes, which is a prerequisite to assess and compare different green sites and their design in a bottom-up approach within a holistic model.

The underlying concept of the framework is adapted from numerical valuation of biotopes in national (or rather regional) evaluation schemata to quantify compensation measures, which is used in various nature conservation and landscape management procedures (Biedermann et al., 2008; Hetzel et al., 2014). The valuation of ecological functions on a biotope-level to assess and compare the quality of nature has a long tradition in landscape ecology. Already in 1991, Ludwig and Meinig developed a systematic, numerical method for the valuation of biotope-types. This approach rates biotopes according to the criteria *naturalness* ("Natürlichkeit"), *rarity* ("Gefährdung/Seltenheit"), *possibility of spatial and temporal replacement* ("Ersetzbarkeit/Wiederherstellbarkeit") and *completeness* ("Vollkommenheit"), which are still used in current planning procedures, for example in the evaluation of habitat types for compensation measures in the federal state of North Rhine Westphalia (Biedermann et al., 2008) or Bavaria (Hetzel et al., 2014), Germany. From these regulating intervention rules, a first draft for a standardized national directive was derived (BMUB, 2013).

In our assessment approach these criteria will be updated for usability of the approach in an urban realm with the concept of ecosystem processes and functions to adequately reflect recent research lines (Hansen et al., 2015) and to generate a multidimensional perspective on urban green spaces. We marry the well-tried, longstanding landscape ecological principles and strategies with innovative concepts addressing functions and services of ecosystems, which is required in urban research (Breuste et al., 2008). Because the scale is on the level of single structural elements rather than urban green spaces as a whole, the assessment will primarily be focused on the evaluation of certain ecosystem functions, since not all ecosystem services are derivable at this small scale. This refers especially to the cultural ecosystem services (such as "recreation and mental and physical health" or "sense of place", Buchel and Frantzeskaki, 2015), as these refer more to urban green spaces as a whole than to single elements of those spaces.

The second gap that was identified refers to the dimensions according to which structural elements are assessed. In our approach, we widen the assessment by integrating microclimatic and social criteria, relating the different perspectives to each other and discussing the implications.

The third gap addresses the quality of the structural elements, which is usually only taken into account in a generic manner. A more detailed categorization is needed to adequately reflect different instances of the same element. For a selection of elements the paper will exemplify that differentiation between natural and artificial instances of the same element is meaningful not only from an ecological but also from a microclimatic and social perspective.

Therefore, we extend the current site-scale research (gap 1) by adopting a multidimensional perspective (gap 2) and by integrating the variability of structural elements (quality of a site, gap 3).

2. Method

2.1. Structure-type classification system

Structural elements of green spaces were classified exclusively based on structural parameters (three-dimensional arrangement of physical matter and degree of biotic coverage). For this procedure "habitat structure" by Byrne (2007) was adopted and slightly modified. The resulting classification represents a system of ecological elementary vegetation units in an urban realm with a specific combination of characteristics. The elements of the classification system subdivide a green space into fifteen different structures and enable to capture structural composition in its entirety (cf. Appendix A, Table A1). This structural level can easily be used as a basis for investigations in various disciplines and for diverse research questions (e.g., ecological, climatic, or social). Due to the general applicability of the system the composition and characteristics of green spaces from different countries and continents can be assessed and compared in a generalized manner.

In order not to overstrain the cognitive load of the test persons, which were requested to evaluate the elements from a social perspective, not all structural elements could be queried. The selection of elements to be analyzed was guided by focusing on elements with large numbers of varieties in design and maintenance. Thus, the study was conducted on the following five different structural elements: (1) Water elements, (2) lawns, (3) flower beds, (4) hedges and (5) margins.

2.2. Identification of structural elements of urban green spaces in the study area

Following the approach of Home et al. (2010), study areas (parks and park elements) which exemplify near-natural and artificial urban green spaces in a medium sized German city (Aachen, Germany) were identified.

Park elements used in this study are ecologically and climatologically distinct and they provide an amount of detail which can be recognized not only by experts but also by laypeople. This was important, as the structural elements were to be evaluated by citizens of the city.

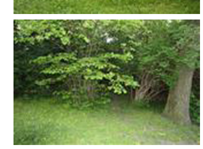
For reasons of comparison, two contrary appearances for each park element – an "artificial" one and a "near-natural" version – were included (Table 1). This procedure takes into account that elements of one class of structural elements can have different characteristics and social or aesthetic values considering ecosystem services. It also implies the hypothesis that social as well as biological and climatic ratings differ depending on the appearance of the element.

2.3. Evaluation of different functions of urban green spaces and their structural elements

2.3.1. Microclimatic evaluation

Up to now, assessment criteria to evaluate microclimatic functions are often based on severely simplified assumptions such as those proposed by the guideline for urban land-use planning processes (Küpfer, 2005). It is widely used in Germany to evaluate anthropogenic intervention due to construction and building projects on the "legally protected goods climate and air". The main focus is on areas of fresh air flow and cold air drainage. Assessment criteria regarding microclimatic functions are classified in five levels which mainly differentiate between degrees of hill slopes. Air quality including pollutant concentration reduction, as well as human bioclimate, are mentioned within the guideline as well. However, room is left for interpretation and the guideline lacks further details concerning the assessment criteria. Our assessment of urban microclimate functions is essentially based on the main principle of this guideline, but was refined assessing five partial atmospheric function categories to evaluate the microclimate functions on a scale from 1.0–6.0 (very low to very high) summarizing the knowledge of recent literature. A worst case scenario was defined as a basis of assessment assuming the urban microclimate of an area which is characterized by fully sealed soil surface including urban morphology with a building-height(H)-to-street-width(W) aspect ratio $H/W > 1.5$ and immediate vicinity to emission sources of air pollutants (oxides of nitrogen (NO_x), aerosol particles) like highly frequented roads or industrial estate. Based on this worst case scenario (score = 1.0), typical structural elements were assigned with raising partial-scores (1.0–6.0) analogous to the scale used in the online survey (see Section 2.3.3) regarding improved properties towards idealized impacts on the urban microclimate. The microclimatic evaluation was performed equally for five partial atmospheric function categories. The influence of the structural elements (see Section 2.2) on the ambient atmosphere were assessed concerning: (1) pollutant concentrations such as NO_x and airborne particulate matter (e.g. Helbig and Baumüller, 1999; Donovan et al., 2005; Seinfeld and Pandis, 2006; Litschke and Kuttler, 2008; Calfapietra et al., 2013, Gromke and Blocken, 2015; Janhäll, 2015; Morakinyo and Lam, 2016a), (2) cold/fresh air emergence and drainage (e.g. Fernando, 2010; Sachsen et al., 2014), (3) latent heat flux i.e. transpirational cooling (Declet-Barreto et al., 2013), (4) turbulence/flow characteristics of the urban boundary layer (e.g. Oke, 2009; Gromke and Blocken, 2015) as well as the (5) radiation budget (e.g. Buttstädt and Schneider, 2014; Larondelle et al., 2014; Jänicke et al., 2015). Categories

Table 1
Structural green space elements chosen for the study.

Structural element	Variety	Description	Picture
Water element	Natural	Small pond with sediment layer and a sealed, concrete bank	
	Artificial	Sealed fountain	
Lawns	Natural	Meadow with a high degree of coverage, large plant density and diversity	
	Artificial	Trimmed, frequently used artificial lawn with low vegetation cover ratio	
Flower bed	Natural	High plant diversity, potential of spontaneous vegetation within beds	
	Artificial	Lower plant diversity, few types of flowers, densely planted	
Hedges	Natural	High volume of green, dense structure, substantial herbaceous layer	
	Artificial	Lower volume of green, trimmed appearance	
Margin	Natural	Characteristic plant community can be developed due to a low level of grooming	
	Artificial	Clear-cut distinction between lawn and grove with just a small transition area	

(2)–(5) are assumed to influence, e.g., the pedestrian thermal comfort (Shashua-Bar et al., 2011; Maras et al., 2016; Zölch et al., 2016). A best possible partial score (6.0) was allocated to a structural park element featuring an optimal positive impact on the urban microclimate for a given atmospheric function category. Generally speaking, it is impossible to assign an optimal score of 6.0 to a given structural park element in all categories at the same time since elements may have opposing influences on ambient air in different categories. For example, avenue-trees in a street canyon are assumed to have positive effects on the thermal comfort (Morakinyo and Lam, 2016b) but appear to have negative effects e.g. on wind field characteristics preventing dilution of polluted air (Gromke and Blocken, 2015).

2.3.2. Ecological evaluation

The benchmark for ecological functions of park elements is primarily based on the normative, numerical evaluation of habitat types for regulating the outline of compensation measures in North Rhine Westphalia (Biedermann et al., 2008). The ecological indices were calculated in the same manner and are using the same range as the partial indicators from the microclimatic evaluation. A theoretical worst case structural element was defined for every single index of score 1.0, the best case was rated with the index score of 6.0. Ecological indices were generated for the habitat potentials for animals as well as for plants. They are defined as the provision of living space with abiotic and biotic conditions that support species richness for animals (e.g. birds, invertebrates and mammals) and vascular plants (indigenous and exotic) on a site. Worst-case scenarios for these indicators include structures that do not provide any opportunity to promote or enhance habitat potential, for example sealed trails of a green space. Best case elements are characterized by a high potential to ensure a stable population for plant and animal communities, e.g. relatively undisturbed groups of shrubs. Provisioning of plant pollination (by maintaining plant-pollinator-networks) as a crucial key-process in resilient and sustainable ecosystems (Bolund and Hunhammar, 1999) is considered as an additional indicator in the ecological assessment. The maintenance of pollination is also directly linked to species richness of plants and pollinators, to fruit and crop production (Jansson and Polasky, 2010) and, in this way to economic and social perspectives. A best case pollination score can be achieved by structural elements with a high amount and diversity of insect pollinating plants which supports the biocoenosis of flower visitors (Wastian et al., 2016).

With the fourth ecological indicator the ecological integrity of the respective park element is valued. This index addresses the ability of a structural element to maintain its structures and functions (Jenssen et al., 2003). Self-organization, functionality and conformity of abiotic and biotic properties with the natural potential of the respective element are crucial characteristics of the intended ecological integrity. Undisturbed groves of the so-called “urban wilderness” were rated as best case elements of ecological integrity.

Assigned indicator values for climatic and ecological properties of structural park elements considering the above mentioned functions are presented in Table 2 of Section 3.1.

2.3.3. Social perceptions and preferences - logic of empirical procedure

In order to assess the perceptions of and preferences for elements of urban green spaces from a social perspective, an empirical study was designed. Ratings for the social desirability of particular park elements cannot and should not be derived from literature or expert judgement but should rather be based on actual citizens' evaluations. In the survey, city residents were shown pictures of different structural elements, each in one natural and one artificial instance, which they had to rate on different dimensions. Two of them will be considered for the index in this study: perceived beauty (“The element shown is beautiful”, agreement measured on a six point Likert-scale from 1.0 = not at all to 6.0 = very) and desired frequency of the element in urban green spaces (“How often should this element be present in urban green spaces?”, measured on a scale from 1.0 = much less frequent to 6.0 = much more frequent). The focus on aesthetics (as a social function) in this context aims to add to the discussion about the interplay between an aesthetic experience of nature and its ecological value (Gobster et al., 2007), while the desired frequency was chosen as a way of a direct recommendation for planners of urban green spaces how to prioritize elements of urban green spaces.

Participants were invited via email and social networks to take part in the study. The participants were citizens of Aachen to ensure that even if they did not know the parks, they would rely on a common frame of reference. A total of 235 participants agreed to take part. After exclusion of incompletely filled in questionnaires, N = 184 remained for statistical analysis. A repeated measurements design was chosen, for which a Wilcoxon signed rank test was used for the comparison of evaluations of artificial and near-natural elements. The significance level was set to 5%. In addition to the questions on the structural elements, participants were asked for their concepts of naturalness and artificiality (“What does naturalness in an urban context mean to you, and according to which criteria did you evaluate an element as natural or artificial?”), in order to explore whether a distinction between natural and artificial elements is justified from a social perspective.

2.3.3.1. Sample. The mean age of the participating citizens was 31.6 (SD = 10.4, age range from 18 to 67 years), 47.8% were male, 52.2% female. The overall educational level was high, with 25.5% holding a qualification for university entrance and 63.6% a university degree. 35 participants (19%) worked or had studied in the fields of biology, ecology, environmental science, landscape conservation, landscape architecture or climatology. 22.3% had a garden of their own, 21.7% used a community garden, 5.4% took part in urban gardening and 56.0% had no garden (multiple answers possible). Concerning the place of residence, 76.6% lived in the city center, 19.6% in the outskirts of the city and 3.8% on the countryside. On average, participants had been living in Aachen for 13.7 years (SD = 13.3, range: from 0 to 57 years). 0.5% of the sample reported to visit public parks more than once a day, 9.8% daily, 33.2% weekly, 37.0% monthly and 19.6% less than once a month.

3. Results

The results section will first present the evaluations of structural elements from the ecological, microclimate and social perspective, followed by results of the question how and if the citizens differentiated between natural and artificial elements of urban green spaces.

3.1. Evaluation of structural elements

The selected structural elements were evaluated according to the procedure described in Section 2.3, while considering ecological, microclimatic and social criteria. Results are presented in Table 2.

Table 2

Assigned indicator values for ecological, climatic and social properties of structural park elements in consideration of the quality (nat. = natural; art. = artificial) of the respective element.

		Ecology (expert judgement, max: 6.0)				Microclimate (expert judgement, max: 6.0)					Social (citizen perception, max: 6.0)	
Structural element	Element quality	Ecological integrity	Habitat animals	Habitat plants	Pollination	Concentration reduction (NO_x/PM)	Cool air	Evapo-transpiration	Turbulence	Radiation budget	Beauty	Desired frequency
Flower bed	Nat.	4.0	4.0	4.5	6.0	3.0	3.0	3.5	2.5	1.0	4.7	4.8
	Art.	1.0	1.5	1.0	5.0	2.5	2.0	2.5	1.5	1.0	3.8	3.9
Hedge	Nat.	3.5	5.0	4.5	3.5	4.5	3.0	4.5	4.0	3.0	4.4	4.8
	Art.	2.0	2.0	1.5	2.5	4.0	2.0	4.0	4.0	2.0	3.1	3.5
Lawn	Nat.	3.0	3.5	4.5	4.5	2.5	5.0	3.5	2.0	1.0	4.5	4.6
	Art.	1.5	1.5	1.0	2.0	2.5	5.0	3.0	2.0	1.0	2.8	3.5
Margin	Nat.	5.0	4.5	5.0	4.5	4.5	3.0	4.5	4.0	4.0	4.5	4.9
	Art.	2.5	2.5	2.5	3.0	4.5	3.0	4.5	4.0	4.0	3.8	4.6
Water element	Nat.	2.5	3.5	3.5	1.0	1.0	1.5	5.0	1.0	1.0	3.9	4.8
	Art.	1.0	1.0	1.0	1.0	1.0	1.5	3.5	1.5	1.0	3.5	3.3

In Table 3, the distribution of indicator values of every single discipline (ecology, climatology, perception) is illustrated by unweighted means and extrema of the related indicator values.

The ecological assessment reveals that there were significant differences in the design of structural elements for nearly every considered structure and ecological criterion (except the contribution of water elements to the pollination performance of parks and cities). The biggest differences between the artificial and natural design of a respective element can be detected for the habitat potential for plants in lawns and flowerbeds (indicator value of M = 1.0 for artificial and M = 4.5 for natural design in each case). Also, the highest overall mean difference between artificial and natural element-quality of all ecological criteria can be found in these two structural elements (difference = 2.4–2.5 points). From an ecological point of view, an ideal structural setup for an urban green space in compact cities should include natural types of all structural elements, with particular consideration of the appearance of margins as transition zones between elements, arising due to a low level of maintenance. These structures support a variety of ecological properties (Table 2).

The creation of natural flower beds will improve the plant-pollinator network of a site and, thereby, increase the pollination performance and the habitat potential for both insect-pollinated plants and pollinators. Hedges and lawns designed with a high level of naturalness will imply a high amount of green volume and dead wood, which is directly linked to a habitat for animals, such as birds, small vertebrates, insects and the soil arthropod community. Furthermore, the diversity of spontaneous vegetation will increase by including these compartments.

Compared to the ecological estimation, the assessment of microclimatic characteristics of the park elements only shows minor differences between natural elements and their artificial counterpart. Only the flower beds and hedges - with a mean difference of 0.6 and 0.7 between their artificial and natural condition - show noteworthy differences, even though they are still smaller than the differences of the ecological estimation for every structural element (Table 3).

From a citizen perspective, it can first of all be deduced that artificial and natural varieties of the elements are perceived significantly different from each other with regard to both perceived beauty and desired frequency (for Wilcoxon Signed rank tests see Appendix Table A3).

The most "beautiful" element was the natural flower bed (M = 4.7 out of 6 points max). The artificial lawn (M = 2.8/6 points max) received the lowest rating for "beauty" relative to the other elements. However, these ratings were still close to midpoint of the scale (3.5 points), so even the least liked elements in terms of beauty were still perceived as fairly beautiful. The desired frequency of all elements, natural and artificial, was close to the midpoint of the scale or above it, which indicates a general wish for more green elements in the city, and that any type of green area is appreciated. The most frequently desired element was the natural margin (M = 4.9/6 points max) while the artificial water element was the least frequently desired element (M = 3.3/6 points max). The largest difference in perceived beauty between a natural and an artificial variety occurred for the element "lawn" (difference = 1.7 points, $z = -9.779$, $p \leq 0.01$), while the hedge was the element for which desired frequency differed most between the two varieties (difference = 1.3 points, $z = -7.681$, $p \leq 0.01$).

Table 3
Unweighted means, minimum and maximum of the indicator values for ecological, climatological and social (perception) assessment.

Structural element	Quality	Ecology mean (min/max)	Microclimate mean (min/max)	Perception mean (min/max)
Flower bed	Natural	4.6 (4.0/6.0)	2.6 (1.0/3.5)	4.8 (4.7/4.8)
	Artificial	2.1 (1.0/5.0)	1.9 (1.0/2.5)	3.9 (3.8/3.9)
Hedge	Natural	4.1 (3.5/5.0)	3.8 (3.0/4.5)	4.6 (4.4/4.8)
	Artificial	2.0 (1.5/2.5)	3.2 (2.0/4.0)	3.3 (3.1/3.5)
Lawn	Natural	3.9 (3.0/4.5)	2.8 (1.0/5.0)	4.6 (4.5/4.6)
	Artificial	1.5 (1.0/2.0)	2.7 (1.0/5.0)	3.2 (2.8/3.5)
Margin	Natural	4.8 (4.5/5.0)	4.0 (3.0/4.5)	4.7 (4.5/4.9)
	Artificial	2.6 (2.5/3.0)	4.0 (3.0/4.5)	4.2 (3.8/4.6)
Water element	Natural	2.6 (1.0/3.5)	1.9 (1.0/5.0)	4.4 (3.9/4.8)
	Artificial	1.0 (1.0/1.0)	1.7 (1.0/3.5)	3.4 (3.3/3.5)

Perceived beauty did not decline linearly with decreasing ecological and climatic value, so artificial elements should not be dismissed because of a low ecological value, as they were shown to have aesthetic value from a social point of view. Apparently, preferences reflect a mixture between ecological and climatic valuable elements as well as "decorative" elements.

The summary in Table 3 illustrates that the valuation of elements might lead to a wide dispersion of indicator values (>2.5), even within a specific discipline. This is particularly evident for the ecological perspective of artificial flower beds and for the microclimatic assessment of lawns and water elements. In addition to that, major differences can also be found between the artificial and natural realization for every element, especially in the ecological assessment.

Two elements presented especially interesting cases and will therefore be discussed in more detail in the following paragraphs. This concerns first of all lawns, because lawns usually cover the largest area in urban green spaces and the evaluations according to the different dimensions were especially diverse. As an opposing example, the element "hedge" will be analyzed in more depth, as this is an element for which the evaluation was more balanced across the three dimensions.

3.1.1. Mismatch of perspectives - example lawn

From a social perspective, especially the difference in perceived beauty between the natural and the artificial variety is noteworthy. The artificial lawn is clearly perceived as much less beautiful and is also less frequently wanted than the natural lawn. In spite of the artificial lawn's low ecological potential, it is however still appreciated by the laypeople-citizens (desired frequency = 3.5/6 points max, Fig. 1).

It is striking that although from an ecological point of view, the natural and artificial lawns differ to a great extent, this is less true from the microclimatic perspective: evaluations reveal differences only for the evapotranspiration performance of different lawns.

The lawn also exemplifies a case that shows that ecological and microclimatic functions do not necessarily depend on each other and not even all microclimatic functions: while the shadowing function of the artificial and natural lawn is rated at 1.0, its function to "cool air" is rated much higher at 5.0.

Especially the natural lawn thus presents an element of urban green spaces that provides a high amount of ecological and social functions but fails to fulfill important city climate functions (e.g., concentration reduction of pollutants or change of the radiation budget as a result of shadowing).

3.1.2. Consensus of perspectives - example hedge

For the element "hedge", evaluations of artificial and natural variety were more balanced between the different dimensions (Fig. 2). While for "lawn" evaluations ranged from 1.0 to 5.0 within the natural and the artificial element for hedge, evaluations ranged from 1.5 to 4.0 for the artificial and from 3.0 to 5.0 for the natural variety.

From a social point of view, the natural hedge was perceived as more beautiful and was desired more frequently than its artificial counterpart. It is noteworthy that the artificial hedge was not perceived as beautiful (M = 3.1, thus below the midpoint of the scale).

The hedge received the highest ratings in its natural variety for "habitat for animals" (5.0/6 points max) and "desired frequency" (4.8/6 points max). Especially from an ecological point of view, the design and maintenance of hedges can have a major influence on functions and processes. A well-developed hedge provides habitat and refuge area for a number of animals (M = 5.0/6 points max), such as birds and the terrestrial biocoenosis among others. In addition, a colonization of a spontaneous plant community in the herb and shrub layer is supported by natural hedges (M = 4.5/6 points max). These ecological

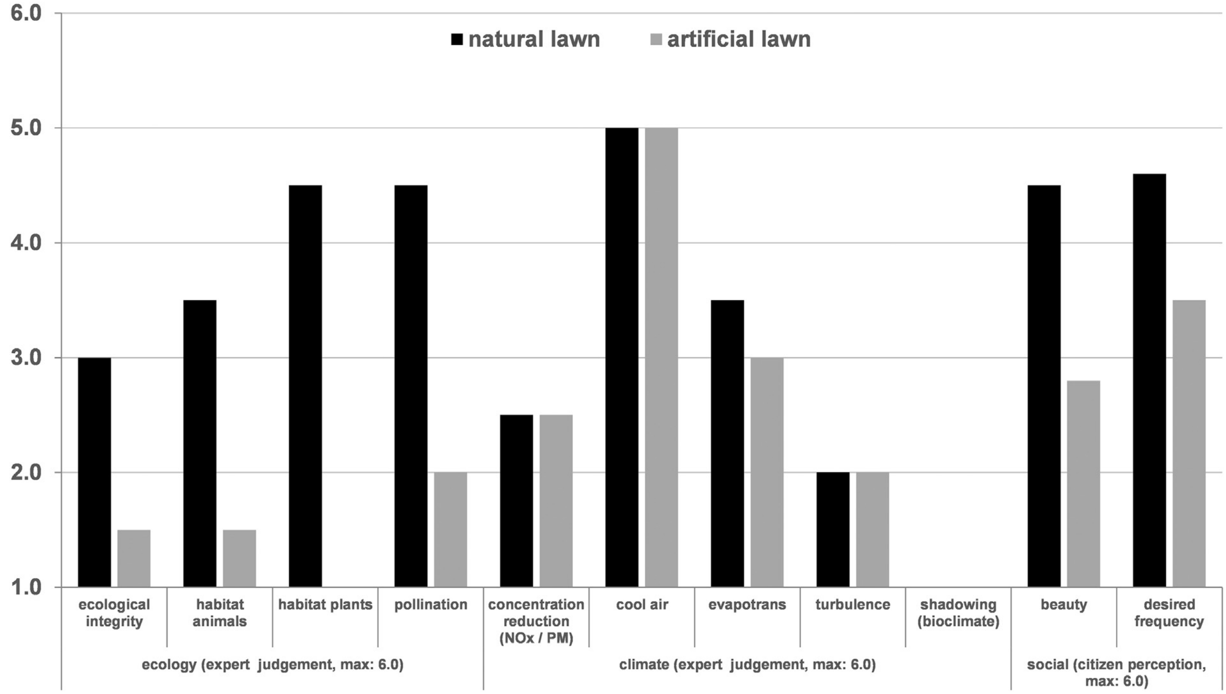


Fig. 1. Evaluation of the element "lawn".

functions of the element are not sufficiently supported by artificial, trimmed hedges, which are frequently realized in an urban environment. The difference between ecological valuation and citizen perception of artificial hedges are clearly stated in the evaluation of hedges.

3.2. Concepts of naturalness and artificiality by citizens

It was of interest for the indicator being developed whether a differentiation between natural and artificial elements of urban green spaces would be valid from a citizen perspective in order to match expert-categorizations with the perceptions and realities of the residents of the city.

This was operationalized in two different ways in the questionnaire. Firstly, by providing an artificial and a natural variety of each element to derive from the results if people had differentiated opinion on natural and artificial instances of the same element. Secondly, at the end of the questionnaire, participants were asked for their concepts of naturalness and artificiality in the context of urban green areas. They were

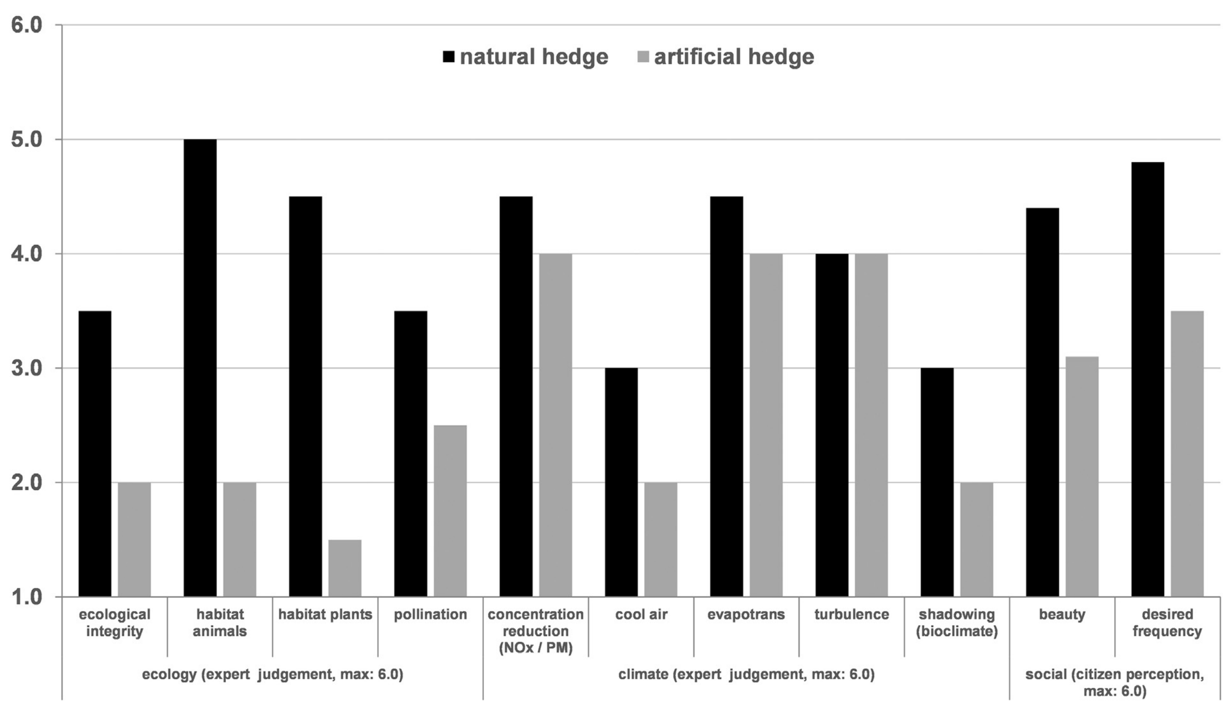


Fig. 2. Evaluation of the element "hedge".

asked what naturalness in an urban context meant to them and how they distinguished between natural and artificial types of elements. A text field was provided in which participants could enter their comments. Figs. 3 and 4 show the results of the question by means of an analysis of the most frequently mentioned terms in the answers. Frequencies of mentions were depicted in word clouds in terms of font size (the larger the font size, the more frequently the term was mentioned).

Looking at the notes of the participants, it becomes clear that naturalness and artificiality appear in different ways to the participants. Participants referred to the plants themselves, such as their look, age, and arrangement ("tidy", "straight", "geometric" vs. "pristine", "untouched") as well as their origin ("domestic") and growth ("proliferating"). Many comments also referred to diversity and different species of plants ("weeds"), which were seen as signs for a natural green area as opposed to "monocultures" in artificial parks.

The overall design of the park was also frequently used as a criterion to judge the naturalness. Participants mentioned certain materials they associated with artificiality ("concrete") but also took into account the required effort for maintaining the park ("mowing", "cutting") and the overall human intervention (as opposed to "letting nature have its way").

Overall, comments showed a detailed idea about what is natural and what is artificial to participants. In the light of the idea that complete "wilderness" in cities is not achievable, participants elaborated on the concept of naturalness in urban areas and indicated a very differentiated view on naturalness and how much naturalness is possible in urban areas. To illustrate participants' views, some sample quotes reflecting on the contrast between an urban environment and nature are presented below:

> "For me, naturalness in an urban context does not mean totally uncontrolled growth. Aesthetic human intervention should be visible, but subtle."
>
> [(Male, 40 years)]

> "Even if grass does not really grow there – the park is well designed. Flowerbeds in the streets are artificial, but still beautiful!"
>
> [(Female, 55 years)]

> "Even natural parks need thoughtful planning."
>
> [(Female, 43 years)]

> "A city should have different types of park, or differently designed areas in one park."
>
> [(Female, 43 years)]

> "A park in the city center does not have to be natural in an ecological sense of the word (…) The role of a park in the city center, to me, is to provide recreation, a social meeting point and a better climate for the people."
>
> [(Female, 47 years)]

From a planning perspective, it became clear that artificiality does not mean that those elements are not appreciated. Quite the contrary, participants are aware that complete "wilderness" is not possible in an urban environment. Instead, they advocated a design that is close to natural appearance but is being cared for. They also found that a variety of parks with different functions (and thus different degrees of artificiality and naturalness) should be present within a city and that not all parks need to fulfill all functions.

4. Discussion

Designing urban green spaces to meet the demands of an integrative view on different scales is a challenging task. The efficient use of free space must balance ecological, social and microclimatic objectives in a trade-off acceptable to all parties involved. This inevitably leads to a

Fig. 3. Associations of participants (n = 184) with naturalness (the larger the font, the more frequently a term was mentioned).

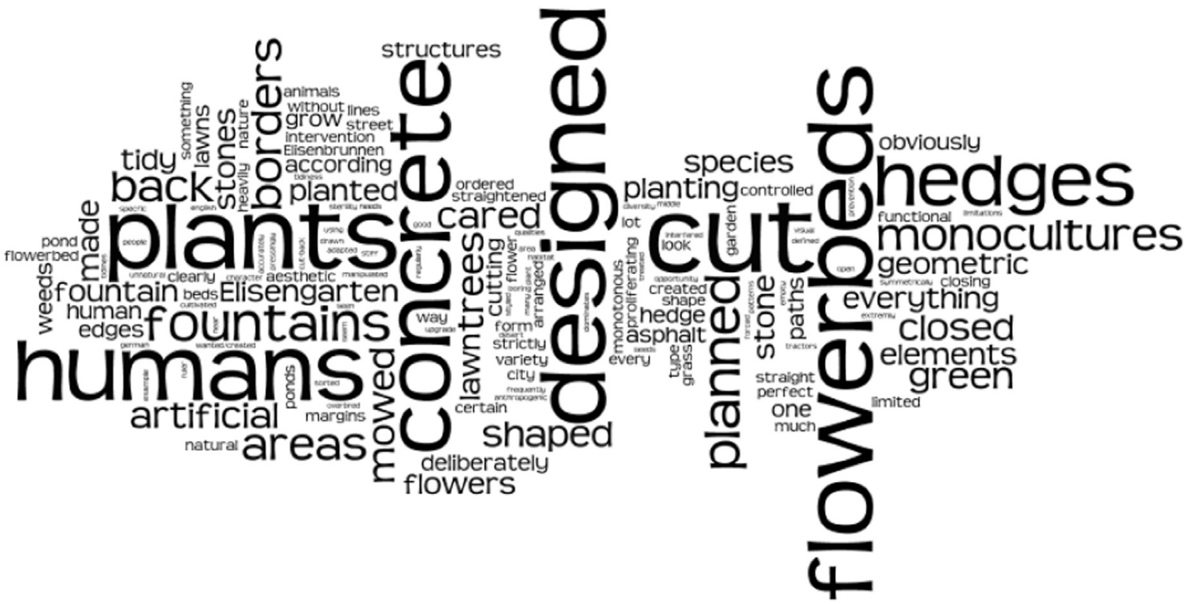


Fig. 4. Associations of participants (n = 184) with artificiality (the larger the font, the more frequently a term was mentioned).

multifunctional design of green spaces which is of particular relevance for the concept of compact green cities. In this study, an indicator-based assessment for structural elements of urban green spaces was developed on the basis of a multidimensional perspective, in order to support a systemic solution for the assessment of urban green spaces to promote compact green cities.

Results of the performed survey on the attractiveness of structural park elements clearly show some major differences in comparison to their ecological and climatic valuation. Also with regard to the respective quality (natural/artificial) of the single elements, differences were found for every discipline. This indicates the high potential of a multidimensional assessment of green spaces on a scale of structural park elements and with respect to the given variability of the condition of all elements. Therefore, an assessment based on a site-scale needs to be adopted to adequately evaluate and compare the contribution of green spaces to the overall provisioning of ecosystem functions and services of cities. By taking into account these principles, the identified gaps (cf. Section 1.1) in the assessment of urban green spaces can be addressed. Nevertheless, the indicator set only contains initial theoretical foundations towards a multidimensional, specific and holistic planning guideline for urban green spaces.

4.1. Discussion of key findings

It was revealed that the assessments of the structural elements varied to a great extent for some elements. For example, the near-natural water element, which was socially highly appreciated, received a rather low evaluation for its biodiversity and an even lower score for its microclimatic functions. This shows that assessing structural elements of parks from only one point of view misses many other facets and supports the thesis that a multidimensional assessment approach to support planning procedures is needed (Luederitz et al., 2015).

Overall, the multidimensional perspective on urban green spaces is useful to cover the multiple functions of structural elements for urban parks and to assess them in an integrative way to ensure that different requirements (decorative functions, support of healthy urban climates etc.) are fulfilled. By the example of the natural lawn, it was shown that one element can fulfill some ecosystem service functions very well, while contributing to a much lesser extent to others.

The two functions "ecology" and "climatology" do not necessarily depend on each other. There were examples where an element received a high ecological and a high climatic rating, which leads to synergies between the ecosystem services from different disciplines (mostly the near-natural instances such as the near-natural hedge or the near-natural flowerbed). But there were also instances receiving low ecological but high climatic ratings (mostly artificial instances, i.e. the artificial lawn or hedge), exemplifying instances of trade-offs between different functions (Haase et al., 2012). The new metrics can thus help to detect which ecosystem functions are not properly, or only to a lesser degree, covered by certain structural elements. A consequence for planners of urban green spaces could be that other elements in the same urban green space should be chosen with a special focus on microclimatic functions which also can be identified using the set of indicators.

Bonnes et al. (2007) argue that there is a contradiction between social and ecological preferences for the design of urban green spaces: while many citizens feel more comfortable and safe when the greenery is trimmed and cultivated, the "wild" green spaces are highly appreciated by ecologists to maintain biodiversity. The study presented here, however, found that "wilderness" or "naturalness" was appreciated, as these elements were preferred over artificial elements. In opposition also to Hofmann et al. (2012), we found that natural elements were perceived as more beautiful and wished for more often than their artificial counterparts. The difference could be due to different reference points: In the study by Herzog and Miller (1998), as cited in Bonnes et al. (2007), entire landscapes or scenes were shown to the participants, whereas in this study, single elements had to be rated. Potentially, parks as a whole with differences in artificiality and naturalness would be evaluated differently than the single elements which constitute the park. It is also possible that the high share of participants with a background in ecology and biology led to this result. The preference for natural park elements by the public is a possible source of conflict in cases where naturalness is not achievable due to the function of the park, for example in highly frequented parks in the city center. This, once more, highlights the necessity of communication between the public and urban planners to avoid disappointments or even worse, protests among the public with the final design.

Overall, the wish for more "green" in the city was clearly voiced by the participants independent of artificial or natural quality of the elements. This outcome is, nevertheless, in line with Bonnes et al. (2007), who found that availability of urban green areas is more important than biodiversity. In our study, especially the more natural variety of structural elements was preferred. This is in opposition to the representative function of urban green spaces in central parts of the city, which are frequently visited. Thus, it has to be distinguished if a park is visited for its recreational value and to experience "wild nature" or if it is used as a place for socializing in a central location, as these functions require different types of structural elements: While, e.g., the near-natural lawn would not survive in the location of a highly frequented green space in the city center, the trimmed lawn may not be appreciated as much but fulfills its function according to the requirements of the respective context.

It should thus be considered that not every type of structural element is suitable for every urban green space. Borgström et al. (2006) thus suggest "zoning" as a solution to this dilemma:

> "A possible strategy for handling this 'multipurpose dilemma' that is explicit in the urban context, may be zoning of urban green spaces, where different purposes are prioritized in different locations."(Borgström et al., 2006: 16)

This approach is further supported by the comments of the citizens who were well aware that frequently visited parks in the city center cannot be "natural" in a way a more decentralized, quiet park can be.

Furthermore, regarding the preferences for natural or artificial instances, it needs to be considered that the data did not allow insights into the reasoning behind participants' choices. Findings by Jim and Chen (2006) for example suggest that there is a relation between plants which are non-regularly maintained and perceived security, an aspect which was not addressed in this study as a possible downside of a more naturalistic park design.

In this paper, it was hypothesized that a differentiation between natural and artificial elements is needed to adequately cover their different properties. Results from the ecological, microclimatic and social perspective show that indeed, structural elements differ with regard to their functions depending on whether a near-natural or an artificial, trimmed variety is considered. From this, it follows that it is not only important which elements are chosen for urban green spaces but also how they are implemented. In addition, it supports the thesis that an assessment of urban green spaces and their structural elements has to consider the specific design and quality of the element. Even if the generation of indicators always implies a reduction of complexity, our results clearly underline the importance of considering the actual design of the regarded structures (which is of similar relevance as the consideration of various functions and services).

From a microclimatic point of view, artificial and near-natural elements differed to a lesser extent. Future research will have to determine which elements have a significant effect on climate and how they should be designed to achieve this effect. It would be of interest to determine if differences between the elements on the level of microclimatology are also reflected, e.g., in the social evaluation.

With regard to the social evaluation of natural and artificial varieties of the same element, it was found that even for laypeople, the distinction between natural and artificial varieties of the same elements is meaningful, as significant differences in the evaluations were found. Furthermore, laypeople were shown to have a differentiated understanding of naturalness in an urban context.

4.2. Structure-type classification system: basis of a multidimensional and multi-scale green space assessment

The applied spatial scale level of differentiating between structural elements within green spaces allows for a consistent assessment of park structures by various disciplines (multidimensional approach). In addition, the dispersion in the valuation of different functions provided by the structural elements within the disciplines clearly indicates that a differentiated evaluation is needed for an appropriate assessment of green spaces. As a result, the approach enables a rating and substantial comparison of the quality of different sites (as a composition of park elements and their combined indices) and not only addresses the number and size of planted area in cities, which is common in former management proceedings for urban green spaces and has frequently been criticized (Pauleit, 2003; Baycan-Levent and Nijkamp, 2009). This bottom-up assessment of urban green spaces can be used to evaluate green areas on different scales from site- to city-level and even between cities and regions (multi-scale approach). This approach, however, requires the survey of all structural elements of the respective sites. The fact that the structure-type classification system is exclusively based on structural parameters (length, width, height and coverage of the surface) in turn encourages the automatic categorization of park structures by using remote-sensing techniques and data. When extrapolating from a site-scale assessment to other spatial scale levels, it is of particular importance to consider the quality (artificial/natural) of the respective elements.

Nevertheless, a normative evaluation of single parks and their structural park elements may also lack an integration of site-specific conditions, such as cultural, demographic and physical properties but also the connectivity of green spaces within an urban realm. Therefore, we consider implementing the multidimensional assessment into a more generic approach. The site-specific conditions of a park can be used to define the most important functions of the green space and to adjust the indicator values of the approach by using weighting factors for each criterion.

4.3. From an assessment to a planning tool for compact green cities

The assessment of structural elements from an ecological, climatic and social perspective has shown that mismatches between the perspectives exist (as exemplified for the structural element "lawn"). Our study served as a first approach to make these mismatches visible and in this way, opens a discussion about possible conflicts, using indicators as "tools which open up dialogue, information sharing, learning and consensus-building across different policy boundaries: between experts and non-experts, formal government and different nongovernment actors, higher-order governments and lower-order governments." (Holden, 2013).

What has been used as a metric for an assessment of urban green spaces can also be integrated into a design and planning tool for urban green spaces, which can provide guidelines on specific elements and their multiple functions. This way, the assessment tool could answer the call for an interdisciplinary planning approach (James et al., 2009).

Regarding the mismatches in the evaluation of structural elements discussed above, a comparative discourse about the importance of single ecosystem services in parks with different site conditions is desperately needed (Wilson and Howarth, 2002). It has to be discussed how the different functions (ecological, climatic, social) can be weighed against each other, especially in cases with mismatching perspectives (like the "lawn"). This inevitably leads to a weighing up of tradeoffs, as the evaluation of functions shows. The practical application of the indicator set will need to show solutions to these situations of mismatch and how they can be dealt with in practice. It has to be defined under which circumstances a certain perspective is given priority over the others, for example if cut-off values for ecological services could be defined that need to be fulfilled before the social dimension can be taken into account. Moreover, the development of compact green cities should also include a consensus about a minimum set of ecological and climatic structures and structural elements to enhance sustainability of these urban landscapes. Compared to the dynamics of the more adaptive social indicators of citizen perception towards green spaces (e.g. depending on the recent zeitgeist), a threshold for the ecological and climatic quality should be defined. These thresholds can be considered within a multidimensional assessment approach.

The added value of this approach can be seen on different levels. Today, many communes and cities are confronted with transformation challenges caused by urbanization processes in line with demographic changes. City planners and local stakeholders have to meet different requirements which evolve from the urgent need to create long-lasting and sustainable living environments for dwellers and to make responsible decisions. The metrics which was introduced in this paper can support this process by classifying, describing and assessing urban green spaces from different point of views. It is not only a visualization instrument for experts, but also a communication tool, as it allows different stakeholders to discuss the impact of different assessments and to make informed decisions. Moreover, the metrics can also be used as a public participation instrument. Based on the interdisciplinary assessment of urban green spaces (and single elements), public can be informed and included in the discourse about design and function of urban green spaces. Different perspectives and arguments can be openly discussed and individually tailored to the specific situation and demographics, representing a novel and informed kind of citizen participation. Extending the indicator set by more structural elements and disciplines (e.g. economy based view on ecosystem service proxies) will further contribute to the development of a systemic solution.

4.4. Methodological strength, limitations and future challenges

While the empirical investigation deliberately focused on an exploratory study of collecting people's evaluations of park elements in a city they are living in, using empirical methods, it should still be discussed in how far the methodology might have some potential for optimization. In the survey, we used photographs to let participants rate structural elements on different dimensions to assure comparability between the assessments. However, the photographs showed the structural elements in their natural surroundings, which could have influenced the evaluation of some participants. Hofmann et al. (2012) addresses the problem of using photographs to assess biodiversity, as they did not find differences between experts and laypeople assessing species richness and attributed this to the lack of details visible in the photographs. However, they also point out that by using photographs instead of an in-situ survey leads to comparable results (for overview see Hofmann et al., 2012). In our study, photographs proved to be an adequate tool to find differences in assessing perceived beauty and desired frequency of structural elements. Employing a variety of methods, e.g. the "Virtual Garden Planner" proposed by Shwartz et al. (2013), would provide the opportunity to verify the results gained in this study, e.g. to explore the underlying concepts of naturalness and artificiality. Besides, isolating the elements from their natural surroundings could provide the opportunity to study the single elements independent of their context and come to a conclusion in how far the background influenced the results.

In addition, other factors, such as e.g. perceived maintenance efforts required or contribution to wellbeing could be worth investigating in future studies.

A further limitation concerns the characteristics of the sample. It contained a large share of highly educated participants with high ecological awareness. This should be considered in the interpretation of results. The preference for natural rather than artificial elements, for example, could be a result of the high share of ecologically educated participants (Jankovska et al., 2010). However, this does not limit the validity of the approach and the development of an integrated indicator set. This approach provided the opportunity to identify possible challenges and opportunities of the indicator set, some of which are independent of the specific empirical data collected from citizens. Therefore, the sample is considered useful for the indicator set in this stage of the development of the metrics. Nevertheless, representativeness of the sample is a research duty that should be addressed in future studies.

Another interesting research question is the impact of user diversity on the evaluation of the structure and the design of urban green spaces. The impact of age, gender and culture could be insightful as the role and the context of using or visiting urban green spaces is influenced by age (and the experience with visiting urban green spaces, Thompson et al., 2008), cultural differences (Özgüner, 2011), as well as gender and pro-environmental attitudes (Bonnes et al., 2007; Jim and Shan, 2013). As the social value of urban green spaces thus depends on user diversity, a closer look into individual differences in evaluating single elements of urban green spaces could merit attention in future research. In addition, it would be insightful to compare urban green space assessment across different geographic areas (as dependent variables), as it is likely that perception of green spaces is influenced by the cultural context (Todorova et al., 2004; Sanesi and Chiarello, 2006; Shackleton and Blair, 2013).

As we only evaluated a selection of five out of fifteen different elements, the approach needs to be extended by a valuation of other elements, especially trees and groves have not been considered so far. Although tree species have been shown to contribute differently to ecosystem functions (ecological and microclimatic) (O'Sullivan et al., 2017), a differentiation of natural and artificial plants based on species only (exotic vs. indigenous) has been shown to be difficult for laypersons (Lindemann-Matthies, 2016).

Also the choice of valued criteria is not limited to the presented functions and services, additional indicators or disciplines (e.g. economic considerations, Barbier, 2007) can be included throughout the approach. By evaluating the single structural elements, also hydrological effects (water retention capacity, water purification, transportation and groundwater recharge) of sustainable green space planning can be considered. Nevertheless, the quality of all these functions and services provided by structural elements are subject of ongoing scientific discussions (e.g. Janhäll, 2015). For this reason, the conducted numerical valuation in this study is not regarded as indisputable since they can be assessed differently, even if the judgement of experts was conducted thoroughly and by taking into account various literature and evaluation guidelines. Therefore, the presented outcome of our research should be recognized as the elaboration of an overall methodical concept with close consideration on benefits and challenges of the multidimensional perspective.

5. Conclusion

In this paper we introduced a novel approach to assess urban green spaces: a methodology in which urban green spaces are assessed quantitatively from three different perspectives using an integrative approach. Taking single elements of green spaces as examples, e.g. lawns or hedges, the metrics reflects an assessment from all perspectives. The underlying idea of the joint approach was to treat all perspectives as equally important and to combine them within one frame of references in order to make different assessment results visible. Accordingly, the study revealed that social perception and functions of structural elements sometimes contradict each other (e.g. high aesthetic, but low ecological function). So, it is all the more important to choose structural elements not only based on a single criterion when designing urban green spaces. It became evident that no structural element is valuable or superfluous per se, but that every element is justified from a specific perspective, be it aesthetic, ecological or climatic in nature. To consider all functions of urban green spaces novel integrative approaches (such as the multidimensional index presented in this paper) are needed as planning tools that exceed conventional urban planning approaches.

Acknowledgements

Authors thank Lisa Schwier for research support. This study is part of the interdisciplinary research project Urban Future Outline (UFO) at the RWTH Aachen University, Germany. The project is funded by the Excellence Initiative of Germany's federal and state governments.

Appendix A

Table A1
List of structural elements in urban green spaces and their explanation.

Code	Structure type	Criteria	Example
1	Class: areas mostly or fully free of vegetation		
1.1	Water element	Water surface	Pond, fountain
1.2	Widely sealed	Very low potential of plant colonization	Asphalt, paving stone, gravelled and compacted trails
1.3	Unsealed	Elevated potential of plant colonization	Compost heap, mulched paths
2	Class: primarily grassland		
2.1	Low	Average height (h) < 0,15 m	Lawn, roof greening
2.2	Medium-rise	0,15 m ≤ h ≤ 0,4 m	Meadow, high lawn
2.3	High	h > 0,4 m	High meadow, fallow land, tall forb field
2.4	Structure type-margins	Linear, at least twice as long as their width, h ≥ 0,15 m, boundary area between structures	Nitrophilous margin
3	Class: primarily shrubs		
3.1	Single shrubs		Single syringe, single hazel
3.2	Group of shrubs	Several individuals, not elongated in one direction	
3.3	Hedge	Linear, at least twice as long as their width, compact	Cutted hedge of *Crataegus* ssp.
4	Class: primarily trees		
4.1	Single trees	freestanding tree > 5 m, no shrub layer	
4.2	Group of trees	Cover ratio (herb layer) < 0,25; no shrub layer	Group of close-standing hornbeam
4.3	Grove	Significant tree contingent, dense shrub layer, not elongated in one direction	
5	Class: vegetable/flower beds	Sharply separated, designed by gardener	
5.1	Vegetable patch	Species composition	Vegetable bed
5.2	Flower bed/decoration bed	Species composition	Flower bed, structuring elements

Table A2
Criteria of the conducted expert assessment, underlying evaluation guideline and additional literature considered.

Discipline	Underlying numerical evaluation guideline	Assessment criteria	Additional literature considered
Ecology	Biedermann et al., 2008; BMUB, 2013	Ecological integrity	Ludwig and Meinig, 1991; Jenssen et al., 2003; Hetzel et al., 2014; Grunewald and Bastian, 2015
		Habitat animals	Farinha-Marques et al., 2011; Nielsen et al., 2014;
		Habitat plants	Farinha-Marques et al., 2011; Nielsen et al., 2014;
		Pollination	Wastian et al., 2016
Microclimate	Küpfer, 2005	Concentration reduction (NO_x/PM)	Helbig and Baumüller, 1999; Donovan et al., 2005; Seinfeld and Pandis, 2006; Litschke and Kuttler, 2008; Calfapietra et al., 2013, Gromke and Blocken, 2015; Janhäll, 2015; Morakinyo and Lam, 2016a
		Cool air	Fernando, 2010; Sachsen et al., 2014
		Evapo-transpiration	Declet-Barreto et al., 2013
		Turbulence	Oke, 2009; Gromke and Blocken, 2015
		Radiation budget	Buttstädt and Schneider, 2014; Larondelle et al., 2014; Jänicke et al., 2015

Table A3
Wilcoxon Signed rank test for repeated measures for the evaluations between artificial and natural varieties of structural elements.

Structural element	Variable	z	Sign. (p)
Water element	...is beautiful	−3.697	<0.01
	desired frequency	−9.468	<0.01
Margin	...is beautiful	−6.089	<0.01
	desired frequency	−3.763	<0.01
Lawn	...is beautiful	−9.779	<0.01
	desired frequency	−7.525	<0.01
Flowerbed	...is beautiful	−6.491	<0.01
	desired frequency	−6.678	<0.01
Hedge	...is beautiful	−7.147	<0.01
	desired frequency	−7.681	<0.01

References

Arnberger, A., Eder, R., 2012. The influence of green space on community attachment of urban and suburban residents. Urban For. Urban Green. 11 (1), 41–49.

Balram, S., Dragićević, S., 2005. Attitudes toward urban green spaces: integrating questionnaire survey and collaborative GIS techniques to improve attitude measurements. Landsc. Urban Plan. 71 (2), 147–162.

Barbier, E.B., 2007. Valuing ecosystem services as productive inputs. Econ. Policy 22 (49), 178–229.

Baycan-Levent, T., Nijkamp, P., 2009. Planning and Management of Urban Green Spaces in Europe: comparative analysis. J. Urban Plann. Dev. 135 (1):1–12. https://doi.org/10.1061/(asce)0733-9488(2009)135:1(1).

Beer, A.R., Delshammar, T., Schildwacht, P., 2003. A changing understanding of the role of Greenspace in high-density housing: a European perspective. Built Environ. 29 (2). https://doi.org/10.2148/benv.29.2.132.54468.

Bertram, C., Rehdanz, K., 2015. Preferences for cultural urban ecosystem services: comparing attitudes, perception, and use. Ecosyst. Serv. 12:187–199. https://doi.org/10.1016/j.ecoser.2014.12.011.

Biedermann, U., Werking-Radtke, J., Woike, M., 2008. Numerische Bewertung von Biotoptypen für die Eingriffsregelung in NRW. Landesanstalt für Natur, Umwelt und Verbraucherschutz (LANUV) NRW, Recklinghausen, Germany.

BMUB, Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit [Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety], 2013. Verordnung über die Kompensation von Eingriffen in Natur und Landschaft (Bundeskompensationsverordnung - BKompV). Draft from April, 13th 2013. Berlin, Germany.

Bolund, P., Hunhammar, S., 1999. Ecosystem services in urban areas. Ecol. Econ. 29 (2): 293–301. https://doi.org/10.1016/s0921-8009(99)00013-0.

Bonnes, M., Uzzell, D., Carrus, G., Kelay, T., 2007. Inhabitants' and experts' assessments of environmental quality for urban sustainability. J. Soc. Issues 63 (1):59–78. https://doi.org/10.1111/j.1540-4560.2007.00496.x.

Borgström, S.T., Elmqvist, T., Angelstam, P., Alfsen-Norodom, C., 2006. Scale mismatches in management of urban landscapes. Ecol. Soc. 11 (2), 16.

Bowler, D.E., Buyung-Ali, L., Knight, T.M., Pullin, A.S., 2010. Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landsc. Urban Plan. 97 (3): 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006.

Breuste, J., Niemela, J., Snep, R.P.H., 2008. Applying landscape ecological principles in urban environments. Landsc. Ecol. 23 (10):1139–1142. https://doi.org/10.1007/s10980-008-9273-0.

Buchel, S., Frantzeskaki, N., 2015. Citizens' voice: a case study about perceived ecosystem services by urban park users in Rotterdam, the Netherlands. Ecosyst. Serv. 12, 169–177.

Burkhard, B., Kroll, F., Müller, F., Windhorst, W., 2009. Landscapes' capacities to provide ecosystem services – a concept for land-cover based assessments. Landscape Online 15, 1–22.

Buttstädt, M., Schneider, C., 2014. Thermal load in a medium-sized European city using the example of Aachen, Germany. Erdkunde 68 (2):71–83. https://doi.org/10.3112/erdkunde.2014.02.01.

Byrne, L.B., 2007. Habitat structure: a fundamental concept and framework for urban soil ecology. Urban Ecosys. 10 (3):255–274. https://doi.org/10.1007/s11252-007-0027-6.

Calfapietra, C., Fares, S., Manes, F., Morani, A., Sgrigna, G., Loreto, F., 2013. Role of biogenic volatile organic compounds (BVOC) emitted by urban trees on ozone concentration in cities: a review. Environ. Pollut. 183:71–80. https://doi.org/10.1016/j.envpol.2013.03.012.

Cohen, P., Potchter, O., Matzarakis, A., 2012. Daily and seasonal climatic conditions of green urban open spaces in the Mediterranean climate and their impact on human comfort. Build. Environ. 51, 285–295.

De Ridder, K., Adamec, V., Bañuelos, A., Bruse, M., Bürger, M., Damsgaard, O., ... Thierry, A., 2004. An integrated methodology to assess the benefits of urban green space. Sci. Total Environ. 334, 489–497.
Declet-Barreto, J., Brazel, A.J., Martin, C.A., Chow, W.T.L., Harlan, S.L., 2013. Creating the park cool island in an inner-city neighborhood: heat mitigation strategy for Phoenix, AZ. Urban Ecosys. 16 (3):617–635. https://doi.org/10.1007/s11252-012-0278-8.
Dennis, M., James, P., 2016. Considerations in the valuation of urban green space: accounting for user participation. Ecosyst. Serv. 21:120–129. https://doi.org/10.1016/j.ecoser.2016.08.003.
Donovan, R.G., Stewart, H.E., Owen, S.M., MacKenzie, A.R., Hewitt, C.N., 2005. Development and application of an urban tree air quality score for photochemical pollution episodes using the Birmingham, United Kingdom, area as a case study. Environ. Sci. Technol. 39 (17):6730–6738. https://doi.org/10.1021/es050581y.
Farinha-Marques, P., Lameiras, J.M., Fernandes, C., Silva, S., Guilherme, F., 2011. Urban biodiversity: a review of current concepts and contributions to multidisciplinary approaches. Innovation 24 (3):247–271. https://doi.org/10.1080/13511610.2011.592062.
Fernando, H.J.S., 2010. Fluid dynamics of urban atmospheres in complex terrain. Annu. Rev. Fluid Mech. 42 (1):365–389. https://doi.org/10.1146/annurev-fluid-121108-145459.
Garritt, J., 2006. "Now who decided that?": experts and the public in biodiversity conservation. Proceedings of the PATH Conference, 4th to 7th June 2006, Edinburgh, Scotland http://www.macaulay.ac.uk/PATHconference/outputs/PATH_abstract_1.1.3.pdf.
Geslin, B., Gauzens, B., Thebault, E., Dajoz, I., 2013. Plant pollinator networks along a gradient of urbanisation. PLoS One 8 (5). https://doi.org/10.1371/journal.pone.0063421.
Gill, S., Handley, J., Ennos, A., Pauleit, S., 2007. Adapting cities for climate change: the role of the green infrastructure. Built Environ. 33 (1):115–133. https://doi.org/10.2148/benv.33.1.115.
Gobster, P.H., Nassauer, J.I., Daniel, T.C., Fry, G., 2007. The shared landscape: what does aesthetics have to do with ecology? Landsc. Ecol. 22 (7), 959–972.
Gromke, C., Blocken, B., 2015. Influence of avenue-trees on air quality at the urban neighborhood scale. Part II: traffic pollutant concentrations at pedestrian level. Environ. Pollut. 196:176–184. https://doi.org/10.1016/j.envpol.2014.10.015.
Gross, C., 2007. Community perspectives of wind energy in Australia: the application of a justice and community fairness framework to increase social acceptance. Energ Policy 35:2727–2736. https://doi.org/10.1016/j.enpol.2006.12.013.
Grunewald, K., Bastian, O., 2015. Ecosystem Services. Concept, Methods and Case Studies. Springer, Berlin Heidelberg.
Haase, D., Schwarz, N., Strohbach, M., Kroll, F., Seppelt, R., 2012. Synergies, trade-offs, and losses of ecosystem services in urban regions: an integrated multiscale framework applied to the Leipzig-Halle region, Germany. Ecol. Soc. 17 (3). https://doi.org/10.5751/es-04853-170322.
Hansen, R., Frantzeskaki, N., McPhearson, T., Rall, E., Kabisch, N., Kaczorowska, A., ... Pauleit, S., 2015. The uptake of the ecosystem services concept in planning discourses of European and American cities. Ecosyst. Serv. 12:228–246. https://doi.org/10.1016/j.ecoser.2014.11.013.
Harrison, C.M., Burgess, J., Clark, J., 1998. Discounted knowledges: farmers' and residents' understandings of nature conservation goals and policies. J. Environ. Manag. 54 (4): 305–320. https://doi.org/10.1006/jema.1998.0242.
Hegetschweiler, K.T., de Vries, S., Arnberger, A., Bell, S., Brennan, M., Siter, N., ... Hunziker, M., 2017. Linking demand and supply factors in identifying cultural ecosystem services of urban green infrastructures: a review of European studies. Urban For. Urban Green. 21, 48–59.
Helbig, A., Baumüller, J., 1999. In: Kerschgens, M.J. (Ed.), Stadtklima und Luftreinhaltung. Springer Berlin Heidelberg, Berlin, Heidelberg Retrieved from. http://link.springer.com/10.1007/978-3-642-58545-6.
Herzog, T.R., Miller, E.J., 1998. The role of mystery in perceived danger and environmental preference. Environ. Behav. 30 (4):429–449. https://doi.org/10.1177/001391659803000401.
Hetzel, I., Müller-Pfannenstiel, K., Zintl, R., Langensiepen, I., Stellmach, M., 2014. Bayerische Kompensationsverordnung (BayKompV) Arbeitshilfe zur Biotopwertliste. Bayerisches Landesamt für Umwelt (LFU), Augsburg, Germany.
Hofmann, M., Westermann, J.R., Kowarik, I., van der Meer, E., 2012. Perceptions of parks and urban derelict land by landscape planners and residents. Urban For. Urban Green. 11 (3):303–312. https://doi.org/10.1016/j.ufug.2012.04.001.
Holden, M., 2013. Sustainability indicator systems within urban governance: usability analysis of sustainability indicator systems as boundary objects. Ecol. Indic. 32, 89–96.
Home, R., Bauer, N., Hunziker, M., 2010. Cultural and biological determinants in the evaluation of urban green spaces. Environ. Behav. 42 (4):494–523. https://doi.org/10.1177/0013916509338147.
James, P., Tzoulas, K., Adams, M.D., Barber, A., Box, J., Breuste, J., ... Handley, J., 2009. Towards an integrated understanding of green space in the European built environment. Urban For. Urban Green. 8 (2), 65–75.
Janhäll, S., 2015. Review on urban vegetation and particle air pollution – deposition and dispersion. Atmos. Environ. 105:130–137. https://doi.org/10.1016/j.atmosenv.2015.01.052.
Jänicke, B., Meier, F., Hoelscher, M.-T., Scherer, D., 2015. Evaluating the effects of façade greening on human bioclimate in a complex urban environment. Adv. Meteorol. 2015:1–15. https://doi.org/10.1155/2015/747259.
Jankovska, I., Straupe, I., Panagopoulos, T., 2010. Naturalistic forest landscape in urban areas: challenges and solutions. Proceedings of the 3rd WSEAS International Conference on Urban Planning and Transportation (UPT'10), Corfu, Greece, pp. 21–26.
Jansson, A., Polasky, S., 2010. Quantifying biodiversity for building resilience for food security in urban landscapes: getting down to business. Ecol. Soc. 15 (3).
Jenssen, M., Hofmann, G., Nickel, S., Pesch, R., Riediger, J., Schroeder, W., 2003. Bewertungskonzept für die Gefährdung der Ökosystemintegrität durch die Wirkungen des Klimawandels in Kombination mit Stoffeinträgen unter Beachtung von Ökosystemfunktionen und–dienstleistungen. Umweltbundesamt (UBA) Texte 87/2013 (381 pp.).
Jim, C.Y., 2004. Green-space preservation and allocation for sustainable greening of compact cities. Cities 21 (4), 311–320.
Jim, C.Y., Chen, W.Y., 2006. Perception and attitude of residents toward urban green spaces in Guangzhou (China). Environ. Manag. 38 (3), 338–349.
Jim, C.Y., Shan, X., 2013. Socioeconomic effect on perception of urban green spaces in Guangzhou, China. Cities 31, 123–131.
Konijnendijk, C.C., Annerstedt, M., Nielsen, A.B., Maruthaveeran, S., 2013. Benefits of urban parks: a systematic review. A Report for IPFRA. IFPRA http://curis.ku.dk/ws/files/44944034/ifpra_park_benefits_review_final_version.pdf.
Küpfer, C., 2005. Empfehlungen für die Bewertung von Eingriffen in Natur und Landschaft in der Bauleitplanung sowie Ermittlung von Art und Umfang von Kompensationsmaßnahmen sowie deren Umsetzung (Teil A: Bewertungsmodell). Landesamt für Umwelt (LFU), Baden-Württemberg.
Larondelle, N., Hamstead, Z.A., Kremer, P., Haase, D., McPhearson, T., 2014. Applying a novel urban structure classification to compare the relationships of urban structure and surface temperature in Berlin and New York City. Appl. Geogr. 53:427–437. https://doi.org/10.1016/j.apgeog.2014.07.004.
Lazo, J.K., Kinnell, J., Bussa, T., Fisher, A., 1999. Expert and lay mental models of ecosystems: inferences for risk communication. Risk 10, 45–64.
Lehmann, I., Mathey, J., Rossler, S., Brauer, 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. https://doi.org/10.1016/j.ecolind.2014.02.036.
Lindemann-Matthies, P., 2016. Beasts or beauties? Laypersons' perception of invasive alien plant species in Switzerland and attitudes towards their management. NeoBiota 29, 15–33.
Litschke, T., Kuttler, W., 2008. On the reduction of urban particle concentration by vegetation – a review. Meteorol. Z. 17 (3):229–240. https://doi.org/10.1127/0941-2948/2008/0284.
Lovett, G.M., Jones, C.G., Turner, M.G., Weathers, K.C. (Eds.), 2005. Ecosystem Function in Heterogeneous Landscapes. Springer, Berlin Heidelberg New York.
Ludwig, D., Meinig, H., 1991. Methode zur ökologischen Bewertung der Biotopfunktion von Biotoptypen. Büro Froelich und Sporbeck Landschafts- und Ortsplanung, Umweltplanung, Bochum, Germany.
Luederitz, C., Brink, E., Gralla, F., Hermelingmeier, V., Meyer, M., Niven, L., ... von Wehrden, H., 2015. A review of urban ecosystem services: six key challenges for future research. Ecosyst. Serv. 14:98–112. https://doi.org/10.1016/j.ecoser.2015.05.001 (Review).
Mace, G.M., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends Ecol. Evol. 27 (1):19–26. https://doi.org/10.1016/j.tree.2011.08.006.
Mahmoud, A.H.A., 2011. Analysis of the microclimatic and human comfort conditions in an urban park in hot and arid regions. Build. Environ. 46 (12), 2641–2656.
Mambretti, I., Lange, E., Schmid, W.A., 2005. Using visualization for the evaluation of safety and aesthetics conflicts in urban parks. Trends in Real-time Landscape Visualization and Participation. Herbert Wichmann Verlag, Heidelberg, pp. 282–290 (361 pp.).
Maras, I., Schmidt, T., Paas, B., Ziefle, M., Schneider, C., 2016. The impact of human-biometeorological factors on perceived thermal comfort in urban public places. Meteorol. Z. 25 (4):407–420. https://doi.org/10.1127/metz/2016/0705.
Meacham, M., Queiroz, C., Norström, A.V., Peterson, G.D., 2016. Social-ecological drivers of multiple ecosystem services: what variables explain patterns of ecosystem services across the Norrström drainage basin? Ecol. Soc. 21 (1):14. https://doi.org/10.5751/ES-08077-210114.
Morakinyo, T.E., Lam, Y.F., 2016a. Simulation study of dispersion and removal of particulate matter from traffic by road-side vegetation barrier. Environ. Sci. Pollut. Res. 23 (7):6709–6722. https://doi.org/10.1007/s11356-015-5839-y.
Morakinyo, T.E., Lam, Y.F., 2016b. Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort. Build. Environ. 103:262–275. https://doi.org/10.1016/j.buildenv.2016.04.025.
Mörtberg, U., Goldenberg, R., Kalantari, Z., Kordas, O., Deal, B., Balfors, B., Cvetkovic, V., 2017. Integrating ecosystem services in the assessment of urban energy trajectories–a study of the Stockholm Region. Energ Policy 100, 338–349.
Næss, P., 1995. Central dimensions in a sustainable urban development. Sustain. Dev. 3 (3), 120–129.
Nielsen, T.S., Hansen, K.B., 2007. Do green areas affect health? Results from a Danish survey on the use of green areas and health indicators. Health Place 13 (4):839–850. https://doi.org/10.1016/j.healthplace.2007.02.001.
Nielsen, A.B., van den Bosch, M., Maruthaveeran, S., van den Bosch, C.K., 2014. Species richness in urban parks and its drivers: a review of empirical evidence. Urban Ecosys. 17 (1):305–327. https://doi.org/10.1007/s11252-013-0316-1.
Niemela, J., Saarela, S.R., Soderman, T., Kopperoinen, L., Yli-Pelkonen, V., Vare, S., Kotze, D.J., 2010. Using the ecosystem services approach for better planning and conservation of urban green spaces: a Finland case study. Biodivers. Conserv. 19 (11): 3225–3243. https://doi.org/10.1007/s10531-010-9888-8.
Oke, T.R., 2009. Boundary Layer Climates (2nd ed., reprinted). Routledge, London.
O'Sullivan, O.S., Holt, A.R., Warren, P.H., Evans, K.L., 2017. Optimising UK urban road verge contributions to biodiversity and ecosystem services with cost-effective management. J. Environ. Manag. 191, 162–171.
Özgüner, H., 2011. Cultural differences in attitudes towards urban parks and green spaces. Landsc. Res. 36 (5), 599–620.
Pauleit, S., 2003. Perspectives on urban greenspace in Europe. Built Environ. 29 (2), 89–93.
Peters, K., Elands, B., Buijs, A., 2010. Social interactions in urban parks: stimulating social cohesion? Urban For. Urban Green. 9 (2), 93–100.
Richardson, E.A., Mitchell, R., 2010. Gender differences in relationships between urban green space and health in the United Kingdom. Soc. Sci. Med. 71 (3):568–575. https://doi.org/10.1016/j.socscimed.2010.04.015.

Sachsen, T., Ketzler, G., Knörchen, A., 2014. Past and future evolution of nighttime urban cooling by suburban cold air drainage in Aachen. Erde 144 (3–4):274–289. https://doi.org/10.12854/erde-144-19.
Sanesi, G., Chiarello, F., 2006. Residents and urban green spaces: the case of Bari. Urban For. Urban Green. 4 (3–4):125–134. https://doi.org/10.1016/j.ufug.2005.12.001.
Seinfeld, J.H., Pandis, S.N., 2006. Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. 2nd ed. J. Wiley, Hoboken, N.J.
Shackleton, C.M., Blair, A., 2013. Perceptions and use of public green space is influenced by its relative abundance in two small towns in South Africa. Landsc. Urban Plan. 113: 104–112. https://doi.org/10.1016/j.landurbplan.2013.01.011.
Shashua-Bar, L., Pearlmutter, D., Erell, E., 2011. The influence of trees and grass on outdoor thermal comfort in a hot-arid environment. Int. J. Climatol. 31 (10):1498–1506. https://doi.org/10.1002/joc.2177.
Shwartz, A., Cheval, H., Simon, L., Julliard, R., 2013. Virtual garden computer program for use in exploring the elements of biodiversity people want in cities. Conserv. Biol. 27 (4):876–886. https://doi.org/10.1111/cobi.12057.
Sillman, S., 2002. Chapter 12 the relation between ozone, NOx and hydrocarbons in urban and polluted rural environments. Developments in Environmental Science. Vol. 1. Elsevier :pp. 339–385 Retrieved from. http://linkinghub.elsevier.com/retrieve/pii/S1474817702800158.
Southon, G.E., Jorgensen, A., Dunnett, N., Hoyle, H., Evans, K.L., 2017. Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. Landsc. Urban Plan. 158, 105–118.
Stevenson, M., Thompson, J., de Sa, T.H., Ewing, R., Mohan, D., McClure, R., ... Woodcock, J., 2016. Land use, transport, and population health: estimating the health benefits of compact cities. Lancet 388 (10062):2925–2935. https://doi.org/10.1016/s0140-6736(16)30067-8.
Stone, B., Hess, J.J., Frumkin, H., 2010. Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? Environ. Health Perspect. 118 (10):1425–1428. https://doi.org/10.1289/ehp.0901879.
Sushinsky, J.R., Rhodes, J.R., Possingham, H.P., Gill, T.K., Fuller, R.A., 2013. How should we grow cities to minimize their biodiversity impacts? Glob. Chang. Biol. 19 (2): 401–410. https://doi.org/10.1111/gcb.12055.
Thompson, C.W., Aspinall, P., Montarzino, A., 2008. The childhood factor: adult visits to green places and the significance of childhood experience. Environ. Behav. 40 (1), 111–143.
Todorova, A., Asakawa, S., Aikoh, T., 2004. Preferences for and attitudes towards street flowers and trees in Sapporo, Japan. Landsc. Urban Plan. 69 (4):403–416. https://doi.org/10.1016/j.landurbplan.2003.11.001.
Van Herzele, A., Wiedemann, T., 2003. A monitoring tool for the provision of accessible and attractive urban green spaces. Landsc. Urban Plan. 63 (2), 109–126.
Voigt, A., Kabisch, N., Wurster, D., Haase, D., Breuste, J., 2014. Structural diversity: a multi-dimensional approach to assess recreational services in urban parks. Ambio 43 (4): 480–491. https://doi.org/10.1007/s13280-014-0508-9.
Wastian, L., Unterweger, P.A., Betz, O., 2016. Influence of the reduction of urban lawn mowing on wild bee diversity (Hymenoptera, Apoidea). J. Hymenopt. Res. 49: 51–63. https://doi.org/10.3897/jhr.49.7929.
Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A.G., Dias, B., ... Yach, D., 2015. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation-Lancet Commission on planetary health. Lancet 386 (10007): 1973–2028. https://doi.org/10.1016/s0140-6736(15)60901-1 (Review).
Wilker, J., Rusche, K., Rymsa-Fitschen, C., 2016. Improving participation in green infrastructure planning. Plan. Pract. Res. 31 (3), 229–249.
Wilson, M.A., Howarth, R.B., 2002. Discourse-based valuation of ecosystem services: establishing fair outcomes through group deliberation. Ecol. Econ. 41 (3), 431–443.
Zaunbrecher, B., Ziefle, M., 2016. Integrating acceptance-relevant factors into wind power planning. A discussion. Sustain. Cities Soc. 27:307–314. https://doi.org/10.1016/j.scs.2016.08.018.
Zölch, T., Maderspacher, J., Wamsler, C., Pauleit, S., 2016. Using green infrastructure for urban climate-proofing: an evaluation of heat mitigation measures at the micro-scale. Urban For. Urban Green. 20:305–316. https://doi.org/10.1016/j.ufug.2016.09.011.