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Analysing urban green space accessibility and quality: A GIS-based model as spatial decision support for urban ecosystem services in Brussels

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A B S T R A C T

With the majority of people living in cities, urban green spaces are the primary source of contact with nature. Access to ecosystem services provided by urban green spaces is increasingly perceived as an important factor for quality of life, and it is a key component of sustainable urban design and planning. This paper presents a novel GIS-based tool to evaluate accessibility to – and quality of – urban green spaces. To demonstrate the tool's applicability, it was implemented in Brussels. A series of indicators to evaluate the proximity to and quality of green spaces is proposed in the light of the analysis with the aim of supporting decision making and planning at the urban scale. The proximity and quality sub-models were parameterised through a comparative study of planning standards and through analysis of local preferences, acquired by means of a questionnaire. Applying the model to Brussels showed that approximately equally sized population groups have low, medium, and high access to green spaces. Concerning the proposed method for measuring green space quality, 62% of the population resides in urban blocks with access to green spaces with a lower than average quality score, which reveals a significant margin for improvement.

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1. Introduction

1.1. Premise

Green infrastructures have gained importance in planning and policymaking (Pulighe et al., 2016), thanks to the ecosystem services (ES) they provide for city dwellers (Tzoulas et al., 2007) and their potential for climate change mitigation and adaptation (Demuzere et al., 2014). Since the last decade of the 20th century, the ES concept has become increasingly important in the debate on sustainability and quality of life (Burkhard et al., 2010; Lappé, 2009). It is considered the missing link between ecosystems and human well-being (Neßhöver et al., 2007). In accordance with the Millennium Ecosystem Assessment (MEA) (2005) report, in this study urban green spaces (GSs) are considered providers of regulating and cultural ES, contributing to the quality of life of urban citizens. The presence of GS has a positive impact on air quality, climate, and the hydrological cycle in urban areas. GSs also provide recreational facilities for residents, offer a place of refuge from the busyness of daily life, and bring residents into contact with nature (Bennett et al., 2016; Reid, 2005; Sandifer et al., 2015).

In cities around the world, urban growth presents numerous challenges for the provision and maintenance of urban GSs and, consequently, also for human health and well-being (Tzoulas et al., 2007). Effects of current and predicted climate change exert additional stress on urban environments through the increased occurrence of heatwaves, droughts, flooding, and water supply problems (IPCC, 2007). These prospects challenge urban planners and policymakers to move beyond solely managing the urban landscape (Pulighe et al., 2016) – and to take up and incorporate the concepts of ecosystems functions, resilience, sustainability, biodiversity, and human well-being into the urban governance agenda and policies (FAO, 2011; Hansen et al., 2015).

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At the policy level, more attention is given to and action directed at the dependence of humans on nature and its ecosystems. However, knowledge about the link between green infrastructure and ES delivery, as well as its potential for urban planning and management, is still limited (Baró et al., 2015). Currently, nature development institutions, planning agencies, urban development agencies, infrastructure departments, and researchers, both internationally (Beatley, 2014) and in the context of Brussels (Loeckx et al., 2016), are calling for combining ES and ecology-driven approaches to achieve sustainable urban development. The Brussels Capital Region (BCR) had an expected population growth of 14,000 per annum over a population of 1,167,951 in 2015 (FOD Economie, 2013). This makes well-informed densification strategies a pressing issue, of which maintaining and improving accessibility and quality of public GSs is a crucial part. Furthermore, to successfully tackle major challenges (sustainability, climate change, social exclusion, economic deprivation, and uneven development) in the field of urban design and planning (Khan, 2010; Madanipour, 2006), an integrated ecosystems approach will be necessary (Khan et al., 2013).

The complexity of the current and future challenges urban areas are facing has led to the development of a diversity of tools and design criteria, especially at the local scale (Beatley, 2000). To arrive at – and support – apt policies and interventions for urban planning and design, reliable methods and means of analysis, scenario development, and assessment are needed. Through this research, we seek to contribute to the development of a robust methodological framework for assessing public GS provision and its ES, focusing on proximity to GSs as well as their perceived quality. This challenge is approached by means of data-driven geographical information system (GIS) modelling, resulting in a GIS-based spatial decision support tool for designers, planners, and policymakers. From existing spatial datasets or user-created scenarios, the tool generates both spatially explicit and general indicators for the availability and quality of GSs for urban residents. The underlying motivation for our research is (1) to arrive at a better understanding of the nature–human interaction for urban design and planning, and (2) to provide an objective basis for interdisciplinary discussion and collaboration on the topic of ES provided by urban GSs.

1.2. Functional levels

Since early modern urban planning, multiple standards and indicators have been developed to quantify access to and attractiveness of urban GSs. These include simple area-based indicators, e.g. open space area per person, as described by Richard Baumeister in 1876, or the open space area ratio (OSR), which is calculated by dividing open space area by the total floor area instead of by the number of people. In 1952, the Stockholm General Plan, inspired by the Regional Planning Association of America (RPAA) and much of Abercrombie's work (e.g. the 1944 Greater London Plan (Abercrombie, 1944)), prescribed a standard of 300 m as the maximum distance to playgrounds, following a questionnaire at Stockholm's kindergartens (Stockholms stadsplanekontor, 1952). This, together with RPAA's neighbourhood unit paradigm, is one of the early examples of mainstreaming the use of an 'accessibility-' or 'location'-based measure for public GS provision in urban planning.

During the 1960s and 1970s different kinds of GS descriptive measures were proposed to define open space standards. The National Recreation and Playground Association in the USA (Lancaster, 1983), the European Common Indicators in the EU (Cassatella and Peano, 2011; Tarzia, 2003), English Nature in the UK (Harrison et al., 1995), and the National Board of Housing Building and Planning in Sweden (Boverket, 1999) published guidelines on GS accessibility. Common among them has been the idea of relating distance to GS (e.g. 300 m) to the size of open space. The rationale behind this approach is that the size of a GS determines the range of functions or activities the GS is able to support. This is referred to as the GS's functional level, and residents will be prepared to cover longer distances to reach a larger GS, because of its improved offer in terms of amenities, potential uses, and benefits. Each functional level is thus linked to a particular size range and to the maximum distance people are willing to cover to get to a GS of that size. Functional level thus reflects attractiveness in terms of size and accessibility in terms of distance. This idea is supported by various empirical studies (e.g. Berggren-Bärring and Grahn, 1995; Crouch, 1994; Grahn, 1986).

GIS has made it relatively easy to work with standards in the literature related to the functional level concept. The question remains, however, whether these distance versus size standards are true to human experience. Few scientific studies have addressed this question (De Clercq et al., 2007; Ståhle, 2010; Van Herzele and Wiedemann, 2003). The findings in these studies indicate that a more thorough consideration of the concepts of attraction and accessibility is needed (Ståhle, 2010). Fundamental to the concept of functional levels is that their classification constitutes a nested hierarchy. The latter allows higher functional levels (related to larger spaces) to embed lower levels (related to smaller spaces). Size can provide only an indication of the functions a particular GS may potentially provide, and it does not necessarily correspond to the actual uses or benefits the GS supports. Therefore, in this paper we will refer to the concept of size-related functionality as theoretical functional level (TFL). Each TFL will be assumed to have a specific attraction radius (i.e. consensus of maximum travel distance). As indicated above, the naming of different TFLs thus usually corresponds to the typical scale of the area the GS is assumed to serve (e.g. neighbourhood scale).

1.3. Combining proximity and quality

Van Herzele and Wiedemann (2003) describe how Coeterier (2000) used Herzberg's two-factor theory (Herzberg et al., 1959) to explain how urban environments are perceived and used. Restrictions determine whether people will actually visit a particular urban environment. These are referred to as 'preconditions' for use. Distance has been found to be the most important precondition for use of GSs (e.g. Grahn, 1994). Once the preconditions are fulfilled, 'satisfiers' (in the case of GSs, qualities such as unity – forming a complete and harmonious whole – naturalness, and facilities) will determine how long users will be inclined to stay. Human–environment studies in different western countries have shown remarkably consistent cross-cultural universal patterns in people's preferred environments (Van Herzele, 2005). Visitors prefer parks combining many features (a diversity of natural and social features), which in turn encourage many activities. Moreover, there is a relation between the availability of different features and the frequency of visits. This makes the variety of features a goal in itself, either within one GS or within the different functional levels within reach of the residents (Berggren-Bärring and Grahn, 1995). Apart from investigating preconditions, namely GS proximity, the quality of GSs in relation to the inhabitants' needs (satisfiers) will be modelled and assessed in this research.

1.4. Approach

This paper presents a model to analyse and assess urban residents' access to public GSs. A proximity sub-model, based on the concept of TFL, is coupled with an existing GS quality model developed in earlier research (Stessens et al., submitted). This will make it possible to assess which TFL and which level of GS quality is within reach of each urban block and thus available to the residents. The proposed approach was applied to the BCR and may be used for scenario evaluation. Survey and questionnaire data were collected to parameterise the model and to compare TFL standards found in the literature with local preferences. The model output has been transformed into a set of spatial and non-spatial indicators that will be potentially useful for the assessment of scenarios addressing the most pressing issues related to the provision, accessibility, and quality of GS in the urban area.

2. Study area, material and methods

2.1. Study area description

The study area defined for this research is the territory of the BCR and its surroundings (Fig. 1, continuous line), corresponding to an area of 26 by 26 km. The study area includes the dense city centre, as well as lower density areas surrounding the centre. It also includes major natural entities in the landscape (e.g. vast forest areas). Two regions are included: the BCR (161 km^2), with an average population density of 7025 inhabitants per km^2 and a continuous built-up area spread over 19 communes; and part of the surrounding area of Flanders characterised by urban sprawl, with an average population density of 477 inhabitants per km^2 (calculated from spatial CENSUS data (FOD Economie, 2011)). To allow correct calculation of GS indicators on the edge of the study area, a buffer of 5 km was added in each direction to define the calculation area (Fig. 1, dashed line). The topography of the area is dominated by the valley of the Zenne river flowing from the undulating south – referred to as Middle Belgium – to the flat north – referred to as Low Belgium. Several small tributary valleys connect transversally, and they form the natural basis of a GS structure in less dense areas. There are several concentrations of very large GSs, such as the medieval Forêt de Soignes, which is situated on the divide of the Zenne valley and the Dijle valley, the royal domain (or gardens), which are not open to the public, and continuous stretches of agricultural and privately owned land.

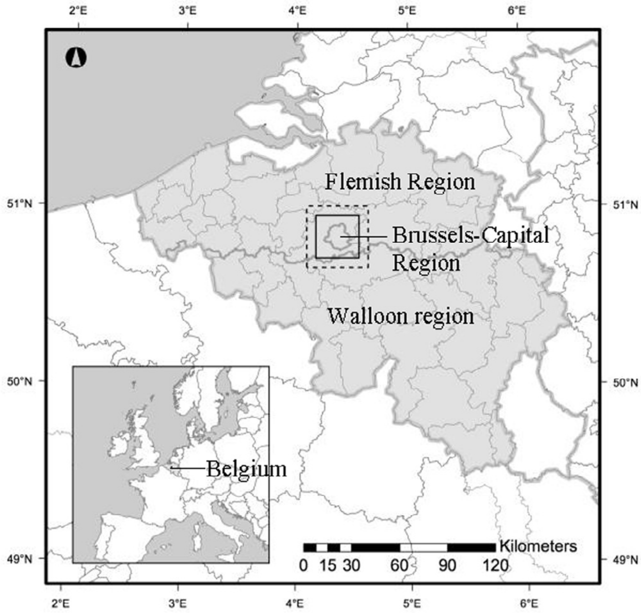

Fig. 1. Indication of the study area (continuous line) and calculation area of the model in order to avoid peripheral inaccuracies (dashed line). Belgium is marked in grey.

2.2. Overall model structure and input data

The model for calculating proximity has been developed in the ModelBuilder environment of ArcGIS for Desktop, which provides a visual programming language for geoprocessing workflows. The meta-structure of the model is shown in Fig. 2. The actual proximity calculation module processes three input maps: a map of urban blocks on which the final output (proximity and quality indicators) is also shown; a path raster image on which distances to GSs are calculated; and the GS layer, enriched with GS quality and sub-quality information. The last is produced for all GSs in the study area by a module for quality assessment that was developed in earlier research (Fig. 2). This module is described in more detail in Stessens et al. (submitted) and is summarised here in Tables 1 and 2. GS quality is described as a weighted linear combination of inherent (e.g. naturalness) and use-related sub-qualities

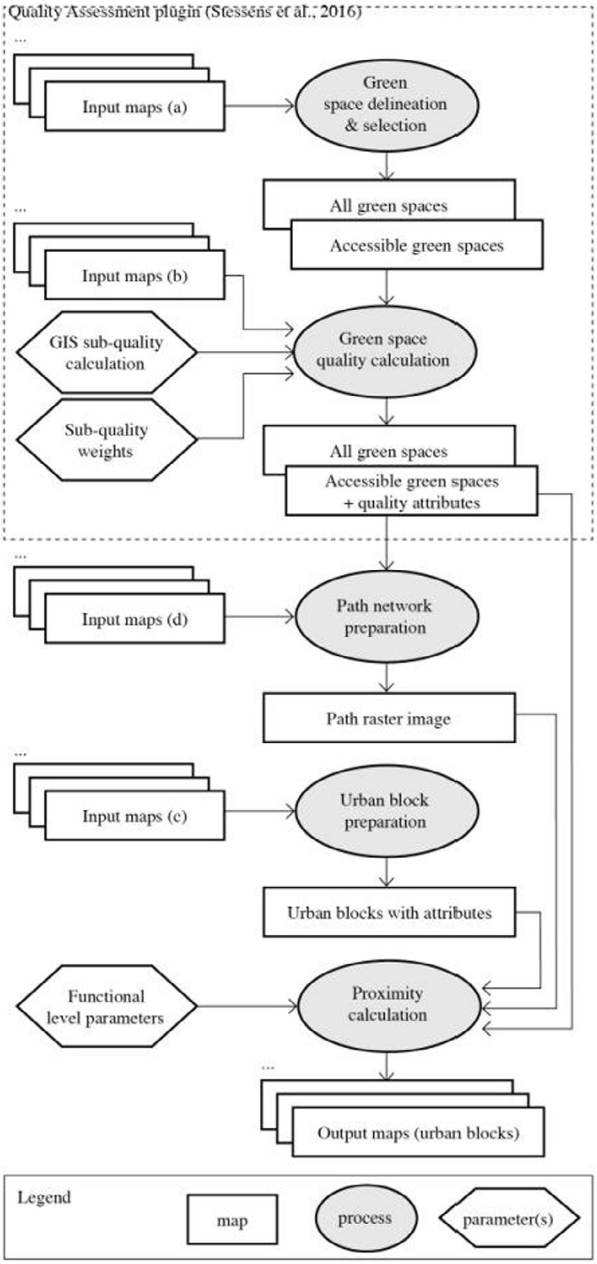

Fig. 2. Model structure (see Appendix 1).

Table 1
Weighting of sub-qualities in the calculation of overall quality.

Code	Sub-quality weights (Stessens et al., submitted)	
Inherent qualities (INH, data based)		
NAT_C	Naturalness and biodiversity	0.10
SPA_C	Spaciousness	0.16
QUI_C	Quietness	0.14
	Share of inherent qualities	*40%*
Use-related qualities (USE, questionnaire based, average of minimum 10 questionnaires per park)		
MNT_Q	Cleanliness and maintenance	0.31
FAC_Q	Facilities	0.20
SAF_Q	Feeling of safety	0.09
	Share of use-related qualities	*60%*

(e.g. feeling of safety) (Tables 1 and 2). The former can be inferred from publicly available GIS data; the latter need to be questioned on site. Therefore, in this study only the inherent qualities were taken into account, making up 40% of the overall quality, which explains why the maximum score for inherent quality is measured on a scale of 0–40. Weights for each sub-quality were obtained through multiple linear regression (MLR) modelling by fitting ratings that GS visitors gave to overall quality (dependent variable) for a sample of GSs, to ratings given to sub-qualities of these GSs (independent variable) (Stessens et al., submitted) (Table 1). The variables used to calculate sub-quality scores for each GS are documented in Table 2. To obtain sub-quality scores for naturalness, spaciousness, and quietness, a multi-criteria approach was used, involving multiple variables. For this study, the inherent quality of all GSs in the study area was calculated with this model, based on GIS data.

Path calculations in the proximity sub-model are based on road axis data (*UrbAdm_Sa* for Brussels and *GRBgis_Wbn* for Flanders). Since the road axis data have an attribute indicating the type (highway, double lane, street, path, etc.) and level (tunnel, street, viaduct) of each road, paths suited to walking and cycling could be easily selected from the dataset. Most trails through forests and fields are not part of these GIS layers. Therefore, in addition, a map of jogging tracks (generated from geo-location points uploaded by running apps for smartphones) was added to the path network. The selected GSs were integrated in the path network. Two additional scenario-specific input files can be specified when producing the final paths map: the paths to be removed in a certain scenario and the paths to be added.

GSs were delineated through selection and spatial overlay of existing GIS data (Stessens et al., submitted), listed in Appendix 1. Roads considered a barrier (of non-local character) were set to automatically divide GSs into parts. Urban blocks were used as the smallest spatial unit for calculating indicators. The benefit of using urban blocks are as follows: (1) indicators at the level of urban blocks can point to problems at scale levels smaller than the neighbourhood or statistical sector (i.e. the smallest unit for socio-economic statistics in Belgium); (2) the block level of detail allows for more effective design interventions; and (3) based on cadastral information, demographic data can be disaggregated from the resolution of statistical sectors to urban blocks, which in turn may be beneficial for defining interventions. In the BCR datasets urban blocks are clearly defined (*UrbMap_Bl*). For Flanders, urban blocks were defined by dissolving neighbouring parcels from the *Grootschalig Referentiebestand* (GRB) into urban block units.

2.3. Defining theoretical functional levels of urban green spaces

Apart from input maps, the model requires parameters describing the relation between GS size and attraction radius. This relation is directly linked to the concept of functional levels of GS (Van Herzele and Wiedemann, 2003). As explained in Section 1.2, the definition of TFLs is based on the idea that different sizes of GS provide different functions. A set of TFLs can be defined in the form of consecutive ranges of GS size, which are usually named in terms of the scale of the area that the GS serves, e.g. residential, neighbourhood, quarter, district, city, urban and metropolitan GS. In most standards, three to seven TFLs are distinguished (Boverket, 1999; Dienst Stedelijke Ontwikkeling en Beheer, 2001; Harrison et al., 1995; Lancaster, 1983; Mayor of London, 2008; Ståhle, 2002). A maximum attraction distance characterises each TFL. The criteria used in this study for defining different TFLs are based on an analysis of international standards found in the literature and used in practice (Table 3).

At first sight, the international literature on threshold values for area and distance used (in Table 3: (a) (Harrison et al., 1995); (b) (Mayor of London, 2008); (c) (Lancaster, 1983); (d) Dienst Stedelijke Ontwikkeling en Beheer, 2001; (e) (Boverket, 1999); (f) (Ståhle, 2002); (g) Van Herzele (2005)) does not seem to show a clear consensus. Based on the definition of the various standards (Table 3), the correlation between GS area (*A*) and maximum distance (*d*) was analysed for each standard over *n* functional levels

Table 2
Parameterisation of GIS- and survey-informed sub-qualities.

Code	Sub-quality equations (Stessens et al., submitted)
Inherent qualities (scale = 100)	
QUAL	=INH + USE
where:	
INH	$= 0.10.NAT_C + 0.16.SPA_C + 0.14.QUI_C$
USE	$= 0.31.MNT_Q + 0.20.FAC_Q + 0.09.SAF_Q$
where:	
NAT_C	$= a + b.f_{BIO} + c.f_{TRE} + d.f_{GRE} + e.f_{WAT} + f.f_{BIO}.f_{TRE} + g.f_{BIO}.f_{WAT} + h.A + i.R_{inscr}$
SPA_C	$= j + k.A + l.f_{TRE} + m.A.f_{TRE} + n.R_{inscr}.f_{TRE}$
QUI_C	$= o + p.NOI_{avg} + q.A + r.R_{inscr}$
MNT_Q	Average of min. 10 questionnaires/park
FAC_Q	Average of min. 10 questionnaires/park
SAF_Q	Average of min. 10 questionnaires/park
where:	
f_{BIO}	Fraction of biologically valuable zones and/or composed zones with presence of biologically valuable elements
f_{GRE}	Fraction of land covered by vegetation
f_{TRE}	Fraction of land covered by dense vegetation or tree canopies
f_{WAT}	Fraction of land occupied by water
NOI_{avg}	GS average of the combined simulated sound pressure level of air, rail and road traffic

Table 3
Functional levels of internationally used green space standards. For each standard minimum size *(ha)* and maximum attraction distance *(m)* corresponding with each functional level are indicated.

Standard's name	Standard's minimum size, *A (ha)* for different TFLs							Standard's max. dist. *d (m)*
Functional level name	Residential	Play	Neighbour-hood	Quarter	District	City	Metropolitan	
English Nature – ANGST[a]								
Natural green space			2					300
Natural green space					20			2000
Natural green space						100		5000
Natural green space							500	5000
Greater London Authority[b]								
Small open spaces		0.4						400
Local parks and open spaces			2					400
District parks					20			1200
Metropolitan parks						60		3200
Regional parks							400	3200
US National Recreation Association[c]								
Neighbourhood park		0.2						800
Playfield				8				1600
Community park					10			3200
Major park						40		2350
Reservation							400	–
US Local Planning Administration								
Playground		1.2						400
Neighbourhood park			2					800
Playfield				7				800
Community park					8			2400
Major park						40		3525
Reservation							200	4700
Eindhoven GS Proximity Standard[d]								
Local parks			2					400
Neighbourhood park				4.25				800
District park					14			1600
City park						135		3200
National open space guidelines[e]								
Pocket parks	0.01							50
Local parks		0.3						200
District parks					10			800
Nature areas							1000	–
Stockholm municipal open space guidelines[f]								
Local parks			0.5					200
District parks				5				500
Nature areas						50		1000
Van Herzele[g]								
Residential green	0.1							150
Neighbourhood green			1					400
Quarter green				5				800
District green					10			1600
City green						60		3200
Urban or metropolitan forest							200	5000

$(r^2(A_i, d_i)\text{for} i = 1 \rightarrow n)$, and for the base 10 logarithm of the standards' values $(r^2(log_{10}(A_i), log_{10}(d_i))\text{for} i = 1 \rightarrow n)$. Correlations were found to be higher on the logarithmic than on the linear scale (Table 4). Therefore, to find out if the TFL definitions used in different standards are comparable, the relation between the minimum size and the maximum distance for different standards was described as a log-transformed linear model: $log_{10}d = a.log_{10}A + b$, or: $d = 10^{(a.log_{10}(A)+b)}$, subsequently referred to as $d(A)$. Eight sets of distance–size (d_i, A_i) tuples representing 36 data points were taken from the different standards (Table 3). The size–distance relationship obtained from the literature was used to calculate maximum distance (d_i) for the different TFL sizes (A_i) applied in this study.

Table 4
Correlation of distance-area values in international green space proximity standards.

Distance-area tuples belonging to:	Linear correlation r^2	Log correlation r^2
English Nature – ANGST[a]	0.53	0.89
Greater London Authority[b]	0.49	0.89
US National Recreation Association[c]	0.19	0.75
US Local Planning Administration	0.69	0.84
Eindhoven GS Proximity Standard[d]	0.89	0.94
National open space guidelines[e]	0.97	1.00
Stockholm municipal open space guidelines[f]	0.91	0.99
Van Herzele[g]	0.84	0.99
All standards combined	**0.48**	**0.80**

To compare internationally applied standards with local references in the BCR, personal preferences for maximum travel time to neighbourhood GS, city GS and metropolitan GS were acquired through a questionnaire. During the summer of 2015 and 2016, a survey in the form of online and on-site questionnaires on GS features, quality preferences, proximity preferences, and perceived quality of GSs were carried out in three languages (English, French, and Dutch). In total, 122 visitors across 56 public GSs in the study area gave their opinion on maximum travel time. The majority of this feedback was received on site, and online participation was limited. As the respondents had to indicate their age, the sample could be verified for representativeness in relation to the actual demography of the BCR. Reported maximum travel times were converted into distance, based on average travel speed using the most suitable mode of transport: walking for neighbourhood GS, and bicycle for city and metropolitan GS. The log-transformed relationship between distance and size in the results of the survey was also investigated.

After deducing the relation $d(A)$ between minimum size and maximum distance (either standard based or survey based), thresholds could be determined for A_i to define the TFLs $((A_1, d_1), \ldots, (A_n, d_n))$. Two options were considered for defining the minimum GS size (Table 5): (i) use of locally defined GS sizes as proposed by Van Herzele and Wiedemann (2003) and promoted in several Belgian studies; and (ii) use of average GS sizes based on the selection of international standards. Similarly, two options were considered for defining the maximum distance: (iii) $d(A_i)$, based on the size–distance relation derived from literature; or (iv) $d(A_i)$, based on the relation derived from the questionnaires. Ultimately two ways of defining TFLs were deemed relevant: A_1, A_2, …, A_n, as determined by Van Herzele and Wiedemann (2003), with $d(A_i)$ based on the questionnaire averages; and A_1, A_2, …, A_n, as determined by literature averages, with $d(A_i)$ based on the literature. The former option is a local and pragmatic citizen-based approach, while the latter is a literature-based approach.

2.4. Measuring proximity and proximity–quality coupling

The GIS-based proximity calculation involves three data layers: urban blocks as destinations, path network data, and selected GSs as origins. GSs were chosen as origins to save computation time. The shortest distance from a defined point in space to any other point was calculated by means of the ArcGIS CostDist function on a raster image that defines all actual walking and cycling (soft mobility) trajectories. The proximity indicators that we chose to work with in this study indicate whether or not an urban block is within reach of a specific TFL of GSs, as well as the number of different TFLs of GSs within reach of each block. The proximity and quality modelling were then coupled to calculate the quality of GSs within reach of each urban block.

GSs with the same TFL and quality (rounded to the nearest integer value) were selected and the cost-distance tool was run for each TFL/quality combination. Then, for each urban block, distance values along the block's perimeter were collected and averaged to characterise the distance between the urban block and the relevant GSs. The urban blocks within acceptable distance of the selected GSs received the quality value for that run. This value was then compared with quality scores that had been obtained in previous TFL/quality iterations for that specific TFL, in order to keep the highest value, resulting in a list of quality values per TFL for each urban block. As most experts and users confirmed that residents will be inclined to visit the GS with the highest quality that is within an acceptable distance, it is assumed that, to depict GS quality (per TFL), as it will be perceived by a resident, it suffices to consider the highest quality GS that is within reach. It should be mentioned that, because of the hierarchical character of TFL definition, GSs of a certain TFL automatically form part of GSs of all lower levels, as they are assumed to provide lower level functions as well. For example, the Forêt de Soignes (metropolitan GS, over 4400 ha) is also part of the set of GSs providing GS at the neighbourhood level for residents living nearby. The model allows for selection of the quality attribute that will be assigned to the urban blocks. The default is 'inherent quality'; however, one may also select sub-qualities or characteristics such as 'presence of water in the GS' for the proximity–quality calculation. Each sub-quality is expressed on a scale from 0 to 100. The inherent quality, being a sum of a selection of sub-qualities, is expressed on a scale from 0 to 40. In the current implementation of the model, overall quality (inherent quality + use-related quality) cannot be documented, as so far not all public GSs have been surveyed to quantify their use-related quality. Once this has been accomplished, the tool will be able to incorporate both quality aspects in the calculation.

Table 5
Four calibration options for defining and/or validating distance–size relationships for different functional levels.

Min.green space size	Max. distance Function $d(A_i)$ from literature (iii)	Function $d(A_i)$ from questionnaire average (iv)
Van Herzele and Wiedemann (2003) (i)	(a)	(b)
Literature average (ii)	(c)	(d)

2.5. Indicators

To facilitate decision making, maps of landscape functions should (besides visualising the presence of a particular landscape function) also show the spatial heterogeneity in the quantity and quality of services provided (Meyer and Grabaum, 2008; Troy and Wilson, 2006). The multiple level proximity assessment allows the calculation of a range of potentially useful indicators (Table 6). The spatial outcome of the model indicates: (1) which urban blocks are within the catchment area of GSs of a certain TFL; (2) the number of different TFLs within reach of an urban block; (3) relative quality (Q_{rel}), which is the average quality obtained over all TFLs within reach of an urban block (taking into account the highest quality per TFL in case multiple GSs are within reach); (4) absolute quality (Q_{abs}), which is a similar average, in which TFLs that are not within reach are taken into account with a quality value of zero. The last two are different in the sense that (4) also takes account of a possible lack of variety of TFLs within reach and not merely

Table 6
List of indicators utilised in the multiple level proximity and quality assessment.

No.	Indicator	Type
1	Urban blocks within reach of residential green	Spatial
2	Population within reach of residential green	Non-spatial
3	Urban blocks within reach of play green	Spatial
4	Population within reach of play green	Non-spatial
5	Urban blocks within reach of neighbourhood green	Spatial
6	Population within reach of neighbourhood green	Non-spatial
7	Urban blocks within reach of quarter green	Spatial
8	Population within reach of quarter green	Non-spatial
9	Urban blocks within reach of district green	Spatial
10	Population within reach of district green	Non-spatial
11	Urban blocks within reach of city green	Spatial
12	Population within reach of city green	Non-spatial
13	Urban blocks within reach of metropolitan green	Spatial
14	Population within reach of metropolitan green	Non-spatial
15	Population within reach of less than three TFLs	Non-spatial
16	Number of TFLs within reach of an urban block	Spatial
17	Average of the highest green space quality within reach across TFLs	Spatial
18	Average of the highest GS quality within reach across TFLs, including TFLs not within reach as having zero quality	Spatial

a lack of quality. In addition, non-spatial indicators can be produced by overlaying maps of TFL proximity with demographic data (e.g. population share within reach of a particular TFL, population share with less than three TFLs within reach, etc.).

3. Results

3.1. Theoretical functional levels

Minimum GS area (*A*) and maximum distance (*d*) for different TFLs, as defined in different standards, show a strong relation on a logarithmic scale. The size–distance correlation for each individual standard, based on the TFLs defined, has an r^2 value between 0.75 and 0.99 (Table 4), and the point cloud of size–distance pairs for all standards combined has an r^2 value of 0.80. The correlation between log *A* and log *d* can thus be considered very high. Therefore, a log-transformed linear model was used to describe $d(A)$, specified as $\log_{10}d = a.\log_{10}A + b$, or $d = 10^{(a.\log_{10}(A)+b)}$, where, based on international standards, coefficient values $a = 0.419; b = 0.985$ ($r^2 = 0.80$) were obtained (Fig. 3).

Table 7 illustrates average maximum travel distance thresholds for neighbourhood green, city green and metropolitan green obtained from the questionnaire by converting travel time by foot (neighbourhood green) or by bike (city green, metropolitan green) to corresponding distances. The distance residents are willing to cover versus GS size shows a strong log-linear relationship with coefficients $a = 0.459, b = 1.080$ ($r^2 = 1.00$) (Fig. 3). As the plot shows, BCR residents tend to be somewhat less demanding with respect to GS proximity than the specifications of the international standards. For adults (18+), including elderly, the sample proved representative, as the maximum relative error, i.e. the difference between sample share and population share, divided by the population share for the BCR, for each age group, is 11.4%. However, children appear to be underrepresented in the sample. When comparing the responses of parents with children less than 12 years old with the responses of the rest of the population, young parents showed a preference for shorter (time) distances of up to −20% compared with the rest of the population. These observations may partly explain the differences between (time) distance preferences observed locally and distance threshold values used in internationally published standards, which are most often geared towards children and the elderly. For this study, it was ultimately decided to use the more demanding international standards-based size–distance relation as a basis for the modelling. Table 8 shows the average sizes of different TFLs obtained from international standards, as well as the corresponding distance thresholds derived through log-linear modelling that were used in this study.

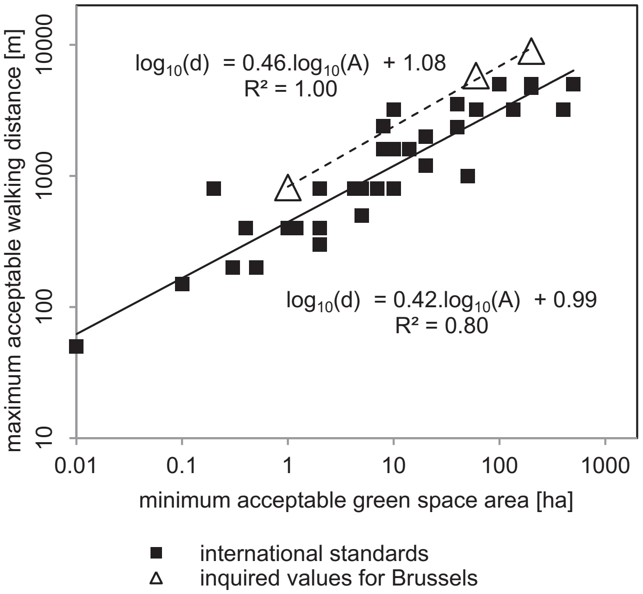

Fig. 3. Log-transformed linear model of maximum distance versus green space area for international standards for green space proximity and questionnaire results.

Table 7
Maximum travel distance to different functional levels of green space, derived from inquired maximum travel time (on-site and online questionnaire).

TFL	Size (ha)	Max. travel time (min)	Speed (km/h)	Max. travel distance (m)
Neighbourhood green space	1	10	4.7	815
City green space	60	25	14	5820
Metropolitan green space	200	38	14	8951

Table 8
Literature-based theoretical functional levels (TFLs) with parameter values used for the proximity modelling. Rounded values in brackets. The TFL names correspond to the type of area they serve (see: Section 2.3).

TFL	Min. surface (ha) park or green space	Max. distance from home (m)
Residential green	0.06 (0.1)	136 (150)
Play green	0.52 (0.5)	348 (350)
Neighbourhood green	1.8 (2)	585 (600)
Quarter green	5.9 (6)	958 (1000)
District green	13 (15)	1345 (1400)
City green	69 (70)	2697 (2700)
Metropolitan green	450 (450)	5903 (5900)

3.2. Proximity analysis and proximity–quality coupling

The proximity analysis for the study area, using the parameters based on international standards, shows that there is a lack of GS proximity for the lowest and highest TFLs: residential, play, city, and metropolitan GSs all reach less than 50% of the inhabitants of the BCR within an acceptable distance (Table 9). The number of different TFLs of GSs that are in reach of each inhabitant shows the diversity of the GSs provided. Four per cent of the inhabitants of the study area have no GS within reach and only 10% has access to all TFLs. The division is as follows: 21% has zero to two TFLs within reach, 29% has three to four TFLs within reach, and 50% has five to seven TFLs within reach (Table 10). The first group can be considered high priority for design and policy interventions. Concerning absolute inherent GS quality (Q_{abs}), the model output shows that 61% of the population is located in urban blocks with a score of less than 20 (50% of the maximum score) (Table 11),

Table 9
Population shares with access to the different theoretical functional levels (TFLs).

TFL	Share of population served (%)
Residential green	48
Play green	47
Neighbourhood green	60
Quarter green	68
District green	70
City green	46
Metropolitan green	32

Table 10
Population shares with respect to combined proximity of theoretical functional levels (TFLs).

Number of TFLs within reach	Population share (%)	Population share (%)
0	4	21
1	7	
2	10	
3	13	29
4	16	
5	23	50
6	17	
7	10	

Table 11
Population shares with respect to absolute inherent quality.

Range of absolute inherent quality of green space (Q_{abs})	Population share (%)	Population share (%)
[0:4]	4	61
[4:8]	7	
[8:12]	10	
[12:16]	15	
[16:20]	20	
[20:24]	16	39
[24:28]	10	
[28:32]	8	
[32:36]	4	
[36:40]	1	

which reveals a significant margin for improvement. The actual share of GS for the BCR is 19% (accessible GS area divided by total study area). However, overall its population does not have optimal access to GS. The lack of GS proximity is not the result of a lack of urban GS, but it reveals a strong spatial inequality in the provision of GS.

In terms of spatial distribution (Fig. 4A), there is a lack of residential GS in the de-industrialised and poor canal zone, while neighbourhood GS is almost non-existent along the southern and western part of the inner ring road (Fig. 4C). The same pattern is observed for quarter GS, with a clear lack of quarter GS in the Matongé area, the area north of the Central Business District (CBD) Manhattan and around the international airport and the city of Evere (Fig. 4D). District GS is well provided for along the regional border and the outer ring road (R0), but it is out of reach of inhabitants of the central parts of the city, including the CBD and the European district (Fig. 4E). While city GS is accessible from various, mainly peripheral, locations in the north and south-south-eastern part of the city (Fig. 4F), metropolitan GS serves the southern part of the BCR only through the Forêt de Soignes (right) and Hallerbos (left) (Fig. 4G). It should be noted that the vast Forêt de Soignes, which could be considered a single GS, is in our analysis fragmented into different smaller areas because the GS quality calculation module interprets a double lane throughway as a fragmenting element (Fig. 5A). To the north, the sole potential for metropolitan GS would be the opening of the royal domain to the public, an option that is currently under discussion. Other options would require active land acquisition and GS development. The combined proximity map, the total number of TFLs within reach (Fig. 5B), shows that the eastern part of Sint-Jans Molenbeek (a), as well as parts of the Kuregem Bara, Anneessens (b), and Dansaert (c) neighbourhoods and the area around Louiza and Matongé (d), lack public GSs within their reach. In the periphery, especially South-Grimbergen (e) and Diegem (f), there is a similar lack. High-proximity GS is found along tributary valleys of the Zenne canal valley, e.g. the Molenbeek valley (g-g’) and the Woluwe valley (h-h′). In general, it can be concluded that the combined indicator for GS proximity increases away from the central canal area and towards the BCR–Flanders border. In the periphery, GS proximity varies depending on radial direction. The absolute inherent quality (Q_{abs}) of GS (Fig.5C) roughly reflects the same pattern, but it enriches it with information on the naturalness, spaciousness, and quietness of GS within reach.

4. Discussion

In this study, a GIS tool has been developed that translates the output of a previously developed GS quality assessment framework (Stessens et al., submitted) into useful, proximity-based indicators on GS provision for the inhabitants of the BCR. GS proximity in this study was modelled through GIS-based calculation of shortest path trajectories between urban blocks and GSs and the definition of thresholds for the maximum distance one is willing to cover to reach a GS in accordance with the well-known concept of functional levels (see: Section 1.2). The proximity analysis builds further upon the methodology proposed by Van Herzele and Wiedemann (2003) and expands it by increasing the detail of trajectory analysis and combining proximity analysis with GIS-driven GS quality assessment as proposed by Stessens et al. (submitted). This allows the reporting of (1) the provision of public GSs, and (2) their quality and sub-qualities for each urban block. Due to subdivision into different aspects of quality, each of the sub-qualities addressed (naturalness and biodiversity, spaciousness, quietness) can be separately documented and can be used to evaluate alternative design scenarios.

By coupling a multi-level proximity assessment model with a quality assessment model, a clear overview of inequalities in the quality and accessibility of GS is obtained, both quantitatively (Tables 9–11) and spatially (Figs. 4 and 5). The maps produced thus facilitate well-informed design and policy interventions not only on GS, the path network connecting residents and GS, but also on densification and general planning strategies. The combined quality–proximity indicator (Q_{abs}) can be used to point out potential GS development areas. Moreover, when overlaid with the public transport network service area, it might also be used for indicating potential sites for densification that have excellent public GS provision. All GIS input in the model can be used to test different design and policy scenarios. The model developed might thus be used by consultants or city and regional officials of GS and planning departments to analyse the existing condition of GSs, to indicate the most pressing interventions, and to test the effect of scenarios for GS (quality) development. Being data driven and objective, the tool can encourage and support interdisciplinary collaboration (Matthies et al., 2007) between nature development institutions, planning agencies, urban development agencies, infrastructure departments, urban designers, and researchers.

In terms of proximity, the standards in the literature for the maximum distance people are willing to cover to reach GSs of a certain size were shown to be more demanding than inquired TFL threshold distances (Fig. 3). Two factors may explain this difference. One is that children were underrepresented in the questionnaires (Stessens et al., submitted), whereas the literature standards take into account all ages and degrees of mobility. A second explanation could be the very diverse cultures in Europe’s capital (Brussels) and its large socio-economic split in comparison with other western cities. This may have led to different results compared with standards that are based on a typical western public space culture. Certain groups have very different values and attitudes towards GSs (Swanwick, 2009). The model could be further improved by collecting more detailed information on the actual use of public GSs in the BCR and by substituting literature-based time–distance thresholds for GS accessibility for

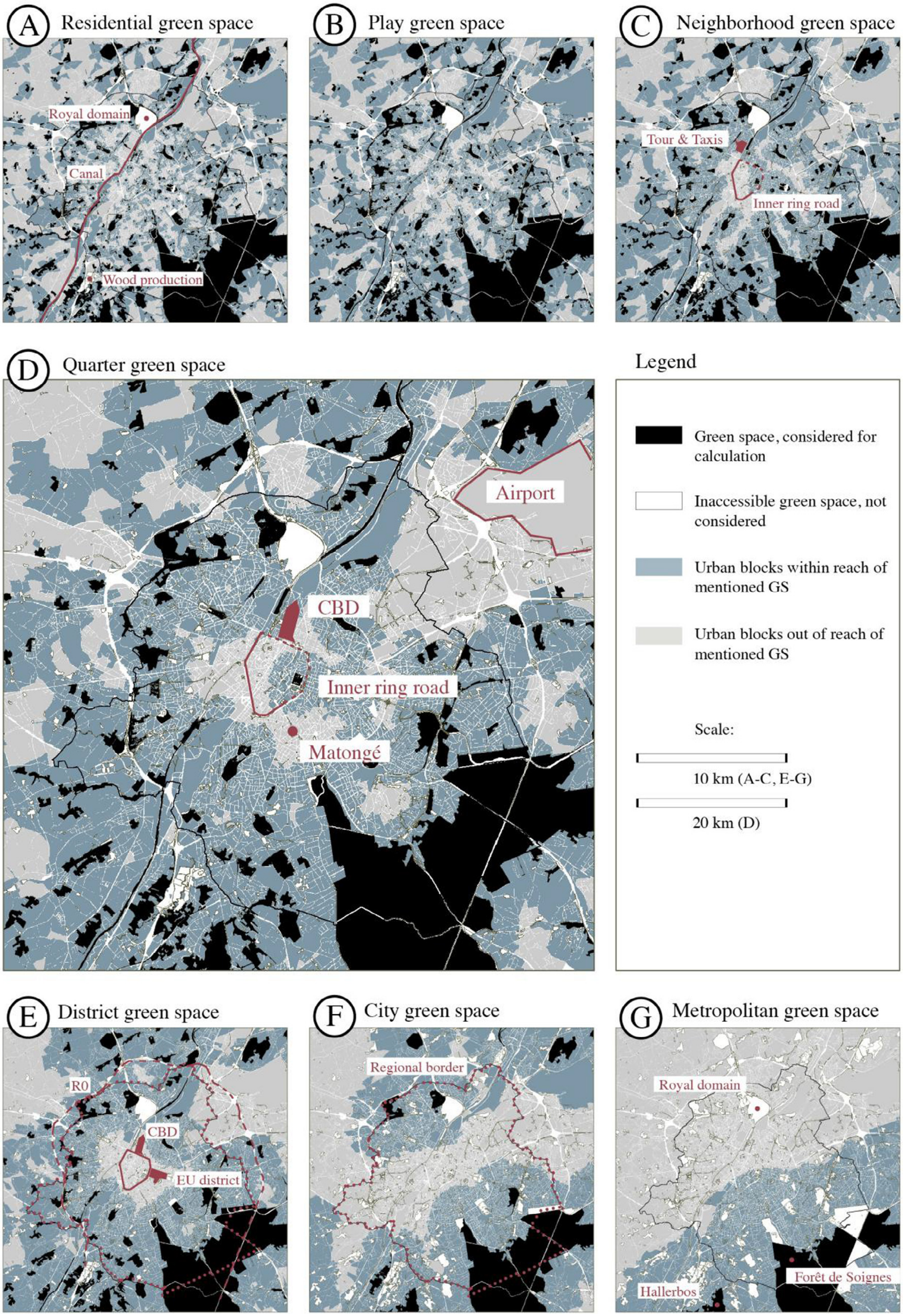

Fig. 4. Green space area of influence per theoretical functional level. The white areas are not publicly accessible.

user-based models of GS proximity. This would require more extensive surveys, as well as the incorporation of more detailed data on transport facilities in the BCR, including public transport such as the metro and the rail express network. The results would enable a more realistic estimate of travel time using different transport modes.

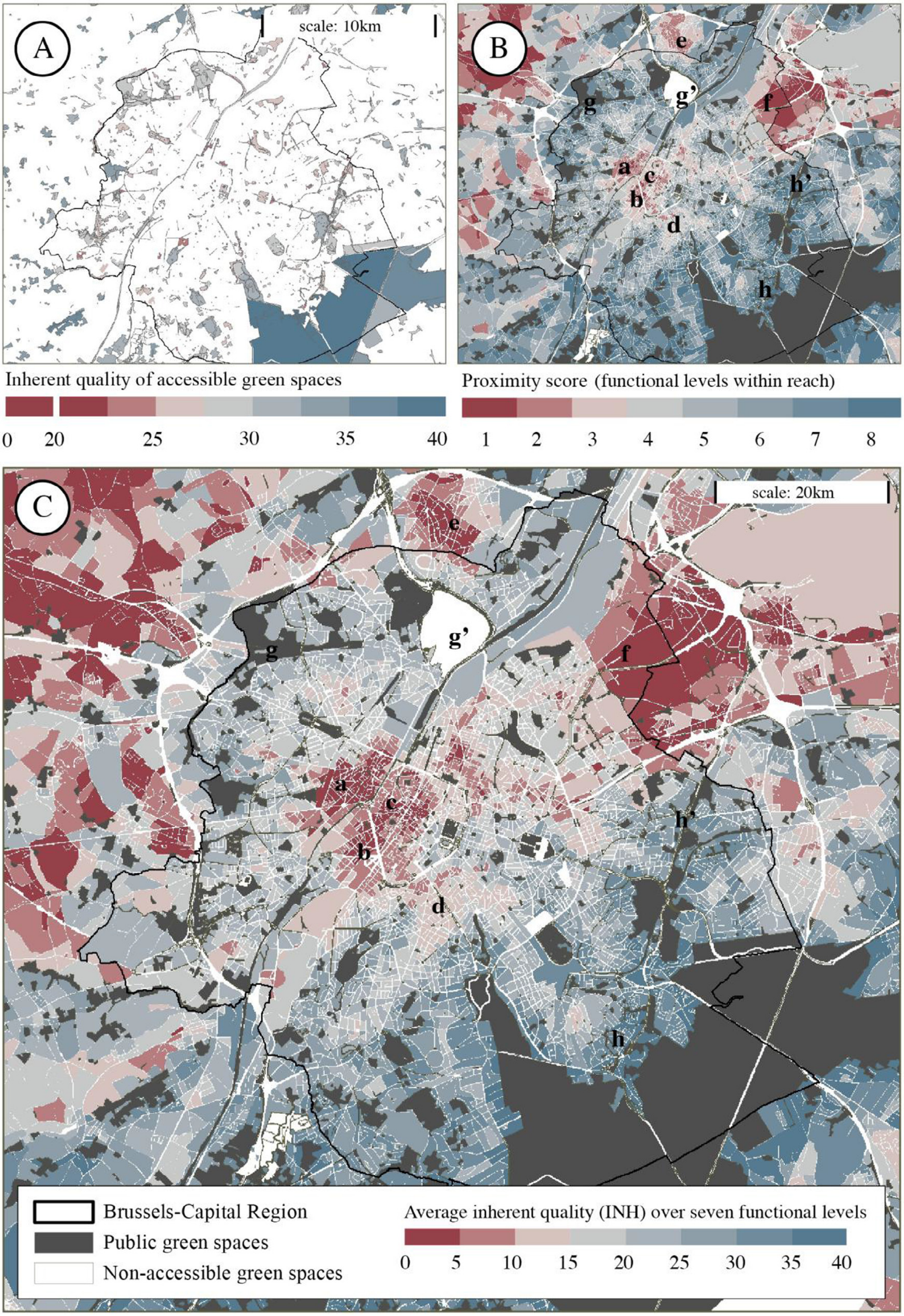

Fig. 5. Three indicators as model output: inherent green space quality (naturalness and biodiversity, quietness, and spaciousness); total number of different theoretical functional levels within reach of each urban block; and average inherent quality of green spaces within reach of each urban block.

The proximity analysis applied to the study area also shows that lack of proximity to GS is most prevalent in the lowest and highest TFLs: residential, play, city, and metropolitan GS all reach less than 50% of inhabitants (Table 9). While studies are under way to address the question of inter-regional metropolitan landscapes (Loeckx et al., 2016), the smallest fractions – residential and play

GS – are a communal matter that needs to be addressed urgently. To this end, ongoing efforts such as the 'Contrats de Quartier Durables' (Sustainable Neighbourhood Contracts) need to be continued. Due to its scale, residential GS development goes hand in hand with public space design, local street layout, and mobility strategies, and therefore it requires interdisciplinary collaboration.

Future research should involve exploring the potential of the indicators generated for urban design and policymaking through design research or design charettes and scenario-based simulation workshops. A similar spatial representation of regulating and provisioning ES could mobilise this design research to its fullest potential. Further research on the relation between socio-economic data and GS proximity and quality is also considered highly relevant for assessing the influence of inequality.

5. Conclusions

The objective of this study was to enable GIS data to be used as an urban green space evaluation and design tool that matches the user's perspective. It presents a new approach for green space analysis in an urbanised environment to map and allow design-based optimisation of the perceived quality and proximity of green spaces as cultural ecosystem services. The approach entails a GIS driven assessment of green space quality and proximity, and unifies these in a spatially explicit model. Green space proximity was modelled through GIS-based calculation of shortest path trajectories between urban blocks and green spaces. In the proximity calculation, use was made of the concept of functional levels, by defining thresholds for the maximum distance people are willing to travel to visit a green space of a certain size. Analysis of functional level definitions described in the international literature, as well as field work done in the Brussels study area showed that a log-transformed linear model is particularly effective for describing the relationship between green space size and maximum travel distance. Based on this relationship, a multi-level modelling approach was proposed for assessing green space proximity at the level of urban blocks.

Combining green space quality assessment with multi-level proximity modeling allowed to objectively assess the current state of green space provision in the Brussels Capital Region. The research demonstrated that:

- Brussels shows a clear concentric pattern of low proximity and quality in the central parts of the region, and high proximity and quality in the periphery. This makes that nearly two third of the population has no access to high quality green spaces, leaving a great margin for improvement.
- The lack of green space proximity is the strongest for the lowest and highest functional levels (residential green and metropolitan green), with their respective proximity maps suggesting locations for possible future green space development. While residential green space development is a question of public space reorganization and housing (and city block) typologies, development of metropolitan green is a complex and multidisciplinary challenge, for which the green space should be considered as a multifunctional green infrastructure.
- Currently, two tributary valleys (Molenbeek, Woluwe) of the Zenne valley cutting through Brussels offer both high proximity and quality of green spaces. A possible strategy could be to further develop the blue and green network structure in the remaining tributary valleys. However, problem areas call for more innovative strategies, as these are mostly situated relatively far from the current blue and green network crossing Brussels

By mapping the zones of influence of green spaces, their qualities, and travel trajectories to these spaces, and relating these to the urban fabric and its population, a tool has been developed for not only the monitoring of urban green ecosystem services. It can also be used for urban design, analysis of policy measures, and by extension, for design research and scenario development. The produced maps allow for well-informed design and policy interventions on green spaces, and on the path network connecting residents to these spaces. The modelling may also support densification and general planning strategies, as densification can be partially based on the indication of areas that provide their residents with sufficient provision of cultural ecosystem services. It is expected that the results of this research will contribute to the scientific basis for design research on urban green space provision and sustainable urban development planning and policymaking.

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Appendix A

Appendix 1.

Appendix 1
GIS input maps (all are in vector format, except for (*), which are in raster format).

TYPE	Name	Source	Date	Coverage	Purpose	Attribute based selection
Natural reserves	Natres	AGIV	2002	Flanders	a, b	CLASS = 400 OR 500 OR 800 (water, forest, parcelled forest)
	Natural_reserve	IBGE	9999	Brussels	a, b	–
Forests	Bos	AGIV	2000	Flanders	a	–
	UrbMap_GB_F	URBIS	2013	Brussels	a	–
Habitat zones	Habrl	AGIV	2008	Flanders	a, b	–
	Natura2000_station	IBGE	9999	Brussels	a, b	–
Parks	LandUse_lam72 (NSN)	AGIV	2014	Flanders	a	FEAT_TYPE = PARK (CITY/COUNTY) OR PARK (STATE)
	Urbmap_GB_B	URBIS	2013	Brussels	a	–

Appendix 1 (*continued*)

TYPE	Name	Source	Date	Coverage	Purpose	Attribute based selection
Water bodies	Wtz20001R500	AGIV	2015	Flanders	a	–
	UrbMap_WB_0	URBIS	2013	Brussels	a	–
Biologically valuable	BWK2	AGIV	2010	Full	a, b	–
Protected landscapes	Bslastdo	AGIV	2001	Full	a, b	OBJTYPE = LAND
Additional (roadside green)	UrbMap_GB_A	URBIS	2013	Brussels	a	–
Noise maps	geluidscontouren_spoorwegen_Lden	LNE	2011	Flanders	b	–
	geluidscontouren_wegen_alles_Lden	LNE	2011	Flanders	b	–
	Geluidskaart_5m*	IBGE	9999	Brussels	b	–
Land cover	vegmap* (water, bare, low veg., dense vegetation)	(Van de Voorde et al., 2010)	2010	Full	b	–
Composed green space delineation	GreenSpace	comp.	–	Full	b	–
Urban blocks	UrbMap_Bl	URBIS	2013	Brussels	c	–
Parcels	GRBgis Adp	AGIV	2015	Flanders	c	–
Road axes	UrbAdm_Sa	URBIS	2013	Brussels	d	–
	Wvb20001R500	AGIV	2015	Flanders	d	MORF ≠ 101, 107, 108, 111, 116
Inaccessible roads (axes)	UrbAdm_Sa_NoWalk	Authors	2016	Brussels	d	(manual selection)
Running tracks	running_tracks	Strava Labs	2015	full	d	–
Planned paths	planned_path	Authors	2016	full	d	(manual input)
Purpose:	a) green space delineation; b) quality assessment; c) urban block; d) path network (see Figure)					
AGIV	https://download.agiv.be					
URBIS	http://cibg.brussels/nl/onze-oplossingen/urbis-solutions/download					
IBGE	http://wfs.ibgebim.be/					
LNE	Through https://www.mercator.vlaanderen.be/zoekdienstenmercatorpubliek/					

References

Abercrombie, P., 1944. Greater London Plan. University of London Press, London.

Baró, F., Haase, D., Gómez-Baggethun, E., Frantzeskaki, N., 2015. Mismatches between ecosystem services supply and demand in urban areas: a quantitative assessment in five European cities. Ecol. Indic. 55, 146–158.

Beatley, T., 2000. Preserving biodiversity. J. Am. Plann. Assoc. 66 (1), 5–20.

Beatley, T., 2014. Planning for sustainability in European cities: a review of practice in leading cities. In: Wheeler, S.M., Beatley, T. (Eds.), Sustainable Urban Development Reader. Routledge, London.

Bennett, G., Cassin, J., Carroll, N., 2016. Natural infrastructure investment and implications for the nexus: a global overview. Ecosyst. Serv. 17, 293–297.

Berggren-Bärring, A.-M., Grahn, P., 1995. Grönstrukturens betydelse för användningen. Rapport 95:3. Sveriges Lantbruksuniversitet, Alnarp.

Boverket, 1999. Gröna områden i planeringen. Boverkets publikationsservice Karlskrona.

Burkhard, B., Petrosillo, I., Costanza, R., 2010. Ecosystem services – bridging ecology, economy and social sciences. Ecol. Complexity 7 (3), 257–259.

Cassatella, C., Peano, A., 2011. Landscape indicators assessing and monitoring landscape quality.

Coeterier, J.F., 2000, Hoe beleven wij onze omgeving? Resultaten van 25 jaar omgevingspsychologisch onderzoek in stad en landschap.

Crouch, D., 1994. The popular culture of city parks, in: Working Paper No. 9, Comedia/Demos.

De Clercq, E.M., De Wulf, R., Van Herzele, A., 2007. Relating spatial pattern of forest cover to accessibility. Landscape Urban Plann. 80 (1), 14–22.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manage. 146, 107–115.

Dienst Stedelijke Ontwikkeling en Beheer, 2001. In: Beheer, D.S.O.e. (Eds.) Hoofdrapport groendbeleidsplan. Gemeente Eindhoven, Eindhoven.

FAO, 2011, UNECE and FAO (2011) State of Europe's Forests 2011. Status and Trends in Sustainable Forest Management in Europe. In: Ministerial conference on the protection of forests in Europe, Oslo, pp. 337.

FOD Economie, 2011. CENSUS 2011 Open Data, Federaal Planbureau België. Federale Overheidsdienst Economie, KMO, Middenstand en Energie. Algemene Directie Statistiek en Economische Informatie.

FOD Economie, 2013, Bevolkingsvooruitzichten 2012-2060, Federaal Planbureau België. Federale Overheidsdienst Economie, KMO, Middenstand en Energie. Algemene Directie Statistiek en Economische Informatie.

Grahn, P., 1986. Grönplanering för människor, in: Stad & land (Alnarp. 1982), 0280-4549; 44, ALA/MOVIUM, Alnarp.

Grahn, P., 1994. Green structures: the importance for health of nature areas and parks. Eur. Regional Planning 56, 89–112.

Hansen, R., Frantzeskaki, N., McPhearson, T., Rall, E., Kabisch, N., Kaczorowska, A., Kain, J.-H., Artmann, M., Pauleit, S., 2015. The uptake of the ecosystem services concept in planning discourses of European and American cities. Ecosyst. Serv. 12, 228–246.

Harrison, C., Burgess, J., Millward, A., Dawe, G., 1995. Accessible Natural Green Space in Towns and Cities, a Review of Appropriate Size and Distance Criteria, English Nature.

Herzberg, F., Mausner, B., Snyderman, B.B., 1959. The Motivation to Work. John Wiley & Sons, New York.

IPCC, 2007. Climate Change 2007-Impacts, Adaptation and Vulnerability: Working Group II Contribution to The Fourth Assessment Report of The IPCC. Cambridge University Press.

Khan, A.Z., 2010. Rethinking Doxiadis' Ekistical Urbanism: Sustainability and Globalization as a dialectical framework for Design. In: Goldhagen, S.W., Mumford, E., Wagenaar, C. (Eds.), Positions #1, Modern Architecture and Urbanism. NAi Publishers, University of Minnesota Press, Rotterdam, pp. 6–39.

Khan, A.Z., Moulaert, F., Schreurs, J., 2013. Epistemology of space: exploring relational perspectives in planning, urbanism, and architecture. Int. Plann. Stud. 18 (3–4), 287–303.

Lancaster, R.A., 1983. Recreation, Park and Open Space Standards and Guidelines. National Recreation and Park Association, Alexandria, Va.

Lappé, F.M., 2009. Questions to ask strategies to save our planet. Solutions 1 (1), 34–35.

Loeckx, A., Corijn, E., Persyn, F., Avissar, I., Smets, B., Mabilde, J., Vanempten, E., 2016. Metropolitan Landscapes: Open ruimte als basis voor stedelijke ontwikkeling – Espace ouvert, base de développement urbain. Vlaams Bouwmeester, Brussels, p. 191.

Madanipour, A., 2006. Roles and challenges of urban design. J. Urban Des. 11 (2), 173–193.

Matthies, M., Giupponi, C., Ostendorf, B., 2007. Environmental decision support systems: current issues, methods and tools. Environ. Model. Software 22 (2), 123–127.

Mayor of London, 2008, Open Space Strategies Best Practice Guidance, CABE Space, Greater London Authority.

Meyer, B.C., Grabaum, R., 2008. MULBO: Model framework for multicriteria landscape assessment and optimisation. A support system for spatial land use decisions. Landscape Res. 33 (2), 155–179.

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-Being. Island Press, Washington, DC.

Neßhöver, C., Beck, S., Born, W., Dziock, S., Görg, C., Hansjürgens, B., Jax, K., Köck, W., Rauschmayer, F., Ring, I., 2007. Das Millennium Ecosystem Assessment-eine deutsche Perspektive. Natur und Landschaft 82 (6), 262–267.

Pulighe, G., Fava, F., Lupia, F., 2016. Insights and opportunities from mapping ecosystem services of urban green spaces and potentials in planning. Ecosyst. Serv. 22 (Part A), 1–10.

Reid, W.V.C.M.E.A., 2005. Ecosystems and Human Well-Being: General Synthesis: A Report of The Millennium Ecosystem Assessment. Island Press, Washington, DC.

Sandifer, P.A., Sutton-Grier, A.E., Ward, B.P., 2015. Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation. Ecosyst. Serv. 12, 1–15.

Ståhle, A., 2002, Urban Planning for a Quality Dense Green Structure – Stockholm Sociotop Map and Park Programme, COST C11.

Ståhle, A., 2010. More green space in a denser city: critical relations between user experience and urban form. Urban Des. Int. 15 (1), 47–67.

Stessens, P., Khan, A.Z., Canters, F., Huysmans, M., submitted, Assessing Urban Green Space Quality: An integrated approach towards GIS-based indicators and the way green space qualities are perceived, Ecol. Indicat.

Stockholms stadsplanekontor, 1952, General plan for Stockholm, 1952, Stockholms Stads Stadsplanekontor.

Swanwick, C., 2009. Society's attitudes to and preferences for land and landscape. Land Use Policy 26 (Suppl. 1), S62–S75.

Tarzia, V., 2003. European common indicators: towards a local sustainability profile. Ambiente Italia, Instituto di Ricerche, Milan.

Troy, A., Wilson, M.A., 2006. Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer. Ecol. Econ. 60 (2), 435–449.

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. Landscape Urban Plann. 81 (3), 167–178.

Van de Voorde, T., Canters, F., Cheung-Wai Chan, J., 2010. Mapping update and analysis of the evolution of non- built (green) spaces in the Brussels Capital Region. Vrije Universiteit Brussel, Brussels, p. 35.

Van Herzele, A., 2005. 'A Tree on your Doorstep, a Forest in your Mind' Greenspace Planning at the Interplay between Discourse, Physical Conditions, and Practice.

Van Herzele, A., Wiedemann, T., 2003. A monitoring tool for the provision of accessible and attractive urban green spaces. Landscape Urban Plann. 63 (2), 109–126.