Applied Geography 141 (2022) 102673

Contents lists available at ScienceDirect

Applied Geography

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

How far do people travel to use urban green space? A comparison of three European cities

Mirjam Schindler[a,*], Marion Le Texier[b], Geoffrey Caruso[c]

[a] School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand
[b] LAGAM | Laboratory for Geography and Territorial Planning in Montpellier, University Paul Valéry, Montpellier 3, France
[c] Institute of Geography and Spatial Planning, University of Luxembourg and Luxembourg Institute of Socio-Economic Research, Luxembourg

ARTICLE INFO

Keywords:
Urban green space
Green space use
Trip distance
European cities
Multilevel model

ABSTRACT

Urban green space (UGS) provision across cities is often assessed from per capita quantities. However these aggregate measures say little about the actual use of UGS because they ignore the relative location of UGS and citizens. Spatial accessibility approaches consider this relative location but mostly assume that benefits happen within close proximity of residences. We challenge this assumption for three European cities comparatively, based on similarly acquired survey data. We study which factors influence how far people travel to their most used UGS, as defined by users themselves. We find that travelled distances (1.4–1.9 km) and inter-city differences are surprisingly high compared to the few hundred meters set in policy targets and accessibility analyses. We identify socio-demographic effects and a role for perceived rather than objective quality of local UGS. More than a spatial interaction trade-off between proximity and size, our results suggest that UGS visits are part of a more complex set of activities, further away from residences and with a diversity of sizes and proximities. Our results call for a re-evaluation of UGS analytical practices and provision policies beyond aggregate and accessibility perspectives, towards multi-scalar and spatially varying measures.

1. Introduction

Urban green spaces (UGS) are vital elements of cities. They provide many environmental benefits and improve citizens' quality of life (e.g. Chiesura, 2004; Konijnendijk van den Bosch et al., 2013; Tzoulas et al., 2007) by improving air filtration (e.g. Jayasooriya et al., 2017; Jim & Chen, 2006), reducing heat islands (e.g. Bowler et al., 2010; Kabisch & Haase, 2014), or contributing mental and physical health benefits (e.g. WHO, 2016). It is not surprising that providing better quality green infrastructures now becomes an integral part of urban policy agendas (e.g. European Commission, 2020).

Although fundamental to sustainability, the provision of UGS within cities is jeopardized by competing land uses, seen as more productive in the short-run (e.g. offices, commercials, residences), especially in core areas of cities where, paradoxically, population density makes UGS even more necessary. UGS provision is also opposed by infill or densification strategies (e.g. Haaland & Konijnendijk van den Bosch, 2015) aiming at sustainability but implemented at coarse scales, without explicitly protecting vegetated spaces.

To benefit from UGS, individuals need to access or get close to them. The World Health Organisation (WHO), for example, recommends to measure health benefits of UGS by summing residential population within 300 m (or 5 min walk as a rule of thumb) around each UGS of minimum 0.5 ha (WHO, 2016). Urban nature researchers also promote similar targets: Konijnendijk van den Bosch (2021) for example recommends that every citizen could see 3 trees, live in a 30% green covered neigborhood and within 300 m of a park. Benefits thus appear to result from both a combination of provision in proximity and size or coverage of UGS. Proximity implies that the spatial distribution of UGS relative to the spatial distribution of the population is fundamental and cannot be picked up by at the city scale (e.g. green cover percentage alone). In other words, the composition is as important as the total surface provided per inhabitant.

Centrality is a key dimension of the variation of the relative proximity of people and UGS within cities (Picard & Tran, 2021b). UGS are obviously easier to provide in the periphery where competition is reduced and land more abundant than close to the center. However, in the periphery, UGS also benefit fewer people. In addition, the socio-economic composition of neighbourhoods changes with centrality thus questioning whether UGS benefits accrue equitably to the

* Corresponding author.
E-mail addresses: mirjam.schindler@vuw.ac.nz (M. Schindler), marion.le-texier@univ-montp3.fr (M. Le Texier), geoffrey.caruso@uni.lu (G. Caruso).

https://doi.org/10.1016/j.apgeog.2022.102673
Received 1 June 2021; Received in revised form 13 February 2022; Accepted 27 February 2022
Available online 12 March 2022

population (Barbosa et al., 2007; Comber et al., 2008; Dai, 2011; Kabisch et al., 2016; Wolch et al., 2014). The relative proximity of UGS to residents is thus to be analysed with intra-urban heterogeneities in mind and with a centrality lens in particular.

Yet, it is still a very strong assumption to imply that close proximity to UGS - even after controlling for citizens' heterogeneity and location - leads to UGS use. Research has addressed the measurement of proximity, e.g. using Euclidean or network buffers, average distances, or distance to the nearest UGS from residences (e.g. Boulton et al., 2018; Le Texier et al., 2018). However, the literature mostly takes for granted that potential supply and accessibility command UGS use. Conversely, much of the literature on UGS use tends to omit location as an explanatory factor. Effects of local provision of UGS, neighbourhood morphology, patterns of type of habitat across the city are therefore rarely explored. Talen (2010) and Boulton et al. (2018) have stressed the need to further research UGS supply and demand links. In order to then liaise supply, demand and actual use, we need to observe what people actually do, given UGS provision and residential location. We choose to look at the distance people actually travel to visit the UGS they use the most, and try to understand how and why those distances vary across the centrality gradient and across different cities. We aim to separate socio-economic characteristics and UGS characteristics effects from locational effects and cities' specificities.

Distances travelled to use UGS are seldom analysed and there is still little comparative research about the determinants of the use of UGS. Comparisons are indeed difficult because case studies are subject to specific populations, different study area definitions or sampling methods, or varying definitions of what a UGS is. This is why we conduct a comparative analysis across three cities: Brussels (Belgium), Rouen (France) and Luxembourg (Luxembourg). They vary in geographic context, population size or socio-economic composition, thus offer a broader scope than a single case study. We have applied the same sampling and survey across the cases, ensuring comparability, and did not give any *a priori* definition of UGS to avoid contextual or interpretation bias.

In Section 2 we review evidence about the provision and use of UGS within and across cities. Section 3 introduces our experimental design and data. Section 4 describes the spatial patterns of distances and explanatory factors, followed by regression results. We discuss implications in Section 5 before concluding.

2. Evidence on UGS provision and use

This section is not aimed to be a comprehensive review but aims to frame expectations with regards to locational aspects of UGS use across and within cities, and distances travelled to UGS. Rossi et al. (2015) offered a wider discussion of how spatial interaction and distance decay relate to green space use, especially visits to natural parks. More recently, Jalkanen et al. (2020) and Zhang et al. (2021) further documented the literature on accessibility measurements. Kabisch et al. (2015) undertook a systematic review of the empirical literature and also stressed the lack of comparative (multi-cities) studies.

We first discuss UGS provision (potential accessibility) studies and second UGS use studies, each time stressing comparative research and then explanatory factors.

2.1. UGS provision

2.1.1. Pan-European and comparative research

Heterogeneities in UGS supply and demand across macro regions - thus the potential use or accessibility to UGS - has been estimated in a few pan-European studies. Fuller and Gaston (2009) explore the relationship between UGS and the surface and population of 386 cities. They focus on core cities (morphological zones) and suggest a potential lack of provision with increased compaction and densification. They also show important discrepancies across Europe (with larger UGS provision per capita in the North) but also across cities within a single country. Their evaluation is *a-spatial*, in the sense that the relative location of the demand (population) and supply (UGS) is not accounted for within cities. Kabisch et al. (2016) provide such a spatial consideration and use a larger city definition including periphery (functional areas). They estimate a green space supply-demand link by computing population within 300 m and 500 m buffers around UGS (designated urban green or forest patches of minimum 2ha). They also report a North-South divide. Boura and Caruso (2020) consider over 800 cities in Europe which they typify according to their green cover and the distribution of vegetated land relative to residential areas within functional regions. They incorporate potential proximity through contiguity and landscape metrics rather than through distance thresholds. They find East-West differences in addition to a North-South effect. Our three case studies fall in separate clusters of this study, with Rouen being part of the average European reference type, Luxembourg being in a more forested city type, and Brussels within a group of more artificialised cities. We can thus expect an ordering of our cities with increasing distances to access UGS from Luxembourg, Rouen and then Brussels.

There are many individual case studies contrasting UGS provision and accessibility within a city and across socio-economic groups but comparative analyses of UGS provision across cities are still rare. Badiu et al. (2016) compare UGS surface per capita across 38 Romanian cities and find that UGS provision reduces when built-up density and distance to important roads increase, and with lower city hierarchy (administrative level and population). Madureira et al. (2015) analyse perceived (not actual) UGS benefits in Paris, Angers, Lisboa and Porto. They find no effect of city size and suggest that national context and local factors explain the small differences across cities. Ngom et al. (2016) compare UGS accessibility (again not use) in Montreal and Quebec using travel costs and spatial interaction approaches. They suggest potential equity issues and longitudinal (time) effects in the provision and access. The smaller city of Quebec is shown to provide more equitable access, while gentrification seems ongoing in some denser neighbourhoods of Montreal.

2.1.2. UGS provision factors

There are few authors who conceptualise the provisioning mechanisms of UGS in relation to demand. Boulton et al. (2018) indicate from their systematic review that regional/municipal budgets, knowledge resources and governance are the most addressed explanatory factors of UGS provision. Spatial mechanisms are seldom addressed. Picard and Tran (2021a) pick up the argument of centrality and formally demonstrate that the provision of UGS is non-linear with distance to the centre. The tension between higher population density close to the centre (thus more demand) and the higher availability of land in the periphery, where demand for UGS is lower, leads to an inverted U-shape of UGS provision along the accessibility gradient. Choumert and Cormier (2011) find evidence of spatial spillover effects in the provision, which they relate to mimetic developments of neighbouring municipalities and a tendency for newer developments to be planned with more parks than before. Yet, while the concavity of Picard and Tran (2021a) or the spillover effects of Choumert and Cormier (2011) progress our understanding of spatial differences in provision within cities, a link to actual UGS use is still missing.

2.2. UGS use

2.2.1. Dimensions and comparative research

There are two main dimensions to UGS use: frequency and duration of visits. In empirical literature, UGS use is mostly addressed by questioning urban residents about the frequency of visits to UGS (e.g. Aziz et al., 2018; Bertram et al., 2017; Conedera et al., 2015; Coombes et al., 2010; Fischer et al., 2018; Giles-Corti et al., 2005; Jones et al., 2009; Neuvonen et al., 2007; Refshauge et al., 2012; Schindler et al., 2018; Schipperijn et al., 2010; Scott et al., 2007) and duration of visits (e.g. Lin et al., 2014; Refshauge et al., 2012).

Most research is based on a single city and transfer to other cases is difficult because of different data gathering or surveying methods. Some research though is comparative, and actually consider distance related questions. Zwierzchowska et al. (2018) compare visitors perceptions and uses of 8 parks across Bucharest (Romania), Poznan (Poland) and Salzburg (Austria). Priess et al. (2021) interviewed visitors of urban parks in central Coimbra (Portugal), Leipzig (Germany) and Vilnius (Lithuania). Distance from the park to their residence and work places were compared to ecosystem services and across cities. Schetke et al. (2016) conduct an online survey in Kharachi (Pakistan) and Ho-Chi-Minh City (Vietnam) and investigate distance and perceived distance effects. A web survey was also conducted by Bertram and Rehdanz (2015) for four European cities.

2.2.2. UGS use factors

Three types of factors are found to determine UGS use in this literature: (i) households' characteristics (education, income, ethnicity, attitudes); (ii) UGS' characteristics (size, equipment, vegetation); and (iii) the local accessibility of UGS. This third aspect is objectively measured by buffers or distance metrics, then associated to spatial units or directly to respondents, or retrieved subjectively from respondents.

Results generally suggest that good local provision and access promote UGS use and satisfaction (e.g. Bertram et al., 2017; Giles-Corti et al., 2005; Havret, 2020; Jim & Chen, 2006; Maat & de Vries, 2006; Neuvonen et al., 2007; Priess et al., 2021; Roovers et al., 2002; Zhang et al., 2015). Mixed results are also obtained where accessibility is not as important as socio-economic, attitudes or perception factors, or showing that both are difficult to disambiguate. For example, Lin et al. (2014) show that individuals' orientation towards nature affect UGS visitation behaviour more than the availability and ease of access. Refshauge et al. (2012) stress cultural effects on the frequency and duration of visits to playgrounds. Priess et al. (2021) observe differences between cities, which the authors explained by differences in both cultural and UGS provision.

Within the corpus of research that explicitly consider distance or time, Schipperijn et al. (2010) find that distance to UGS is not always a limiting factor of use. Bertram et al. (2017) identify reduced effects of time and distance for weekend visits. They also find inconsistent effects across different distance buffers. Zwierzchowska et al. (2018) find no meaningful relationship between the time travelled to the investigated parks and the local provision in terms of the distance to the closest park from home. They also find that in 66% of cases, respondents have travelled more than 800 m to reach the park.

Distance to UGS is definitely used to explain UGS visits (frequency and duration), but travelled distances to UGS have so far not been considered as an outcome to be explained as such. To the best of our knowledge, there are only two exceptions where a regression is reported of travelled distance to UGS against a series of factors: In the case of Brisbane, Lin et al. (2014) find a relation with age and attitudes towards nature, but no significant effect of local provision (park cover in buffers ranging from 250 to 1000 m). In the case of Brussels, Schindler et al. (2018) report a quantile regression as part of a larger estimation of the willingness to substitute private space or to pay for more UGS. Low local provision and larger UGS are found to increase distances travelled. The authors also suggest a self-selection effect: both attitudes relative to UGS and socio-economic characteristics impact residential choices, which in turn impact frequency of UGS use, and then the distance travelled to UGS. Similar self-selection or identification problems due to residential choice are suggested by Maat and de Vries (2006); Spielman et al. (2013).

Factors explaining the actual distance travelled to UGS are clearly under-reported. This is an important gap because distance is a dimension of UGS provision that speaks to planners and because policy targets are set in maximum distance terms (e.g. WHO, 2016). The current situation leads to the limited assumption that benefits automatically accrue to the population within 300/500 m of a formally defined UGS and that promoting local provision everywhere would suffice as a policy instrument. But such a policy is both unlikely in times of densification and is prone to side effects, such as a mismatch between the provision and the location of those more in need or green gentrification. We engage in deconstructing this by analysing how locational factors, especially distance to the city centre and the local provision of UGS, and individual factors can explain the distance travelled to UGS.

3. Empirical methodology

Our general methodology consists in (i) collecting the location of the most used UGS among surveyed inhabitants of three European cities (Luxembourg (Luxembourg), Brussels (Belgium) and Rouen (France)), (ii) measuring the distance between this declared UGS and home for each respondent, and (iii) regressing that distance against potential explanatory factors. We detail below the survey design, the computation of the distance, the variables and the hypotheses attached to each variable (covariate), and the specification of the regression model. In the Results section, we report the spatial pattern of distances and covariates, then the results of the regression model.

3.1. Survey design and sample

Face-to-face surveys with closed questions were conducted using the same protocol in spring 2016 in Brussels, and 2017 in Luxembourg and Rouen. For internal validity and consistency across cases, the same team (including at least one of the author accompanied by trained students) conducted the survey in all three places with one author present in all cases. Pilot tests were conducted among students (any departments) in Luxembourg to validate the questions and to refine languages (choice was given to respond in German, French or English). The survey included questions on (i) respondents' stated attitudes towards UGS and use patterns (e.g. frequency of use, travelled distance, location of preferred UGS), (ii) their residential location, and (iii) their socio-economic background.

We applied a convenience sampling approach, without setting an explicit geographic boundary for respondents. Rather, survey sites were carefully identified along a series of urban-suburban transects in all directions from the main center for each city. This sampling allowed us to capture individuals with different socio-economic backgrounds and the effect of different residential environments, especially in terms of centrality and UGS local endowment. The transect approach also leads to a continuum in space, both for UGS types and residences, thus avoiding an artificial differentiation between urbanites and suburbanites. Our study areas are indirectly defined by the sampling: presence at survey sites simply demonstrating a functional link with the considered city. Where respondents were obviously passing-by with little connection to the city or its close suburbs, they appeared as outliers and were removed from the data (most actually declined answering the survey when the goal was explained).

All survey sites were publicly accessible locations (shopping center entrances, street intersections, or public squares). On purpose, they were not designated UGS in order to (i) avoid bias from a specific UGS; (ii) allow for informal UGS to be declared as destinations; and (iii) include frequent, rare and non UGS users, thus avoiding the selection bias one could find when interviewing directly within one or more UGS. The method also *de facto* selected citizens with a certain degree of autonomy and mobility, which is important given our focus on travelled distance (although we agree with Stafford and Baldwin (2018) that accounting for all abilities is important for a fair access to UGS).

Further information on the survey content and process (for Brussels) can be found in Schindler et al. (2018). After data cleaning, this study is based on 562 responses in Luxembourg, 503 in Brussels and 510 in Rouen (i.e. 94% of collected data).

3.2. Most used UGS and walking distance

Survey respondents were invited to point both their home and the UGS they use the most on a digital map (using ODK Collect, see https://getodk.org). Unconstrained moving, zooming and search tools of the app, as well as interaction with the investigator were used to solve orientation problems if any.

No information about what a 'green space' is was provided at the start of an encounter, so that the definition of UGS is eventually left to respondents. In case respondents raised a difficulty, the following was suggested by the investigator: "any publicly accessible space with natural elements in either small or large quantities". Eventually, 50 UGS were pointed out in Brussels and around 100 in the case of Rouen and Luxembourg. They comprise a large diversity of UGS types, informal or formal (playgrounds, pocket parks, public gardens, allotments, managed forests), with size varying from 0.005 to 15 ha in Brussels, 0.001–63 ha in Luxembourg, and 0.001 ha–50 ha in Rouen.

For sampling control, survey respondents also reported UGS use frequency. In case of a mismatch, i.e. a UGS located but 'never' reported as a frequency, respondents were removed.

Based on each pair of residential and UGS points, an objective walking distance along the network was computed using the Google routing algorithm (R-package *ggmap* implementation (Kahle & Wickham, 2013)). While the algorithm may under-perform for pedestrian travel compared to driving, it is better than Euclidean at such a micro-scale and comparable across cases. Alternative algorithms based on Open Street Map for example might be prone to important data differences for pedestrian tracks and sidewalks. Origin and destination coordinates precision was obtained directly from respondents, e.g. including accurate destination points within a larger park, without therefore the need to model UGS limits and entry points.

3.3. Variables and hypotheses

Following the literature, we expect travelled distances to depend on: (H1) UGS characteristics; (H2) the centrality of respondents' residence; (H3) UGS provision around residence; and (H4) individual socio-economic characteristics. The measurement of these factors and related expectations are described below. In addition, we expect inter-city differences due to different overall green coverage and city size, making up a fifth hypothesis (H5).

H1. Characteristics of visited UGS

Only the size of the most used UGS is considered here, partly due to the difficulty of characterising UGS similarly across different cities and the impossibility to survey all reported UGS. The size of each reported UGS is retrieved from OSM (OpenStreetMapcontributors, 2016). Although this is a strong assumption, considering size as the key UGS characteristic is in line with previous studies (Giles-Corti et al., 2005; Schindler et al., 2018; Schipperijn et al., 2010; Van Herzele & Wiedemann, 2003) and more generally with spatial interactions research. We expect UGS size to command longer travelled distances.

H2. Residential location

We compute the Euclidean distance between respondent's home and the respective city centre (city hall). Large outliers (i.e. > 20 km) are removed to ensure that each sampled person is connected to the city region and that the expansion of the three cities relative to their size is similar (following the general law of urbanisation profiles given by Lemoy and Caruso (2020)). Besides being a control, the distance to the centre is our indicator of centrality. It accounts for the urban-suburban gradient along which residents trade-off a higher proximity to central activities with a generally greener periphery. It also captures unmeasured locational qualities related to centrality, such as local built-up density or air quality (Schindler & Caruso, 2020). Our expectation is that the more central a location is, the longer residents need to travel to enjoy UGS. This is not likely to be linear however as Picard and Tran (2021a) found that UGS provision peaks near the city fringe.

In connection with centrality, we also consider the dwelling type of respondents (3 categories: flat; semi-detached or terraced; detached). Our hypothesis is that having more living space available reduces the need to use local UGS, which may push respondents to travel further in order to experience a different environment or a larger UGS. If this assumption is valid and housing type correlated with distance to the centre, we can expect it counteracts the centrality effect. (Note that owning a private garden or not was also recorded, but the type of housing was more discriminatory in our model selection).

H3. Local UGS provision

The provision of UGS around home is measured subjectively and objectively. Respondents were asked how satisfied they are with the quality of UGS within 5 min walking distance from home (3 categorical responses: not at all; somewhat; very). As an objective measure, we compute the share of UGS within a 400 m walking distance around each home (in line with e.g. Van Herzele & Wiedemann, 2003; Schindler et al., 2018) using OSM data (OpenStreetMap contributors, 2016). In addition, we compute the network walking distance to the nearest UGS for each residential location. We expect low objective or subjective UGS provision to act as constraint and require respondents to travel further to use UGS.

H4. Socio-economic characteristics

Various individual and household characteristics of respondents were retrieved, including age, gender, occupational status, household size, education level, car ownership and nationality (European/non-European). As previous studies found (e.g. Barbosa et al., 2007; Comber et al., 2008; Ernstson, 2013; Shafer et al., 2013; Tyrväinen et al., 2007), residents' socio-economic background might pose constraints to UGS use and therefore impact the distance travelled.

H5. Inter-city differences in UGS use patterns

Our cities differ at least in size and overall provision of UGS. Although our study areas are not strictly defined, the corresponding Urban Atlas population for these functional urban regions are: Brussels 1.2 million; Luxembourg 590,000; and Rouen 466,000 inhabitants. According to Boura and Caruso (2020) they also differ with respect to the provision and integration of green space within their urban fabric.

We therefore expect that the average distance travelled varies per city and that the effects of the above factors are influenced by city size and overall UGS provision. For a similar city size, we expect respondents of Rouen to travel further to use UGS because of the lower provision of UGS in general, and particularly in the central part of the city compared to Luxembourg. In Brussels, the lower general provision of UGS should lead to longer travel distances. However neighbourhood and socio-economic effects might be stronger in this larger city. Following Schindler et al. (2018) we thus expect the size of a UGS and respondents' socio-economic background to have a more discriminatory effect than in the other two cases.

3.4. Model specification

We apply a multi-level model with random slopes and intercepts to account for the hierarchical (spatial) structure of our data, i.e. distributed across the three case study cities. The framework allows for varying explanatory effects for each city, and quantifying heterogeneity of effects across cases is one of our explicit goal. Various sets of simpler regression models were run but failed to account for the spatial variability within our dataset. Despite the low number of cities we concluded a multi-level modelling approach is appropriate given our goal and along with relevant multi-level modelling literature (Gelman & Hill, 2007; Huang, 2018). Our model is estimated using the 'lme4' package of the R statistical software (Bates et al., 2015).

In our final model, the travelled distance to the most used UGS is logged to account for expected non-linearities and the skewed distribution (see results). We therefore estimate the following:

$$log(dist)_{ij} = \beta_{0j} + \beta_{1j}X_{1ij} + \beta_{2j}X_{2ij} + \beta_{3j}X_{3ij} + \beta_{4j}X_{4ij} + \varepsilon_{ij} \quad (1)$$

with $dist_{ij}$ the walking distance, subscripts i indicating individual respondents, and subscripts j their city. ε_{ij} is the within-city random residual at the respondents' level. X_1 to X_4 are explanatory variables related to the four sets of hypotheses raised above (Section 3.3). Our fifth hypothesis is expected to result in variations of the estimated coefficients β_1 to β_4 across cities j, which are composed of a fixed and random (per city) part. β_{0j} are the random intercepts, showing variations in travelled distances across cities after controlling for all the effects.

Our model specification and selection was made with the intention of testing the 4 sets of hypotheses while gauging improvement with respect to the hierarchical null model (χ^2 test) and any remaining spatial structure in residuals (visual inspection).

4. Results

We first describe and analyse the spatial pattern of distances travelled to the most used UGS (Section 4.1). We then describe our hypothesized covariates and their variations across cases (Section 4.2). We finally present and discuss the estimates of the multilevel model where the travelled distance is regressed against explanatory factors (Section 4.3).

4.1. Distance to most used UGS

On average, respondents in Rouen (4.4 km) and Luxembourg (3.9 km) travel significantly further (Welch Two Sample *t*-test) than respondents in Brussels (2.9 km). Given the long skewed distribution (Fig. 1), medians, respectively 1.9 km (Rouen), 1.7 km (Luxembourg), and 1.4 km (Brussels) are better indicators. A first important finding is that these values are strikingly high compared to the few hundred meters or 5 min walk used in supply or accessibility literature. The ranges also suggest a significant recourse to motorised trips.

Note that there are important differences in terms of frequency of UGS use across cases, with about twice as many respondents seldom visiting UGS in Rouen compared to the other two cases, thus calling for cautious interpretation.

Figs. 2–4 show the spatial pattern of UGS use as reported by respondents, overlayed on top of the UGS location as of OSM maps. Each arrow depicts a link between a respondent's home and their most used UGS. Patterns are markedly different across the three cities:

Brussels has its largest UGS in the South East of the city and it is the most visited. There are also a number of small-sized UGS spread across the more central area and links show that these are destination points, sometimes attracting users from distant parts of the city. Other than in Luxembourg and Rouen, where patterns are centrality related, we find a multiple-stars-like pattern of use.

The overall provision of UGS for Rouen and Luxembourg is more spatially balanced than in Brussels, with a green periphery in all directions. Only few UGS are located in or near the centre in Rouen while Luxembourg has a green belt just next to the city centre in addition to a large UGS provision beyond the city ring road. Mapped links show that many respondents visit UGS in the city centre of Luxembourg and some specific UGS a few km around the centre. The arrows thus indicate both centrifugal and centripetal patterns in Luxembourg. In Rouen, the lack of UGS availability in the centre leads to a largely centrifugal pattern of use.

4.2. Sample and factors description

The share of responses for each categorical variable and means for the continuous variables are reported in Table 1 to understand the range of variation and uncover inter-city differences (H5) in potential explanatory factors.

First (H1), we find substantially larger UGS for Rouen (1.5 ha) and Brussels (1.4 ha) compared to Luxembourg (0.4 ha). Given the travelled distances, a simple spatial interaction hypothesis does not seem well suited: much lower distances would be expected for the case of Luxembourg.

Second, regarding centrality (H2), the average distance to the city centre is similar across cases, suggesting that the sampling led to comparable catchment areas. Given the size of the city we unsurprisingly capture a larger proportion of respondents living in more compact dwellings in Brussels.

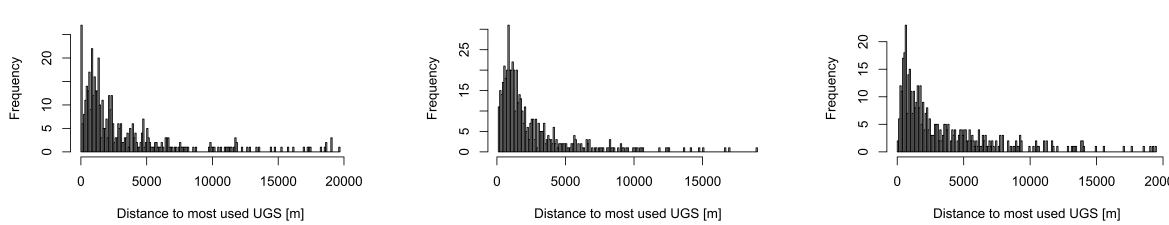
Third (H3), our subjective measure of local UGS provision shows that overall our respondents are very satisfied with the quality of the local provision. Given the large travelled distances, this comes rather as a surprise and suggests that visiting a UGS is not necessarily the same consumption 'good' as living in close proximity to one. We note a clear advantage of Luxembourg over the two other cases in terms of satisfaction. Note that satisfaction was aggregated into two classes only for the model. The objective measure of the share of UGS around homes is in line with Luxembourg doubling the shares found in Brussels and Rouen. The average distance to the nearest UGS, however, is largest in Luxembourg (1.2 km). The 300 and 400 m of Rouen and Brussels put those cities close to typical policy targets.

Finally (H4) our sample exhibits similar distributions of socio-economic characteristics across the three cities. Yet, car ownership is higher in Luxembourg (Luxembourg has the highest car ownership rate in Europe, see ACEA, 2021) compared to Brussels, where most respondents have no car. Rouen respondents are slightly older while Brussels and Luxembourg, both capital cities, have a higher share of non-European nationals. All these variations definitely support our comparative analysis as a way to feed in a larger set of combined variations to better grasp UGS use processes.

Note that, after some tests, age was categorized into 6 classes and both household size and car ownership into 2 for the model.

4.3. Model results and hypotheses testing

Regression results are reported in Table 2 where effects on estimated travel distances are shown.



(a) Luxembourg (b) Brussels (c) Rouen

Fig. 1. Histograms of the distance to the most used UGS for the three case study cities.

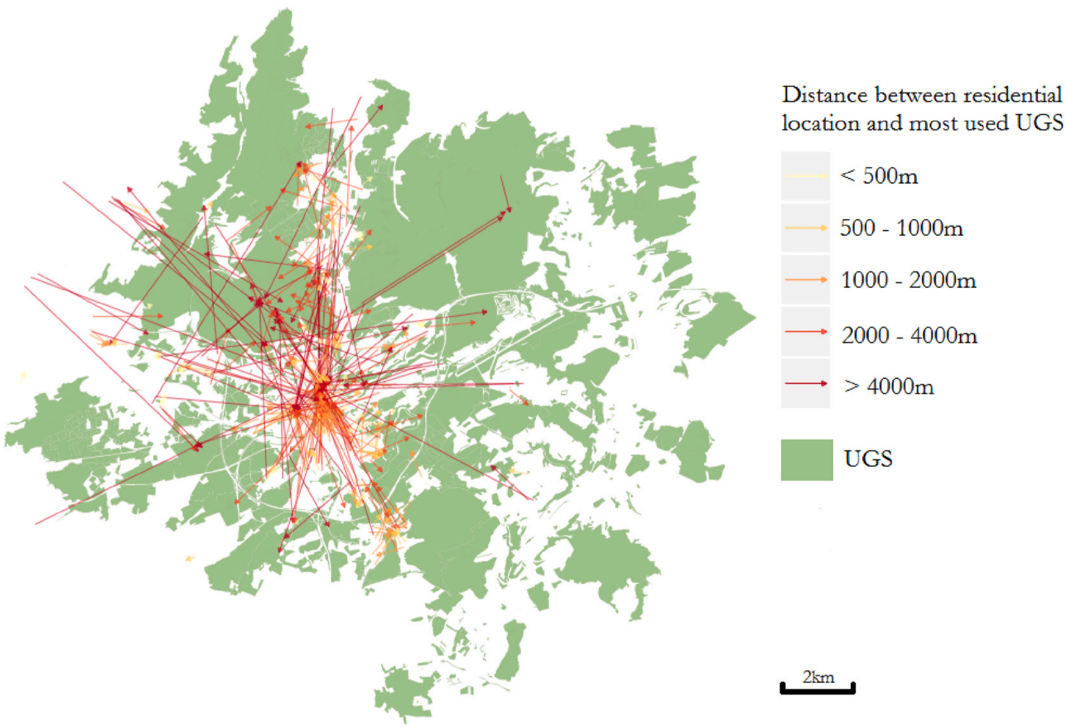


Fig. 2. Spatial pattern of UGS use (arrows) overlayed on UGS supply (as of OSM, green polygons) in Luxembourg (zoom to the commune of Luxembourg). Link colors indicate the (network) distance of the trip (yellow - short to red - long).

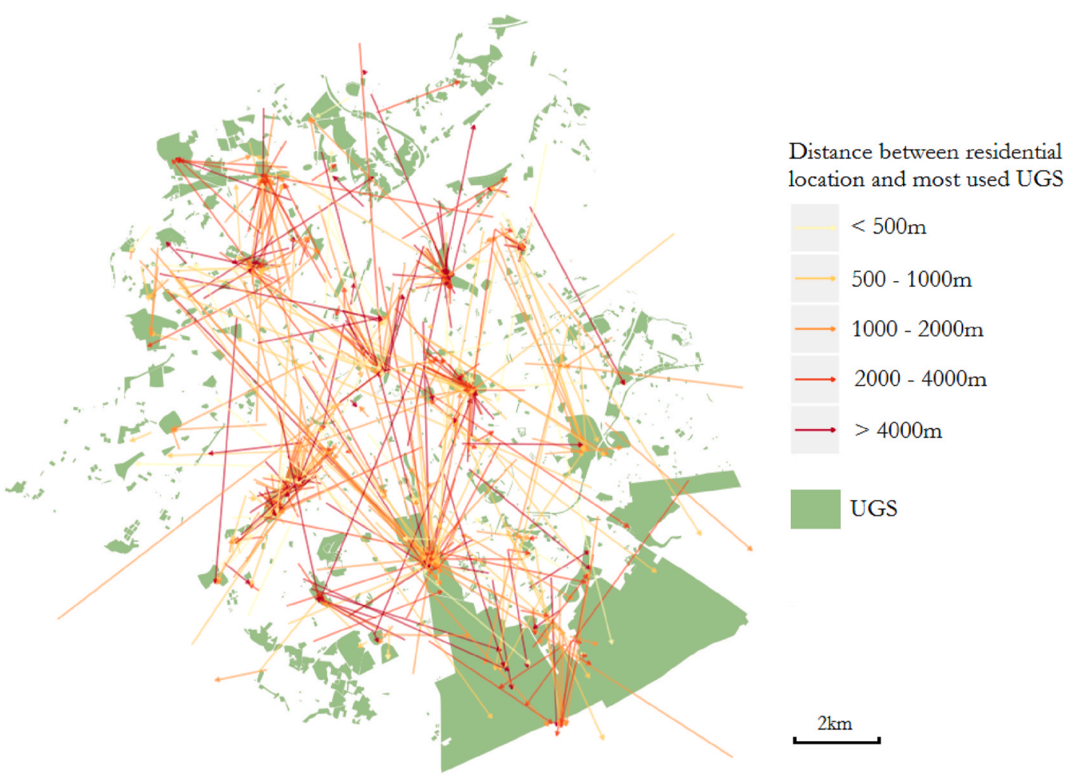


Fig. 3. Spatial pattern of UGS use (arrows) overlayed on UGS supply (as of OSM, green polygons) in Brussels. Link colors indicate the (network) distance of the trip (yellow - short to red - long).

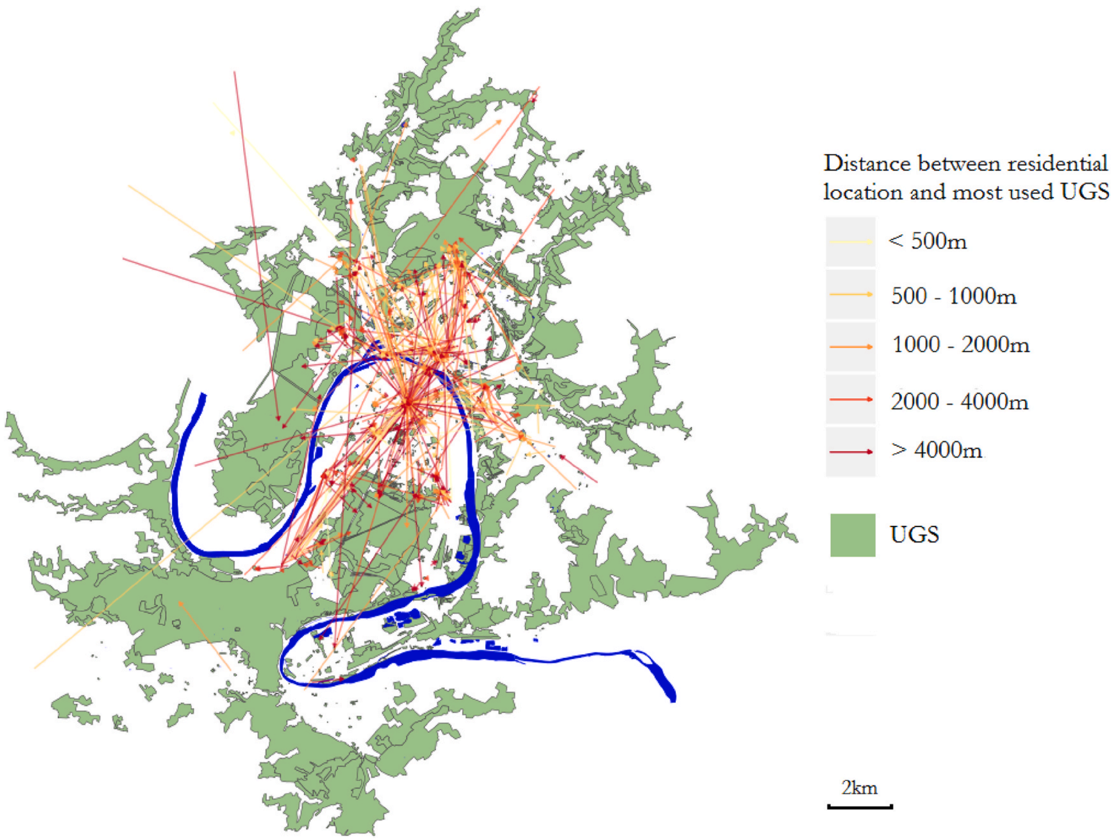


Fig. 4. Spatial pattern of UGS use (arrows) overlayed on UGS supply (as of OSM, green polygons) in Rouen. Link colors indicate the (network) distance of the trip (yellow - short to red - long).

We forced the inclusion of gender into the final model to align with previous research and since the use of p-values is not recommended anyway for decision in mixed models. Also, no fixed effect is measured for the size of the most used UGS because several respondents can use the same UGS (thus size) within a city without a correspondence across cities.

4.3.1. *General inter-city difference (H5)*

From the intercepts in Table 2 we find that, everything else equal, living in Rouen increases the average distance travelled to use UGS by almost 1 km compared to living in Luxembourg or Brussels. Beyond the reasons for such a specificity of Rouen, this means that after controlling for different population characteristics and the intra-urban distribution of the population and UGS, large differences remain across cities, with an order of magnitude equal to 2 or 3 times the normative or agreed provision/accessibility targets of 300 or 400 m distance. It is a very large effect and a first important result of our comparison. Further differences across cases are discussed below together with the effects of each covariate.

4.3.2. *Effects of the size of UGS (H1)*

We find that the size of UGS has a weak negative impact on travelled distance to use UGS in Luxembourg and Rouen (not in Brussels). Although this is a small effect, it is unexpected. The availability of many and large forested places in the periphery of the centre (especially in Rouen), which are actually well used (see maps) is a potential explanation for this. This result suggests that the size of an UGS is not directly a choice component, but rather an implicit characteristic of the use of peripheral UGS. It is also another argument against a simple spatial interactions view of UGS use.

4.3.3. *Effects of centrality (H2)*

Across all cities, for every kilometer residents live further away from the city centre, they add on average 73 m (Luxembourg), 67 m (Brussels) or 21 m (Rouen) to their trip to the most used UGS. These are not large values but the signs contrast with the expectations that were formulated with the idea that peripheries are greener and thus command shorter trips.

Looking at the influence of the type of housing, results are mixed. We find that respondents who live in a detached house rather than a flat tend to have shorter UGS trips in the case of Brussels and even more in Rouen (where the share of respondents in this group is very large). This suggests a substitution of UGS with more private green space (usually related to detached houses). The positive value for Luxembourg then tends to support the assumption that respondents search another experience than their private space, for example formal UGS with desired facilities which are more present near the city fringe, or for example a different time of use (e.g. lunch time versus weekends). This second assumption is also supported by the fact that coefficients are positive for the semi-detached houses, which is a less dense building form than flats (used as reference). The difference with detached houses, however, remains quite difficult to understand and would require a fuller comparative analysis of the distribution of building stocks across each area. Despite a transect-based sampling and thus a similar catchment area, we had more respondents living in flats in Brussels, indicating a steeper urban-suburban density gradient.

4.3.4. *Effects of the local UGS provision (H3)*

Respondents who stated that they are very satisfied with the quality of local UGS tend to travel less far to reach an UGS. This is one of the clearest results of our experiment. It is consistent across cases and fully in line with our expectations: a well perceived local provision reduces travel distances. The impacts are also substantial in range, leading to

Table 1
Percentage of survey respondents per category or variable mean per city. Data type: c-continuous, d-discrete.

Number of survey respondents	Luxembourg	Brussels	Rouen	type
	562	503	510	
Travelled distance				
Distance of most used UGS [km]	3.9	2.9	4.4	c
[1] Characteristics of used UGS				
Size of most used UGS [ha]	0.4	1.4	1.5	c
[2] Residential location				
Distance to centre [km]	3.5	3.7	3.8	c
Housing type				d
Flat	55.2	63.9	51.0	
Semi-detached	14.8	23.1	7.8	
Detached	30.1	5.6	41.2	
[3] Local UGS provision				
Satisfaction with local UGS quality				d
Not at all	7.3	14.7	15.3	
Somewhat	15.8	28.4	26.5	
Very	76.9	56.9	58.2	
Share of UGS within 400 m of home [%]	20.7	10.2	10.5	c
Distance to nearest UGS [km]	1.2	0.4	0.3	c
[4] Socio-economics				
Age [years]	44.0	42.3	48.3	c
Car ownership				d
None	17.3	48.7	18.2	
One	45.7	40.0	55.3	
Two	37.7	10.7	26.5	
Education				d
Primary	6.2	9.7	7.3	
Secondary	36.8	34.4	58.8	
University	56.9	55.9	33.9	
Household size				d
Single	18.5	22.5	26.5	
2	33.8	28.4	37.1	
3 or 4	37.9	33.6	28.3	
>4 members	9.8	15.5	8.2	
Nationality				d
European	79.5	80.9	96.6	
Non-European	20.5	19.1	3.3	
Occupational status				d
At home	31.1	33.2	40.6	
Parttime	10.1	10.5	7.6	
Student	8.9	9.1	7.8	
Working	49.8	47.1	44.5	

reductions from 170 to 316 m on average.

4.3.5. *Effects of socio-economic characteristics (H4)*

We do not find a significant effect of gender despite other studies finding gender-related differences in UGS use (e.g. Shan, 2014). In general, all other socio-economic factor estimates are as expected. As discussed below, some coefficients show similar signs and intensity across the three cities but some are not uniform.

Among the very clear and systematic effects across cities, we find influences of education and nationality:

- First, higher education clearly leads to shorter distances. Since education is usually highly correlated with income, we think here of an effect of sorting on the housing market with wealthier residents located in greener neighbourhoods, but not necessarily related to a centrality effect.
- Second, being of non-European nationality also has a negative and systematic decreasing impact on distances. This is potentially explained by more investment in their local neighbourhood compared to European residents with potentially wider social connections beyond the neighbourhood. The result echoes cultural differences in UGS use reported by Rossi et al. (2015); Madureira et al. (2015).

Table 2
Results of the multi-level model: Fixed and combined coefficients (exponentiated coefficients minus 1). For example, a 1 km increase of the distance to the centre is associated with an increase of 0.01% of the walking distance in Luxembourg. Significant codes: 0 '***', 0.001 '**', 0.01 '*'.

Predictor variables	Fixed effects	Random + fixed effects		
	(Std err)	Luxembourg	Brussels	Rouen
[1] Characteristics of used UGS				
Size of most used UGS [ha]		0.001	−0.002	0.001
[2] Residential location				
Distance to centre [km]	0.003*** (0.000)	0.01	0.001	−0.001
Housing type: flat	ref			
semi-detached	0.113 (0.107)	0.155	0.066	0.120
detached	−0.085*** (−0.008)	0.028	−0.157	−0.117
[3] Local UGS provision				
Very satisfied with local UGS quality	−0.084*** (−0.007)	−0.110	−0.053	−0.089
[4] Socio-economics				
Age: younger than 25	ref			
25 to 35	0.285 (0.215)	0.249	0.300	0.307
35 to 45	0.234 (0.211)	0.248	0.207	0.249
45 to 55	0.434** (0.151)	0.310	0.411	0.603
55 to 65	0.151(0.140)	0.102	0.150	0.203
older than 65	−0.106* (0.011)	−0.232	0.388	0.286
Car ownership: none	ref			
(≥1 car)	−0.004* (−0.001)	−0.185	0.013	0.197
Education: primary	ref			
secondary	−0.138** (−0.014)	−0.110	−0.138	−0.164
university	−0.174 (−0.101)	−0.143	−0.157	−0.220
Household size: ≤ 2 members	ref			
≥3 members	−0.014 (0.010)	0.017	0.019	0.005
Nationality: European	ref			
Non-European	−0.005 (0.005)	0.028	−0.092	0.087
Occupation: full-time	ref			
part-time	0.215*** (0.019)	0.216	0.232	0.196
at home	0.149 (0.013) ***	0.509	−0.014	0.027
student	−0.117 (−0.124)	−0.246	−0.101	0.013
Gender: female	0.000 (0.000)	−0.109	0.051	0.069
Intercept	1705.846***	1721.570	1710.195	2662.401
Marginal R^2 0.026 Conditional R^2 0.20				

Results are also quite similar across cases with respect to respondents' age and occupational status, but with substantial differences in intensity:

- Residents of the most active ages (25–55) tend to make longer trips. In particular the age group 45 to 55 travel furthest to use UGS (450–2370 on average), which we relate to working patterns (having kids is controlled below). Beyond 55, results are more mixed but distances are generally lower than in active ages and even negative (i.e. a reduction compared to the <25 reference) for the eldest. This suggests a general influence of ageing on mobility, both by active modes or by car, as observed for example by Artmann et al. (2019) in Salzburg (Austria) or by Priess et al. (2021) in Vilnius (Lithuania). It seems though, comparatively, to be more strongly the case in Luxembourg.

– Respondents without an occupation (retired or at home) or working part-time tend to travel much further to use UGS. These are actually the strongest impacts of all variables in our model. Part-time status leads to an average 1.2–1.4 km increase in distance across cases, and home-based occupation leads to an average distance increase of 470 m in Brussels and up to a very long leap of 2.1 km in Luxembourg. The time budget saved in home-based and part-time occupations potentially leads to taking the best UGS opportunity, even if it means longer trips. It also probably relates to parents taking care of young children and to the physical/leisure activity of retired residents and part-time workers over weekdays. The reverse effect, but systematic across cases, is the shorter distance travelled to UGS by students. This may be a similar local community effect as for non-Europeans, or due to a lower availability of transportation modes

Finally, non-uniform resuts are found across cases - with Luxembourg standing out - for the last two variables: car ownership and household size.

– Households with three or more members tend to use UGS closer to their home in Brussels (- 100 m on average) but further away (+120 m on average) in Luxembourg, suggesting that for larger families the ease of access is more important in bigger and denser cities, while in smaller cities with a balanced green space offer, longer trips are made to find a better match in terms of UGS facilities or family amenities.
– Car ownership leads to an expected increase in travelled distances to UGS in Brussels and more so in Rouen. In Luxembourg, the impact is negative, reminding that Luxembourg is quite specific since both car ownership and use have been reported to be particularly high for many activities (Caruso et al., 2015; Perchoux et al., 2019). We think we rather capture an impact of more wealthy and greener neighbourhoods close to the centre than an increase in potential mobility. This differs from Brussels and Rouen where having a car is definitely a means for increasing mobility ranges, and more so for central residents.

5. Discussion

We find that the travelled distance to the most used UGS is well beyond the 300–500 m buffer distance used in provision or accessibility measurements. Residents travel a lot farther to their regular UGS, i.e. a median of 1.4–1.9 km (and often more given the long queued distribution). These distances also raise the question of motorised transport to access nature on a regular basis and the related equity. Also, we expected trips of residents living in the peripheries to be shorter as peripheries are greener. In the case of Luxembourg many suburban residents actually use an UGS near the centre, potentially during their lunch break or combined with a shopping trip to the centre. One explanatory aspect is thus the potential combination of UGS visit with a chain of other activities. It is important for policy to know that UGS use is not simply an encounter around residential places but likely part of a more complex chain of activities.

Our results also point to a self-selection issue (as suggested by Maat & de Vries, 2006; Schindler et al., 2018) whereby the availability of UGS in the periphery is a quality valued in the residential choice process by those residents who are more prone to value UGS and can afford it. It is thus also in line with Lin et al. (2014) who stress that the orientation toward nature is more important than the actual distance.

Another finding is the heterogeneity across cases despite our cities being culturally quite similar. The spatial pattern of links between home and UGS shows a hub and spoke structure in Brussels but more centre-periphery structures in Rouen and Luxembourg. The city context does not only lead to a difference in geographical structures but also a substantial 1 km difference between cases. Again in view of the 300 or 500 m accessibility buffers or policy targets, this context effect represents a very large (i.e. 2- or 3-fold) uncertainty. This heterogeneity certainly calls for more comparative analyses where a similar survey is applied and the spatial structure of the city accounted for, including the distribution of UGS and population segments. More generally there is a strong need to further research differences between cities and to find out if systematic variations exist that we can relate to the integration of nature within the urban fabric to support planning policy.

Further, we have identified a set of socio-demographics, especially influences of age and occupational status. Retirement, home-based activities and part-time work lead to much increased trips, the implications of which may be particularly important in an ageing society or if home-based work patterns become more frequent. We can also conjecture about an increase in electric-aided mobility (e.g. e-bikes, scooters), which may relieve the proximity constraint further.

We had to dismiss classical spatial interaction effects in the sense that UGS size was unexpectedly found to command shorter trips in two of our cases, and because the objectively measured local provision of UGS did not prove to be a determining factor. Rather, it is the perception of a provision of quality UGS around homes which seems to reduce travel distances. This finding departs from other studies (e.g. Chiesura, 2004; Neuvonen et al., 2007) and suggests that improving peoples' perception of UGS is more promising to increase UGS use and benefits than an objective provision of UGS alone. We can think of a need for a policy to invest in UGS facilities in line with users' needs and to promote vegetation that is sufficiently perceived as providing benefits; rather than a focus on quantity of land and proximity.

In addition to residents' socio-economic characteristics and residential environment considered in this study, the reason for UGS use might impact UGS use patterns (e.g. increased frequency of UGS visits for dog walkers (Schindler et al., 2018)) and might be relevant information for management of UGS facilities and decisions on which type of UGS to provide where. Due to the interconnections of UGS use motivation and the factors considered in this study, this is an avenue for future research.

One could also split UGS use patterns based on travel mode used to access UGS. While this could give valuable insights for transport planners, actual travel distances regardless of transport mode - as considered in this study - provide urban planners with unmasked information to evaluate actual UGS accessibility with respect to given policy target measures and provision plans. In this study, car ownership serves as indication for such discussions. Future research could collect and consider such information to inform transport planning.

6. Conclusion

This study attempted to understand the distance that people usually travel to use UGS and the variations thereof across three different cities, and across socio-economic groups and locations within these cities. In times of densification and infill development strategies our question fits into the debate of how best to provide green space relative to demand. The question is particularly important in programmatic terms because land and budget resources are limited and other human activities (residences, commerce, offices) compete for undeveloped parcels. In normative terms it also makes sense to keep these other activities centralised to foster sustainability, hence a complex and paradoxical agenda.

Much of the evidence obtained so far across many cities focuses on aggregate provision of UGS or spatial proximity. In case study analyses the distance to provisioned UGS is at best one factor explaining use. Here we have turned the question on its head and asked what are the determinants of the distance actually travelled to UGS because the distance itself may reveal different behaviours or provision mismatch within the city or across cities.

Our results call for a re-evaluation of UGS analytical practices and provision policies beyond aggregate and accessibility perspectives and towards spatially varying measures. For example, the fact that we find much larger catchment areas than expected for an 'UGS that one uses the most' plus the fact that some results suggest that UGS visits are part of a more complex set of activities, further away from residences, point to a nested or multi-scalar thinking of UGS provision, with a diversity of sizes and proximities.

This study obtained unexpected results with respect to centrality within cities, stressing a need for further research and more advanced techniques to overcome the fact that the differentiated provision of UGS along the centre-periphery gradient correlates with socio-economic dimensions and residential sorting.

Declaration of competing interest

None.

Acknowledgements

The authors acknowledge funding from the University of Luxembourg through its competitive research scheme and the project SOSBUGS - Spatial Optima and the Social Benefits of Urban Green Space.

References

ACEA. (2021). *Vehicles in use: Europe*. Technical Report European Automobile Manufacturers Association Brussels https://www.acea.be/uploads/publications/.

Artmann, M., Mueller, C., Goetzlich, L., & Hof, A. (2019). Supply and demand concerning urban green spaces for recreation by elderlies living in care facilities: The role of accessibility in an explorative case study in Austria. *Frontiers in Environmental Science, 7*, 136. https://www.frontiersin.org/article/10.3389/fenvs.2019.00136. doi:10.3389/fenvs.2019.00136.

Aziz, N. A. A., Konijnendijk van den Bosch, C., & Nillson, K. (2018). Recreational use of urban green space in malaysian cities. *International Journal of Business and Society, 19*, 1–16.

Badiu, D. L., Iojă, C. I., Pătroescu, M., Breuste, J., Artmann, M., Niță, M. R., Grădinaru, S. R., Hossu, C. A., & Onose, D. A. (2016). Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. *Ecological Indicators, 70*, 53–66. https://doi.org/10.1016/j.ecolind.2016.05.044. https://www.sciencedirect.com/science/article/pii/S1470160X16302928. Navigating Urban Complexity: Advancing Understanding of Urban Social – Ecological Systems for Transformation and Resilience.

Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P., & Gaston, K. J. (2007). Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning, 83*, 187–195.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1–48. https://doi.org/10.18637/jss.v067.i01

Bertram, C., Meyerhoff, J., Rehdanz, K., & Wüstemann, H. (2017). Differences in the recreational value of urban parks between weekdays and weekends: A discrete choice analysis. *Landscape and Urban Planning, 159*, 5–14. https://doi.org/10.1016/j.landurbplan.2016.10.006

Bertram, C., & Rehdanz, K. (2015). Preferences for cultural urban ecosystem services: Comparing attitudes, perception, and use. *Ecosystem Services, 12*, 187–199. https://doi.org/10.1016/j.ecoser.2014.12.011. doi:10.1016/j.ecoser.2014.12.011.

Boulton, C., Dedekorkut-Howes, A., & Byrne, J. (2018). Factors shaping urban greenspace provision: A systematic review of the literature. *Landscape and Urban Planning, 178*, 82–101. https://doi.org/10.1016/j.landurbplan.2018.05.029. https://www.sciencedirect.com/science/article/pii/S0169204618304341

Boura, M., & Caruso, G. (2020). Land cover, landscape metrics and typology of European cities for Urban Forest Ecosystem Services (UFES) evaluation. https://doi.org/10.5281/zenodo.4301952. doi:10.5281/zenodo.4301952.

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. *Landscape and Urban Planning, 97*, 147–155. https://doi.org/10.1016/j.landurbplan.2010.05.006

Caruso, G., Gerber, P., Hesse, M., & Viti, F. (2015). Challenges, specificities and commonalities of transport research and policy within the benelux countries–the case of Luxembourg. *European Journal of Transport and Infrastructure Research, 15*.

Chiesura, A. (2004). The role of urban parks for the sustainable city. *Landscape and Urban Planning, 68*, 129–138. https://doi.org/10.1016/j.landurbplan.2003.08.003

Choumert, J., & Cormier, L. (2011). The provision of urban parks: An empirical test of spatial spillovers in an urban area using geographic information systems. *The Annals of Regional Science, 47*, 437–450.

Comber, A., Brunsdon, C., & Green, E. (2008). Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. *Landscape and Urban Planning, 86*, 103–114. https://doi.org/10.1016/j.landurbplan.2008.01.002

Conedera, M., Del Biaggio, A., Seeland, K., Moretti, M., & Home, R. (2015). Residents' preferences and use of urban and peri-urban green spaces in a Swiss mountainous region of the Southern Alps. *Urban Forestry and Urban Greening, 14*, 139–147. https://doi.org/10.1016/j.ufug.2015.01.003. doi:10.1016/j.ufug.2015.01.003.

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine, 70*, 816–822. https://doi.org/10.1016/j.socscimed.2009.11.020

Dai, D. (2011). Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landscape and Urban Planning, 102*, 234–244. https://doi.org/10.1016/j.landurbplan.2011.05.002. URL: https://www.sciencedirect.com/science/article/pii/S0169204611001952.

Ernstson, H. (2013). The social production of ecosystem services: A framework for studying environmental justice and ecological complexity in urbanized landscapes. *Landscape and Urban Planning, 109*, 7–17. https://doi.org/10.1016/j.landurbplan.2012.10.005. Special Issue: Urban Ecosystem Services.

European Commission. (2020). *The New Leipzig Charter: The Transformative Power of Cities for the Common Good*. https://ec.europa.eu/regional_policy/en/information/publications/brochures/2020/new-leipzig-charter-the-transformative-power-of-cities-for-the-common-good.

Fischer, L. K., Honold, J., Botzat, A., Brinkmeyer, D., Cvejić, R., Delshammar, T., Elands, B., Haase, D., Kabisch, N., Karle, S. J., Lafortezza, R., Nastran, M., Nielsen, A. B., van der Jagt, A. P., Vierikko, K., & Kowarik, I. (2018). Recreational ecosystem services in European cities: Sociocultural and geographical contexts matter for park use. *Ecosystem Services, 31*, 455–467. https://doi.org/10.1016/j.ecoser.2018.01.015

Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in european cities. *Biology Letters, 5*, 352–355.

Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models volume Analytical methods for social research*. New York: Cambridge University Press.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Lange, A., & Donovan, R. J. (2005). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine, 28*, 169–176. https://doi.org/10.1016/j.amepre.2004.10.018

Haaland, C., & Konijnendijk van den Bosch, C. (2015). Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry and Urban Greening, 14*, 760–771. https://doi.org/10.1016/j.ufug.2015.07.009. URL: https://www.sciencedirect.com/science/article/pii/S1618866715001030X.

Havret, M. (2020). *Substituer de l'espace vert privé par de l'espace vert public: Un choix multifactoriel. l'exemple de l'unité urbaine de rouen. Espace populations sociétés*. Space populations societies.

Huang, F. L. (2018). Multilevel modeling myths. *School Psychology Quarterly, 33*, 492–499.

Jalkanen, J., Fabritius, H., Vierikko, K., Moilanen, A., & Toivonen, T. (2020). Analyzing fair access to urban green areas using multimodal accessibility measures and spatial prioritization. *Applied Geography, 124*, 102320. https://doi.org/10.1016/j.apgeog.2020.102320. URL: https://www.sciencedirect.com/science/article/pii/S0143622820303568.

Jayasooriya, V. M., Ng, A. W., Muthukumaran, S., & Perera, B. J. (2017). Green infrastructure practices for improvement of urban air quality. *Urban Forestry and Urban Greening, 21*, 34–47. https://doi.org/10.1016/j.ufug.2016.11.007

Jim, C. Y., & Chen, W. Y. (2006). Recreation-amenity use and contingent valuation of urban greenspaces in Guangzhou, China. *Landscape and Urban Planning, 75*, 81–96. https://doi.org/10.1016/j.landurbplan.2004.08.008

Jones, A., Hillsdon, M., & Coombes, E. (2009). Greenspace access, use, and physical activity: Understanding the effects of area deprivation. *Preventive Medicine, 49*, 500–505. https://doi.org/10.1016/j.ypmed.2009.10.012

Kabisch, N., & Haase, D. (2014). Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landscape and Urban Planning, 122*, 129–139.

Kabisch, N., Qureshi, S., & Haase, D. (2015). Human-environment interactions in urban green spaces - a systematic review of contemporary issues and prospects for future research. *Environmental Impact Assessment Review, 50*, 25–34. https://doi.org/10.1016/j.eiar.2014.08.007

Kabisch, N., Strohbach, M., Haase, D., & Kronenberg, J. (2016). Urban green space availability in European cities. *Ecological Indicators, 70*, 586–596. https://doi.org/10.1016/j.ecolind.2016.02.029. http://www.sciencedirect.com/science/article/pii/S1470160X16300504

Kahle, D., & Wickham, H. (2013). ggmap: Spatial visualization with ggplot2. *The R Journal, 5*, 144–161. http://journal.r-project.org/archive/2013-1/kahle-wickham.pdf.

Konijnendijk van den Bosch, C. (2021). *Introducing-the-3-30-300-rule*. https://iucnurbanalliance.org/promoting-health-and-wellbeing-through-urban-forests-introducing-the-3-30-300-rule/. (Accessed December 2021).

Konijnendijk van den Bosch, C. C., Annerstedt, M., Nielsen, A. B., & Maruthaveeran, S. (2013). *Benefits of urban parks. A systematic review. A Report for IFPRA*. Copenhagen & Alnarp.

Le Texier, M., Schiel, K., & Caruso, G. (2018). The provision of urban green space and its accessibility: Spatial data effects in brussels. *PLoS One, 13*, Article e0204684.

Lemoy, R., & Caruso, G. (2020). Evidence for the homothetic scaling of urban forms. *Environment and Planning B: Urban Analytics and City Science, 47*, 870–888.

Lin, B. B., Fuller, R. A., Bush, R., Gaston, K. J., & Shanahan, D. F. (2014). Opportunity or orientation? Who uses urban parks and why. *PLoS One, 9*, 1–8. https://doi.org/10.1371/journal.pone.0087422

Maat, K., & de Vries, P. (2006). The influence of the residential environment on green-space travel: Testing the compensation hypothesis. *Environment and Planning A, 38*, 2111–2127. https://doi.org/10.1068/a37448

Madureira, H., Nunes, F., Oliveira, J. V., Cormier, L., & Madureira, T. (2015). Urban residents' beliefs concerning green space benefits in four cities in France and Portugal. *Urban Forestry and Urban Greening, 14*, 56–64. https://doi.org/10.1016/j.ufug.2014.11.008. https://www.sciencedirect.com/science/article/pii/S1618866714001320

Neuvonen, M., Sievänen, T., Tönnes, S., & Koskela, T. (2007). Access to green areas and the frequency of visits – a case study in helsinki. *Urban Forestry and Urban Greening, 6*, 235–247. https://doi.org/10.1016/j.ufug.2007.05.003

Ngom, R., Gosselin, P., & Blais, C. (2016). Reduction of disparities in access to green spaces: Their geographic insertion and recreational functions matter. *Applied Geography, 66*, 35–51. https://doi.org/10.1016/j.apgeog.2015.11.008. https://www.sciencedirect.com/science/article/pii/S014362281530014X

OpenStreetMap contributors. (2016). *OpenStreetMap Data*. https://www.openstreetmap.org.

Perchoux, C., Brondeel, R., Wasfi, R., Klein, O., Caruso, G., Vallée, J., Klein, S., Thierry, B., Dijst, M., Chaix, B., et al. (2019). Walking, trip purpose, and exposure to multiple environments: A case study of older adults in Luxembourg. *Journal of Transport & Health, 13*, 170–184.

Picard, P., & Tran, T. (2021a). Small urban green areas. *Journal of Environmental Economics and Management, 106*, 102418. https://doi.org/10.1016/j.jeem.2021.102418. https://www.sciencedirect.com/science/article/pii/S0095069621000012

Picard, P. M., & Tran, H. T. T. (2021b). Geographical stratification of urban green areas in European cities. *Journal of Economic Geography*. https://doi.org/10.1093/jeg/lbab004

Priess, J., Pinto, L. V., Misiune, I., & Palliwoda, J. (2021). Ecosystem service use and the motivations for use in central parks in three european cities. *Land, 10*. https://www.mdpi.com/2073-445X/10/2/154. doi:10.3390/land10020154.

Refshauge, A. D., Stigsdotter, U. K., & Cosco, N. G. (2012). Adults' motivation for bringing their children to park playgrounds. *Urban Forestry & Urban Greening, 11*, 396–405.

Roovers, P., Hermy, M., & Gulnick, H. (2002). A survey of recreation interests in urban forests, the influence of travel distance. In *Monitoring and management of visitor flows in recreational and protected areas, Conference Proceedings* (pp. 277–283).

Rossi, S. D., Byrne, J. A., & Pickering, C. M. (2015). The role of distance in peri-urban national park use: Who visits them and how far do they travel? *Applied Geography, 63*, 77–88. https://doi.org/10.1016/j.apgeog.2015.06.008. https://www.sciencedirect.com/science/article/pii/S0143622815001526

Schetke, S., Qureshi, S., Lautenbach, S., & Kabisch, N. (2016). What determines the use of urban green spaces in highly urbanized areas? – examples from two fast growing asian cities. *Urban Forestry and Urban Greening, 16*, 150–159. https://doi.org/10.1016/j.ufug.2016.02.009. URL: https://www.sciencedirect.com/science/article/pii/S1618866715300406.

Schindler, M., & Caruso, G. (2020). Emerging urban form–emerging pollution: Modelling endogenous health and environmental effects of traffic on residential choice. *Environment and Planning B: Urban Analytics and City Science, 47*, 437–456.

Schindler, M., Le Texier, M., & Caruso, G. (2018). Spatial sorting, attitudes and the use of green space in brussels. *Urban Forestry and Urban Greening, 31*, 169–184.

Schipperijn, J., Ekholm, O., Stigsdotter, U. K., Toftager, M., Bentsen, P., Kamper-Jørgensen, F., & Randrup, T. B. (2010). Factors influencing the use of green space: Results from a Danish national representative survey. *Landscape and Urban Planning, 95*, 130–137. https://doi.org/10.1016/j.landurbplan.2009.12.010

Scott, M. M., Evenson, K. R., Cohen, D. A., & Cox, C. E. (2007). Comparing perceived and objectively measured access to recreational facilities as predictors of physical activity in adolescent girls. *Journal of Urban Health, 84*, 346–359.

Shafer, S. C., Scott, D., Baker, J., & Winemiller, K. (2013). Recreation and amenity values of urban stream corridors: Implications for green infrastructure. *Journal of Urban Design, 18*, 478–493. https://doi.org/10.1080/13574809.2013.800450

Shan, X. Z. (2014). Socio-demographic variation in motives for visiting urban green spaces in a large Chinese city. *Habitat International, 41*, 114–120. https://doi.org/10.1016/j.habitatint.2013.07.012. doi:10.1016/j.habitatint.2013.07.012.

Spielman, S. E., Yoo, E.-H., & Linkletter, C. (2013). Neighborhood contexts, health, and behavior: Understanding the role of scale and residential sorting. *Environment and Planning B: Planning and Design, 40*, 489–506. https://doi.org/10.1068/b38007. doi.org/10.1068/b38007.

Stafford, L., & Baldwin, C. (2018). Planning walkable neighborhoods: Are we overlooking diversity in abilities and ages? *Journal of Planning Literature, 33*, 17–30.

Talen, E. (2010). The spatial logic of parks. *Journal of Urban Design, 15*, 473–491. https://doi.org/10.1080/13574809.2010.502335

Tyrväinen, L., Mäkinen, K., & Schipperijn, J. (2007). Tools for mapping social values of urban woodlands and other green areas. *Landscape and Urban Planning, 79*, 5–19. https://doi.org/10.1016/j.landurbplan.2006.03.003

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 and Urban Planning, 81*, 167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001. https://www.sciencedirect.com/science/article/pii/S0169204607000503

Van Herzele, A., & Wiedemann, T. (2003). A monitoring tool for the provision of accessible and attractive urban green spaces. *Landscape and Urban Planning, 63*, 109–126. https://doi.org/10.1016/S0169-2046(02)00192-5

WHO. (2016). *Urban green spaces and health. Technical report World health Orgnisation Copenhagen: WHO regional office for Europe*.

Wolch, J. R., Byrne, J., & Newell, J. P. (2014). Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landscape and Urban Planning, 125*, 234–244. https://doi.org/10.1016/j.landurbplan.2014.01.017

Zhang, W., Yang, J., Ma, L., & Huang, C. (2015). Factors affecting the use of urban green spaces for physical activities: Views of young urban residents in Beijing. *Urban Forestry and Urban Greening, 14*, 851–857. https://doi.org/10.1016/j.ufug.2015.08.006

Zhang, J., Yue, W., Fan, P., & Gao, J. (2021). Measuring the accessibility of public green spaces in urban areas using web map services. *Applied Geography, 126*, 102381. https://doi.org/10.1016/j.apgeog.2020.102381. https://www.sciencedirect.com/science/article/pii/S0143622820314806

Zwierzchowska, I., Hof, A., Iojă, I.-C., Mueller, C., Poniży, L., Breuste, J., & Mizgajski, A. (2018). Multi-scale assessment of cultural ecosystem services of parks in central european cities. *Urban Forestry and Urban Greening, 30*, 84–97. https://doi.org/10.1016/j.ufug.2017.12.017. https://www.sciencedirect.com/science/article/pii/S1618866717304442. Special feature: Strategic gardens and gardening: Inviting a widened perspective on the values of private green space.