KU LEUVEN

FACULTY OF BIOSCIENCE ENGINEERING

Developing an Urban Green Accessibility Index for Flanders

A Comprehensive Analysis of Accessible Urban Green Spaces

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Scientific summary

The course of humanity has been marked by an acceleration of urbanisation. Urban Green Spaces (UGS) have been recognised as a crucial factor for promoting mental and physical health and thereby tackling challenges associated with urbanisation. Given the relationship between UGS and human health benefits, there is a need for evidence-based guidelines for policymakers and urban planners to ensure sufficient and equitable access to UGS and its benefits.

Therefore, the primary objective of this thesis was to deliver an instrument that could guide policymakers by evaluating UGS accessibility. To achieve this, several components were required. First, a workflow was created to delineate UGS in Flanders based on processed OpenStreetMap (OSM) data. To validate this map, a reference dataset for UGS in Flanders was created. Second, a pedestrian-and cyclist-centred Urban Green Accessibility Index (UGAI) for Flanders was developed, which considered the quantity, quality, and context of UGS. For the quantity, a traffic network analysis was performed using the OSM traffic network and entrance points to calculate isochrones of a 10-minute walk and bike ride. The quality of UGS was introduced in the index by combining four indicators - size, biological value, tree cover and land cover diversity - and incorporated into the UGAI together with the accessibility. The context was introduced by three indicators - the population density, overall green cover and garden area - to reflect the demand for additional UGS in a statistical sector, and implemented in the corrected UGAI (cUGAI).

The accuracy assessment of OSM data revealed that the UGS class had a user's accuracy of 70.3% and producer's accuracy of 89.2%, surpassing other sources evaluated. This made OSM the most suitable map for conducting further analysis. The traffic network analysis showed that only 55.2% of the population could access UGS within walking distance from their home, and 99.5% found UGS within a 10-minute bike ride. The UGAI and cUGAI for Flanders were calculated based on quality and context, uncovering distinct patterns. Specifically, the city centres of larger cities, like Leuven and Ghent, displayed the lowest scores and the highest need for urgent action.

The outcomes present important implications for urban planners and policy makers, emphasising the need to enhance UGS accessibility through walking and investing in cycling infrastructure. The proposed UGAI and cUGAI model offers municipalities a valuable tool that provides information on UGS quantity, quality, and context, separately or combined. The tool's potential lies in its adaptability to policymakers' needs and its transferability beyond Flanders' boundaries.

List of Abbreviations

cUGAI	Corrected Urban Green Accessibility Index
ES	Ecosystem Services
FME	Feature Manipulation Engine
GIS	Geospatial Information Systems
Gsg	*Grootstedelijk gebied* (metropolitan area)
h	Hour
ha	Hectares
km	Kilometres
Ksg	*Kleinstedelijk gebied* (small urban area)
m	Metres
min	Minutes
OA	Overall Accuracy
OSM	OpenStreetMap
PA	Producer’s accuracy
QGIS	Quantum Geographic Information System
QNEAT3	QGIS Network Analysis Toolbox 3
Rsg	*Regionaalstedelijk gebied* (regional urban area)
s	Second
UA	User’s accuracy
UGAI	Urban Green Accessibility Index
UGS	Urban Green Space(s)
UHI	Urban Heat Island
UN	United Nations
VGI	Volunteered Geographic Information
WHO	World Health Organization

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1. Introduction

1.1 Challenges and opportunities for human health

The course of humanity has been marked by an acceleration of urbanisation, concentrating large numbers of people in small areas (Britannica, 2022). By the beginning of the 21st century, more than half of the world population lived in urban areas. Projections of urbanisation by the United Nations Department of Economic and Social Affairs (2019) estimate that 68% of the global population will reside in cities by 2050. Although urbanisation creates opportunities, such as education and employment, it is also accompanied by specific challenges and problems, such as higher temperatures, decreased levels of air quality and disconnection from nature.

One of the primary motivations for addressing this issue, is the potential negative impact it may have on the physical and mental health of the population. In this regard, Urban Green Spaces (UGS) have been recognised as a crucial factor for promoting health and well-being and thereby tackling challenges associated with urbanisation (World Health Organization. Regional Office for Europe, 2016). With the context of health in mind, the World Health Organization (WHO) Regional Office for Europe (2016) defines UGS as public green areas for predominantly recreational use, including parks, urban forests, and suburban natural areas that are managed as urban parks. Urban areas are not abundantly provided with this UGS.

In literature, there is a strong consensus that the health benefits from UGS are beyond doubt. UGS are linked to people through pathways relating contact with nature to health, which are approached in multiple ways. Pathways can be summarised as (1) indirect benefits on health from ecosystems delivered by UGS in the surroundings, such as Urban Heat Island (UHI) mitigation and air quality improvement, (2) short-term physiological and psychological effects, such as improved attention restoration and vitality, and (3) positive effects on physical activity and social cohesion by encouraging healthy behaviour (Zhang et al., 2021a). It is important to note that the impact on mental and physical health is contingent upon how individuals perceive and experience the natural environment (Bratman et al., 2019). Therefore, the perceived quality of an UGS is critical in determining the eventual health benefits that people derive from them. In this regard, the level of naturalness and biodiversity present in UGS is fundamental, as it not only supports the delivery of ecosystem services, but also directly influences the quality of nature experience and, consequently, human health (Marselle et al., 2021).

Given the relationship between UGS and human health benefits, it is imperative to ensure there is adequate provision of these spaces to meet the needs of all members of the population. Moreover, socially vulnerable communities have less access to qualitative UGS and their benefits (Watkins & Gerrish, 2018), which is referred to as tree inequity (Konijnendijk, 2022). Therefore, there is a need for evidence-based guidelines for policymakers and urban planners to ensure sufficient and equitable access to UGS and its benefits (Konijnendijk, 2022).

Developing an 'Urban Green Accessibility Index' can support city planners and municipalities in evaluating and managing available UGS. This tool is a valuable instrument that focusses on the availability and accessibility of UGS and can identify areas where the latter is lacking. Here, accessibility refers to how easy something is to reach, enter, use, or see (Oxford University, n.d.). The index presented in this study is based on a theoretical framework that emphasises the relationship and pathways between contact with nature and human health. Especially in Flanders, one of the most urbanised regions in Europe (Poelmans & van Rompaey, 2009), there is a need for such an index.

1.2 Towards an Urban Green Accessibility Index for Flanders

Previous attempts to develop similar indices have been made by multiple researchers in the field (Maroko et al., 2009). Within this field, certain gaps of knowledge can be identified. A major knowledge gap in Flanders is the absence of reliable reference data on public green. Typically, land cover and land use maps incorporate the presence of vegetative cover in an area, but they often do not provide details on the public or private character of green space. Thereby, the use of OpenStreetMap (OSM) as a data source for UGS remains limited in literature. Furthermore, there is a lack of the use of bicycles as a transport mode in accessibility analyses based on the traffic network. For this traffic network analysis, it was also pointed out that a measure of access needs to consider actual points of entry, because this influences the actual accessibility of UGS (Maroko et al., 2009), but no publications implemented this because of a lack of data. Additionally, there is a lack of studies that try to implement biological and ecosystem valuation as a quality indicator. Finally, no studies compare the accessibility of UGS to the context of a neighbourhood where these UGS are supplied in their index. Introducing this, would represent a novel contribution to the existing literature on this topic.

The thesis presented here tackles the knowledge gaps mentioned above. The primary objective is to analyse and evaluate the accessibility of UGS in Flanders. To achieve this, several components are required. First, a map of UGS in Flanders is needed. Therefore, multiple data sources will be assessed and the suitability of OSM data will be investigated for urban areas in Flanders. Next, a pedestrian-and cyclist-centred urban green accessibility index for Flanders will be developed, which will consider the quantity, quality, and context of UGS. The resulting product can be customised to meet the specific needs of policy makers and provide answers to important questions such as the number of individuals that have adequate access to qualitative green within 10-minute walk to their residence.

2. Literature review

2.1 Challenges for an urbanising world

Urbanisation presents various opportunities, such as education and employment, but specific challenges and problems as well, not at least concerning public health. The World Health Organization (2022) for example identified several health-related challenges associated with living in cities, related to heavy traffic, air and noise pollution, violence, social isolation, increased rate of disease transition and large inequalities.

First, the changing climate has a large effect on the urban living environment (United Nations Development Programme, 2022). Locally, temperatures can rise significantly due to Urban Heat Islands (UHIs). The intensity of these UHIs also tends to increase with increasing city size and population (Arnfield, 2003), leading to a higher risk of heat-related deaths, especially among the elderly population.

A second major threat to urban areas is air pollution. The European Environment Agency (2022) estimated that in 2020, 71% and 96% of the urban population were exposed to higher PM_{10} and $PM_{2.5}$ levels, respectively, exceeding the concentrations marked as dangerous by the World Health Organization (WHO) guidelines.

Furthermore, urban demographics and the growing economy have put increasing pressures on ecosystems by causing densification, sprawl and ultimately, fragmentation. These developments alter the nature of activities carried out within the city and pose a risk on people to become disconnected from nature due to decreased opportunities to connect and diminished emotional connection (Palliwoda et al., 2017; Soga & Gaston, 2016). This loss of interaction with nature, reduces a lot of physical and mental health-related benefits that come from contact with nature, such as stress reduction and positive changes in physiological activity (Hartig et al., 2014). Moreover, it discourages a positive attitude towards the environment (Soga & Gaston, 2016).

2.2 The benefits of urban green

2.2.1 Definition of urban green spaces

When examining Urban Green Spaces (UGS) with a focus on public health, the definition of UGS must be aligned with the specific requirements and objectives of public health (Annerstedt van den Bosch et al., 2015). A commonly used standard is the Accessible Natural Greenspace Standard

(ANGSt) definition, which refers to accessible green spaces as vegetation zones that are available to the public without any time or financial restrictions (Harrison et al., 1995). The most common definition in Europe is the one provided by the WHO's Regional Office for Europe (2016). This is based on the definition from the European Urban Atlas (European Union, 2011). According to this definition, Green Urban Areas include

> *Public green areas for predominantly recreational use such as gardens, zoos, parks, castle parks and cemeteries (cemeteries were included in class 1.2.1 for UA2006). Suburban natural areas that have become and are managed as urban parks. Forests or green areas extending from the surroundings into urban areas are mapped as green urban areas when at least two sides are bordered by urban areas and structures, and traces of recreational use are visible* (p.21).

This definition excludes private gardens within housing area, buildings within parks and patches of natural vegetation or agricultural areas enclosed by built-up areas without being managed as UGS. However, similar to the standard of the WHO's Regional Office for Europe (2016), it could be useful to include waterbodies enclosed by green space as UGS as they are attractive features enjoyed by people.

2.2.2 The ecosystem services provided by urban green

Having sufficient, qualitative urban green spaces (UGS) is crucial for tackling a multitude of the challenges of urban living environments. Natural ecosystems such as UGS provide services with direct and indirect contributions to human wellbeing, which are referred to as ecosystem services (ES). ES consist of provisioning, regulating, cultural, and supporting services (Millennium Ecosystem Assessment, 2005; Kumar, 2012). Bolund and Hunhammar (1999) already defined the concept of urban ecosystems in 1999 and concluded that these locally generated services improve the quality-of-life in urban areas and should be addressed in policy.

Bertram and Rehdanz (2015) researched ES provision by UGS and concluded that regulating services, such as climate, water regulation, and air quality regulation, are highly crucial in cities. They stated however that within the context of UGS, cultural ES are likely the most important. These include tourism, recreation, aesthetic appreciation, education, and spiritual experiences.

Besides the benefits provided by ES for the basic needs and well-being of people and other organisms, urban green can also provide municipalities and citizens with economic benefits (Bertram & Rehdanz, 2015). They have the potential, for example, to increase property values, reduce energy costs (e.g., for air-conditioning) and boost tourism (Heidt & Neef, 2008).

2.2.3 The positive effect of urban green on human health

Recently, improvement of mental and physical health by ecosystems is considered more frequently as an ES. These health benefits can be obtained from direct interaction with nature, as well as indirectly, through other ES, like filtering air pollution or reducing UHIs (cf. §2.2.2). People can interact with green by doing physical activities, by relaxing or by socially interacting in, or with a view on, urban green. This means benefits can be obtained by either viewing or intentionally entering and using UGS (Zhang et al., 2021a). First, a summary of important health benefits is provided. Second, possible pathways explaining the relationship between contact with nature and health are discussed. Knowing the elements that underlie these pathways is crucial for developing a tool to monitor UGS effectively. The third paragraph explains indirect pathways through which nature can promote health benefits, primarily by influencing people's experience and perception. The section concludes with an explanation of how biodiversity underpins all these aspects.

2.2.3.1 Physical and mental health benefits

As residents use green spaces for relaxation, recreation, and sports, Ulrich et al. (1991) stated that contact with nature involved a reduce of stress and positive changes in physiological activity with sustained attention. Hartig et al. (2014) added improved air quality and greater social cohesion due to green spaces as a contribution to public health and suggested that other health problems traceable to chronic stress could be reduced as well, although explaining the association is not straightforward. Additional direct physical health benefits are reduced obesity (Fox et al., 2004) and increased longevity (Takano et al., 2002). Stas et al. (2021) even found that exposure to green space is inversely associated with allergy symptoms. This summary of health benefits is also part of an overview by the WHO's Regional Office for Europe (2016) categorising some major health benefits, including improved mental health and cognitive function, reduced cardiovascular morbidity, reduced prevalence of type 2 diabetes, improved pregnancy outcomes and finally, reduced mortality. Furthermore, the WHO added some potential pathogenic effects of green spaces, like exposure to disease vectors through, for example, ticks and accidental injuries.

2.2.3.2 Pathways through which contact with nature relates to health

To identify which aspects of urban green spaces are important for mental and physical health benefits, the pathways through which contact with nature relates to health should be elaborated on. In literature, various approaches are taken to identify these pathways, but the focus is on exploring how health benefits are derived from contact with nature.

Bratman et al. (2019) traced a pathway from the environment to receiving mental health benefits by identifying four successive steps. The steps comprise (1) defining natural features, assessing (2) the nature exposure and (3) experience, and finally, (4) assessing the mental health benefits obtained from this experience. Hartig et al. (2014) distinguished four pathways through which contact with nature influences human health: air quality, physical activity, social cohesion, and stress reduction. The WHO’s Regional Office for Europe (2016) added improved functioning of the immune system, anthropogenic noise buffering and the production of natural sounds, optimised exposure to sunlight and improved sleep as possible pathways in their literature review.

Zhang et al. (2021a) summarises all these pathways into three categories of pathways underlying the relationship between UGS and health: (1) benefits from ecosystem services delivered by UGS in the surroundings, such as UHI mitigation and air quality improvement, providing a better living environment for people; (2) short-term physiological and psychological effects, such as improved attention restoration and vitality; and (3) positive effects on physical activity and social cohesion by encouraging healthy behaviour. A few of these pathways are selected and discussed in more detail.

Air quality

Air quality is a first pathway relating contact with nature to health, according to Hartig et al. (2014), although they recognised that this pathway does not necessarily require direct contact with nature. Air quality is improved by UGS directly, e.g., through reduction of air pollution or indirectly, e.g., through the cooling effect that causes less pollution from cooling devises. Trees in UGS are often pointed out as the main drivers of these positive effects (Janowiak et al., 2021; Konijnendijk, 2022; Yan et al., 2019).

Reduction of the Urban Heat Island effect

Another pathway that does not require direct contact with nature, is the reduction of the UHI effect. This is the effect caused by the transition from natural vegetation to artificial infrastructure that raises the thermal storage capacity of urban areas, leading to a substantial alteration in the urban climate. Increasing the relative amount of UGS has been shown to promote cool cities, resulting in less heat-related deaths (Luber & McGeehin, 2008). Yan et al. (2019) observed that tree cover is the most influential factor in causing urban cooling. and especially buffers high summer temperatures (Janowiak et al., 2021).

Physical activity

It is largely confirmed by scientists that physical activity improves the health status (Warburton et al., 2006). By providing suitable spaces for recreative activities and experiences, the amount of natural environment available for people to recreate might influence how physically active an individual is (Hartig et al., 2014). De Vries et al. (2013) found a mixed result in several studies, but overall, there was a positive relationship between physical activity and the availability of urban green space, although the causality is unclear (Annerstedt van den Bosch et al., 2015; Maas et al., 2008). Furthermore, they stated that there was a stronger relationship between the quality of greenery (e.g., aesthetics or attractiveness) and specific types of activity. Most studies associated good access to large, attractive open green space with higher levels of walking (Giles-Corti et al., 2005; World Health Organization. Regional Office for Europe, 2016). Hereby, people consider features such as a perception of safety as important (Jansson et al., 2013). Studies have also shown that proximity to UGS is positively correlated with physical activity (Zhou & Parves Rana, 2012).

Social cohesion, attention restoration and stress reduction

De Vries et al. (2013) concluded that stress reduction and social cohesion were the strongest mediators in exerting positive effects on health from greenery. Through experimental evidence, contact with nature was shown to provide restoration from stress and attentional fatigue (de Vries et al., 2013; Hartig et al., 2003), as well as social cohesion.

2.2.3.3 The perception of urban green

There are many direct links between nature and human health. There are, however, also indirect links where the mental and physical health effects depend on nature experience (Bratman et al., 2019) and not merely the presence of urban green alone. Here, the individual's perception of an UGS is important and will influence the frequency and experience of urban green space visits, resulting in actual health benefits. This means, that to receive cultural ES, the quality of the green space is important (Stessens et al., 2020; Paragraph 2.5.2.2).

Knowing people's motives to visit natural areas and activities they perform, can help decision makers to formulate strategies that fulfil the public needs and improve their wellbeing (Chiesura, 2004). This results in different types of subjective indicators, like self-reported UGS availability, quality and mental health benefits, which can be measured as well, e.g., through surveys. As such, perceived usage quality was associated positively with mental health (Zhang et al., 2021a). A literature review by Zhang et al. (2021a), observed four main perspectives, influencing the perception of UGS usage quality: (1) existing manmade infrastructures for physical activity (e.g. paths and benches), (2) the environmental setting (e.g., plant life, shade and water features), (3) preconditions of visiting (e.g., accessibility, safety and cleanliness), and (4) supplementary elements (e.g., maintenance and overall attractiveness).

It must also be noted that not all UGS elicit a positive effect on preference. It was, for example, proven that some people perceive urban woodland as unsafe because of bad maintenance, high tree density and a lack of overview and control (Jansson et al., 2013).

2.2.3.4 The interaction of biodiversity and human health

Biological diversity, or biodiversity, is defined by the Convention of Biological Diversity as *"the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems"* (United Nations, 1992, p. 3).

In general, green spaces in cities comprise a high biodiversity as they are species rich and contain many native, rare or threatened species, worth conserving through management and planning (Ives et al., 2016). It is, however, not straightforward to make a direct link between biodiversity, human health and preference. Some authors observed that recreational preferences are negatively related to high biodiversity values (Botzat et al., 2016). Yet most studies observed a positive relationship with biodiversity and valuation of green space, with subsequent health consequences, concluding that management should emphasise biological complexity to enhance human well-being (Botzat et al., 2016; Carrus et al., 2015; Fuller et al., 2007; Gunnarsson et al., 2017; Ode Sang et al., 2016). It is shown that appreciation of naturalness is positively correlated with biological value and a higher perceived naturalness generates more activities, self-reported well-being (Ode Sang et al., 2016) and associated health benefits (Stessens et al., 2020). Southon et al. (2018) found that high perceived biodiversity increases psychological well-being through a greater satisfaction and connection to nature

It is less complicated to observe a relationship between biodiversity and human health through ES. Aerts et al. (2018) stated that accumulating evidence confirmed the 'biodiversity-ecosystem functioning theory:' high biodiversity is likely to be more efficient in offering high levels of ES and diverse systems are also more resilient to shocks. As biodiversity is an element of ecosystem structure and function, it supports ES that impact human health, like reducing the UHI (Haines-Young & Potschin, 2018).

Furthermore, Marselle et al. (2021) stated that biodiversity founds human health as an essential life-support system, and therefore should be considered in spatial and urban planning policies. The authors presented an integrated biodiversity-health framework with four domains, relating to psychological, social, and biophysical processes. Three beneficial pathways are: (1) reducing harm (e.g., through provision of food, medicines and reducing the exposure to air pollution), which depends on the tree canopy cover in neighbourhoods, (2) restoring capacities (e.g., through stress reduction and attention restoration) and (3) building capacities (e.g., through promoting physical activities). The fourth pathway is (4) causing harm (e.g., through wild animals, diseases and allergens).

2.2.3.5 Summary

There are several pathways relating contact with nature to health benefits, either directly or through perception and nature experience (Figure 2.1). These benefits can either directly influence mental and physical health, such as by increased physical activity or stress reduction, or indirectly, by provisioning of ES, such as air quality improvement and microclimate regulation. This entire framework is supported by biodiversity that can have a direct effect on human health, either through perception or direct contact with nature, or an indirect effect, through support of ES.

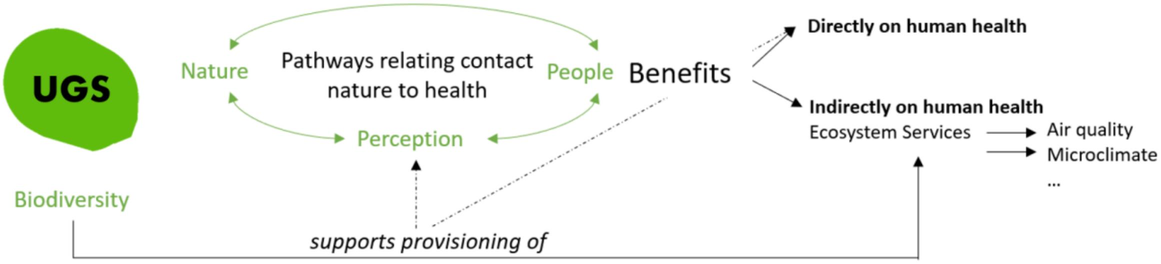

Figure 2.1: Linkages between Urban Green Spaces (UGS) and human health benefits through pathways relating contact with nature to health. This can either go directly, or through perception and nature experience, and can cause direct health effects or indirect health effects, through other ecosystem services, like air quality and microclimate regulation. Biodiversity supports the provisioning of ecosystem services or underpins direct health benefits, through contact with nature or nature experience and perception. Source: author, based upon literature review (Hartig et al., 2014; Konijnendijk, 2022; Stessens et al., 2020; Zhang et al., 2021a)

2.3 Green space inequity

The benefits of UGS to people provides policy makers with the responsibility to strive for environmental justice. This means ensuring the fair and equitable distribution of both environmental “bads”, such as air pollution, and “goods”, such as UGS and recreational opportunities.

Unfortunately, the environmental justice hypothesis predicts that minority groups, like poor communities or communities of colour, will have less access to environmental amenities. This translates to for example living in areas with disproportionately low urban green canopy cover (Watkins & Gerrish, 2018), which is observed among marginalised communities (Heynen et al. 2006).

Furthermore, Zhou et al. (2021) found that socially vulnerable urban residents tend to live in hotter zones with fewer trees, and less cycling and walking paths (Crawford et al., 2008; Zhou & Parves Rana, 2012). Because of this lack of ‘tree equity’, these communities also experience less benefits provided by these green spaces, such as the cooling effect of a dense canopy cover (Konijnendijk, 2022) and other health benefits discussed in the previous paragraphs. To aggravate the situation, the physically and socially most vulnerable groups, tend to have the least economic and political influence (Millennium Ecosystem Assessment, 2005). For these reasons, it is crucial for policy makers to address the issue of green space inequity in policy making.

2.4 Policy calls for health supporting urban environments

When the loss of ecosystem services is purposefully addressed, and urban systems are managed in such way that reduces inequalities, the benefits to human wellbeing can be abundant and significant (Millennium Ecosystem Assessment, 2005). Therefore, there is a consensus on the need of evidence-based guidelines for policymakers and urban planners to ensure equitable access to UGS and their benefits (Konijnendijk, 2022).

The call for health supporting urban environments is also included in the United Nations (UN) Sustainable Development Goal 11, aiming to make cities and human settlements inclusive, safe, resilient and sustainable by 2030 (United Nations, 2022). This is made specifically clear in target 11.7, of which the goal is to, by "*2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities*" (United Nations General Assembly, 2015, p. 22). However, there is still a long road ahead, as only 45.2% of the urban population lives in a neighbourhood that is conveniently located within 400 metres (m) walking distance to an open space (United Nations, 2022).

The need for guidelines is already addressed by existing theoretical and practical guidelines. The report of the WHO's Regional Office for Europe (2016) on Urban Green Spaces and Health aims to inform policy makers on the benefits of providing UGS and to put the visions of fair and equitable access to UGS as a basic human right into practice. Therefore, it proposes harmonised, objective, and comparable measures and indicators to reflect the amount, the availability and accessibility of UGS.

Furthermore, following the 10-20-30 guideline for urban tree diversity from Santamour (1990), Konijnendijk (2021) created guidelines based on the recognition of the importance of urban trees and green spaces for human health and wellbeing. He developed a concept, called the 3-30-300 rule (Figure 2.2), to help city planners successfully set up UGS and forest programs and at the same time make sure everyone has equal access to this green. This rule considers three aspects of urban green, focussing especially on urban forests and trees. The first element concerns the visibility of green from people's homes, stating that at least three decently large trees should be visible. In the second element, Konijnendijk (2021) suggested to use 30% as a minimum threshold of the canopy or vegetative cover at the neighbourhood level to ensure that residents enjoy benefits like cooling, reduced air pollution and noise (Bolund & Hunhammar, 1999). However, as there is no indication whether the spaces belonging to this cover are accessible by everyone, it is not certain that all benefits, such as enjoying aesthetical appeal, are experienced by everyone, nor that this canopy cover is distributed equally (Ling, 2021). The final element '300' refers to the European Regional Office of the World Health Organization (2016) that recommends urban green spaces of at least 1 hectare at a maximum distance of 300 m to encourage recreational use with all its benefits.

Figure 2.2: A visualisation of the 3-30-300 rule by Konijnendijk (2022), derived from UNECE (2022)

Few efforts have been undertaken in developing guidelines that combine the importance of all the aspects of accessibility, including visible, living, accessible, and usable UGS (Konijnendijk, 2022). One exception is the Singapore Index or City Biodiversity Index (Calcaterra et al., 2014; Konijnendijk, 2022), which serves as a self-evaluation instrument for cities to monitor the progress of their biodiversity conservation efforts against their own baselines with 23 indicators.

2.5 Challenges in analysing and monitoring UGS

To provide policy makers and urban planners with effective management tools for UGS, the available UGS should be evaluated. Various possible evaluation methods have been studied from different perspectives, such as functions in the urban context, appreciation, availability, and accessibility (Laan & Piersma, 2021). The main focus of this thesis is assessing the accessibility of UGS, which is a commonly accepted indicator to assess UGS (Fan et al., 2017; la Rosa, 2014; Laan & Piersma, 2021; Maroko et al., 2009; Zhang et al., 2021b). Accessibility refers to how easy something is to reach, enter, use, or see (Oxford University, n.d.). It can also broadly be defined as the ease with which an activity at one location may be reached from another location using a particular travel model (Liu & Zhu, 2004), or the quantification of green space available to public groups in relation to distance (Laan and Piersma, 2021). Accessibility is not only a measure of

UGS, but also one of the major factors influencing frequent use of urban green space while improving the well-being of its users (Neuvonen et al., 2007).

Annerstedt van den Bosch et al. (2015) recognised that there is currently no agreed-upon method for evaluating access to green space and formulated certain specific challenges that need to be addressed. These challenges include establishing a clear definition on UGSs with a minimum relevant size and a reflection on what measure of accessibility is appropriate. Such accessibility measures may include any or all of: (a) the proximity of UGS to residences, (b) UGS that are publicly accessible, and (c) specific entry points (e.g., paths or gateways) (World Health Organization. Regional Office for Europe, 2016).

By creating an urban green accessibility index, the accessibility of green spaces in the urban environment from a certain location can be evaluated through an accessibility analysis. This represents the consumer's perspective by assessing the distribution and structure, and thereby possible requirements, of UGS (Zhou & Parves Rana, 2012). In the following paragraphs, different estimations methods to measure accessibility are discussed, including the traffic network analysis. Furthermore, different metrics to measure UGS that can be introduced in an urban green accessibility index are introduced, including quantitative and qualitative metrics. Finally, some possible confounding variables in assessing UGS are discussed.

2.5.1 Different estimation methods to measure accessibility

In previous studies, different estimation methodologies have been used to measure the accessibility to UGS. Maroko et al. (2009) stated that one of the most common methods used to examine access to parks is the "container approach", which only measures if there is a park or recreational facility within a geographic unit of aggregation, like a zip code. This approach does not account for the size of a park, nor if there are parks in the vicinity, but not in the same geographical unit. Therefore, they suggested a proximity analysis based on "walkability", a more refined measure of access.

Due to a lack of traffic network data and Geographical Information System (GIS) tools, most previous studies used the Euclidean distance in measurements for the accessibility of UGS (Kabisch et al., 2016; la Rosa, 2014; Van Herzele & Wiedemann, 2003). However, this approach neglects the road network of a city and systematically presents higher scores in the analysis, as observed by la Rosa (2014) and Gupta et al. (2016). These authors compared a simple Euclidean buffer analysis with a traffic network analysis. They proposed to use traffic network data to include building distribution and road networks in a network distance analysis. In such analyses, parameters as travel mode and speed are used to create a realistic walking distance, which improves the accuracy of the accessibility estimation (Gupta et al., 2016; la Rosa, 2014). The next paragraph provides a more detailed explanation of the traffic network analysis.

2.5.1.1 Traffic network analysis

It is possible to identify four broad categories of accessibility measures in a traffic network analysis that use parameters like travel mode, cost, time, and distance: (a) opportunity-based measures, (b) utility-type measures, (c) space-time measures, and (d) gravity-type measures (Appendix 8.1; Liu & Zhu, 2004; Zhou & Parves Rana, 2012). Opportunity-based measurements count the number of opportunities or objects of interest, in this case UGS, within a certain distance from the origin or find the nearest destination and calculate the distance (Liu & Zhu, 2004; Zhou & Parves Rana, 2012). They have the advantage of simplicity, but do not take the attributes of UGS into account (Breheny, 1978; Liu & Zhu, 2004; Zhou & Parves Rana, 2012). Utility-type measures relate accessibility to microeconomic utility theory behaviour and the space-time measures recognise both the spatial as the temporal dimension (Liu & Zhu, 2004). The final type, a gravity-type measure, looks at the potential of opportunity between locations and is negatively related to the travel impedance between two locations and positively related to the attractivity (Liu & Zhu, 2004). By incorporating attractiveness and population density, this method can address two limitations of opportunity-type measurements, although this approach requires additional data (Zhou & Parves Rana, 2012). Based on the gravity-type measurement, a general way of presenting accessibility in an equation is given by Jang et al. (2020) and Jiang et al. (1999):

$$A_{ij} = f\left(w_i, d_{ij}\right) \tag{1}$$

Where A_{ij} is the accessibility index of a point j on a distance d_{ij} from point i that has a certain weight or attractiveness w_i. In this context, the accessibility refers to the relative proximity of two points, with a positive correlation of the attractiveness or weight variable and a negative correlation of the travel impedance or distance variable (Liu & Zhu, 2004).

One factor that all these measures have in common, is the use of the travel impedance, the spatial separation between origin and destination, which is commonly measured in terms of travel distance, time, or cost (Liu & Zhu, 2004). For a traffic network analysis, the distance is calculated by network distance along actual travel routes (Liu & Zhu, 2004). To calculate this distance from the associated travel time, the travel speed should be known. As confirmed by Bosina and Weidmann (2017), a value of 1.34 m/s is considered an average pedestrian speed. It should be noted, however, that providing an average walking speed is not straightforward, as it is influenced by many factors. This walking speed is based on an average of a combination of many studies, with standard conditions, middle aged people (10-70 years), average gender and people without or with small luggage in the central business district with a flat inclination, on a walkway and alone, with average weather conditions. For biking, Baptista et al. (2015) found an average biking speed between 7.1 km/h and 14.5 km/h.

The specific need for green space within a certain distance from people's residence arises from both the overarching advantage of having greenery nearby (e.g., for air purification), as well as the ability to quickly reach it for recreation, and associated health benefits. Although, there are various suggestions regarding the maximum distance from where an UGS provides health benefits for people, there is no evidence or consensus on the threshold (Annerstedt van den Bosch et al., 2015).

The WHO's Regional Office for Europe (2016) suggested to aim for a walking distance of 300 m from an UGS of at least 1 hectares (ha) for all people. Similarly, Konijnendijk (2021) suggested that the nearest high quality park should be no further than 300 m. Others, like Schipperijn et al. (2010), stated that the pull effect of UGS of 5 ha started to diminish after 600 m, or a 10-minute walk. This 10-minute walk has been used as well for accessibility measurements by Poelman (2018), based on the Urban Atlas. Gupta et al. (2016) suggests aiming for residential green of 0.1 to 0.2 ha at a 1-minute walking distance. Based on a review of e literature and case studies, Annerstedt van den Bosch et al. (2015), found that a 300 m maximum distance to the UGS of a minimum size of 1 ha is recommended as default. Van Herzele and Wiedemann (2003) introduced different functional levels, referring to sizes, of green space that should be evaluated differently in relation to their relevant functional scale. This means that smaller UGS should be available at a lower distance, while larger UGS can be further away. They, for example, suggested that each resident should have an UGS of at least 1 ha within a 400-m reach, or 5-minute walk, and an UGS of at least 10 ha within an 800-m reach, or 10-minute walk, from their residence.

2.5.2 Metrics to measure UGS

In addition to travel impedance, an urban green accessibility index can incorporate other metrics such as attractiveness, as proposed in gravity-type measures, to measure UGS. The selection of metrics can be associated with pathways through which contact with nature relates to health (Zhang et al., 2021a; cf. §2.2.3.2). Key UGS characteristics linked to different health effects include the size of UGS, the land cover type, the presence of water, and environmental qualities like biodiversity (World Health Organization. Regional Office for Europe, 2016).

Zhang et al. (2021a) acknowledged that metrics to measure UGS can be categorised as quantitative or qualitative and as objective or subjective. Quantitative metrics focus on measuring the amount of UGS available, while qualitative metrics focus on the characteristics explaining the performance of UGS related to ES (Zhang et al., 2021a) and health. Furthermore, indicators can be objective and measurable or subjective and based on individual experience (Zhang et al., 2021a). In the following paragraphs, some of the most used quantitative and qualitative metrics and their relationship to human health are listed.

2.5.2.1 Quantitative metrics

Quantitative metrics are the most widely studied metrics, reflecting on the amount of UGS available. The availability or amount of UGS forms the physical basis for, and is relevant to, all pathways regarding the health-greenery relationship (Zhang et al., 2021a). There is widespread evidence that a significant positive association is found between the objectively measured quantity of green space and perceived physical and mental health (van den Berg et al., 2015).

The size of the green space is the most used quantitative metric (Fan et al., 2017; Van Herzele & Wiedemann, 2003; Zhang et al., 2021b). The size of UGS will likely influence the levels and types of activity people perform in them (World Health Organization. Regional Office for Europe, 2016). Some studies included the size of urban green space combined to an accessibility measure. This was done by labelling them with different functional levels based on their functional scale (e.g., neighbourhood, district, city) and attributing different levels of access by assigning different minimum distances (e.g., Van Herzele et al., 2000; van Herzele & Wiedemann, 2003; Zhang et al., 2021b). An often referred to example is given by van Herzele and Wiedemann (2003) in their minimum standards for urban green space, derived from the MIRA-S 2000 report (Van Herzele et al., 2000; Table 2.1). In addition to UGS size, other quantitative measures are vegetation cover or canopy cover (Zhang et al., 2021a). Canopy cover showed to be significantly positively correlated with mental health (Zhang et al., 2021a).

Table 2.1: Minimum standards for urban green spaces (Van Herzele et al., 2000; van Herzele & Wiedemann, 2003)

Functional level	Maximum distance from home (m)	Minimum surface (ha)
Residential green	150	
Neighbourhood green	400	1
Quarter green	800	10 (park: 5 ha)
District green	1600	30 (park: 10 ha)
City green	3200	60
Urban forest	5000	>200 (smaller), >300 (bigger cities)

2.5.2.2 Qualitative metrics

Most correlations with assumed benefits of UGS have been based on their quantity, rather than their quality (Haaland & Konijnendijk van den Bosch, 2015). The implementation of quality of urban green is often forgotten or omitted due to a lack of data, as well as a lack of evidence on the relationship between quality or green space characteristics and perceived mental and physical health (van den Berg et al., 2015). However, Zhang et al. (2015) found that, when introducing the same quantity of UGS and physical and socio-demographic factors, there is more attachment to a neighbourhood with more attractive, accessible, and qualitative UGS, resulting in a higher wellbeing of the residents (Zhang et al., 2017). Furthermore, they were associated with higher levels of walking (de Vries et al., 2013; Giles-Corti et al., 2005; World Health Organization. Regional Office for Europe, 2016) and a correlated reduced risk of obesity and overweight (Knobel et al., 2021). Therefore, recent studies have confirmed the importance of including (perceived) quality in addition to quantity when optimising the benefits received of UGS (Bertram & Rehdanz, 2015; Ode Sang et al., 2016; Stessens et al., 2020; Zhang et al., 2017), especially those benefits related to health (Stessens et al., 2020). Type, quality and context of green spaces, should be assessed when the goal is to have these spaces for improved human health and wellbeing and to inform policy and city planners (Wheeler et al., 2015). In this regard, it is recommended to explore methods that consider taking parameters concerning quality into account when considering accessibility.

Certain studies have already implemented qualitative parameters into their green accessibility index (Fan et al., 2017; Giles-Corti et al., 2005; van Herzele & Wiedemann, 2003; Zhang et al., 2021b), after verifying their link to human health. Jang et al. (2020), for example, included the greenness based on the NDVI and topological importance of the nearest street segment as quality indicators. Dadvand et al. (2014) showed that higher greenness was associated with lower prevalence of being overweight or obese. Giles-Corti et al. (2005) implemented quality indicators by measuring 35 indicators within four categories (e.g.,. environmental quality, safety, amenities and activities).

Based on this, Fan et al. (2017) used spaciousness, quietness, and affordability as quality indicators. Through an expert survey, weights were assigned to each of these indicators, enabling the calculation of green space quality for each patch. Furthermore, they found that people gave a relative importance of accessibility of 65% and 35% for quality. Stessens et al. (2020) uncovered quietness, spaciousness, maintenance and cleanliness, facilities, naturalness, and perceived safety as important quality indicators of UGS for Belgian inhabitants of Brussels, by a compilation of the literature.

Laan & Piersma (2021) stated that previous models in urban green space analysis did not account for the population size. Hence scores for accessibility might look too optimistic for neighbourhoods with high population densities. Therefore, crowdedness might be an important metric for quality. The study showed that the accessibility of green space is further specified when adding the population density in the vicinity of urban green areas, if the population size data is added with enough local detail. Other quality indicators related to health benefits are land cover diversity and density and local biodiversity (Wheeler et al., 2015).

The attractiveness or quality of a destination is typically assessed based on its characteristics (Liu & Zhu, 2004). The measurement of quality can be carried out through expert assessments or by gathering feedback from the civil population, utilising tools, such as checklists, in situ observations, and GIS analyses (Zhang et al., 2017). In addition to measuring quality objectively by experts, it is important to have an idea of the perceived quality by people, as this often has a closer correlation with wellbeing (Zhang et al., 2017), e.g., through surveys. Several other studies use a monetary valuation of UGS (Stessens et al., 2020), such as hedonic price modelling or contingent valuation (Brander & Koetse, 2011; Jim & Chen, 2006; Kong et al., 2007). When large-scale studies are not achievable, the relationship between different features of UGS and perceived quality is assessed based on the relative appreciation of sub-qualities (Fan et al., 2017; Giles-Corti et al., 2005; Stessens et al., 2020). Surveys are the most direct way to get this information (Stessens et al., 2020).

Another approach involves developing GIS-based models, derived from spatially explicit data layers, that link GIS metrics, quality and perception and quality metrics. For example, naturalness, quietness, spaciousness (Stessens et al., 2020) and greenness (Jang et al., 2020) can be inferred from green space properties (Stessens et al., 2020). They found that naturalness was correlated with perceived user quality and spatially explicit variables, like the biological value and water fraction. However overall, still little research is done connecting such GIS-based quality indicators with perception (Stessens et al., 2020) and therefore assessments are often based on objective metrics related to health benefits.

2.5.2.3 Confounding variables

When assessing UGS, the possible variability in consumption of UGS must also be considered. This variability depends on a non-exhaustive list of parameters (Zhou & Parves Rana, 2012). Studies have shown that different health outcomes (World Health Organization. Regional Office for Europe, 2016) and a different perception of quality (van den Berg et al., 2015) are obtained depending on demographic factors. These factors include age, profession, education, ethnicity and socio-economic status (Zhou & Parves Rana, 2012).

The benefits from the proximity of UGS can specifically be important for children (Davison & Lawson, 2006), women (Krenichyn, 2006) and elderly people (Sugiyama & Ward Thompson, 2008). Furthermore, it is assumed that people from different backgrounds, prefer different landscapes (Zhou & Parves Rana, 2012). Race or cultural background might influence the selection of outdoor recreation and UGS (Gentin, 2011). Qualitative measurements usually analyse this aspect of intuitive accessibility to UGS (Zhou & Parves Rana, 2012). Additionally, the profession or degree of ecological knowledge might influence preferences (Qiu et al., 2013).

2.6 Towards an integrated accessibility index for urban green

2.6.1 Gaps of knowledge

In this study, an urban green accessibility index for Flanders is introduced. Previous attempts to develop similar indices have been made by multiple researchers in the field (Maroko et al., 2009). This study tries to identify gaps of knowledge in current literature on the accessibility of UGS. In Flanders, a significant knowledge gap exists due to the lack of reliable reference data on public green spaces. While land cover and land use maps may indicate the presence of vegetative cover, they often do not differentiate between the public and private character of green space. Besides, the use of OpenStreetMap as a data source for UGS remains limited in literature.

To measure accessibility, it is agreed among many researchers that including a network analysis based on transportation times represents this the most accurately (Gupta et al., 2016; la Rosa, 2014; Laan & Piersma, 2021; Maroko et al., 2009; Van Herzele & Wiedemann, 2003). Many of these studies also suggested to take a different radius of service into account for different hierarchical levels, based on sizes of green while determining the accessibility index (Gupta et al., 2016). Often walking distances or public transport is used to determine accessibility (Jang et al., 2020; Laan & Piersma, 2021; Zhang et al., 2021b). However, transport via bicycle is often not included (Zhang et al., 2021b). Including this in the index for Flanders could be an asset, since surveys showed that 50% of Flemish people often take the bike to get around in their free time (Burgerbevraging Gemeente-Stadsmonitor, Agentschap Binnenlands Bestuur, 2020). Maroko et al. (2009) also pointed out that a measure of access needs to consider actual points of entry, as it can have a significant influence on the actual accessibility of a green space. Someone might reside close to green spaces, but still needs to walk a few more minutes to entry them. This study wants to implement these as well.

Quality is mostly only implemented by looking at the size of green space (Maroko et al., 2009). This study introduces some quality aspects in the index by weighing the different green spaces differently. There is especially a lack of studies that attempt to implement biological and ecosystem valuation as a quality indicator, to encompass all aspects linking contact with nature to health. Overall, there is still little evidence linking health benefits to characteristics of UGS (World Health Organization. Regional Office for Europe, 2016). Therefore, further research is needed to identify characteristics of UGS that are associated to health. Moreover, there have been no studies that compare UGS accessibility and supply to the context of UGS in a neighbourhood, although Wheeler et al. (2015) suggested this should be considered when evaluating their overall health benefits. Introducing this, would represent a novel contribution to the existing literature on this topic.

2.6.2 The Urban Green Accessibility Index for Flanders

This thesis proposes an Urban Green Accessibility Index (UGAI) for Flanders that is grounded in the theoretical framework of health outlined in the previous paragraphs. The UGAI is designed to address the identified knowledge gaps by integrating UGS accessibility, quality and context. In pursuit of this objective, the research seeks to answer the following questions:

- What is the extent and distribution of public green spaces in Flanders, and how do they vary in size, quality, and accessibility?
- To what extent can OpenStreetMap data be used as a reliable source of information on urban green spaces in Flanders, and what are the limitations of this approach?
- How can UGS accessibility and quality be integrated with the context of the environment in an urban green accessibility index and what are the resulting spatial patterns?
- How can the resulting accessibility index be used to inform policy decisions and improve the provision and management of urban green spaces?

3. Material and methods

3.1 Study area

3.1.1 Flanders

The study area is Flanders, the northern and Dutch-speaking part of Belgium (Figure 3.1). The official capital is the City of Brussels. Flanders covers an area of 13,626 km² and has a total of 6.7 million inhabitants (Statbel, 2022). With a population density of around 470 inhabitants per km², it is one of the most densely populated regions in the world (Poelmans & Van Rompaey, 2010). Furthermore, Flanders stands out as one of the most urbanised and fragmented areas of Europe (Poelmans & Van Rompaey, 2009, 2010) due to its high proportion (33.3%) of built-up area (including housing, industrial and commercial purposes, transportation infrastructure or recreational purposes) (Statbel, 2021; Pisman et al., 2021). Agricultural areas dominate the open spaces, covering over half of the region (Poelmans et al., 2021; Nys, 2014). Forests account for 10% of the land cover (Poelmans et al., 2021), while parks for a little under 1% (Nys, 2014). Domestic gardens, which technically belong to the built-up area, are estimated to occupy 12.5% of the Flemish region (GARMON, 2020). Open spaces in general are under threat in Flanders, as natural unsealed areas further decrease, and the population density keeps increasing (Nys, 2014).

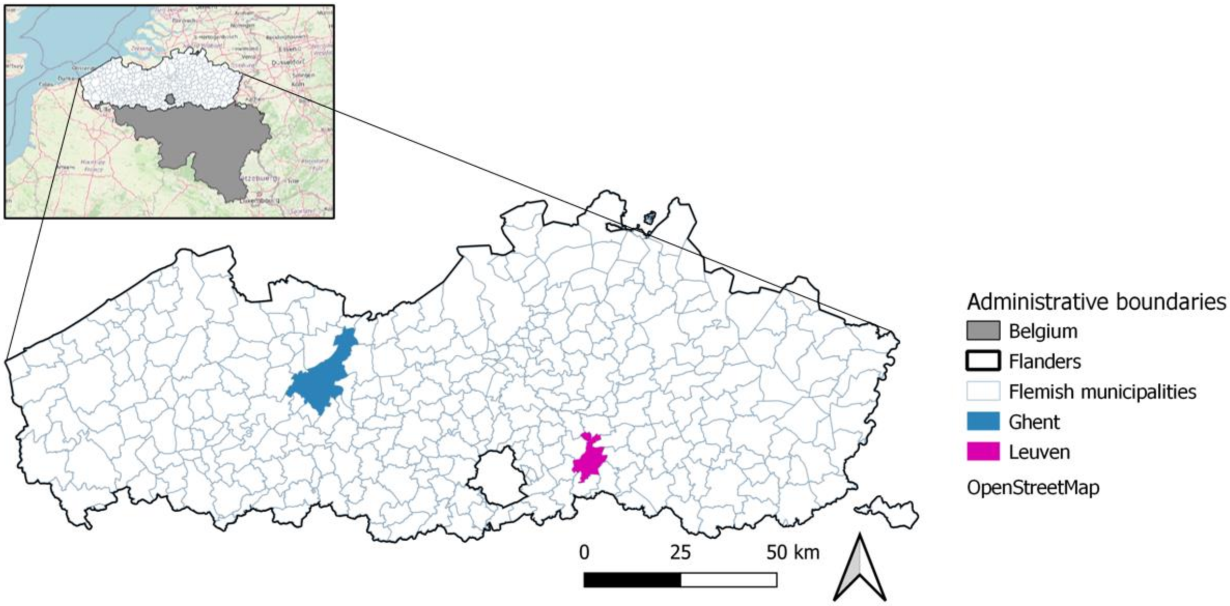

Figure 3.1: Belgium on OpenStreetMap (OpenStreetMap foundation, n.d.) with Flanders indicated in white (top). Flanders with its municipalities and Ghent (blue) and Leuven (purple) indicated (bottom; Agentschap Digitaal Vlaanderen, 2017)

3.1.2 Case studies Ghent and Leuven

Two case studies in Flanders were selected: Ghent and Leuven. These municipalities were selected to enable a more detailed analysis and identify patterns at a smaller spatial scale.

Ghent is the capital and largest city of the province of East Flanders (Figure 3.1). The municipality lies at the junction of the canalised Lys and Scheldt rivers and is one of Belgium's oldest cities (Britannica, T. Editors of Encyclopaedia, 2023). With a population of around 265,000 inhabitants and an area of about 158 km², it is also one of Belgium's largest cities (Stad Gent, 2022a). According to a study conducted by Natuurpunt (Nys, 2014), the city of Ghent is reported to have a shortage of urban green spaces. They stated that the province of East Flanders falls significantly below the average of Flanders, with only 30% of inhabitants finding district green, defined as a contiguous nature reserve of at least 30 ha, within 1.6 km of their residence. In Ghent specifically, this number is only 8%. To smaller residential green (at least 0.2 ha), 82% of the residents have access within 400 m (Bral et al., 2014). Questioned by a survey from Stadsmonitor (Bral et al., 2014), 65% of the population indicated to be satisfied with the offer of green spaces in their city.

The second case study is the municipality of Leuven, the capital of the province of Flemish Brabant (Figure 3.1). Leuven lies central in Flanders, along the Dyle River and is connected by canal with the Scheldt (Britannica, T. Editors of Encyclopaedia, 2013). With an area of 57.4 km² and a population around 91,500, the municipality is smaller than Ghent. Leuven scores higher on the presence of district green, as 29% of the residents finds district green within 1.6 km of their residence, which is lower than the average for Flemish Brabant and Flanders at 50% (Nys, 2014). This is partly caused by the presence of forests in the north, such as Egenhoven forest, Heverlee forest and Meerdaalwoud. A little over 80% of the inhabitants has access to residential green (Bral et al., 2014). This resulted in 75% of the population being satisfied with UGS availability in their city (Bral et al., 2014).

Both case studies are complementary to each other. The city of Ghent belongs to the larger metropolitan urban areas of Flanders, while the city of Leuven belongs to the regional urban areas (Dutch: *grootstedelijk gebied* and *regionaalstedelijk gebied*) of Flanders (Vlaamse Overheid – Departement Omgeving – Afdeling Vlaams Planbureau voor Omgeving, 2023). Furthermore, Ghent scores rather low on the accessibility to district green, compared to Leuven (Nys, 2014).

3.2 Development of the Urban Green Accessibility Index

This thesis proposed and implemented a theoretical framework as foundation for the development of a model for the Urban Green Accessibility Index (UGAI) for Flanders.

The framework is centred around human health since this is a vital aspect to human wellbeing. As described in the literature study (cf. §2.2.3.2), several pathways relate contact with nature to health benefits. This can occur either directly or through perception and experience, with direct effects on health or through the delivery of ecosystem services that impact health. Because of the benefits of urban green spaces (UGS), they are crucial for improving mental and physical health in cities and for mitigating problems associated with urbanisation, such as the UHI effect, air pollution and sedentary lifestyles. Both the quality as the quantity of UGS play a role in this matter. Therefore, the proposed index evaluates three layers: (1) the quantity of UGS (including its accessibility), (2) the quality, and (3) context (Figure 3.2).

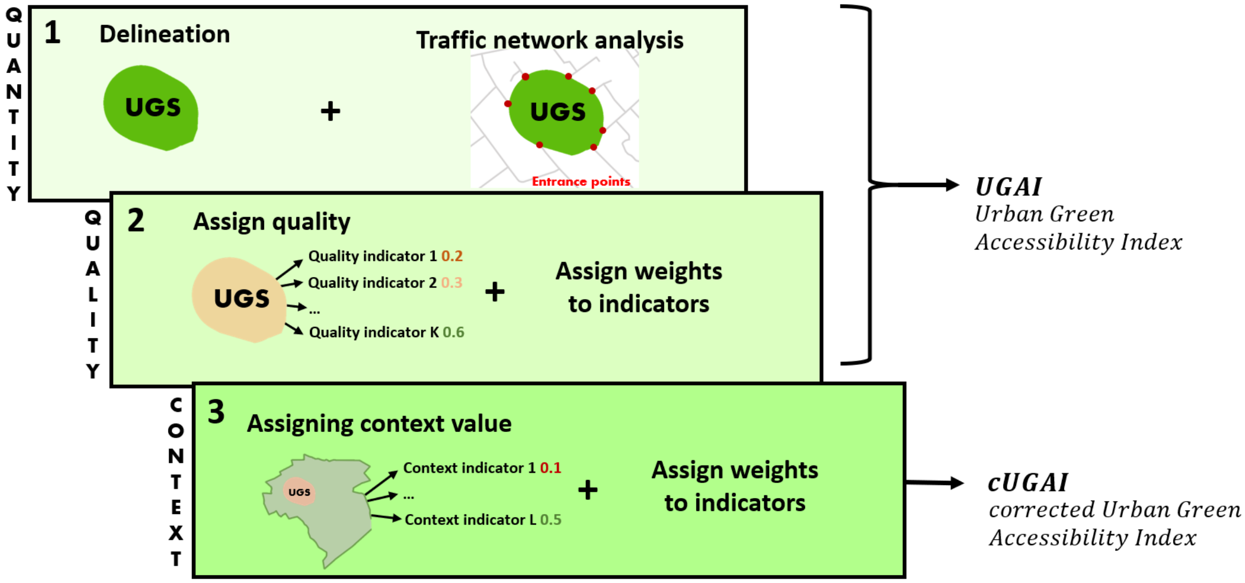

Figure 3.2: The tri-layered model. The first layer represents the quantity of Urban Green Spaces (UGS) by first delineating them and subsequently performing a traffic network analysis on them using their actual entrance points. The second layer introduces the quality of UGS by scoring them on different quality indicators and weighing those indicators. The combination of these layers results in the Urban Green Accessibility Index (UGAI). The final layer introduces the context by assigning a value to each neighbourhood through scoring context indicators and weighing those indicators. By combining this to the UGAI, the corrected UGAI (cUGAI) is obtained. Source: author

Figure 3.3 gives an overview of the specific steps required to implement the tri-layered index. First, a definition of UGS was technically defined. Based on this definition of UGS, a workflow was set up to spatially delineate UGS in Flanders. Next, the traffic network analysis was performed using the road network. In the second layer, quality scores were assigned to each UGS. Finally, a score based on the context was attributed to a mapping unit to calculate the final corrected UGAI (cUGAI).

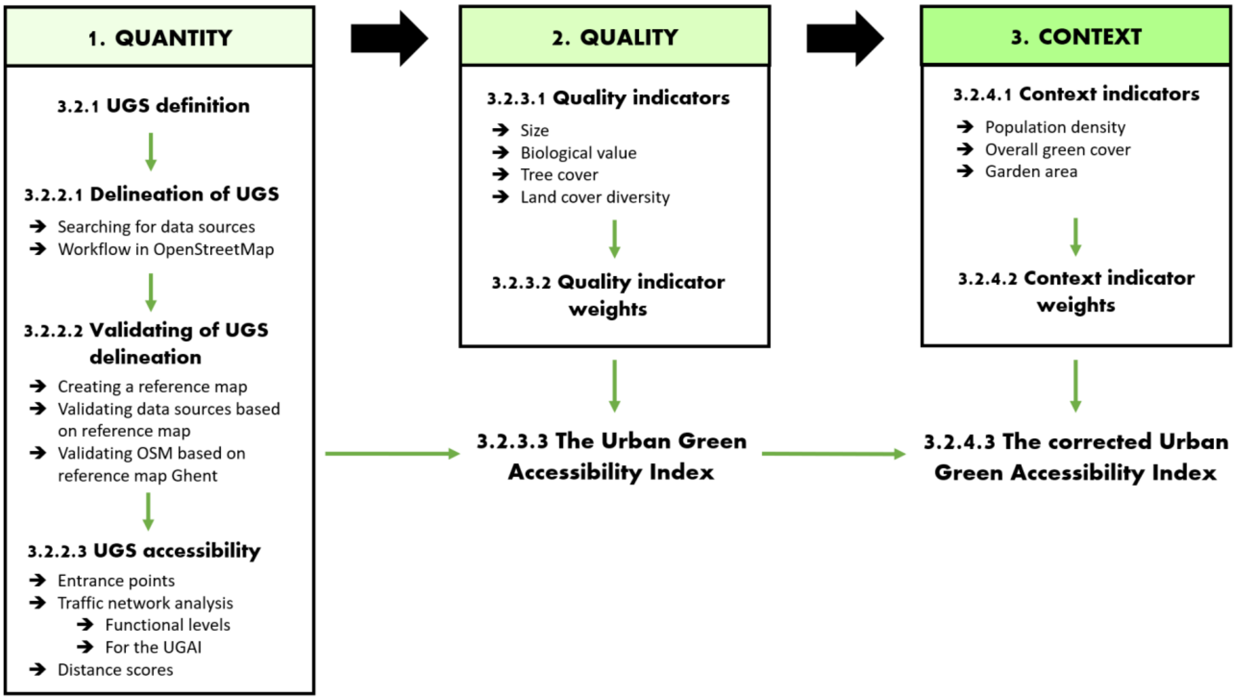

Figure 3.3: Overview of subsequent steps of the implementation of the tri-layered model, with their respective paragraphs. First, the quantity of urban green spaces (UGS), including their accessibility, is calculated, using OpenStreetMap (OSM) data. Then, the quality is assigned to the different UGS. Using these two steps, the Urban Green Accessibility Index (UGAI) is calculated. Thirdly, the context of UGS is introduced and incorporated with the UGAI in the corrected UGAI (cUGAI). Source: author

Different tools were combined in the implementation of the tri-layered model. Quantum Geographic Information System (QGIS) version 3.16 was used for the creation, analysis, and visualisation of geospatial data (QGIS Development Team, 2021). Furthermore, Feature Manipulation Engine (FME) was used for data integration, processing, and transformation (FME Community, n.d.). Finally, the programming language R through the integrated development environment RStudio *version 4.2.3* was used for further statistical computing and data analysis (R Core Team, 2021).

In the following paragraphs, the different stages involved in constructing the final index are explained in detail. In each instance, the theoretical framework is presented first, followed by the workflow adopted to achieve the index and an elaborate description of its implementation steps.

3.2.1 Urban Green Space definition

To spatially delineate the UGS of Flanders, a definition of these UGS should be established. Definitions usually differ slightly between studies, resulting in different outcomes. Urban Green Spaces were defined in this study as public green areas, predominantly for recreational use, that are freely accessible to the public, based on the definitions of the European Union (2011) and World Health Organization, Regional Office for Europe (2016). This definition includes public gardens, parks, cemeteries, castle parks, suburban natural areas that are managed as urban parks and urban forests as UGS, and excludes private gardens within housing area and agricultural areas or areas of natural vegetation enclosed by built-up areas without being managed as green urban areas. As suggested by the WHO, this definition also includes waterbodies, enclosed by green space, as it is an attractive feature and enjoyed by people.

A considerable amount of the physical (Kaczynski & Henderson, 2007) and mental (Lackey et al., 2021) health benefits of UGS relate with being able to recreate in a (semi-)natural environment. Therefore, the focus of the study is on UGS that are **accessible to reach, enter and use,** and will be viewed from a recreational perspective. In order to do this, the UGS first needs to be large enough. In line with the City Monitor of Flanders a **minimum area of 0.2 ha** was chosen for the UGS to have a certain recreational value (Bral et al., 2014). Second, the UGS should be **accessible by foot and/or bicycle**, meaning a foot and/or cycle path must reach the UGS, therefore excluding green spaces such as those in between highways. This definition does not include green spaces that are merely visible and do not provide opportunities for direct interaction, such as streetscape greenery and agricultural fields.

3.2.2 Quantity of Urban Green Space

3.2.2.1 Delineation of Urban Green Space

Given the wide-ranging evidence pointing to a positive association between the quantity of green space and perceived physical and mental health (cf. §2.5), the quantity of UGS is the most studied metric (Figure 3.2 &Figure 3.3). The first step in the analysis involved the collection of spatial data on UGS based upon the UGS definition (cf. §3.2.1). Yet, there is a lack of reference data for UGS in Flanders, and when available, it is limited to the extent of the municipalities. Typically, land cover and land use maps incorporate the presence of vegetative cover in an area, but they often do not provide details on the public or private character of green space. Furthermore, municipal UGS definitions usually differ significantly from each other and from the definition used in this study. Based on the available data, two data sources with potential to serve as a basis for the UGS map in this study were compared.

The first data source was the ‘Green Typologies map’ of the situation in 2019 (Verachtert & Poelmans, 2022). This is currently the most comprehensive open access map for UGS in Flanders.

The second data source was ‘OpenStreetMap’ (OSM; OpenStreetMap foundation, n.d.). This data source is widely recognised as one of the most popular Volunteered Geographic Information (VGI) or crowd-sourced projects and is a serious alternative geodata source (Barron et al., 2014). More than two million users contribute to this project through multiple data sources, such as manual surveys, Global Positioning System (GPS), cadastral data (Le Texier et al., 2018), and other open data sources. The goal is to create a global, free, and editable map of the world’s land features (Giuliani et al., 2021).

OSM data was accessed through Geofabrik’s free download server, which extracts data from the OpenStreetMap project (OpenStreetMap foundation, n.d.) and updates it daily (Geofabrik downloads, n.d.). Data was downloaded for Belgium on 24/10/2022. To consider UGS of neighbouring areas, data was also downloaded for three regions in the Netherlands (Limburg, Noord-Brabant, and Zeeland) and France (Nord pas de Calais) on 16/03/2023.

The OSM data layer containing the land use classes was relevant for mapping UGS. Since not all relevant tags were included in this layer, QuickOSM, a QGIS plugin using Overpass API (Trimaille, 2022), was used to generate these remaining classes from OSM. Table 3.1 displays the tags of features in OSM that were retrieved in the first step and on which further processing was performed. The tags were selected after comparing the conformity of their descriptions by the Map features on the OpenStreetMap Wiki (n.d.) to the definition of an UGS (cf. §3.2.1).

Table 3.1: OpenStreetMap features included as urban green spaces, their sources and additional tags (OpenStreetMap foundation, n.d.)

Source	Map feature tag	Additional tags
Geofabrik	Park, recreation_ground, nature_reserve, forest, cemetery, heath, meadow, scrub, grass	
QuickOSM (Overpass API)	natural = wood landuse = village_green leisure = dog_park boundary = national_park garden:type = arboretum garden: type = botanical leisure = playground	Exclude ‘playground’ if tag ‘surface’ = artificial_turf, asphalt, concrete, dirt, dirt/sand, fine_gravel, gravel, paved, paving_stones, pebblestone, poured_rubber_surfacing, ground, rubber, rubber_tiles, rubbercrumb, sand, sand;grass, sand;ground, unpaved, woodchips, wood, wood chipping

To conform to our definition, additional processing was necessary to obtain the final UGS map. Figure 3.3 displays the workflow that was adopted to get to final map. All input vector layers (A-J) were reprojected to the correct Coordinate Reference System (CRS: 31370) and their geometries were validated. Next, the layers were clipped to Flanders (Agentschap Digitaal Vlaanderen, 2017), surrounded by a 3 km buffer (C) to take into account UGS from neighbouring countries on the edges. This is visualised for the initial data collection in OpenStreetMap (B).

In the first step (1) of data collection, additional processing was performed on polygons with the tag of ‘forest’ or ‘wood’. Because these areas were often large, but not always fully accessible, a rule was set up, to only include forests in a buffer of 40 m around the road network. Therefore, first the road network (D) within Flanders’ 3 km buffer had to be set up.

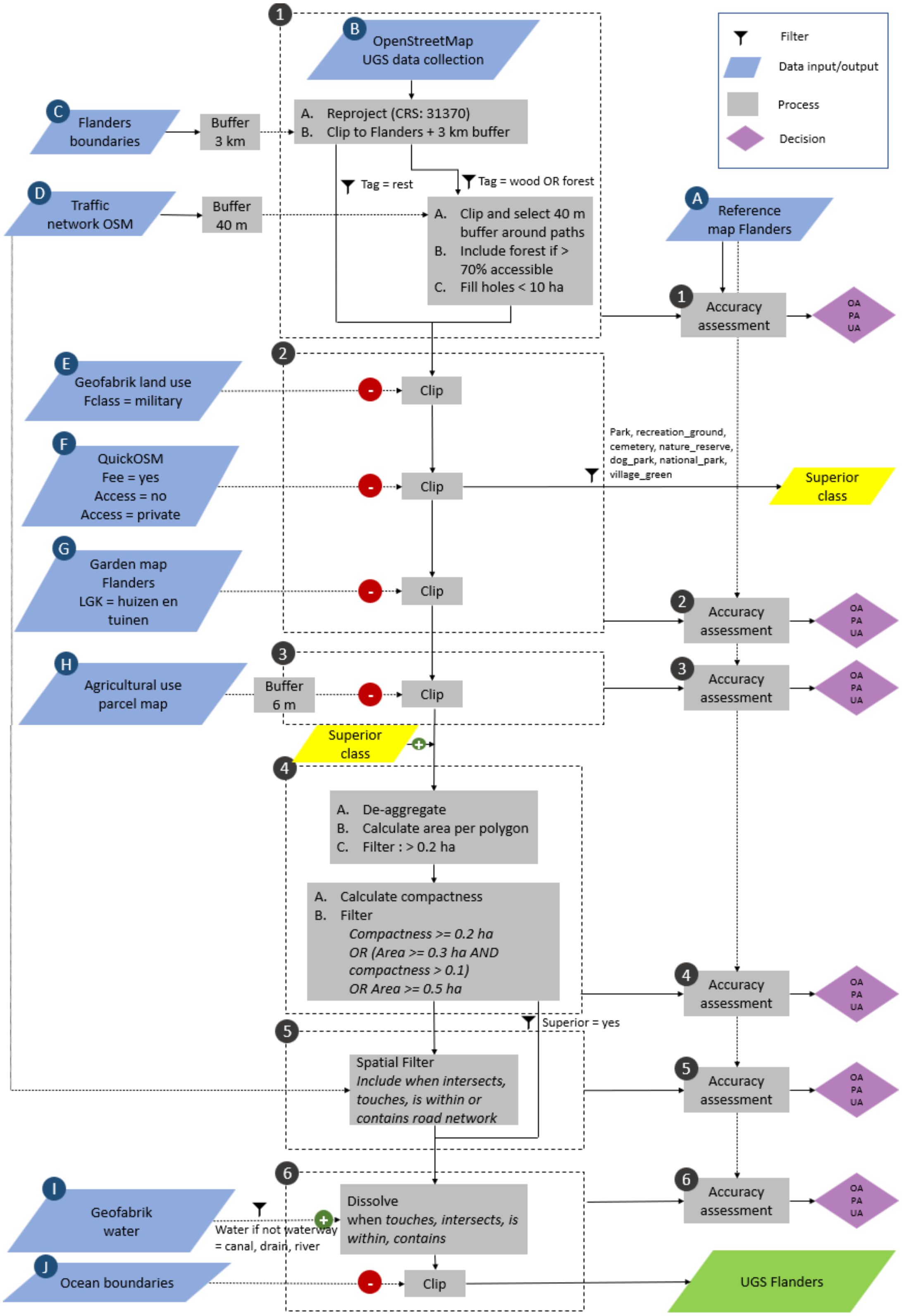

Figure 3.4: Workflow developing Urban Green Space (UGS) map for Flanders for an urban green accessibility index. There are 6 steps, labelled 1 to 6 with each time an accuracy assessment performed afterwards. There are 9 data inputs in blue (A-J). Arrows represent the connections and order between the steps or the input of data. A minus sign represents the removal of data and a plus sign represents the addition of data. Abbreviations: UGS = urban green space, OA = overall accuracy; PA = producer's accuracy; UA = user's accuracy

The pedestrian and cyclist traffic network

The road network by OSM was chosen, because it generally is very accurate in urban areas (Barron et al., 2014) and contains a lot of detail regarding paths and pedestrian roads. Data on 'roads' was downloaded for Belgium from Geofabrik on 24/10/2022, and for neighbouring areas on 16/03/2023. The tags of 'corridor' and 'crossing' were not included in Geofabrik and therefore downloaded through QuickOSM. Table 3.2 gives an overview of the tags that were considered for the road network for pedestrians and cyclists, respectively. For the final road network, all roads where the tag 'Access' was 'No' or 'Private' were removed, the lines were reprojected to the Project CRS, clipped to Flanders' 3 km buffer and their geometries were validated.

Table 3.2: OpenStreetMap features included as pedestrian and cyclist roads and their sources. (OpenStreetMap foundation, n.d.)

Source	Map feature tag FOOT	Map feature tag BIKE
Geofabrik	Bridleway, footway, cycleway, living_street, path, pedestrian, primary, primary_link, residential, secondary, secondary_link, steps, tertiary, tertiary_link, track (grade 1, 2, 3, 4 and 5), unclassified	Cycleway, living_street, path, primary, primary_link, residential, secondary, secondary_link, tertiary, tertiary_link, track (grade 1, 2, 3, 4 and 5)
QuickOSM (Overpass API)	Corridor Crossing	Crossing

Using this road network, only forested areas within a 40-m buffer surrounding the paths were selected. When a forest was present for more than 70% within this buffer, the whole forest was included. Patches in between paths were considered as accessible if they were smaller than 10 ha and, therefore, included. Accessible areas, in this context, were those managed as UGS, and therefore containing paths for recreation.

In the second step (2), areas with a fee, private, and inaccessible areas were removed, as our definition of UGS only included public and free spaces. This was achieved by spatially clipping out 'military areas', retrieved from Geofabrik (E), as well as areas with the tags 'fee = yes', 'access

= no’ or ‘access = private’ from QuickOSM (F) and the class ‘houses and gardens’ from the garden map of Flanders (G; GARMON, 2020).

In the third step (3), all agricultural areas were removed by spatially clipping out the ‘agricultural use parcel’ map (H; Departement Landbouw en Visserij, 2021). These parcels were not publicly accessible, nor managed as UGS. Additionally, a buffer zone of 6 m was implemented around the agricultural parcels, to account for the small spaces between them, and thereby prevent their inadvertent inclusion. The garden map and agricultural parcel map of Flanders were external data, not originating from OSM. These external maps were clipped from more general classes, such as ‘grass’, ‘forest’, ‘scrubs’ and ‘meadows’ in Flanders. However, certain classes hold a higher importance. That is why, after clipping out inaccessible areas from QuickOSM (F), the tags ‘park’, ‘recreation_ground’, ‘cemetery’, ‘nature_reserve’, ‘dog_park’, ‘national_park’ and ‘village_green’ were assigned to a priority class. These were inserted again after the third step and were not clipped by the external maps. It should be noted that the extent of the external maps was limited to Flanders and, therefore, this was not performed on the 3 km buffer surrounding Flanders.

In the fourth step (4), the remaining polygons were de-aggregated, after which their area was calculated. Areas smaller than 0.2 ha were removed. A next step accounted for the shape of the polygons. To get rid of very narrow and small green spaces, a compactness measure of the shape was calculated for each of the polygons. The Polsby-Popper test was used (Polsby & Popper, 1991), computing the compactness as:

$$Compactness = \frac{Area\ of\ polygon}{Area\ of\ circle\ with\ same\ perimeter\ as\ polygon} = \frac{4\pi * Area\ of\ polygon}{Perimeter\ polygon^2} \quad (2)$$

To determine the appropriate parameter value, a range of values was empirically tested and evaluated to identify optimal values that would achieve the desired outcome. As a result, all polygons with a compactness larger or equal to 0.2, or a compactness larger or equal to 0.1 combined with an area larger than 0.3 ha, or an area larger than 0.5 ha, were included, while the rest was excluded.

In the fifth step (5), only UGS that had a spatial intersection with the pedestrian road network (D) were retained to confirm their accessibility. The priority class, including features such as parks, cemeteries, and dog parks, was excluded from this step as it was presumed these UGS would be easily accessible based on their tag definition.

As water features within UGS also belong to the UGS definition, the final steps (6) insert these water features. Water features were retrieved from the Geofabrik water data layer, including only the ‘Water’ class, and excluding ‘Wetlands’, ‘Riverbanks’, ‘docks’ and ‘Reservoirs’. After this, all water features intersecting with the ‘river’, ‘canal’ and ‘drain’ classes from the waterway layer from Geofabrik were filtered out, as well as water with a compactness score lower than 0.2. This final water map (I) was tested on spatial intersection with the UGS map. Water features intersecting with the UGS map were included and merged with the UGS map. Finally, the map containing the global oceans and seas (J; Flanders Marine Institute, 2021) was clipped from the final map.

After the last step (6), the UGS map was finalised, and its accuracy was assessed using a reference map (A) of UGS for Flanders. The creation of this reference map and the subsequent validation of the UGS map for Flanders is described in detail in the next paragraph.

3.2.2.2 Validating the Urban Green Space delineation

Due to the lack of reference maps of UGS in Flanders, the first step of validating the UGS map was to construct a reference map through a sampling protocol. For the sample and response design, the main steps by Stehman and Czaplewski (1998) and Wulder et al. (2006) were followed.

Step 1: Sampling design

Since the goal of the study was to develop and calculate an index for urban areas in Flanders, the sampling protocol focused on urbanised areas using the “Demarcations of the urban areas in implementation of the Spatial Structure Plan Flanders” (Vlaamse Overheid – Departement Omgeving – Afdeling Vlaams Planbureau voor Omgeving, 2023). These urban areas were divided in different types: metropolitan areas (*grootstedelijk gebied*, gsg), regional urban areas (*regionaalstedelijk gebied*, rsg) and small-town areas (*kleinstedelijkgebied,* ksg) (Figure 3.5), which were used as strata in the sampling design. A 4 km buffer was taken to ensure that the accuracy metric is also valid for UGS outside the ‘urban areas’ that can be reached by bike from within the urban area in a time span of 10 minutes. This 4 km buffer was therefore labelled as ‘rural’ area.

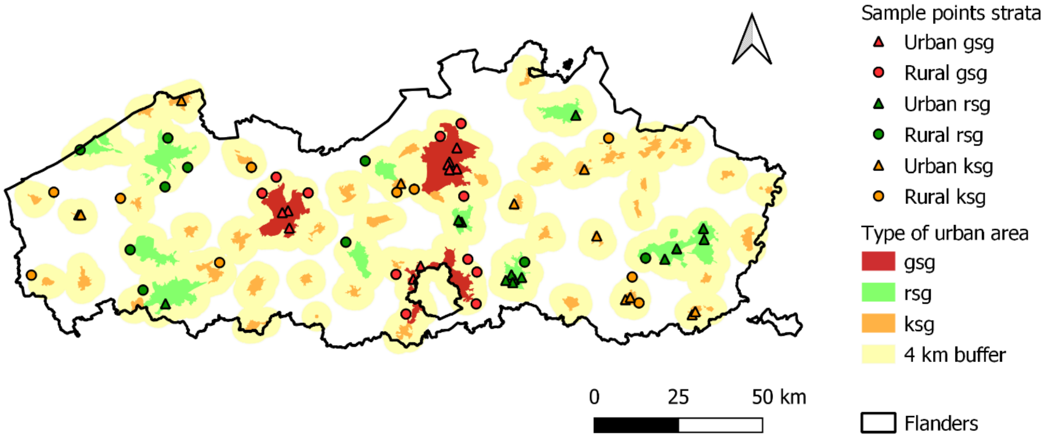

Figure 3.5: Location sample points and their strata on demarcation urban areas (RSP Vlaanderen) (Vlaamse Overheid – Departement Omgeving – Afdeling Vlaams Planbureau voor Omgeving, 2023) with gsg = metropolitan area, rsg = regional urban area and ksg = small-town area, in Flanders (Agentschap Digitaal Vlaanderen, 2017)

A stratified random sample design was used to select the sample units. These sample units were fixed circular area plots with a radius of 300 m centred around the sample points. This approach ensured that no assumption based on the homogeneity of land cover needed to be made in advance (Stehman & Czaplewski, 1998). The study aimed to sample at least 60 points in the study area, contributing to almost 1,700 ha of sampled area in total.

The stratification was done by selecting 20 points in each urban area class (ksg, rsg and gsg). Within each stratum, 10 points were selected in 'urban' areas, within the demarcation of the Spatial Structure Plan, and 10 points in 'rural' areas, outside the urban areas, within the 4 km buffer. Within these groups of 10 points, it was ensured that at least 50% of the fixed area plots contained at least one UGS as mapped by OSM. This stratification approach ensured an overall accuracy that represented UGS in all types of urban areas in Flanders and allowed to compare the accuracies of the different strata separately. The sample points are represented in Figure 3.5 and Appendix 8.2 depicts the exact distribution of the samples.

To select the sample points, a list of addresses and municipalities of acquaintances from the university of KU Leuven was set up to have expert knowledge available at the locations. These points accounted for about half of the sample points and were approximately randomly distributed, but there was a strong bias towards the east of the region. Therefore, 30 additional points were randomly selected towards the west of Flanders. All points were located on the street network. The sampling was then done by multiple expert collectors combining field observations, expert knowledge of the locations, and Google Street View (Google, n.d.) image analysis.

Step 2: Response design

To spatially delineate all UGS within the sample units, the definition of UGS was used (cf. §3.2.1). To facilitate the determination of ground condition labels, a green cover map was created for each sample unit to locate green areas. An example is shown in Appendix 8.3. The classes 'grass and shrubbery', 'trees', and 'other uncovered surfaces' were selected from the land cover map of 2018 (Agentschap Digitaal Vlaanderen, 2021) and converted to vector data. Private gardens were clipped out using the class 'houses and gardens' of the garden map of Flanders (GARMON, 2020). The resulting polygons were dissolved, and small holes were removed. The final map was overlaid on Google Satellite Images (Google, 2023), together with a delineation of agricultural areas and water areas.

The ground cover maps were delivered to the sample collectors. Based on this map (Appendix 8.3) and a provided response form (Appendix 8.4), the collectors delineated all accessible UGS within, and intersecting with, the sample unit. Also, they checked on OSM if there were any additional UGS that might have been deleted from the green map when removing the private gardens.

After double checking if the sample UGS matched the definition, they were manually added to a vector layer in QGIS, based on Google Satellite Images (Google, 2023). Additional processing was performed in FME to improve the alignment with the definition and to prevent errors in other data sources to cause a lower accuracy for the use of OSM. Also here, private gardens and agricultural parcels were removed, based on the garden map (GARMON, 2020) and agricultural use parcel map of Flanders (Departement Landbouw en Visserij, 2021) because they did not conform to the definition and to make sure the accuracy of OSM and not these external maps was tested. Finally, UGS smaller than 0.2 ha or with a compactness smaller than 0.2 were removed. This map then consisted of the area within the circular sample plots and was used as a reference map for UGS in Flanders.

Step 3: Accuracy assessment

It is crucial to verify the quality of geodata sources, particularly for OSM data, since the data collection and tag assignment are unrestricted. This causes the reliability and accuracy of the data to be uncertain (Barron et al., 2014). Therefore, the accuracy of OpenStreetMap and the green typology map of Flanders were evaluated, reflecting the difference between the target and reference dataset. A detailed description of the accuracy assessment used in this study can be found in Appendix 8.5, including the reasoning behind its selection.

The overall accuracy (OA) explains how well the overall classification of OSM is performed, for both the UGS class as well as for the non-UGS class (Equation 3). Since this gives a large weight to the area not classified as UGS, which will be larger than the UGS area, the producer's and user's accuracy for UGS can give better insights on how well UGS are mapped by OSM. The user's accuracy of the UGS class (UA_{UGS}) indicates how reliable the map is, or the probability that a location classified as an UGS by OSM is also classified as UGS by the reference map (Equation 4; Jokar Arsanjani et al., 2015). The producer's accuracy of the UGS class (PA_{UGS}) indicates how well the situation on the ground can be mapped as it refers to the probability that an UGS from the reference map is classified as such (Equation 5; Jokar Arsanjani et al., 2015).

$$OA = \frac{Area\ (UGS\ OSM) \cap Area\ (UGS\ REF) + Area(nonUGS\ OSM) \cap Area(nonUGS\ REF)}{Area} * 100\% \qquad (3)$$

$$UA_{UGS} = \frac{Area\ (UGS\ OSM) \cap Area\ (UGS\ REF)}{Area\ UGS\ OSM} * 100\% \qquad (4)$$

$$PA_{UGS} = \frac{Area\ (UGS\ OSM) \cap Area\ (UGS\ REF)}{Area\ UGS\ REF} * 100\% \qquad (5)$$

where '*Area (UGS OSM) ∩ Area (UGS REF)'* denotes the area that is classified as UGS by both OSM and the reference map, and '*Area (nonUGS OSM) ∩ Area (nonUGS REF)'* is classified as non-UGS by both OSM and the reference map. '*Area*' depicts the entire area used for the accuracy assessment.

This can also be done for the non-UGS by replacing 'UGS' by 'non-UGS' in Equation 4 and 5, although this holds less information as the overlapping area will generally be large because a lot of land cover classes are combined within the non-UGS class.

The UGS resulting from the workflow in Paragraph 3.2.2.1 and reference map (A) were both loaded into FME and the OA, UA_{UGS} and PA_{UGS} were calculated. This was also performed after each step of the workflow to see if it added value and increased the accuracy. For the final UGS map, the accuracy for the classes 'urban', 'rural', 'gsg', 'rsg' and 'ksg' was determined separately as well.

The accuracy of the Green Topologies map of Flanders (Verachtert & Poelmans, 2022) was also compared to the UGS reference map of Flanders. Furthermore, to get an idea of the accuracy compared to an actual existing reference map, the accuracy of the UGS map for Ghent was also computed compared to the reference map of the municipality of Ghent (Stad Gent, 2022b; Stad Gent, 2022c). To make this map comparable to ours, all UGS smaller than 0.2 ha were filtered out.

3.2.2.3 Urban Green Space accessibility

With the newly developed UGS map, availability measures were calculated. These measures quantify the amount of UGS without considering their proximity or accessibility (World Health Organization. Regional Office for Europe, 2016). To account for accessibility, a traffic network analysis, based on the road network obtained from OSM data (cf. §3.2.2.1), was performed. The methodology consists of the following three steps. First, the entrance points to the UGS from the OSM map were retrieved to use as starting point for the traffic network analysis. Second, distances between the entrance points and all pixels in Flanders were calculated based on different functional levels for different sizes of urban green, using the pedestrian traffic network. Third, these distances were assigned a score based on their travel time, ranging from 0 to 10 minutes, per travel mode, namely 'pedestrian' and 'cyclist'. These scores were used to calculate the final UGAI and cUGAI.

Step 1: The entrance points

We assumed people enter an UGS at the location where a pedestrian road crosses the UGS. The entrance points were obtained in FME by identifying the points where the UGS intersected with the pedestrian road network. Since not all UGS crossed the road network, some UGS did not have entrance points assigned to them. This was due to the retention of the priority class in the fifth step of obtaining the UGS map (cf. §3.2.2.1) regardless of the condition of intersection with the road network. Consequently, for these UGS, it was assumed the polygons were accessible from multiple sides, and therefore, 10 random entrance points were assigned to each polygon with a minimum distance of at least 20 m in between. These points were aggregated to the other points.

Step 2: Traffic network analysis

After evaluating various applications, the QGIS plugin QGIS Network Analysis Toolbox 3 (QNEAT3) was used for the traffic network analysis. It provides shortest path and iso-area algorithms in the field of network analysis (Raffler, 2020). This application delivers the highest detail within time constraints, offering flexibility because your own traffic network can be inserted. The 'Iso-Area as Polygon (from Layer)' function was used. This algorithm delivered both an interpolation raster with values of the closest distance of each pixel to the entrance points of UGS and iso-areas with multiple contours.

1. The pedestrian traffic network analysis

Calculating accessibility from MIRA-S 2000 functional levels

Van Herzele and Wiedemann (2003) concluded that one needs UGS within a different reach for different functional levels of UGS, because they fulfil different functions at the different levels. Therefore, the MIRA-S 2000 minimum standards (Van Herzele et al., 2000) for UGS in Flanders (Table 2.1) were used to perform different calculations for different functional levels. In practice, a different algorithm in QNEAT3 was performed for each of the parameters in Table 2.1. The input variables were the entrance points of UGS, the pedestrian traffic network, and the maximum distance from home as value for the iso-area. With the resulting iso-areas, the number of people living within these areas was calculated in QGIS through zonal statistics of the population density (Vlaamse Overheid – Departement Omgeving, 2022) per iso-area. These population numbers could then be compared with the study by Natuurpunt (Nys, 2014), who did a similar analysis.

Calculating accessibility for the Urban Green Accessibility Index

To calculate the UGAI, an aggregated distance score for Flanders had to be constructed. There was no consensus on what the maximum walking distance or travel time for an UGS should be from a person's residence (Paragraph 2.5.2.1). Generally, a 5-minute walk is mentioned as the distance at which at least one quality park should be available to people. The furthest limit used in greenery guidelines is 10 minutes. To convert this to maximum distances, the travel speed should be known. Bosina and Weidmann (2017) proposed a value of 1.34 m/s as an average pedestrian speed. By multiplying this speed with the time, a distance of approximately 400 m is taken as a travel distance for a 5-minute walk and 800 m for a 10-minute walk.

To use the determined upper limit of an 800-m walk, the functional level table (Table 2.1) was transformed into Table 3.3. Quarter green, district green, city green and urban forests were all merged into one class, ‘municipal green’, as it was determined distances greater than 800 m are beyond the threshold of pedestrian accessibility.

Table 3.3: Updated functional levels of urban green. With their maximum distance from home (m), minimum surface (ha) and corresponding approximate walking time (min) used in the traffic network analysis for pedestrians

Functional level	**Maximum distance from home (m)**	**Minimum surface (ha) to maximum surface (ha)**	**Corresponding approximate walking time (min)**
Residential green	200	0.2 - 1	2.5
Neighbourhood green	400	1 – 10 (park: 5 ha)	5
Municipal green	800	10 (park: 5 ha)	10

For each of these new functional levels, an analysis was performed, using different parameters. First, the entrance points and traffic network were isolated for each class. A buffer of 200 m, 400 m and 800 m of the pedestrian traffic network was taken for each of the functional levels, respectively, as input for the QNEAT3 algorithm. These two inputs were divided in several groups to limit computation time and inserted to the distance-optimisation algorithm.

The resulting interpolation raster layers had a 20 x 20 m resolution. They were clipped to Flanders’ 3 km buffer and aligned in QGIS. Next, the layers were merged by removing ‘no data’ values and taking the minimum cell value per overlapping pair of raster pixels. This distance was assigned the $dist_{walk,FLi,j}$ value. It should be noted that algorithm provides a merged isochrone and not an isochrone per point. Therefore, in the next step, an approximation for where isochrones are dissolved must be made to calculate the final UGAI and cUGAI.

2. The cyclist traffic network analysis

For the details of the method and materials of the cyclist traffic network analysis, we refer to Appendix 8.6.1.

Step 3: Distance scores

The scoring of the distances for the pedestrian analysis was dependent of the different functional levels (Table 3.3) and inspired by Fan et al. (2017). Each time, a ‘1’ value was assigned to distances closer than half of the maximum distance, a ‘0’ value to distances larger than the maximum distance, and values between ‘0’ and ‘1’ for values in between.

This resulted in the following scoring rules:

For residential green R$_i$ on walking distance $dist_{walk,R_{i},j}$ of a pixel j, the score was $d_{walk,R_{i},j}$,:

$$d_{walk,R_i,j} = \begin{cases} 0, & dist_{walk,R_i,j} > 200 \\ 1 - \dfrac{(dist_{walk,R_i,j} - 100)}{100} \\ 1, & dist_{walk,R_i,j} < 100 \end{cases} \tag{6}$$

For neighbourhood green N$_i$ on walking distance $dist_{walk,N_{i},j}$ of a pixel j, the score was $d_{walk,N_{i},j}$,:

$$d_{walk,N_i,j} = \begin{cases} 0, & dist_{walk,N_i,j} > 400 \\ 1 - \dfrac{(dist_{walk,N_i,j} - 200)}{200} \\ 1, & dist_{walk,N_i,j} < 200 \end{cases} \tag{7}$$

For municipal green M$_i$ on walking distance $dist_{walk,M_{i},j}$ of a pixel j, the score was $d_{walk,M_{i},j}$,:

$$d_{walk,M_i,j} = \begin{cases} 0, & dist_{walk,M_i,j} > 800 \\ 1 - \dfrac{(dist_{walk,M_i,j} - 400)}{400} \\ 1, & dist_{walk,M_i,j} < 400 \end{cases} \tag{8}$$

3.2.3 Quality of Urban Green Space

The second layer of the analysis involved the evaluation of the quality of UGS (Figure 3.2 & Figure 3.3). Quality metrics focus on the characteristics explaining the performance of UGS related to ES (Zhang et al., 2021a), including the provision of health benefits. The implementation of quality is often overlooked and there is a lack of evidence on the relationship between quality and health benefits (van den Berg et al., 2015). However, few studies have found a higher attachment to attractive and qualitative green spaces, resulting in higher reported wellbeing, as well as increased physical activity (Zhang et al., 2015) and other benefits, as discussed in Paragraph 2.2.3.1.

3.2.3.1 Quality indicators

Proposed quality indicators in this study were metrics associated with pathways through which contact with nature relates to health (cf. §2.5.2.2). It was also important these indicators were transferrable to GIS-based models for which data for the UGS of Flanders was available. Table 3.4 shows the chosen quality indicators, their data sources and relevant literature.

Table 3.4: Quality indicators, their data source and examples of literature on their link with health and on their use

Quality indicator	**Data source**	**Literature on the link with health**	**Literature using the quality indicator**
Size	The UGS map (cf. §3.2.2.1)	(World Health Organization. Regional Office for Europe, 2016)	(Fan et al., 2017; Stessens et al., 2020; Van Herzele & Wiedemann, 2003; Zhang et al., 2021b)
Biological value	The biological value map (Instituut voor Natuur-en Bosonderzoek, 2020)	(Aerts et al., 2018 ; Marselle et al., 2021 ; Wheeler et al., 2015)	Stessens et al. (2020)
Tree cover	Green map Flanders 2021 (Agentschap Natuur en Bos, 2022)	(Giles-Corti et al., 2005; Zhang et al., 2021a)	Stessens et al. (2020)
Land cover diversity	Land cover map Flanders 2019 (Agentschap Digitaal Vlaanderen, 2021)	(Wheeler et al., 2015)	Stessens et al. (2020)

These objective quality indicators specifically focus on the "Naturalness" aspect of UGS because of its data availability and proven health benefits (Stessens et al., 2020). It was generally established that a larger size, biological value, tree cover, and land cover diversity were preferred and delivered more health benefits (cf. §2.5.2). The following paragraph describes the scores $q_{i,k}$ assigned to the values of UGS i for these quality indicators k.

Size

First, the size of each UGS was calculated in FME. The larger the size, the higher the preference for, and health benefits of, UGS. The highest score '1' was assigned to all UGS that were larger than 60 ha (Stessens et al., 2020). The lowest score of '0.1' was attributed to the minimum area of UGS of 0.2 ha. Residential green, up to 1 ha, received a score between 0.1 and 0.2. All values in between 1 ha and 60 ha received a score in between 0.2 and 1. The scoring QS_i of an UGS i with a size S_i for an UGS i then consisted of:

$$QS_i = \begin{cases} 0.1 + \dfrac{(S_i - 0.2\,ha)}{0.8\,ha * 10}, & 0.2\,ha \leq S_i < 1\,ha \\ 0.2 + \dfrac{(S_i - 1\,ha)}{59\,ha * 1.25}, & 1\,ha \leq S_i < 60\,ha \\ 1, & S_i \geq 60\,ha \end{cases} \tag{9}$$

Biological value

The criterion of biological quality is directly related to the species diversity of plants and animals. This biological value was obtained from the Biological Valuation Map of Flanders (Instituut voor Natuur-en Bosonderzoek, 2020). This map assigns a biological value to various mapping units based on four criteria: rarity, biological quality, vulnerability, and replaceability.

This value of this map ranges from "biologically highly valuable", “biologically valuable” to "biologically less valuable", with complexes containing combinations of all in between. These classes were converted in FME into numerical values ranging from 0 to 1 (Table 3.5) by assigning a value 0, 0.7, and 1, to the “biologically less valuable”, “biologically valuable”, and “biologically highly valuable” class, respectively. The complexes were subsequently assigned average values based on combinations of these numerical values.

Table 3.5: Biological valuation and indication (Instituut voor Natuur-en Bosonderzoek, 2020) with numeric transformation

Valuation	Indication	Numerical value
Biologically highly valuable	z	1
Complex of biologically highly and biologically valuable elements	wz	0.85
Biologically valuable	w	0.7
Complex biologically less valuable, valuable and highly valuable elements	mwz	0.56
Complex of biologically less valuable and highly valuable elements	mz	0.5
Complex of biologically less valuable and valuable elements	mw	0.35
Biologically less valuable	z	0

The biological value map was clipped in FME to the UGS map. Next, the final biological value per UGS was determined by a weighted average based on the area of each mapping unit in the UGS. Since this value was already standardised between 0 and 1, and increased with an increasing biological value, it served as the final biological value quality score QB_i..

Since the biological value map was limited to the extent of Flanders, a different method was adopted for UGS outside of Flanders. When more than 50% of the area of an UGS was within the boundaries of Flanders, the biological value of the portion inside of Flanders was extrapolated to the entire UGS. When an UGS was situated for less than 50% inside of Flanders, the median score of 0.58 was assigned to those UGS because of the non-normal distribution of the scores.

Tree cover

The Green Map of Flanders, version 2021 (Agentschap Natuur en Bos, 2022), was used to obtain tree cover data. The 1 m resolution tiles were resampled to 5 x 5 m pixels and merged using FME software. All pixels with a height greater than 3 m were designated as ‘high green’ in the green map. These pixels were classified as pixels covered by trees and given a value of 1. Other cell values received a 0 value. This process enabled the computation of zonal statistics of the raster layer per UGS in QGIS. The mean value by the tree cover raster layer per UGS polygon, multiplied by 100, was used as the percentage of tree cover T_i.

An increasing tree cover is associated with increasing health benefits related to air quality improvement, UHI reduction and physical and mental health improvement. Since landscape preferences of tree cover density stabilise when coverage is around 60% (Jiang et al., 2015), this value and higher values were given a maximum score of 1. When there was no tree cover, it was assigned a 0 score, while scores QT_i between 0 and 1 were assigned to areas with intermediate levels of tree cover density:

$$QT_i = \begin{cases} \dfrac{T_i}{60\%}, & 0\% \leq T_i < 60\ \% \\ 1, & T_i > 60\ \% \end{cases} \tag{10}$$

The extent of the Green Map was again limited to Flanders. UGS located for more than 50% inside of Flanders received the score assigned to the part inside of Flanders. Since the distribution of tree cover quality scores was not normally distributed, UGS located for more than 50% outside of Flanders, received the median score of 1.

Land cover diversity

People tend to recreate more and do multiple activities in landscapes with a high diversity of land cover (Wheeler et al., 2015). Consequently, a higher diversity in land cover relates to health benefits. Furthermore, water features are appreciated (World Health Organization. Regional Office for Europe, 2016).

The land cover diversity was calculated and implemented as a quality indicator. The land cover map of Flanders, version 2018 (Agentschap Digitaal Vlaanderen, 2021), was resampled from a 1 m to 5-m resolution and the different tiles were merged in FME. The classes ‘water’, ‘agriculture’, ‘low green’ and ‘high green’ were selected as land cover classes for which the diversity was determined. In QGIS, the zonal histogram for these classes per UGS was calculated. This made it possible to calculate the Shannon diversity index in R, using the *vegan* package (Oksanen et al., 2021), which combines a measure for the richness and the evenness. These values were standardised between 0 and 1. The maximum diversity of 1.32 received the 1 value and the minimum diversity of 0 a 0 value, resulting in a higher score QL_i for a higher land cover diversity. Since the extent of the land cover map was limited to Flanders and the scores were not normally distributed, UGS located more than 50% inside of Flanders, received the score assigned to the part inside of Flanders and those located less than 50% inside Flanders, the median value of 0.278.

For each combination of quality indicators, the Spearman correlation and its p-value were calculated using the *corrplot* package in R (Wei & Simko, 2021) to determine whether the choice of these indicators delivered sufficient complementary information.

3.2.3.2 Quality indicator weights

Multiple studies use weights to determine the importance of different quality indicators in the final index (Fan et al., 2017; Stessens et al., 2020). Due to a lack of evidence on linkages of these indicators with direct health benefits (van den Berg et al., 2015) and studies comparing them within this framework of health, these weights can be based on indirect health benefits. This approach considers preferences of people for the quality characteristics, impacting the number of visitations, wellbeing, and the reception of cultural ecosystem services (Stessens et al., 2020). However, there is no study directly comparing these specific indicators of size, biological value, tree cover and land cover diversity, to each other. The most intuitive way to determine weights for the different indicators is to rank them based on existing literature. This can be easily understood and adapted to a stakeholders’ preference. In most studies, size was selected as most important and therefore it received the first rank. Following size, the land cover diversity was important and finally, the natural elements of tree cover and biological value entered in a shared final rank (Bertram & Rehdanz, 2015; Stessens et al., 2020).

Weights w_k (Table 3.6) were obtained using the rank sum, where r stands for the rank, w_k for the weight of an indicator k and n for the number of indicators:

$$w_k = \frac{n - r_k + 1}{\sum_s (n - r_s + 1)} \tag{11}$$

Table 3.6: Quality indicators, their rank, weight and normalised weight

Quality indicator	Rank	Weight	Normalised weight
Size	1	4	0.363636
Biological value	3	2	0.181818
Tree cover	3	2	0.181818
Land cover diversity	2	3	0.272727

3.2.3.3 The Urban Green Accessibility Index

At this point, for each UGS i and quality indicator k, a quality score $q_{i,k}$ was determined. To assign a final quality score Q_i, weights w_k were introduced per indicator k. The final quality score Q_i for an UGS i could be computed through:

$$Q_i = \sum_{i=0}^{K} w_k * q_{i,k} \tag{12}$$

$$Q_i = 0.36 * QS_i + 0.18 * QB_i + 0.18 * QT_i + 0.27 * QL_i \tag{13}$$

Combining this with the first layer, that resulted in a score for the distance d_{ij}, the UGAI could be calculated as a function of d_{ij} and Q_i for a pixel j by summing the values for each functional level of UGS i in their vicinity:

$$UGAI_j = \sum_{i=0}^{n} UGAI_{ij} \tag{14}$$

$$UGAI_j = Q_{R_i} * d_{walk,R_i,j} + Q_{N_i} * d_{walk,N_i,j} + Q_{M_i} * d_{walk,M_i,j} \tag{15}$$

In practice, first, for each functional level, isochrone contours were subtracted from the distance score interpolation layers obtained in Paragraph 3.2.2.3.. Each isochrone was assigned an average distance score by Equation 6, 7 or 8. Next, these contours were compared with a buffer of the same distance in Euclidean distance as the contour. This step fixed mistakes made by the traffic network analysis and assigned the quality values of the UGS through these buffers to the isochrones.

Overlapping polygons within the same functional level received an average quality score. By multiplying the distance score with the quality score, the UGAI per functional level was obtained. Finally, the resulting UGAIs per functional level were summed where there was an overlap. These calculations were performed in FME.

3.2.4 Context of Urban Green Space

The calculations for the quantity and quality aspects (cf. §3.2.2 & 3.2.3) provide an estimation of the supply of UGS in a spatial unit. However, not all neighbourhoods have the same need for UGS. These needs or this demand depend on their environmental context, like the availability of open green space in their administrative mapping units (Figure 3.2 & Figure 3.3), being the 'statistical sectors' of Belgium. These sectors divide the territory of Belgium based on morphological and/or socio-economic characteristics and are the smallest administrative spatial unit (Statistics Belgium, 2023). The scores assigned to these statistical sectors could later be assigned to their respective pixels.

First, context indicators were selected that accurately reflected the need for UGS. Once the relevant context indicators were identified, each one was assigned a weight based on its relative importance in the final context value. This final context value was calculated and could then be compared to the UGAI. Lastly, the corrected UGAI (cUGAI) was calculated.

3.2.4.1 Context indicators

The need for UGS depends both on the population, and the environmental context of the residential area. Therefore, population density, overall green cover and garden area were chosen.

Population density

A certain level of UGS per capita is necessary. Overcrowding is a crucial factor affecting quality of UGS (Laan & Piersma, 2021). The higher the population density, the higher the demand for UGS. Yet, existing models in the literature of UGS analysis do not account for the population, hence scores for accessibility might look too optimistic for statistical sectors with high population densities (Laan & Piersma, 2021).

In this study, the population density per statistical sector was determined by computing zonal statistics per statistical sector in QGIS of the map describing the population density in Flanders expressed in number of people per ha (Vlaamse Overheid – Departement Omgeving, 2022). This population density was then translated into a context score.

Since the average population density in a statistical sector was 15 people/ha, population densities from 30 people per ha onwards were set as the highest score, equal to 1. Lower values of population density received a value between 0 and 1. The context score CP_j for population density P_j for a pixel j in a certain statistical sector was:

$$CP_j = \begin{cases} \dfrac{P_j}{30\,\dfrac{people}{ha}}, & P_j \leq 30\,people/ha \\ 1, & P_j > 30\,people/ha \end{cases} \tag{16}$$

Overall green cover

The inherent greenness of a neighbourhood including both UGS and non-UGS, hence its overall green cover, is an important indicator reflecting the demand for UGS. Overall green, including agricultural areas, private gardens, and streetscape greenery, delivers important health benefits to people (van Dillen et al., 2012). Moreover, streetscape greenery and agricultural areas can have an important recreational value as well. So, following Konijnendijk (2022), the overall green indicator includes the following additional aspects of nature exposure: opportunities to see nature, as well as exposure by living amongst it.

The higher the overall green cover, the lower the demand for additional UGS in a statistical sector. The green map (Agentschap Natuur en Bos, 2022) was used to estimate this indicator. In FME, the map was resampled to a 5 x 5-m resolution and the classes ‘high green’, ‘low green’ and ‘agriculture’ were given a 1 value, while the other classes, showing no green, received a 0 value. In QGIS, the zonal statistics per UGS were calculated and the mean value multiplied by 100 was considered as the overall green cover (%) of the area. When the green cover O_j of a pixel j in a statistical sector was 0, this was considered as the highest demand and given a context score CO_j of 1. The higher the green cover, the lower the context score and when it reached 60%, this was given a score of 0:

$$CO_j = \begin{cases} \dfrac{60\% - O_j}{60\%}, & O_j \leq 60\% \\ 0, & O_j > 60\% \end{cases} \tag{17}$$

Garden area

Not all overall green is accessible, for example private garden area. With a measure for 'garden area' in a neighbourhood, the extent of private greenery already available to residents becomes clear. We assume that high private green cover reduces the need for UGS.

The map used to determine the garden area was the garden map of Flanders (GARMON, 2020). Within this map, the polygons within the class 'houses and gardens' were selected as private gardens. Next, an overlap analysis in QGIS was performed with the statistical sectors. The percentage of overlap between a statistical sector and garden area was considered as the garden cover (%) G_j for a pixel j in a statistical sector. For this indicator, it was assumed that a higher garden area coverage resulted in a lower demand for UGS and therefore received a lower context score CG_j for a pixel j in a statistical sector. With an average garden area of 12.5% in Flanders (GARMON, 2020), a garden area of 25% was considered to have context score of 0, or the lowest demand. A garden area between 0 and 25% was given a score CG_j between 1 and 0, with a higher score attributed to a lower garden area:

$$CG_j = \begin{cases} \frac{25\% - G_j}{25\%}, & G_j \leq 25\% \\ 0, & G_j > 25\% \end{cases} \tag{18}$$

For each combination of context indicators, the Spearman correlation and its p-value were calculated using the *corrplot* package in R (Wei & Simko, 2021) to determine whether the choice of these indicators delivered sufficient complementary information.

3.2.4.2 Context indicator weights

The weights v_l for each context indicator l were assigned by ranking the indicators based on importance and using the rank sum weight (Equation 11) to translate the ranks into weights. For this study, population density was ranked first, followed by overall green cover, and lastly, garden area (Table 3.7).

Table 3.7: Context indicators with their respective ranks, weights and normalised weights

Context indicator	Rank	Weight	Normalised weight
Population density	1	3	0.5
Overall green cover	2	2	0.333333
Garden area	3	1	0.166667

Then, the final context score could be calculated. Including the weights v_l and the scores per context indicator $c_{j,l}$, the context score Cj of a pixel j in a statistical sector became:

$$C_j = \sum_{i=0}^{L} v_l * c_{j,l} \tag{19}$$

$$C_j = 0.5 * CP_j + 0.33 * CO_j + 0.17 * CG_j \tag{20}$$

3.2.4.3 The corrected Urban Green Accessibility Index

In the final layer, the demand for UGS, as represented by the context, and the supply of UGS, as represented by the UGAI, were compared to each other. Considering this aspect, an Urban Green Accessibility Index can be calculated, corrected for demand (cUGAI). This can be calculated as a function of the distance, quality and context layer for each pixel j associated with each UGS i, or as a function of the $UGAI_j$ and the context score C_j of a pixel j (Equation 21). A simple formula comparing supply and demand was used for this purpose where supply S is equal to the $UGAI_j$ and demand D is equal to the context value C_j. The factor u stands for a certain weight assigned to each factor:

$$cUGAI_j = f(UGAI_j, C_j) = f\left(d_{ij}, Q_i, C_j\right) \tag{21}$$

$$cUGAI_j = u_S * S + u_D(1 - D) = u_S * UGAI_j + u_D\left(1 - C_j\right) \tag{22}$$

Both vector layers of the UGAI and the context were first rasterised in QGIS with a 20-m resolution, as used for the traffic network analysis. Subsequently, the UGAI was normalised between 0 and 1 and the raster layers were aligned. To execute Equation 22, the raster calculator was used. Different weights were applied to see its effect on the result:

$$u_S = 0.8 \,\&\, u_D = 0.2$$

$$u_S = 0.5 \,\&\, u_D = 0.5$$

4. Results

4.1 Model development

The first result was the conceptual model for the Urban Green Accessibility Index (UGAI) and corrected UGAI (cUGAI), which was proposed in Paragraph 3 (Appendix 8.7).

4.2 Quantity of Urban Green Space

The second group of results included insights in the use of OSM for an UGS map, the quantity of UGS in Flanders and its accessibility.

4.2.1 Delineation of Urban Green Space

4.2.1.1 Green Typologies map – situation 2019

The Green Typologies map of 2019 by Verachtert and Poelmans (2022) comprised 5 functional levels, corresponding to those outlined in Table 2.1 (Appendix 8.8). All public green larger than 0.2 ha covered 323,645 ha or 23.8% of the area of Flanders. The distribution of UGS showed a clear majority towards the eastern part of the region and a minority towards the west, particularly in the southwest. This pattern was most pronounced for the two largest functional levels of city green and urban forests.

4.2.1.2 Urban green spaces by OpenStreetMap

With the map of UGS we created with OpenStreetMap (OSM) data (cf. §3.2.2.1), 21,973 UGS were identified within Flanders and its 3 km buffer, which occupied an area of 165,296 ha. When clipped to Flanders, 18,439 UGS were delineated (Figure 4.1), covering an area of 127,597 ha, which amounted for 9.3% of the area of Flanders. Consistent with the Green Typologies map, a significant portion of UGS was situated in the eastern part of the region, while considerably fewer UGS were present in the west. Municipal green spaces in the southwest were particularly scarce.

After zooming in on Leuven and Ghent (Figure 4.1), a comparison of their amount of UGS was made. In Ghent, 28 municipal UGS were found. The largest is the nature reserve Bourgoyen Ossemeersen of 231 ha, followed by the Blaarmeersen park and the nature reserves Vinderhoutse forests and Hoge Lake. Leuven contained 182 UGS covering an area of 979 ha, corresponding to 17% of the city's total area. In Ghent, 404 UGS covered 1,538 ha, which was equivalent to 9.8 % of the area. Among the 11 UGS belonging to municipal green in Leuven, the largest was the

Heverlee forest (north), which is divided into two parts due to the E40 highway. Other large UGS included Arenbergpark, provincial domain Kessel-Lo, and Egenhoven forest.

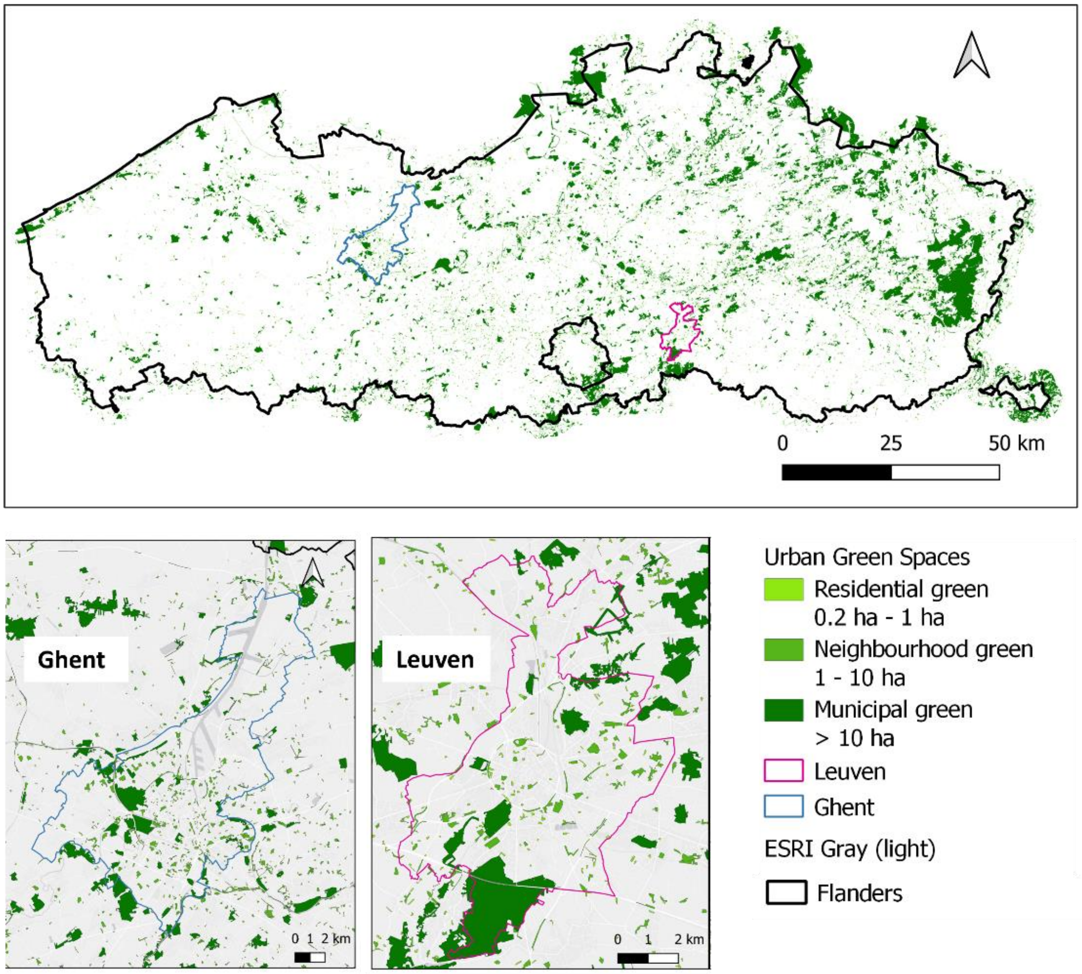

Figure 4.1: Urban Green Spaces using OpenStreetMap with their functional levels, with Flanders, Leuven and Ghent indicated (OpenStreetMap foundation, n.d.; Agentschap Digitaal Vlaanderen, 2017)

4.2.2 Validating Urban Green Space delineation

The Green Typologies map vs. OpenStreetMap

Within the reference map of UGS in Flanders, 142 UGS were delineated, covering 7% of the plots. The overall accuracy (OA), producer's accuracy (PA) and user's accuracy (UA) of UGS of the Green typologies map of 2019 (Verachtert & Poelmans, 2022) and the OSM UGS map were calculated. For the Green Typologies map, an OA of 86.4% was established. The UA for UGS was 27.5% and the PA was 87.9%. These values were lower than those obtained using the UGS OSM map, but the difference was smaller for the PA than for the UA.

For the OSM UGS map, these accuracies were calculated after each step of the workflow (cf. §3.2.2.1; Table 4.1). The study extracted an initial dataset of 368,076 UGS from OSM in Flanders, along with a 3 km buffer. After following the workflow steps, the dataset was reduced to 21,973 UGS, keeping approximately one-third of the area. The OA improved from 89.5% to 96.8%. The PA decreased by from 94.6% to 89.2%, indicating a slight decrease in the proportion of actual presence correctly identified by the map. This drop was very small compared to the significant increase of more than 38.3% to over 70% in the UA. This means that the map initially showed more UGS than actually present, but this decreased over time.

Table 4.1: Amount, area and accuracies of UGS map by OSM per step of the workflow. The number of urban green spaces (UGS), their total area (ha), overall accuracy, user's accuracy of UGS and producer's accuracy of UGS (%) based on an overlap analysis between the UGS reference map and UGS map based on OpenStreetMap (OSM) data

	Number of UGS	Area (ha)	Overall accuracy (%)	User's accuracy (UGS) (%)	Producer's accuracy (UGS) (%)
Step 1	368,076	471,903	89.5	38.3	94.6
Step 2	345,240	455,395	90.1	39.6	94.5
Step 3	296,128	232,555	94.9	57.2	93.5
Step 4	113,638	220,526	95.5	60.9	90.1
Step 5	44,691	161,105	96.8	70.2	89.0
Step 6 (UGS map)	21,973	165,296	96.8	70.3	89.2

Accuracy of OpenStreetMap data per stratum

When the results were divided per stratum, it was shown that the rural and urban class had a similar OA, UA and PA (Figure 4.2). Furthermore, the analysis revealed that regional urban areas exhibit a considerably lower UA than small or metropolitan areas.

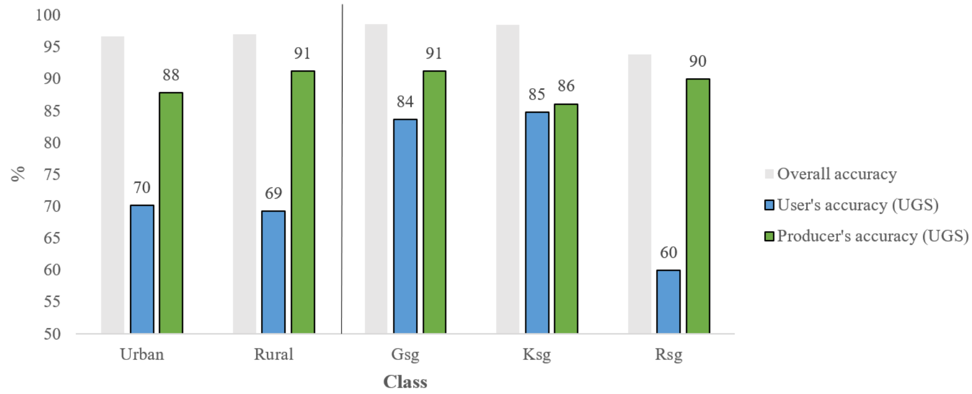

Figure 4.2: Overall accuracy, user's and producer's accuracy of the class Urban Green Spaces (UGS) based on an accuracy assessment comparing the UGS map based on OpenStreetMap to a reference UGS map. Results are given per strata where 'gsg' = metropolitan area, 'rsg' = regional urban area and ksg = 'small urban area'

Finally, the accuracy of our UGS map was determined based on the reference map for Ghent (Appendix 8.9), which consisted of a combination of the map of parks (Stad Gent, 2022b) and their map of neighbourhood and residential green (Stad Gent, 2022c). Here, the OA was 94.5%, the PA 85.3% and the UA 51.7% for the class UGS.

4.2.3 Urban Green Space accessibility

1. The pedestrian traffic network analysis

We extracted 873,213 pedestrian road segments from OSM and a total of 126,658 entrance points. On average, this was approximately 6 entrance points per UGS.

Calculating accessibility from MIRA-S 2000 functional levels

When the iso-areas surrounding the entrance points of different functional levels according to Van Herzele et al. (2000) were calculated, it became apparent that not the whole of Flanders was covered (Figure 4.3). A map per functional level can be found in Appendix 8.10. Calculating the availability of each functional level to the population of Flanders resulted in the following statistics:

- **Residential green** (larger than 0.2 ha), was present to a population of 1,006,971 within 150 m in Flanders. This was approximately 15.3% of the people. Note that the initial definition does not give size restrictions.
- **Neighbourhood green** (larger than 1 ha), was present to a population of 2,152,347 within 400 m in Flanders. This was approximately 32.7% of the people.
- **Quarter green**, which is green larger than 10 ha, or parks larger than 5 ha, was present to a population of 2,399,193 within 800 m in Flanders. This was approximately 36.4% of the people.
- **District green**, which is green larger than 30 ha, or parks larger than 10 ha, was present to a population of 3,394,210 within 1600 m in Flanders. This was approximately 51.6 % of the people.
- **City green**, which is green larger than 60 ha, was present to a population of 3,739,491 within 3200 m in Flanders. This was approximately 56.8 % of the people.
- **Urban forests**, which is green larger than 200 ha, was present to a population of 2,586,349 within 5000 m in Flanders. This was approximately 39.3% of the people.

For Leuven, 27% of the population had residential green within a 150 m walking distance from their homes (Figure 4.3, Appendix 8.10). Furthermore, 52.3% of the population had neighbourhood green within 400 m, 43% of the population had quarter green within 800 m, 66.4% of the population had district green within 1600 m, 78.1% of the population had city green within 3200 m, and 72.9% of the population had an urban forest within 5000 m. For Ghent, this was 27.9%, 51.6%, 53.5%, 64.9%, 52.9% and 68.9%, respectively.

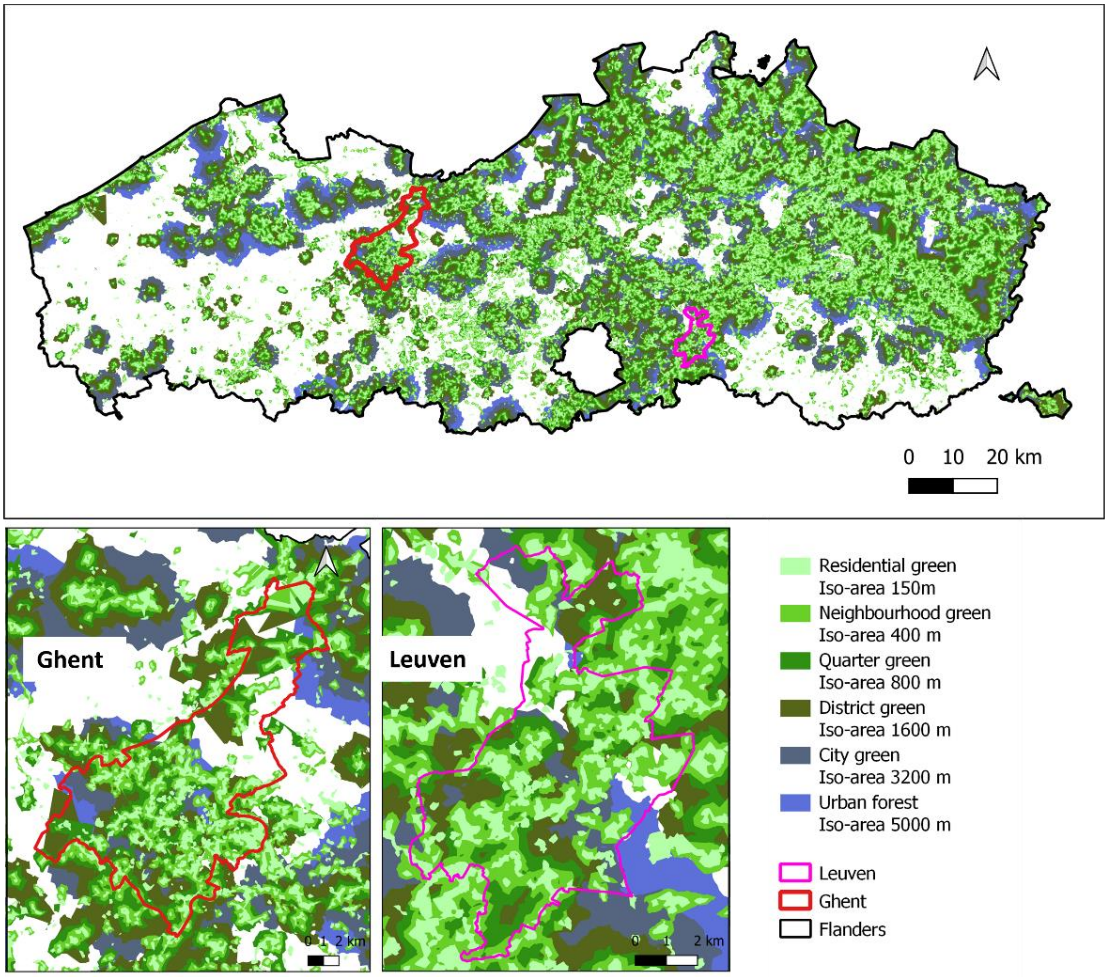

Figure 4.3: Iso-areas surrounding entrance points of urban green spaces for 6 different functional levels, with each a different maximum distance, with Leuven, Ghent and Flanders indicated (Agentschap Digitaal Vlaanderen, 2017)

Calculating accessibility for the Urban Green Accessibility Index

Performing the algorithm by QNEAT3 for the functional levels residential, neighbourhood and municipal green (Table 3.3), three separate iso-areas were obtained with each a different score for the distance (Figure 4.4). White areas represent areas without green at walking distance, attributed a zero score. This was visualised for Leuven and Ghent in greater detail.

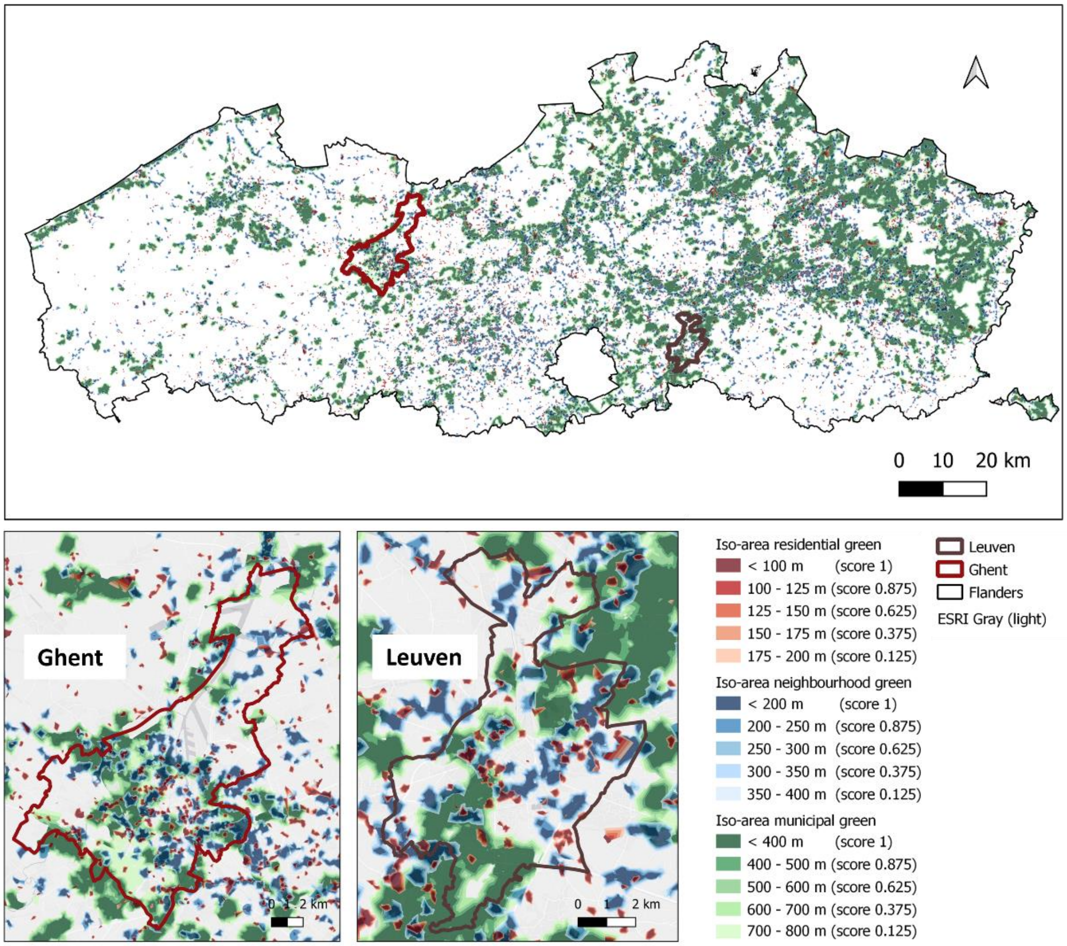

Figure 4.4: Iso-areas for three new functional levels: residential green, neighbourhood green and municipal green, according to Table 3.3 with for each iso-area a different distance score. With Leuven, Ghent and Flanders indicated (Agentschap Digitaal Vlaanderen, 2017)

When these iso-areas were merged (Appendix 8.11), they covered 43.3% of the Flemish area. When the population was counted within this area, it was observed that 55.2% of the Flemish population had green within walking distance from their residence. White areas represent areas without green at walking distance, attributed a zero score. For Leuven, the iso-area covered 68.4% of the area and it was found 70.6% of the population resided in this area, having green within walking distance from their home, and for Ghent, this was 61.8% and 78.6%, respectively.

2. The cyclist traffic network analysis

For the cyclist network, 721,343 road segments were extracted. The results for the cyclist traffic network analysis, showed a large coverage of Flanders (Appendix 8.6.2). In Flanders, 95.3% of the area was covered, and 99.5% of people had access to green larger than 0.2 ha within 2100 m, or a 10-minute biking trip, from their residence.

4.3 Quality of Urban Green Space

4.3.1 Quality scores

The scores for each quality indicator separately, showed different patterns (Appendix 8.12). It was apparent that some UGS located more than 50% outside of Flanders received the same score for biological value, tree cover and land cover diversity, equal to the median of the distribution of the other scores. In the final score (Figure 4.5), they did differ because of their different size score.

The scores for size were intuitively higher for larger UGS. These larger areas that were visible on the map of Flanders also seemed to align relatively well with areas with a higher biological value and high tree cover. For the land cover diversity, these scores however dropped to the lower ranging scores. To get a clear view on these correlations, they were calculated using the Spearman correlation (Appendix 8.13). The correlation was significant for all indicators ($p < 0.05$). The size was slightly positively correlated with biological value, tree cover and land cover diversity, while the land cover diversity was slightly negatively correlated with biological value and tree cover. There was a stronger correlation of 0.52 between the indicator biological value and tree cover. This could be considered as moderately high and was yet not excessively high.

In Leuven, the Heverlee forest stood out as the largest UGS (Appendix 8.12). Forested areas like this typically received high scores for size, biological value, and tree cover. Due to the prominence of one land cover ‘forest’ however, the land cover diversity score was rather low. Another example of a large UGS, was the Arenberg Park that scored average on land cover diversity, while the size was large, the biological value was moderate and the tree cover was high.

In Ghent, the Bourgoyen Ossemeersen nature reserve, located in the centre-west, received a high score for size and biological value, a lower score for tree cover and a medium score for land cover diversity. On the other hand, the smaller nature reserve to its right scored also high for size, medium for biological value and high for tree cover and land cover diversity.

These patterns were reflected in the final scores (Figure 4.5), where size carried the most weight. Thus, the largest UGS in Flanders received the highest scores. In Leuven, Heverlee forest achieved the highest quality score, whereas Arenberg Park scored average. Similarly, in Ghent, the Bourgoyen nature reserve received a higher score than the smaller nature reserve because of the impact of the higher size.

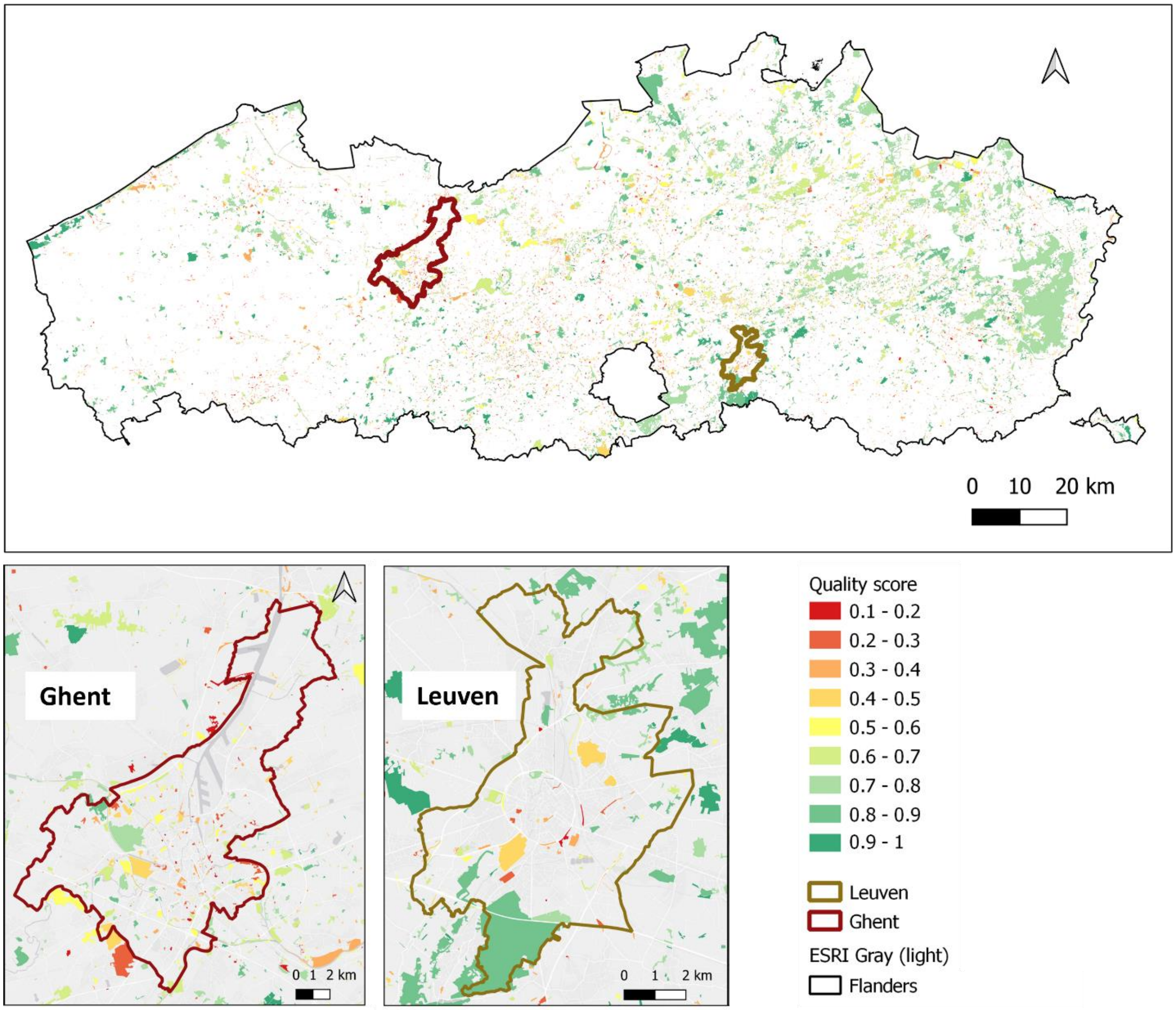

Figure 4.5: Final quality score for Urban Green Spaces in Flanders, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

4.3.2 The Urban Green Accessibility index

The UGAI was calculated by combining the quantity and quality layer (Figure 4.4 & Figure 4.5). The resulting layer was a raster layer with a 20 x 20-m resolution.

For the pedestrian analysis, it became apparent that all areas outside of the 10-minute isochrone received a zero score (Figure 4.6). Within this iso-area, it was also visible that the score systematically decreased towards edges. In locations where there was a combination of residential, neighbourhood and municipal green, the score could be higher than 1. Areas that have high quality UGS nearby also showed higher scores. This became apparent in Ghent, where areas close to the nature reserves received high scores, while in the north, low scores were obtained.

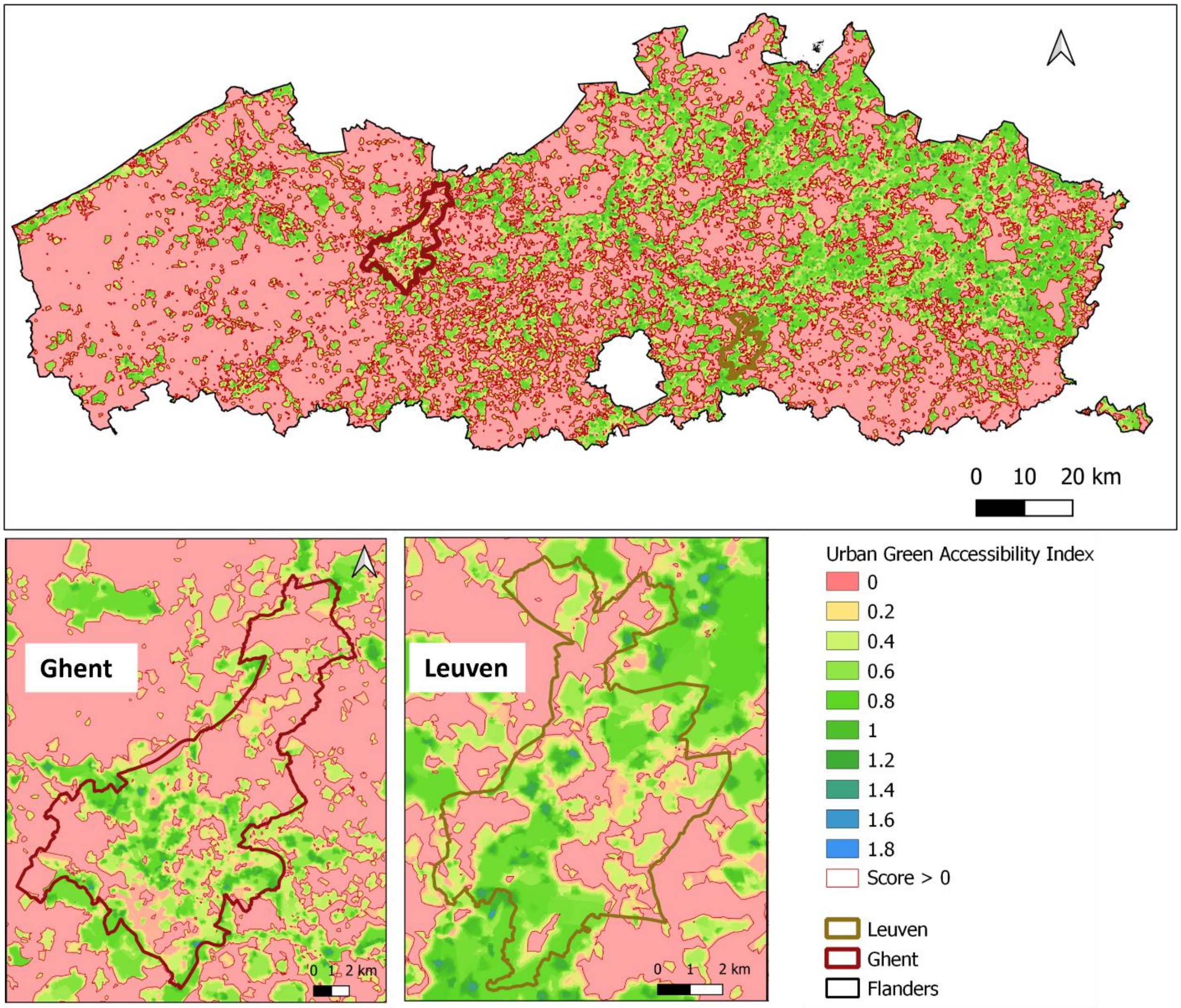

*Figure 4.6: Pedestrian Urban Green Accessibility for Flanders and isochrone for 10-minute walking time to entrance points, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 20*17)

Similarly, where the cyclist UGAI is zero, UGS were not accessible within a 10-minute biking trip (Appendix 8.6.2). Here, however, this area remained relatively limited, but was the largest towards the west. For Flanders, the distribution of UGS scores showed a clear gradient from east to west, with higher scores in the east.

4.4 Context of Urban Green Space

4.4.1 Context scores

The context score was computed per statistical sector for each context indicator (Figure 4.7). It should be noted that a high context score signifies a greater demand or requirement for UGS and is represented in red.

Several patterns emerged while evaluating the scores for Flanders separately (Appendix 8.14). The score for population density was the highest in urbanised regions, like Ghent, Antwerp and Leuven. This seemed to align with areas where the overall green coverage was relatively lower, and where the context score for overall green was greater, although it was more concentrated. The indicator ‘garden area’ followed an opposing trend, with greater coverage in regions with higher population density, and hence, a lower demand and context score for garden area.

To confirm this, the Spearman correlation was calculated (Appendix 8.13). The correlation between all indicators was significant ($p < 0.05$). Garden area and overall green cover score were slightly negatively correlated (-0.21). The correlation between the overall green cover and population density score was moderate (0.57). The garden area and population density scores were highly negatively correlated (-0.75).

In Leuven and Ghent (Appendix 8.14), a high population and population score were mainly observed in the centre of the municipality. The overall green cover was lowest in the centre and towards the north of both municipalities and therefore, the score for demand was highest there. This overall green cover was rather high (> 60%) for Leuven in the south, near the forested areas and for Ghent in the west, where there are a lot of agricultural parcels. Therefore, the demand score was relatively low (0 - 0.2) there. The population was highest (> 30 people/ha) in the centre, the garden area was lower there, resulting in a high demand score (0.6 – 1). The highest garden areas surrounded the centre and resulted in the lowest scores.

In the final context score, these patterns re-appeared, with the largest focus on population density, because it was given the highest weight (Figure 4.7). Therefore, in Flanders, the highest context scores hence highest demands were situated in urbanised areas.

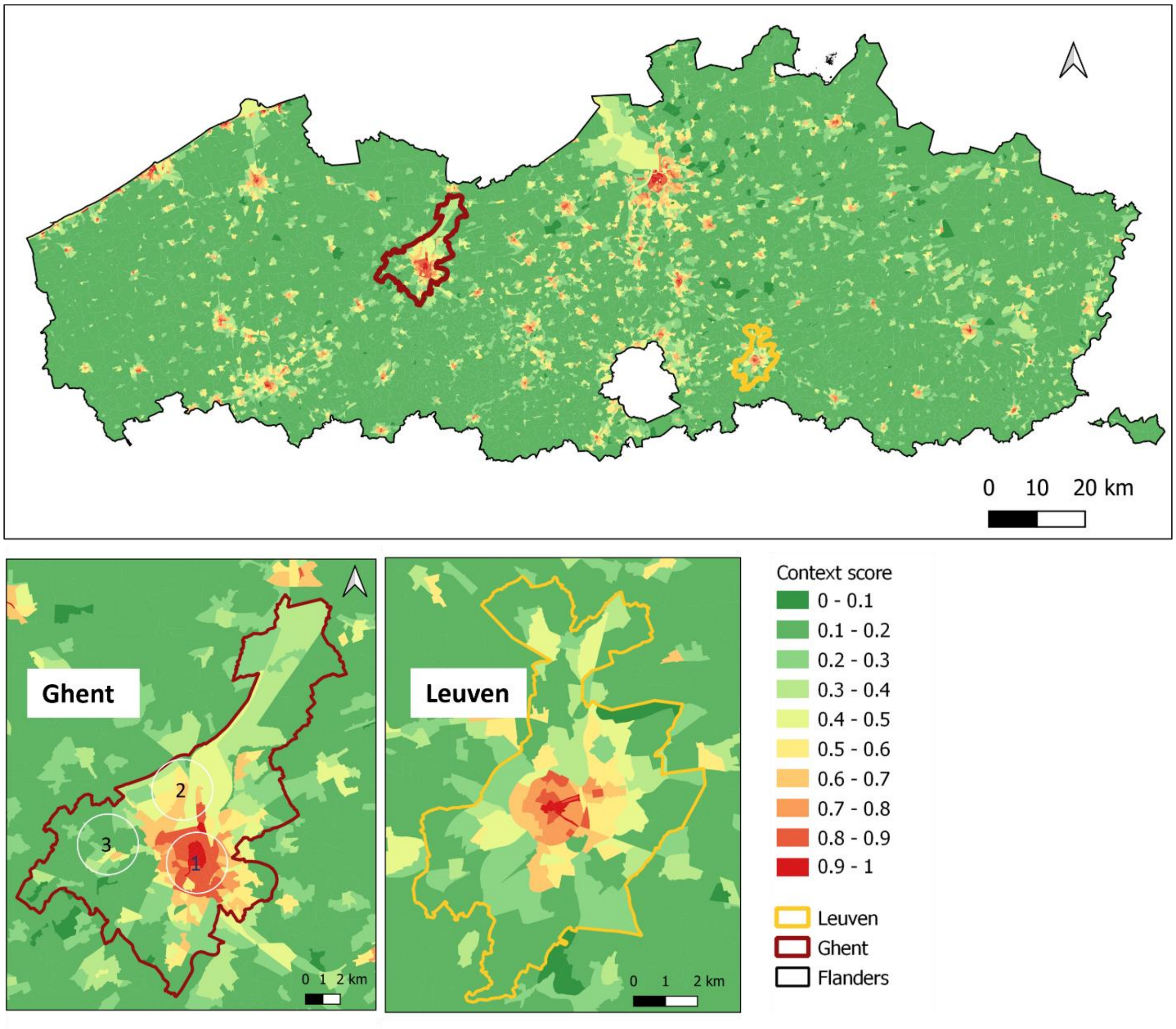

Figure 4.7: Context score for Flanders, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017). Three zones are indicated in Ghent: (1) a high context score in the city centre, (2) a medium context score in an industrial area, (3) a low context score in an agricultural area.

In Leuven and Ghent, the highest scores (0.8 - 1) were found within the centres of the municipalities (Figure 4.7). For the discussion, three zones in Ghent were indicated. The first one, was in the city centre with a high population density, a low overall green cover and low garden area, and therefore, one of the highest context scores (0.8 - 1). The second one, was an industrial zone near the port with a low population density, low overall green cover and low garden area, and therefore a medium context score (0.4 - 0.6). The third one, was an area with a lot of agricultural fields, with a lower population density, high overall green cover and medium garden area, and therefore, a low context score (0.1 - 0.4).

4.4.2 The corrected Urban Green Accessibility index

By combining the context score with the pedestrian UGAI with Equation 22, the corrected UGAI (cUGAI) was calculated. First, the supply, represented by the UGAI (Figure 4.6), was given a larger weight of 0.8 and the demand, represented by the context (Figure 4.7), was given a lower weight of 0.2 (Figure 4.8, Appendix 8.15). Therefore, the resulting index resembled the UGAI the most. Unlike the UGAI, where beyond the iso-area there was initially a zero score, the score was now higher than zero when the context score is smaller than 1, because the complement was added to the score. The context score became slightly noticeable, especially when examining the city centres of Ghent and Leuven (Figure 4.8), that received the lowest scores. Likewise, within accessible areas in the city centres, the score decreased because of the high context score.

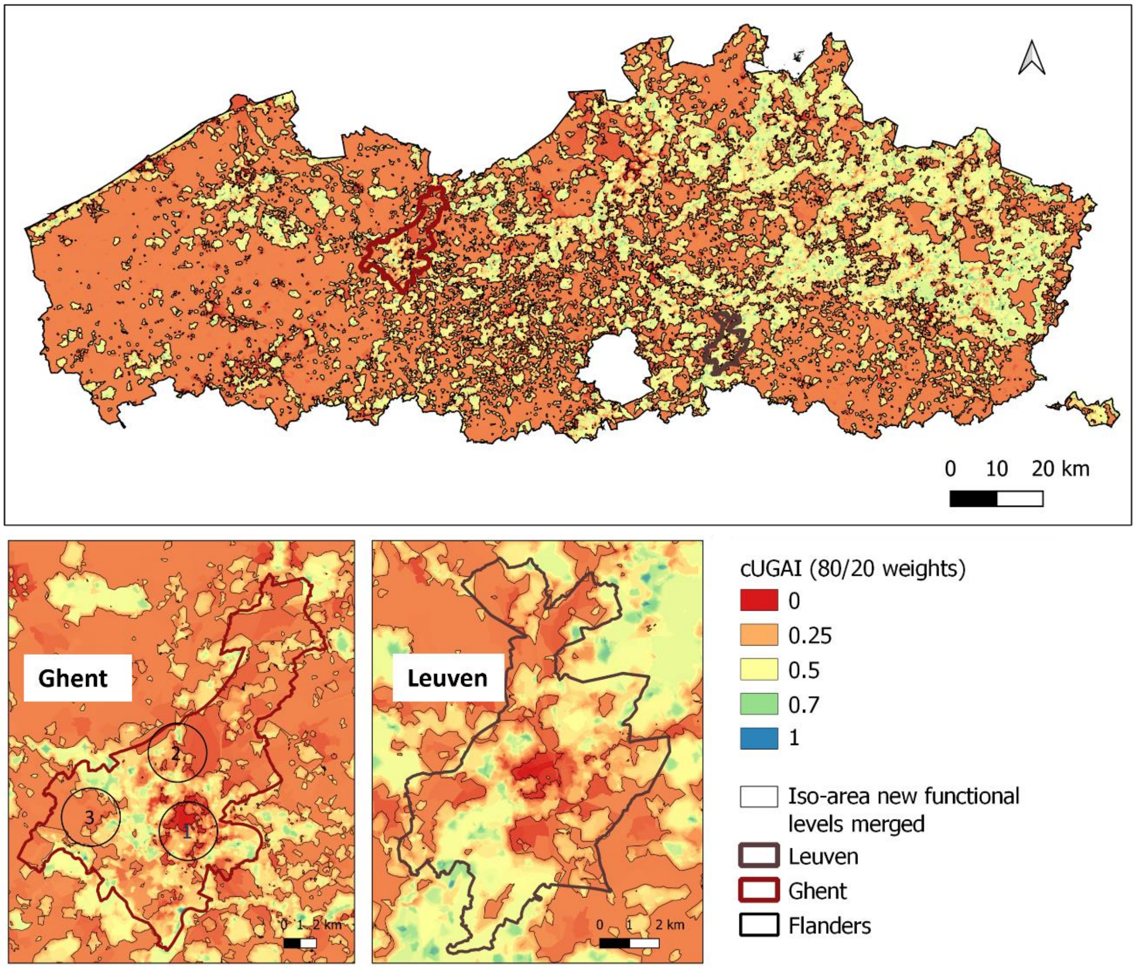

Figure 4.8: Pedestrian corrected Urban Green Accessibility Index (cUGAI) for Flanders, Leuven and Ghent based on a 0.8 weight for the supply and 0.2 for the demand, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017). Three zones are indicated in Ghent: (1) a high context score in the city centre, (2) a medium context score in an industrial area, (3) a low context score in an agricultural area.

Second, 50/50 weights were assigned. This resulted in more evident patterns. In Flanders, most areas beyond a walking distance of 10 minutes received a medium score instead of zero, because of the low demand for green in these spaces (Figure 4.9; Appendix 8.16). Furthermore, areas in the highly populated city centres systematically obtained lower scores than areas in the more natural forest areas in the north of Leuven and southwest of Ghent.

In Ghent, the trend observed in the context also became very clear outside of the accessible area. The lowest scores were situated in the city centre (1), followed by the industrial area (2), and the highest scores, were found along agricultural fields (3), where the demand for UGS was the lowest.

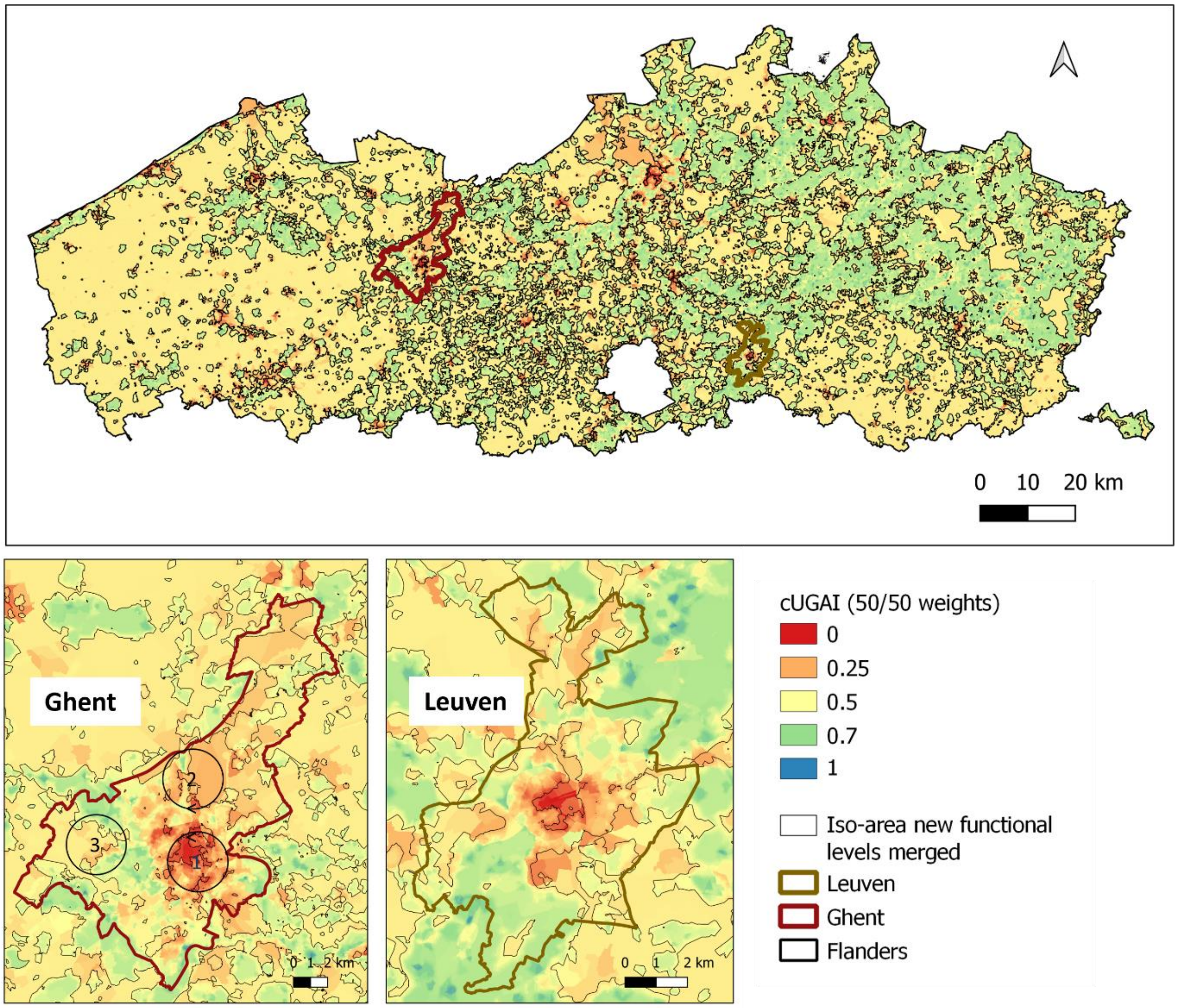

Figure 4.9: Pedestrian corrected Urban Green Accessibility Index (cUGAI) for Flanders, Leuven and Ghent based on a 0.5 weight for the supply and 0.5 for the demand, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017). Three zones are indicated in Ghent: (1) a high context score in the city centre, (2) a medium context score in an industrial area, (3) a low context score in an agricultural area.

For the cyclist cUGAI, we refer to Appendix 8.6.2.

5. Discussion

5.1 Implementation of the Urban Green Accessibility Index

5.1.1 Development and accuracy of an Urban Green Space map for Flanders

Comparison OSM and the Green typologies map

The Green Typologies map indicated that 23.8% of Flanders was covered by public green, while the OpenStreetMap (OSM) Urban Green Space (UGS) map showed only 9.3 %. It is important to note that there may be differences in the definition of green spaces used by the two maps, causing different results and conclusions. Verachtert and Poelmans (2022) defined public green based on categories of the land use map of 2019 by Poelmans et al. (2021). Like our definition, they included parks and managed green if they are larger than 0.2 ha and excluded private green and military areas. They, however, excluded cemeteries, because they did not see them as accessible. Furthermore, they clustered green spaces based on certain barriers, including small water features and agricultural parcels if enclosed by public green. Similarly to our definition, inaccessible areas were excluded based on their accessibility by the road network, but unlike our definition, UGS were included solely based on adjacency, even without an intersection.

Our definition of UGS closely matched that of the Green Typologies map, with only minor deviations. Despite this, there was a significant difference in coverage between both maps. Furthermore, the overall accuracy (OA) of the OSM UGS map (97%) was significantly higher than that of the Green Typologies map (86%). The high producer’s accuracy (PA) for the OSM UGS map (89%) suggests that almost all actual UGS are represented by the map, while the Green Typologies map only covered 65% of the UGS area. The low user’s accuracy (UA) of the Green Typologies map (28%) indicates that it includes many more areas as UGS that are not actually accessible or managed for recreational purposes, compared to the OSM map (70%). A possible explanation for this difference is the inclusion of agricultural parcels surrounded by public green and complete forests by the Green Typologies map, regardless of their UGS character. Furthermore, they also included UGS that are adjacent to the road network and do not intersect with it. To indicate actual accessibility and management for recreational purposes, we can therefore argue that our map of UGS by OSM is a better representation of actual UGS in Flanders, confirmed by the UA and PA.

In addition to the accuracy assessment, various other arguments both in favour and against each map can be considered. The main benefit of a green map based on satellite data, is that its accuracy is less affected by the degree of urbanisation. In contrast, OSM relies heavily on user input, which is more abundant in urban areas (Le Texier et al., 2018). However, in Flanders, the accuracy of both maps was found to be similar across urban and rural areas (Figure 4.2). Also, the use of satellite and raster imagery has some limitations, including the lack of clear boundaries and a relationship to the street network. This has direct effects on the accuracy of the traffic network analysis and determination of entrance points. Thereby, the pixelated view makes it more difficult for policy makers to use this data effectively. Finally, the Green typologies map is created for Flanders and therefore cannot be expanded beyond its boundaries, unlike OSM data which has a broader coverage. This additional coverage was needed to accurately depict the Urban Green Accessibility Index (UGAI) on the edge of Flanders, considering UGS and their accessibility right outside of the region. Another advantage of using OSM data is that it is a popular Volunteered Geographic Information (VGI) project, where people can include their perceptions of green spaces by assigning additional tags for accessibility, fees, the land use etc. This can be a disadvantage if you want to make a very specific classification, but when a broad classification such as UGS is desired, multiple feature tags can be included. It is also important to note that there is a clear definition for people to base their classification on within OSM. After considering the factors outlined above, the decision was made to employ the OSM UGS map for subsequent analysis. This map provides us with a more accurate depiction of green that is actually public and serves the purpose of recreation, which is in line with our specific definition. Furthermore, the vector-based nature of OSM makes it a more practical and powerful tool for decision-making processes.

Finally, when comparing the OSM UGS map to the reference map of Ghent, the OA and PA are considered sufficient, based on the minimum threshold of 85%. However, the UA was relatively low (51.7%), implying that our UGS map indicates almost twice as much UGS area as the reference map. Mainly some larger forests were not included in the reference map for Ghent (Appendix 8.9). There were also differences in the smaller green spaces. In the reference map of Ghent, there was no specification of accessibility, which is likely the main cause of these differences.

The accuracy of the Urban Green Spaces map retrieved from OpenStreetMap data

There are few studies using OSM to map UGS, but an important barrier to extrapolate their results to the current study, is the absence of a unified definition (Le Texier et al., 2018). Le Texier et al. (2018) found in Brussels, Belgium, that OSM mainly does not adequately depict private UGS, and therefore total greenness, but reflects public UGS similarly well as other data sources. They also found that OSM contributions and completeness, and therefore accuracy and reliability, increases towards the city centre.

After extracting relevant features from OSM, a significant number of green spaces was identified. Therefore, when calculating the accuracy after each step, it was anticipated that the PA would be high in the initial stages, since the majority of the actual UGS would be included. However, this would result in a low UA, as a significant amount of additional green spaces would also be indicated on the map. This was a compelling reason for implementing the workflow, as it aimed to improve these accuracy scores. Notably, the UA increased substantially, while the PA was only slightly compromised, thus enhancing the reliability of the final UGS map.

Zooming into the steps of the workflow, we observed an expected increase in UA after removing private areas, agricultural parcels, and small/narrow UGS in steps 2-4, as these steps were performed on the reference map as well and conformed to the UGS definition (Table 4.1). Removing private gardens using the garden map was advantageous, as OSM struggles to differentiate between public and private green areas (Le Texier et al., 2018). The highest increase in accuracy was observed when removing agricultural parcels. A possible reason is that OSM can be prone to semantic errors when multiple tags can describe a single feature, or when a single tag is used to describe multiple types of features. For instance, if a feature is assigned the tag “grass”, it may be difficult to differentiate between an agricultural field and a park. On the other hand, when mapping UGS specifically, features from multiple tags are gathered, reducing very specific semantic errors. Based on these results, it is recommended to perform the step of removing private gardens and agricultural parcels in any further research using OSM for UGS.

Step 5, which removed UGS without a path crossing unless they had superior tags, improved the UA by approximately 10 % with only a 1% loss in PA. This can provide a valuable indication of path accuracy, though not necessarily of their precise location. Nonetheless, this information can yield an approximate perception of accessibility. The final OA of the OSM UGS map was very high (96.8%). This value is, however, not very informative as it includes the non-UGS class, which is much larger in area than the UGS class. The UA had improved to 70.3%, while the PA was 89.2%. This means that our map will likely represent a modest overestimation of the total coverage of UGS in Flanders. The conventional accuracy threshold for the identification of land use and land cover categories from remote sensing data should be at least 85% (Wulder et al., 2006). We can therefore conclude that overall, the map is sufficiently accurate, although there is still improvement possible, mainly for the UA. Some possible limitations and suggestions for further research and improvements are suggested in a next paragraph.

The individual accuracies for each stratum of the UGS map compared to the reference map, revealed noteworthy results (Figure 4.2). It was anticipated that the accuracies of the urban class would be higher, based on prior studies indicating improved classification in urban areas (Le Texier et al., 2018). However, the calculated OA, PA and UA for the rural and urban class were nearly identical. This implies that our findings can be extrapolated to the whole of Flanders, rather than concentrating solely on urban areas. Moreover, the UA of regional areas, both rural and urban, was significantly lower than those of metropolitan or smaller urban and rural areas. The reason behind this is not immediately evident. It is possible that, because many regional sample points were selected in forested regions, our specific forest delineation technique was not accurately depicted in the reference map. In the future, this can be processed on the reference map as well.

Limitations and future research recommendations

The mapping and validation of UGS does not come without limitations. First, the external maps used in the workflow, like the garden map and agricultural use parcel map, are not 100% accurate or up-to-date and are limited to the extent of Flanders. Furthermore, the fact that forests are not included in their entirety, but are instead represented by a buffer around accessible paths with certain conditions for their inclusion, is new and possibly controversial. While this may result in a more accurate depiction of forest accessibility and proper UGS classification, future research should consider the accuracy of OSM paths to ensure validity. Also, it is important to note that the 6-m buffer used to remove errors between agricultural parcels may unintentionally remove parts of adjacent UGS, and the methodology should be re-evaluated to avoid this issue. Finally, some UGS may be removed in step 2 or 3 if they are not tagged as a park, nature reserve or village green in OSM by users. An example could be ‘Abdij van park’, which is a park in Leuven, but not classified as one in OSM, and therefore, partly removed because of its agricultural parcels. However, an overall improvement of the UGS map is expected in time, when OSM users assign better tags to land use features, rather than only land cover.

Furthermore, while the UGS reference map was utilised as a baseline, it was not entirely precise. The positional accuracy may be lower due to a potential shift between Google images and OSM. Additionally, the delineation of UGS for the reference map was not based on GPS coordinates, but manually selected using rough estimations. There also might be a time lag between Google satellite images, Google Street view, and the current actual UGS presence. In addition, because of different surveyors with possibly different perceptions of the definition of UGS, the thematic accuracy can vary depending on the sample point. However, it was double checked by one expert to limit these issues. Finally, it should be noted that the sample size used in this study was relatively small, representing 0.15% of the total area of Flanders. Thereby, the samples were largely concentrated in urban areas or bordering rural zones. Lastly, since not all samples were completely randomly selected, this might have introduced bias towards specific regions or socio-economic groups.

The limitations that exist in creating the UGS map mainly consisted of removing UGS when removing agricultural parcels and insufficient mapping of land use by OSM users. Despite these limitations, the map remains suitable for further analysis, as evidenced by the acceptable OA, PA and UA. However, it is recommended that future research focusses on expanding the sample survey to cover the entire region of Flanders and addresses potential issues related to positional, temporal and thematic accuracy, by, e.g., using GPS coordinates and up-to-date satellite images.

5.1.2 Urban Green Space accessibility

Then entrance points

To obtain the most accurate measure of UGS accessibility, it is essential to consider the actual entry points of UGS as they can significantly influence the accessibility of green space. Larger UGS with limited entrance points, for example, can have a distance score of zero for a pixel despite being adjacent to the UGS area. As no such dataset existed, the study intersected the pedestrian road network with the UGS map to determine the entry points. For this road network, OSM data was preferred due to its high accuracy in urban areas (Barron et al., 2014) and inclusion of many pedestrian roads and paths. However, no accuracy assessment was conducted on this road network nor entrance points, and assumptions were made for priority UGS without intersections, which could affect the results of the traffic network analysis. Therefore, it is suggested that when policy makers analyse and map UGS, they also consider entrance points and maintain data for them.

The pedestrian traffic network analysis

Calculating accessibility from MIRA-S 2000 functional levels

Van Herzele and Wiedemann (2003) argued that one needs UGS within a different reach for different functional levels of UGS, as they fulfil different functions at these different levels. We found by calculating the availability of UGS in Flanders (Figure 4.3) based on the pedestrian traffic network and functional levels by Van Herzele and Wiedemann (2003), that only 15.3% of the Flemish population had access to green larger than 0.2 ha within 150 m of their residence. However, a study by Verachtert and Poelmans (2022) using the Green Typologies map found that 90.7% of the population had access to UGS larger than 0.2 ha within 400 m. For quarter green, district green, city green and urban forests, we observed 36.4%, 51.6%, 56.8% and 39.3% of the population had access to these functional levels, respectively, while Verachtert and Poelmans (2022) observed 63.2%, 72.7%, 87.5% and 81%, respectively, which are systematically larger portions of the population. This can be attributed to the fact that the map they used includes a much larger area of UGS, as discussed in the previous paragraph. Additionally, their traffic network analysis did not include actual entrance points. Due to our stricter definition of accessibility, it can therefore be predicted that the actual availability of green spaces to the population is lower than the numbers predicted by Verachtert and Poelmans (2022). Consequently, there is a pressing need for policy interventions in Flanders to enhance the availability and accessibility of UGS.

In Leuven, it was found that 66.4% of the population had district green within 1600 m of their residence, while a study by Natuurpunt (Nys, 2014) that used a Euclidean buffer, found 29%. They however only included contiguous nature reserves in their definition of district green. For Ghent, the difference was 64.9% and 8% respectively. Bral et al. (2014) found that 80% of the population of Leuven had access to residential green, while we found 27%. For Ghent this was 82% and 27.9%, respectively. This can mainly be attributed to the different definitions of municipalities used for UGS and their different maximum distance of 400 m instead of 150 m. Hence, there is a need for municipalities to adopt standardised definitions of UGS to enhance the accuracy and comparability for reference datasets.

Calculating accessibility for the Urban Green Accessibility Index

When performing the traffic network analysis based on the updated functional levels (Table 3.3) and the pedestrian road network, the resulting 10-minute isochrone covered 43.3% of the Flemish area, where 55.2% of the Flemish population resides. This means only this proportion of the population has access to green within walking distance from their residence. When spatially evaluating the map (Figure 4.4 & Appendix 8.11), it was clear that the west of the country had significantly less access than the east. When comparing it to all data of OSM (OpenStreetMap foundation, n.d.) and the agricultural use parcel map (Departement Landbouw en Visserij, 2021), this could mainly be attributed to the large number of agricultural areas in the west, which were not included in our definition of UGS. Furthermore, military areas, such as the one in Leopoldsburg in Limburg, and industrial areas, such as the port of Antwerp, were not included. However, not all of these places had the same need for UGS. When they had a low population, a high green cover, and/or a lot of private green, the need for UGS was lower. To reveal these patterns, it was decided to include the extra dimension of the context to the UGAI, described in a next paragraph.

In Leuven, this overlap was higher, with 68.4% of the area covered, where 70.6% of the population resides. For Ghent, this was 61.8% and 78.6% respectively. The image of Ghent of having very low scores on UGS availability and accessibility (Nys, 2014), is therefore changing. In the north of Ghent, there is clearly a lack of accessible UGS. However, as this is industrial area with a low population, this should not matter as much. In contrast, for Leuven, the central area of the municipality, situated within and around the ring road in a highly populated zone, also lacked sufficient access. This was later accentuated by the context map and the cUGAI.

The cyclist traffic network analysis

In the cyclist traffic network analysis (Appendix 8.6.2), almost the whole of Flanders was covered by the iso-area, resulting in 99.5% of the people having access to UGS within a 10-minute biking-trip. Here, the same spatial patterns became visible as for the pedestrian analysis, highlighting the agricultural areas in the west, the north of the province of Antwerp, and military areas, such as in Leopoldsburg, even more. For the remainder of the discussion, the cyclist traffic network will be omitted, as subsequent statements will pertain to both the pedestrian and cyclist UGAI and cUGAI.

Limitations and future research recommendations

Multiple tools were tested to decide on which to use for the traffic network analysis. In the end, it was decided to use the QNEAT3 plugin in QGIS, because of its fast and cheap, but also accurate analysis. However, sometimes mistakes were introduced in the interpolation, especially when there was a significant lack of roads or entrance points, like within military areas or agricultural areas in the west of the country. For this reason, an overestimation of the accessibility is possible. This is for example visible in the north of Ghent, when looking at the accessibility of district green (Figure 4.3 & Appendix 8.10). This problem was partially avoided by increasing the total distance and number of contours for the analysis, as the problems usually appeared at the edges of iso-areas. The biggest downside of the QNEAT3 tool, however, was that it could not be automatised, and provided one merged iso-area per analysis and not a separate polygon for each entrance point. This did not affect the distance scores, but did impact the assignment of quality values to pixels, which is discussed in a next paragraph.

A suggestion for further research is to focus on performing an accuracy assessment on both the pedestrian and cyclist road network presented by OSM in Flanders. Thereby, for the purpose of developing the UGAI, it is especially crucial to focus on the accuracy of entrance points obtained by intersecting the road network with UGS, which are related to the accuracy of paths within UGS.

5.1.3 Quality of Urban Green Spaces

Previous studies have often neglected the implementation of quality indicators when evaluating UGS due to a lack of evidence on the relationship between the quality and characteristics of UGS and mental and physical health (van den Berg et al., 2015; World Health Organization. Regional Office for Europe, 2016). However, recent research has confirmed the importance of including quality in addition to quantity when optimising the benefits received from UGS (Bertram & Rehdanz, 2015; Ode Sang et al., 2016; Stessens et al., 2020; Zhang et al., 2017), and implemented quality indicators in an UGAI (Fan et al., 2017; Stessens et al., 2020). In the next paragraphs, first the quality indicators and their respective weights are discussed, followed by the implementation of quality and accessibility of UGS in the urban green accessibility index.

5.1.3.1 The quality indicators and weights

There are several quality indicators available in literature (cf. §2.5.2.2). In this study, the choice for the specific quality indicators (Table 3.4) was based on three factors. First, it was crucial to select quality metrics that explained the relation of contact with UGS to health benefits, based on an assessment of the literature. Furthermore, it was important that the indicators were transferrable to GIS-based models for which data was available in Flanders. For instance, safety was deemed as one of the most important indicators by UGS visitors (Giles-Corti et al., 2005; Jansson et al., 2013), but data on safety in Flanders was limited. Ultimately, quality indicators that represent the link between health and the naturalness of an UGS, like by Stessens et al. (2020), where chosen.

The scoring of these indicators was usually based on the simple fact that a higher value for each indicator resulted in more health benefits and thus a higher score. For the biological value, some studies have found a negative relationship between biological diversity and preference (Botzat et al., 2016). However, the majority found this relationship to be positive (Botzat et al., 2016; Carrus et al., 2015; Fuller et al., 2007; Gunnarsson et al., 2017; Ode Sang et al., 2016). Positively associated with this, is the fact that UGS comprise a unique and high biodiversity, which is also worth conserving through planning (Ives et al., 2016).

By calculating the Spearman correlation (Appendix 8.13), no major problematic correlations were found between indicators. The negative correlation between tree cover and land cover diversity could however be questioned. While increasing tree cover is known to have beneficial effects on air quality, UHI reduction and physical and mental health improvement (Janowiak et al., 2021; Konijnendijk, 2022; Yan et al., 2019), some studies suggest that people may prefer more savannah-like land cover types with scattered trees (Harris et al., 2018), reflected in the preference for higher land cover varieties (Wheeler et al., 2015). However, this potential issue was addressed by using a threshold of 60% for the maximum score, because of a plateau in preference (Jiang et al., 2015).

The spatial pattern of UGS quality scores (Figure 4.5) in Flanders revealed that the size had the strongest influence on the score (Appendix 8.12). The higher weight for size was decided upon, because of widespread agreement among studies regarding its significance (cf. §2.5.2). Other factors had lower weights for perceived importance (Stessens et al., 2020; Swetnam et al., 2017), but land cover diversity, biological value and tree cover affected the score when sufficiently high or low, indicating the importance of naturalness on the final quality score.

Limitations and future research recommendations

It should be acknowledged that the selection of quality indicators, their scoring, and weights, was arbitrary and multiple other approaches could have been adopted. There is also still little research connecting these quality indicators with perceived quality (Stessens et al., 2020), especially in Flanders. Thus, it is recommended that future research explores the association between quality, preference, and health in relation to selected indicators in Flanders, e.g. through a comprehensive survey. With this, it will also be possible to use exact weights for the indicators, instead of ranks.

Another limitation of the study was the restriction of data availability for some of the quality indicators to the extent of Flanders. Consequently, for UGS located outside of Flanders, the median score of the distribution of values within Flanders was assigned to UGS located for more than 50% outside of Flanders. This could result in an over- or underestimation of the quality of UGS, and therefore could affect the UGAI, but this remained limited to the edges of Flanders. Future research could try to solve this problem by using other data sources outside of Flanders.

5.1.3.2 The Urban Green Accessibility Index

The UGAI proposed in this study can be categorised as a gravity-type measure, which is negatively related to the travel impedance or distance between two locations and positively related to the attractivity, introduced in this study as the quality (Liu & Zhu, 2004). This type of index is already implemented in several studies, like by Fan et al. (2017) and Jang et al. (2020).

In the pedestrian and cyclist UGAI, both the quantity, including the accessibility, and the quality of UGS was reflected. The accessibility became apparent by the zero score outside the 10-minute isochrones. When isochrones of UGS belonging to more than one functional level overlapped, the score was higher. The quality was also reflected, as areas close to high quality green, received the highest UGAI, although these smaller differences were not always discernible on the UGAI map.

Limitations and future research recommendations

This approach, like Fan et al. (2017), included both the quantity, including accessibility, as the quality in the UGAI. Fan et al. (2017), however, proposed to introduce a weight for the quality, of 35%, and accessibility of UGS, of 65%, based on preferences obtained through a survey in Shanghai. Future research could explore the preferences of individuals in Flanders to incorporate more relevant weights in the UGAI calculation.

One limitation of the calculated UGAI that requires further analysis is caused by a downside of the QNEAT3 tool used. The resulting output of this tool is a raster with cell values of the closest distance to the closest UGS. This resulted in one merged iso-area instead of separate polygons for each entrance point, which would have been an ideal way to attribute quality scores to a certain iso-area for the overlap analysis. However, since this was not possible, an approximation of iso-areas in between UGS was taken into account by using Euclidean distance buffers instead of the actual traffic network. Other tools were available that could have avoided some of these issues, like the TravelTime plugin (Dalang, 2022) in QGIS or the *cppRouting* package version 3.1 (Larmet, 2022) in R. However, the first option required payment to conduct large-scale analyses, while the second option was not feasible within the given time frame. To improve the accuracy and precision of the UGAI, it is recommended to further explore the potential of these tools. Alternatively, researchers could search for other tools that provide separate iso-area polygons for each entrance point that can handle large scale analysis with over 100,000 entrance points.

5.1.4 Context of Urban Green Spaces

Although Wheeler et al. (2015) suggests including the context of UGS when measuring their health benefits, incorporating context into the UGAI is still a novel concept in literature. First, we will discuss the calculation of the context score, followed by a discussion of how context is incorporated into the corrected UGAI (cUGAI).

5.1.4.1 The context indicators and weights

For this study, three context indicators were introduced. The incorporation of the first indicator, population density, into an UGAI was suggested by multiple studies. When neglected, scores for accessibility might look too optimistic for areas with high population densities and UGS might be crowded and lose qualitative aspects (Laan & Piersma, 2021). By including overall green as second indicator of context, the study considers all types of green space in a neighbourhood, not just recreational UGS, which are represented in the UGAI. This is because overall green cover has been linked to various health benefits, including the reduction of the UHI effect (Janowiak et al., 2021) and air quality improvement (Hartig et al., 2014). Van Dillen et al. (2012), for example, stated that streetscape greenery is at least as important as UGS for self-reported health. Therefore, streetscape greenery, agricultural areas and other green spaces were considered using this approach. Finally, garden cover was included to reflect the availability of private green space.

The scores for context showed expected patterns in Flanders (Appendix 8.14). Highly urbanised areas had a high context score, signifying a higher demand for additional UGS, because of their high population density and a low overall green cover, which were moderately positively correlated. Between the garden area and overall green cover score, a weak negative correlation (-0.21) was found, despite garden area being part of the overall green cover. A highly negative correlation was found between the garden area and population density score. This meant that, as the population density increased, and thus the demand for additional UGS increased, the score for garden area generally decreased, indicating an increase in garden area and decrease in demand towards more populated areas. However, in very densely populated city centres, such as in Leuven and Ghent, it was confirmed that the garden area score is high, indicating a small garden area cover. Therefore, it is likely that in most cities in Flanders, the highest garden areas can be found just beyond the city centres. When garden area would be calculated per capita, the image might change.

Since for population, overall green cover and garden area, high context scores were obtained in the city centres, the final context score also reflected the highest demand in these zones (Figure 4.7). In Flanders in general, this highest demand score is observed in urbanised areas. The main pattern visible in the UGAI, is the one of the population density indicators, as it received the highest rank and weight, because the population is the primary reason for demand of UGS. However, in areas with an additional low overall green cover, the effect is even more pronounced.

Limitations and future research recommendations

The context score is influenced by the spatial unit selected for calculation, which can vary in size, often being smaller in areas with a higher population density. Hence, using different spatial units, might result in different outcomes. Therefore, there might be further research needed to determine the optimal spatial unit for this analysis.

Furthermore, the choice of indicators and weights is again subject to a certain degree of subjectivity, but can therefore be adapted for future users. As seen in this study, some strong correlations existed among these indicators due to the relationship between indicators. This issue should be addressed in further research, because non-correlated indicators might provide complementary information. For instance, calculating the overall green cover and garden area per capita could be a potential solution.

5.1.4.2 The corrected Urban Green Accessibility Index

While the UGAI, reflecting the supply of UGS, could in itself be compared to the context layer, reflecting the demand for additional UGS, it is also possible to calculate a corrected UGAI (cUGAI) that incorporates both. Therefore, a simple Equation 22 comparing and weighing demand and supply was calculated. This is a novel approach in the literature. Different weights were tested to determine their effect on the final score. In one test, the supply was given the most weight (Figure 4.8), while in the other test, equal weights were assigned to both the demand and the supply (Figure 4.9). In both cases, the score beyond the isochrones increased to a value larger than zero, allowing the comparison of these zones as well. Mainly in the second trial, the context score became more evident, with urban regions consistently receiving lower scores than more rural areas.

When assessing the three example locations in Ghent, the context score became visible in the cUGAI (Figure 4.8 &Figure 4.9). Area (1) received a high context score in the city centre because of a high population, low overall green cover, and low garden area. The industrial area (2) received a medium context score because of a low population, low overall green cover and low garden area. Area (3) received a low context score for a lower population density, high overall green cover due to the abundance of agricultural fields, and medium garden area. These patterns were the most clear in the 50/50 cUGAI, with the areas receiving a low value for the cUGAI corresponding to higher context scores, and the areas with a high value corresponding to lower context scores. This highlights the importance of including context in the analysis.

Using this cUGAI, municipalities can now identify areas where the priority for implementing additional UGS is the highest to ensure the health of its residents, both within as outside of the accessible iso-area. This priority was, broadly speaking, the highest in the city centre. For example, the north of Leuven received high cUGAI scores because of high accessibility, high quality, and a low context score, while the centre with accessible green received lower scores due to lower quality (e.g., lower biological value, size, and tree cover) and a higher context score. Lower accessibility at the edges, resulting in a lower distance score and UGAI, was also reflected.

Limitations and future research recommendations

One important thing to note is that the weights used in the cUGAI were set arbitrary to compare different approaches and can be adapted to the user's preferences. By adjusting these weights, different patterns become visible.

Furthermore, it is crucial to understand that the values of the supply and demand indices are not directly comparable to each other. Thus, there is no straightforward interpretation if one is higher than the other. The primary purpose of these values is to compare two points with the same supply score and different demand scores or vice versa. Additionally, it is yet to be established or decided, which values of the cUGAI are considered too low or too high, e.g. by policymakers.

Further research could investigate the ideal threshold value and explore ways to make the supply and demand directly comparable. Additionally, the best weights to implement in the formula could be examined to obtain the most interpretable cUGAI scores. It is important that when different cities calculate these cUGAI, they use the same weights to make them comparable to each other.

5.2 Assessing the concept of the Urban Green Accessibility Index

In this section, the concept of the proposed UGAI and cUGAI is evaluated. This concept, based on the framework of health and human wellbeing, was similar to most other UGAI models (cf. §2.5). These UGAIs use multiple existing metrics to measure UGS, which were categorised as quantitative or qualitative and selected based on their association with pathways through which contact with nature relates to health (Zhang et al., 2021a). In this study, both the quantity and quality of UGS were introduced, like other studies such as by Fan et al. (2017) and Stessens et al. (2020). However, the proposed UGAI concept differed from other UGAI in terms of the specific aspects that it focused on. The main difference was introduced when incorporating the measure of the context, into the corrected UGAI.

First, we discuss how our study and index addressed gaps of knowledge in the literature of UGS accessibility. Here, the significance of the concept and index for Flanders is indicated. Second, we summarise some limitations of the concept and suggest future research recommendations.

5.2.1 Filling gaps of knowledge

The evaluation of UGS accessibility in the current literature has been limited by several gaps. In this study, we aimed to address these gaps by developing an UGAI for Flanders. Flanders, being one of the most densely populated regions in the world (Poelmans & Van Rompaey, 2009, 2010), particularly faces health-related challenges that come with urbanisation and because of this, needs UGS. Therefore, a tool to evaluate these UGS, such as the UGAI, is essential for policy makers in Flanders.

To address the lack of data on public green, the first step of this study was to develop an UGS map based on OSM data. Since the accuracy of this type of data was not measured for Flanders, the findings also filled an additional knowledge gap. They showed that the accuracy of OSM data was sufficient and the UGS map created was the most accurate map for public green in Flanders. However first, additional processing on raw OSM data was needed, including removing private open green spaces to solve for inaccuracies in OSM and to comply with the UGS definition.

Another limitation in previous studies was the absence of using actual entrance points in the traffic network analysis. In this study, a trial implementation of such entrance points was attempted by using points where the pedestrian road network intersected with UGS, although some limitations were noted (cf. §5.1.2). This method significantly improves the results of an accessibility analysis compared to studies that assume UGS can be entered from all sides. Another knowledge gap in the traffic network analysis was the inclusion of biking into the UGAI and cUGAI. Including this (Appendix 8.6), was particularly important in Flanders, since surveys showed that 50% of the Flemish people often take the bike to get around in their free time (Burgerbevraging Gemeente-Stadsmonitor, Agentschap Binnenlands Bestuur, 2020).

In the existing literature, the application of UGS quality remains limited. Furthermore, to date, there have been no studies comparing the accessibility and supply of UGS to residents with the contextual factors of where they live. The context indicators of overall green cover and garden area were especially applicable in Flanders. Almost 50% of the total space is covered by agricultural areas. Therefore, certain areas might have a high overall green cover, while the supply of UGS might be low. This extra dimension of information is added by the context layer. Moreover, the garden area indicator reflects the substantial fraction of the area in Flanders which is covered by gardens (12.5%), which might reduce the need for additional UGS to individuals.

5.2.2 Limitations and future research recommendations

The UGAI and cUGAI attempt to combine various aspects, including the theoretical concept, data sources, calculation and interpretation, each of which is prone to potential errors and subjective choices. These errors can accumulate and affect the final score, limiting the reliability of the results. To mitigate this issue, future research should focus on addressing the limitations in each aspect and evaluate their accuracy. Moreover, adding too many parameters may risk compromising the indicator’s function of simplifying communication (Van Herzele & Wiedemann, 2003).

Furthermore, confounding variables that may influence UGS consumption, such as age, education and socio-economic status, were not considered. This is a limitation since individuals have varying accessibility ranges, UGS needs, quality preferences and contextual requirements. For example, in the traffic network analysis, walking and biking speeds were based on averages of middle-aged, mobile people and do not account for elderly, little children or people with physical or cognitive impairments. Preferences and weights for specific quality indicators may differ among different demographic groups (cf. §2.5.2.3). While it may be challenging, future research could explore ways to adapt the indices to better comply with the needs of different population groups.

A recommendation for future research is to conduct a survey to gain a more comprehensive understanding of the preferences and needs of the Flemish people regarding UGS. Hereby, it is suggested to investigate all aspects, including accessibility and qualitative and contextual preferences. Using this data in future research can lead to more accurate and reliable results, based on indicators and weights fitted to Flanders. Also, based on the preferences of people, it is suggested to create similar functional levels for biking as were created for walking (e.g., like Van Herzele and Wiedemann (2003)) to improve the cyclist UGAI and cUGAI.

Finally, a hotspot analysis with the results of the UGAI and cUGAI, like by Fan et al. (2017) to identify problematic areas in terms of UGS accessibility, quality and context is suggested. These results can be further analysed and compared to a map with socio-economic information to identify any inequities in access to green spaces and prompt necessary actions to address them.

5.3 Implications for theory and practice

In this paragraph, we address possible implications of the index for policy making in theory and practice and how this index can be adapted towards specific policy needs.

The results of this thesis highlighted a shortage of accessible UGS within walking distance for the Flemish population. The UGAI showed that only 55 % of the Flemish population had public green within a 10 minute walk from their residence. Even fewer people (15%) had UGS within a 2-minute walk from their homes. Because of the multitude of health benefits from UGS in people's vicinity, policy makers must strive to increase these numbers significantly. In contrast, almost every Flemish citizen had an UGS within a 10-minute bike ride from their home. These findings highlight the importance for policy makers to promote cycling and invest in cycling infrastructure.

Upon analysing the UGAI, it was found that the areas with the greatest need for improvement were concentrated in the west of the region. However, when considering the context in the cUGAI, a higher score was found, because of the low population and high overall green cover in those areas. This means other patterns become visible when calculating the cUGAI. The areas with the greatest need for improvement were concentrated in centres of urbanised regions, including municipalities like Ghent, Antwerp, Bruges and Mechlin. This trend was specifically evident in the map that represented the 50/50 weighted cUGAI (Figure 4.9). Thus, the tool is particularly useful for municipalities with low scores to identify areas that require urgent attention. In summary, the results of the index hold information that could potentially be useful for policy makers and urban planners when planning the implementation of new UGS and adaptation of existing ones.

All aspects included in the UGAI and cUGAI, individually or combined, provide valuable information for policy makers. The difference between different index values can be explained by each of the separate factors included in the index. A low UGAI or cUGAI can be improved through multiple actions, including (1) implementing new UGS, (2) improving the accessibility of UGS, through investing in pedestrian and cycling paths, (3) improving the accessibility of UGS, through adding additional entries and paths to UGS, (4) improving the quality of UGS by e.g., increasing the size, species richness, tree cover or land cover diversity, and (5) improving the circumstances of the environment by e.g., expanding the overall green cover. Here, the population is considered as a constant and expanding the garden area often only improves the situation for a small fraction of the residents. Understanding the individual results of each element is crucial for policy makers to identify what causes issue areas and to prioritise elements to tackle. This underlines the importance of communicating results in an understandable way to policy makers.

Finally, the potential of this tool lies in its adaptability to the needs of policy makers. Each layer provides valuable information on the Flemish public green status and can be used separately in decision making. Moreover, the elements of the index can be customised to fit the policy maker’s needs and preferences. For instance, in the quantity layer, the distance scores can be adjusted to the desired ideal distance for walking. In the quality layer, indicators relevant to the municipality can be selected and given weights based on the population’s preferences. The same applies to the context layer. Last, a potential of the tool lies in its transferability beyond the boundaries of Flanders, as the workflow is based on global OSM data and the factors can be adapted to the region.

6. Conclusion

This thesis proposed and implemented an urban green accessibility index (UGAI) for Flanders that focusses on the availability and accessibility of Urban Green Spaces (UGS). The concept of this UGAI is based on a theoretical framework of human health. The final index was obtained by combining several components.

First, a map of UGS in Flanders was created based on OpenStreetMap (OSM) data. After creating a reference map for Flanders, an overall accuracy of 96.8%, a user's accuracy of 70.3% and producer's accuracy of 89.2% were obtained in an accuracy assessment based on an overlap analysis. These were significantly higher than the accuracy of other sources, such as the Green Typologies map by Verachtert and Poelmans (2022). Therefore, the map retrieved from OSM was used for the analysis.

Second, a pedestrian-and cyclist-centred UGAI for Flanders was developed, which considered the quantity, quality, and context of UGS. By performing a traffic network analysis using the OSM traffic network and actual entrance points to UGS, it was observed that only 55.2% of the population had access to UGS within walking distance from their residence, while 99.5% had access to UGS within a 10-minute bike ride from their residence. The quality of UGS was introduced in the index by the combination of four indicators - size, biological value, tree cover, and land cover diversity - and implemented together with the accessibility into the UGAI. To differentiate areas with the same UGAI score, but different demands for additional UGS, the context score was introduced as additional dimension in the corrected UGAI (cUGAI). Here, population density, overall green cover, and garden area provided an idea of the need for UGS in a statistical sector. The cUGAI showed lower scores for urban than rural areas, even for those with the same UGAI indicating a low supply, representing their additional need for UGS.

The outcomes present important implications for urban planners and policy makers. They highlight the importance to improve the accessibility of UGS in Flanders by walking, as well as the importance to promote cycling and invest in cycling infrastructure. Furthermore, the model proposed for the UGAI and cUGAI provides municipalities with a valuable tool containing information on quantity, quality, and the context of UGS, separately or combined. The ultimate potential of the tool lies in its utility and adaptability to the needs of policy makers and its transferability beyond the boundaries of Flanders.

7. References

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8. Appendix

8.1 Accessibility measurements of social benefits urban green

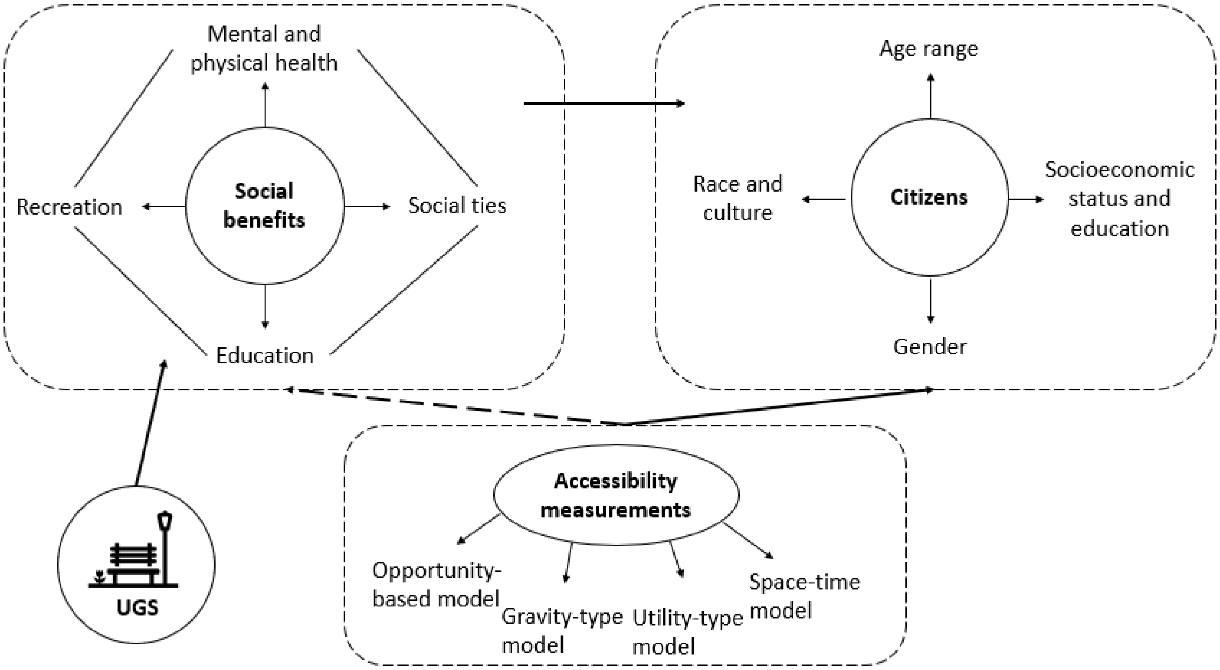

Figure 8.1: Framework measurement social benefits of UGS, adapted from Zhou and Parves Rana (2012) with the framework by Liu & Zhu (2004). Urban Green Spaces (UGS) deliver social benefits, like mental and physical health benefits, to citizens. Their consumption varies in terms of age, race, culture, socioeconomic status, education and gender. This can be measured by different accessibility measurement models: the opportunity-based model, gravity-type model, utility-type model and space-time model. It is useful to consider the characteristics of citizens and look at citizens as a whole, or a specific group. Benefits should be considered when evaluating accessibility (Zhou & Parves Rana, 2012)

8.2 Distribution of samples per stratum in accuracy assessment

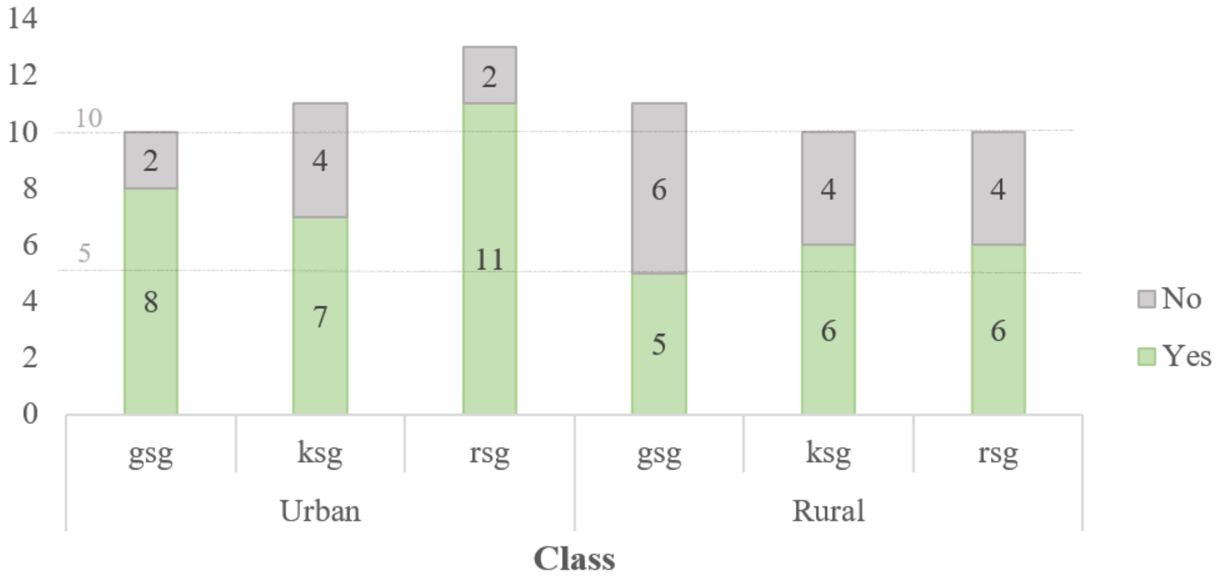

Figure 8.2: Distribution of samples in each class. At least 10 samples should be present in each class and at least 5 samples should be present with an Urban Green Space (UGS) by the UGS map ('Yes'). 'Gsg' = metropolitan area, 'ksg' = small urban area, 'rsg' = regional urban area

8.3 Sample point: example

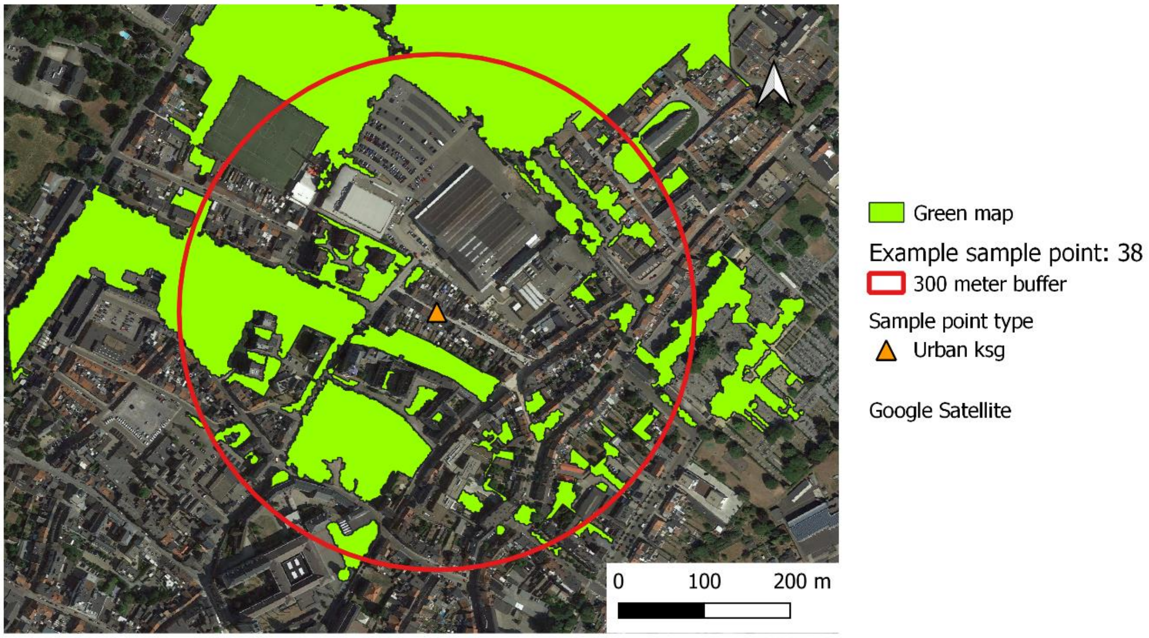

Figure 8.3: Example sample point 38 with green map created based on land cover map (Agentschap Digitaal Vlaanderen, 2021). A 300 m buffer around the sample point is indicated. The sample point type is urban ksg (which stands for 'kleinstedelijk gebied', meaning small urban area)

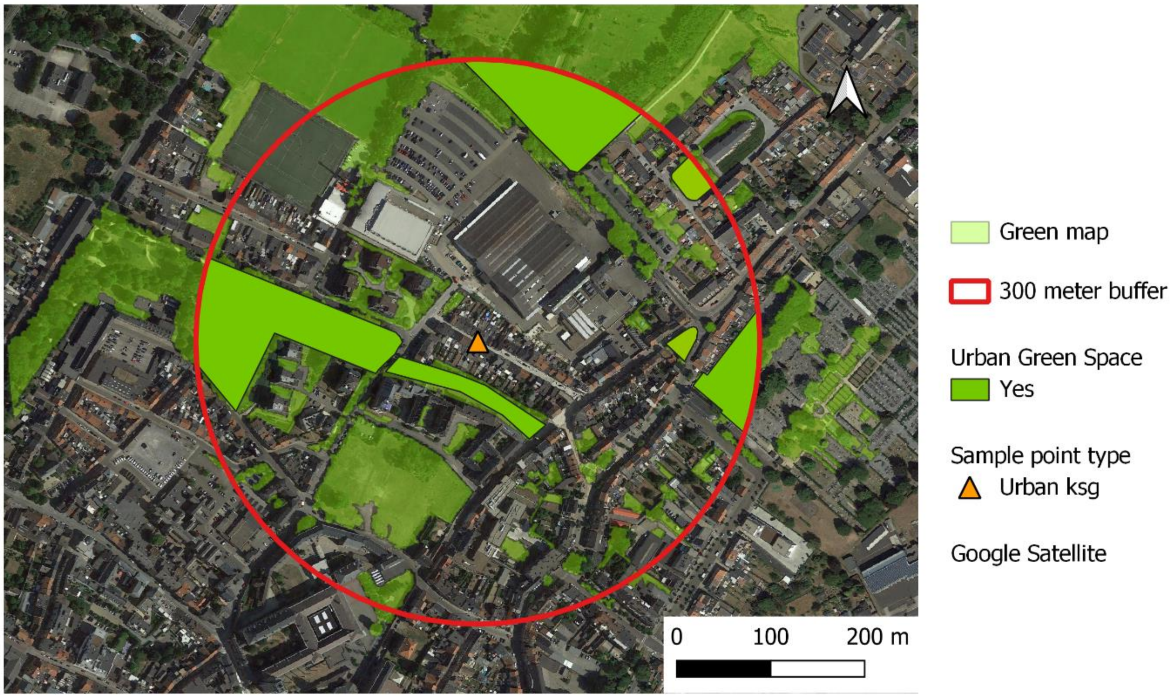

Figure 8.4: Example sample point 38 with green map created based on land cover map (Agentschap Digitaal Vlaanderen, 2021). A 300 m buffer around the sample point is indicated. The sample point type is urban ksg (which stands for 'kleinstedelijk gebied', meaning small urban area). The delineated Urban Green Spaces are indicated as well.

8.4 Response form Urban Green Space sampling

8.4.1 Explanation response form

PART 1: The green map polygon will be provided to the collector.

QUESTION 1: Fill in: for all polygons belonging to a sample point.

Fill in the polygon id. The polygons can be numbered on the map and the corresponding polygon id should be filled in on the sheet. Q2, 3, 4 and 5 must be filled in per polygon.

QUESTION 2: How?

ANSWER:

- ⇨ Google Street View
- ⇨ Field observations
- ⇨ Previous knowledge

QUESTION 3: Is it an UGS?

Urban Green Spaces are here defined as public green areas, predominantly for recreational use. This includes

- public gardens
- zoos
- parks
- castle parks
- cemeteries
- nature reserve
- suburban natural areas that are managed as urban parks
- forests or green areas extending from the surroundings into urban areas
- water enclosed by urban green

NOT

- private gardens
- front yard
- buildings within parks
- patches of natural vegetation or agricultural areas enclosed by built-up area without being managed as urban green
- tree rows
- small piece of decorative green
- barricaded
- agriculture (see yellow areas)

ANSWER:

- ***Yes → Please delineate the boundaries on the map, give the polygon a number and fill in the form regarding that polygon***
- ***Doubt → Please take pictures of the green space***
- ***No***

QUESTION 4: Can you enter it?

Say yes when the polygon has an entrance in OR outside of the buffer circle. Show on the map where the entrance points are (approximately)

Answer:

- ***Yes***
- ***Yes, but limited in time (e.g. park with opening hours)***
- ***Yes, but limited in people (e.g. university garden)***
- ***Yes, you could, but there are no paths***
- ***No***

QUESTION 5: Why?

Depending on the answer of question 3 and 4, fill in different answer to question 5

Question 3	Question 4	What to add for Q5
Yes	Yes	Type of UGS (choose) - public gardens - zoos - parks - castle parks - cemeteries - nature reserve - suburban natural areas that are managed as urban parks - forests or green areas extending from the surroundings into urban areas - OTHER: … Explain limitation:
Doubt	Yes, yes_limitedintime, yes_limitedinpeople, no	Describe the green space and describe why there is doubt + add pictures
No	/	Describe the green space: - private gardens - front yard - buildings within parks - patches of natural vegetation or agricultural areas enclosed by built-up area without being managed as urban green - tree rows - small piece of decorative green - barricaded - OTHER: …

PART 2

Now look at the map of OpenStreetMap that is delivered.

Do you see additional UGS that are not depicted as green on the green map polygon? Check those as well and use the same methodology as in PART 1. Mention you used this figure by selecting figure you used.

8.4.2 Response form

Question 1:

Sample id (coordinator)+ coordinate:…………………………………………………………......

Collector: ……………………………………………………………………………………….

Place of collection (municipality): ………………………………………………………..

Date and time of sampling: ……………………………………………………………….

Notes:

……
……
……
……

Polygon id …

Q2: How?	**Q3: UGS?**	**Q4: Entrance?**	**Q5: Why?**
Google Street View Field Previous Knowledge	Yes	Yes Yes_limitedtime Yes_limitedpeople Yes_nopaths No	- public gardens - zoos - parks - castle parks - cemeteries - nature reserve - suburban natural areas that are managed as urban parks - forests extending from the surroundings into urban areas - OTHER: … Explain limitation:
	Doubt	Yes Yes_limitedtime Yes_limitedpeople Yes_nopaths No	Explain doubt:
	No	No	- private gardens - front yard - buildings within parks - patches of natural vegetation or agricultural areas enclosed by built-up area without being managed as urban green - tree rows - small piece of decorative green - barricaded - OTHER: …

8.5 Accuracy assessment

The ISO/TC 211 standards (2002) list important elements to evaluate the quality of spatial data: the completeness of the dataset, the logical consistency, the positional accuracy, the temporal accuracy and the thematic accuracy.

In general, Barron et al. (2014) found a high positional accuracy of the OSM road network in urban areas in the literature, which tends to decrease towards more rural areas. In the current study, as in most land use mapping exercises (Jokar Arsanjani et al., 2015), the most important criterion to assess is the accuracy of attributing land use classes to land parcels. The number of studies comparing OSM with authoritative datasets is limited, although there is consensus that the spatial heterogeneity in quality is high and often maps are completer and more accurate in more densely populated urban areas (Jokar Arsanjani et al., 2015; Le Texier et al., 2018; Vandecasteele & Devillers, 2015). However, Jokar Arsanjani et al. (2015) noticed that in many parts of the world VGI datasets are more complete and accurate than authoritative datasets, violating a basic assumption of reference datasets. Furthermore, semantic quality can vary spatially, as different tags can represent similar land use classes (e.g., “forest” vs “wood) or one tag can represent different land use classes (Ballatore et al., 2013).

In this study, evaluating thematic accuracy holds greater significance than assessing positional accuracy, given that small shifts in position are not likely to significantly impact the interpretability of the results of a traffic network analysis. Since there is no measure for thematic accuracy available for mapping public UGS in Flanders, a basic accuracy assessment, reflecting the difference between the target and reference dataset (Jokar Arsanjani et al., 2015) was conducted.

The general pattern of accuracy assessments of land use classifications was followed (Jokar Arsanjani et al., 2015; Stehman & Czaplewski, 1998; Wulder et al., 2006), usually based on the comparison with a reference raster image based on satellite imagery (Jokar Arsanjani et al., 2015). When working with two vector datasets, this method can be extended by calculating the overlapping areas and comparing them to overall areas. This approach is used by Zhou et al. (2022) in one accuracy metric. For this study, it is interesting to extend the Zhou et al. (2022) method of overlap analysis to multiple metrics applied on two classes of ‘UGS’ and ‘non-UGS’, including the overall accuracy, producer’s and user’s accuracy of mapping UGS.

The overall accuracy (OA) explains how well the overall classification of OSM is performed, for both the UGS class as well as for the non-UGS class (Equation 3). Since this gives a large weight to the area not classified as UGS, which will be larger than the UGS area, the producer's and user's accuracy for UGS can give better insights on how well UGS are mapped by OSM. The user's accuracy of the UGS class (UA_{UGS}) indicates how reliable the map is, or the probability that a location classified as an UGS by OSM is also classified as UGS by the reference map (Equation 4; Jokar Arsanjani et al., 2015). The producer's accuracy of the UGS class (PA_{UGS}) indicates how well the situation on the ground can be mapped as it refers to the probability that an UGS from the reference map is classified as such (Equation 5; Jokar Arsanjani et al., 2015).

$$OA = \frac{Area\ (UGS\ OSM) \cap Area\ (UGS\ REF) + Area(nonUGS\ OSM) \cap Area(nonUGS\ REF)}{Area} * 100\% \tag{3}$$

$$UA_{UGS} = \frac{Area\ (UGS\ OSM) \cap Area\ (UGS\ REF)}{Area\ UGS\ OSM} * 100\% \tag{4}$$

$$PA_{UGS} = \frac{Area\ (UGS\ OSM) \cap Area\ (UGS\ REF)}{Area\ UGS\ REF} * 100\% \tag{5}$$

where '*Area (UGS OSM) ∩ Area (UGS REF)'* denotes the area that is classified as UGS by both OSM and the reference map, and '*Area (nonUGS OSM) ∩ Area (nonUGS REF)'* is classified as non-UGS by both OSM and the reference map. '*Area*' depicts the entire area used for the accuracy assessment.

This can also be done for the non-UGS by replacing 'UGS' by 'non-UGS' in Equation 4 and 5, although this holds less information as the overlapping area will generally be large because a lot of land cover classes are combined within the non-UGS class.

The UGS resulting from the workflow in Paragraph 3.2.2.1 and reference map (A) were both loaded into FME and the OA, UA_{UGS} and PA_{UGS} were calculated. This was also performed after each step of the workflow to see if it added value and increased the accuracy. For the final UGS map, the accuracy for the classes 'urban', 'rural', 'gsg', 'rsg' and 'ksg' was determined separately as well.

8.6 The cyclist traffic network analysis

8.6.1 Material and methods

For biking, no functional levels with their ideal maximum distances were defined in literature. Therefore, the UGS were not split up into different levels and one scoring was used for biking distances. For comparison with the pedestrian analysis, the same durations were used for the bicycle analysis of at least 5 minutes and maximum 10 minutes for a biking trip. The biking speed used to transform these to distances was 12.6 km/h or 3.5 m/s, based on Witlox and Tindemans (2004), who found a biking speed between 11 km/h and 13 km/h in Ghent. This resulted in a biking distance of 1050 to 2100 m.

The cyclist traffic network analysis algorithm was performed for several groups of UGS entrance points in the same way as the pedestrian traffic network analysis, using the cyclist traffic network (cf. §3.2.2.1) and the iso-area size of 2100 m based on the travel speed. The final $\text{dist}_{\text{bike,i,j}}$ was obtained by taking the minimum distance per pixel.

For the cyclist analysis, the distances to all UGS i were attributed through the same scoring rule, resulting in the score $d_{bike,ij}$ for a distance $dist_{bike,ij}$ of a pixel j:

$$d_{bike,ij} = \begin{cases} 0, & dist_{bike,ij} > 2100 \\ 1 - \dfrac{(dist_{bike,ij} - 1050)}{1050} & \\ 1, & dist_{bike,ij} < 1050 \end{cases} \tag{23}$$

8.6.2 Results

For the cyclist network, 721,343 road segments were extracted. The results for the cyclist traffic network analysis, showed a large coverage of Flanders (Figure 8.5). In Flanders, 95.3% of the area was covered, and 99.5% of the people had access to green larger than 0.2 ha within 2100 m, or a 10-minute biking trip, from their residence

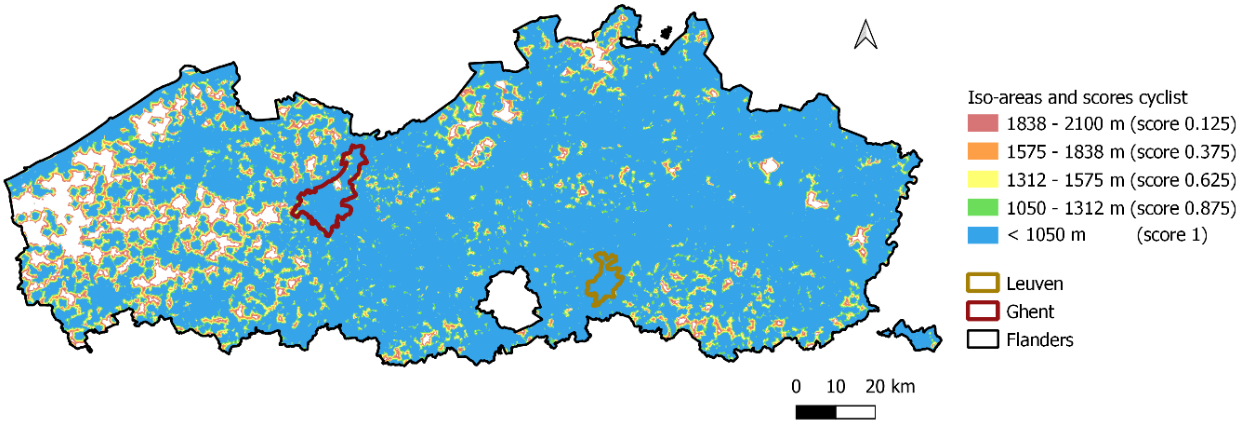

Figure 8.5: Iso-areas and distance scores for the cyclist traffic network analysis, with Leuven, Ghent and Flanders indicated (Agentschap Digitaal Vlaanderen, 2017)

In Leuven, 100% of the population had UGS within a reach of 2100 m or a 10 minute biking trip of their residence. For Ghent, this was 100% of the people within 98.3% of the area.

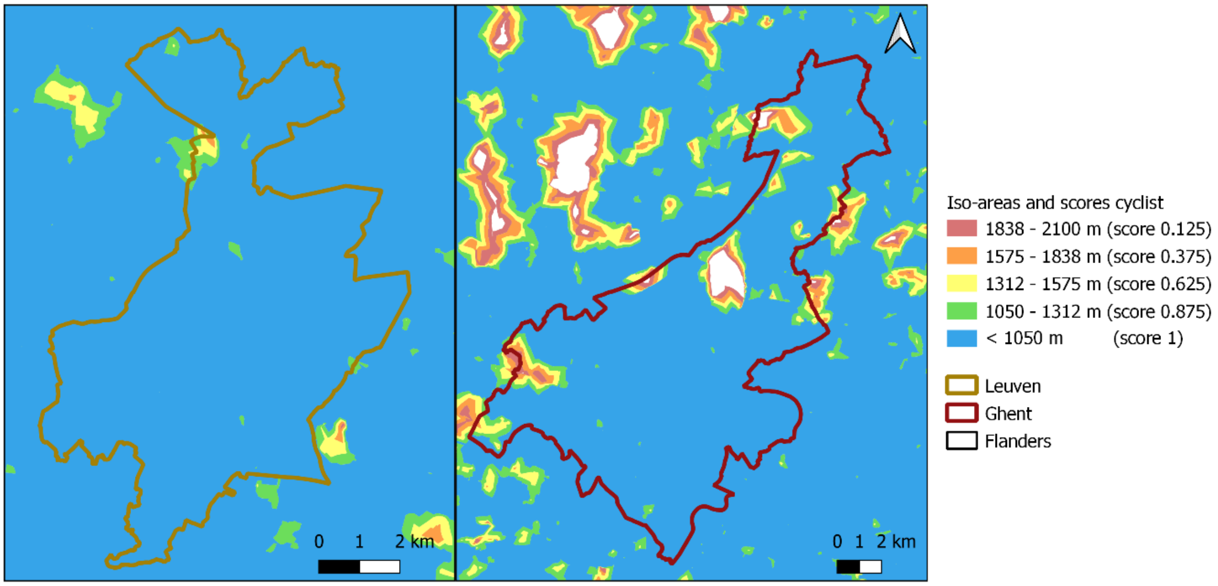

Figure 8.6: Iso-areas and distance scores for the cyclist traffic network analysis, with Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

After calculating the UGAI based on the accessibility measures from the cyclist traffic network analysis, it became apparent that UGS were not always accessible within a 10 minute biking trip (Figure 8.7). Here, however, this area remained relatively limited, but is the largest towards the west. For Flanders, the distribution of UGS scores shows a clear gradient from east to west, with higher scores in the east. Leuven is completely covered, while in Ghent only a small part is not covered (Figure 8.8)

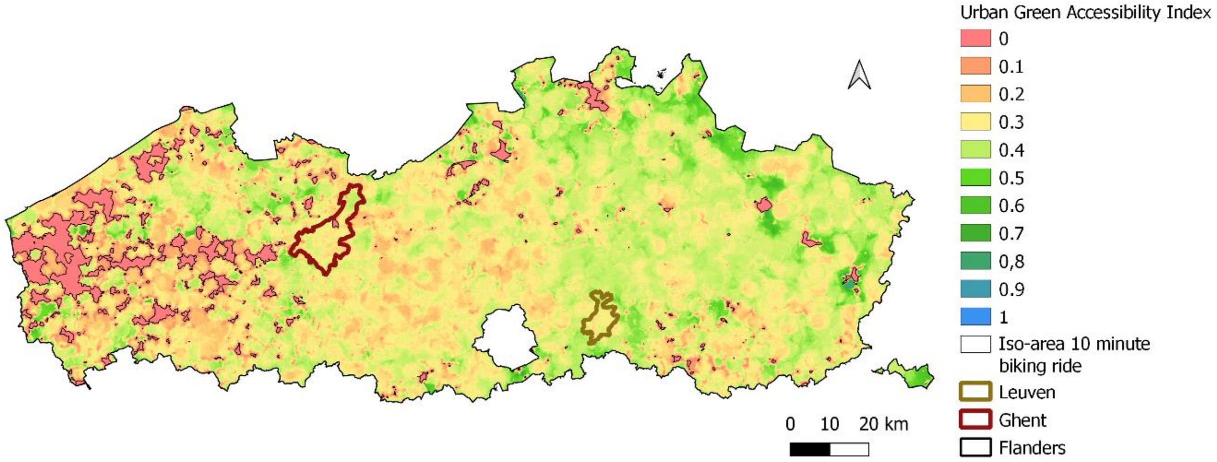

Figure 8.7: Urban Green Accessibility for Flanders and isochrone for 10 minute biking trip to entrance points, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

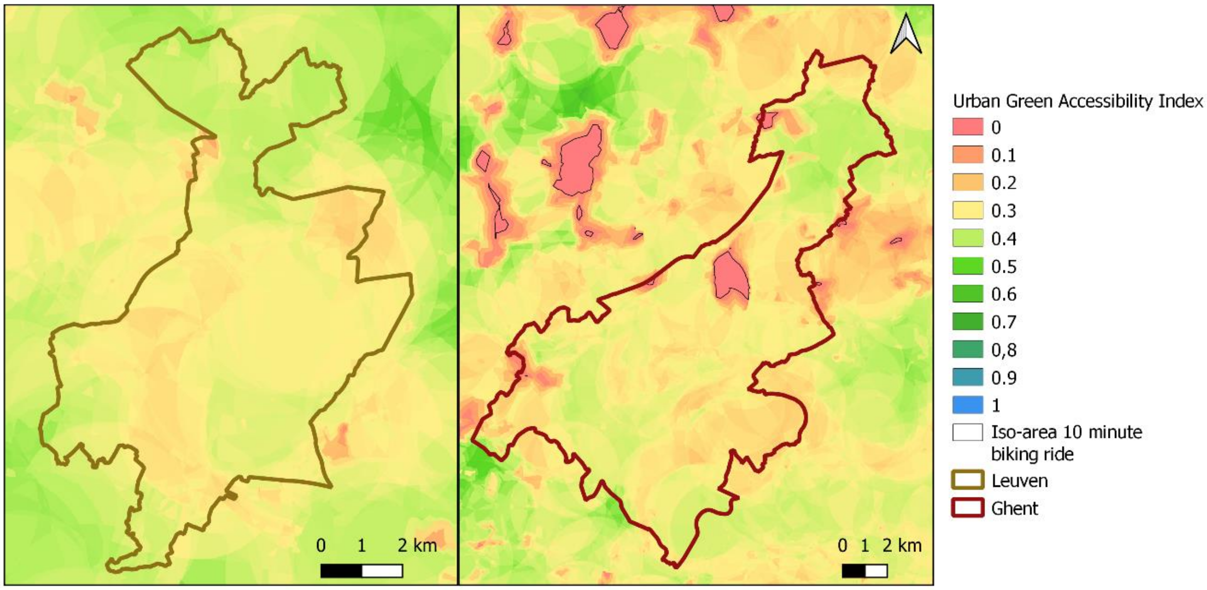

Figure 8.8: Urban Green Accessibility for Leuven and Ghent, and isochrone for 10 minute biking trip to entrance points, with Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

For the cyclist cUGAI, the trend of the context was more apparent for the 50/50 weight (Figure 8.9b), than for the 80/20 weights (Figure 8.9a). Overall in Flanders, the 50/50 weighted cUGAI provides a higher score, because of the high context score in rural areas. This effect is slightly less visible for the 80/20 weights.

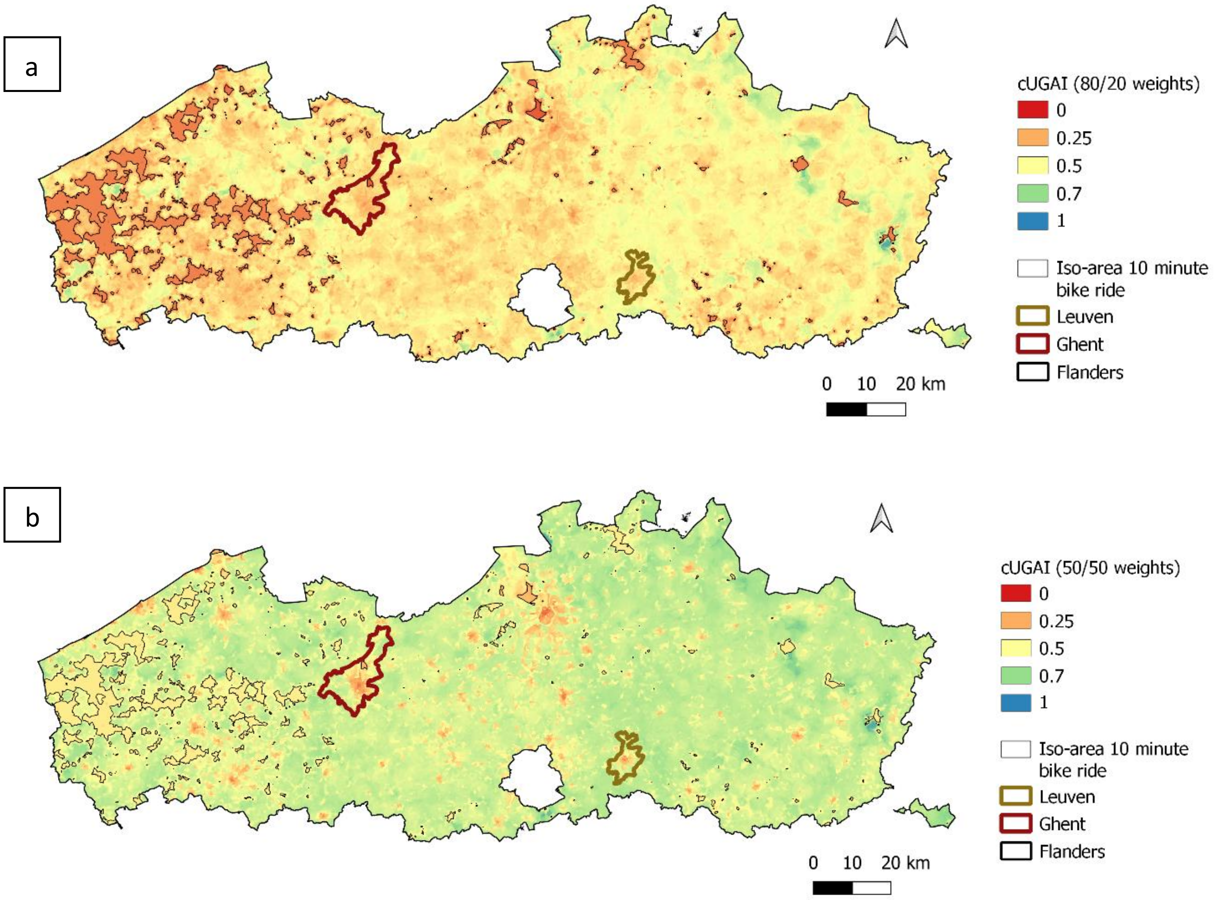

Figure 8.9: Cyclist corrected Urban Green Accessibility Index (cUGAI) for Flanders based on a 0.8 weight for the supply and 0.2 for the demand (a) and a 0.5 weight for the supply and 0.5 for the demand (b), with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

For Leuven and Ghent, the differentiation between the city centre and surrounding areas mainly becomes apparent in the 50/50 weighted cUGAI (Figure 8.10b), compared to the 80/20 weighted cUGAI (Figure 8.10a).

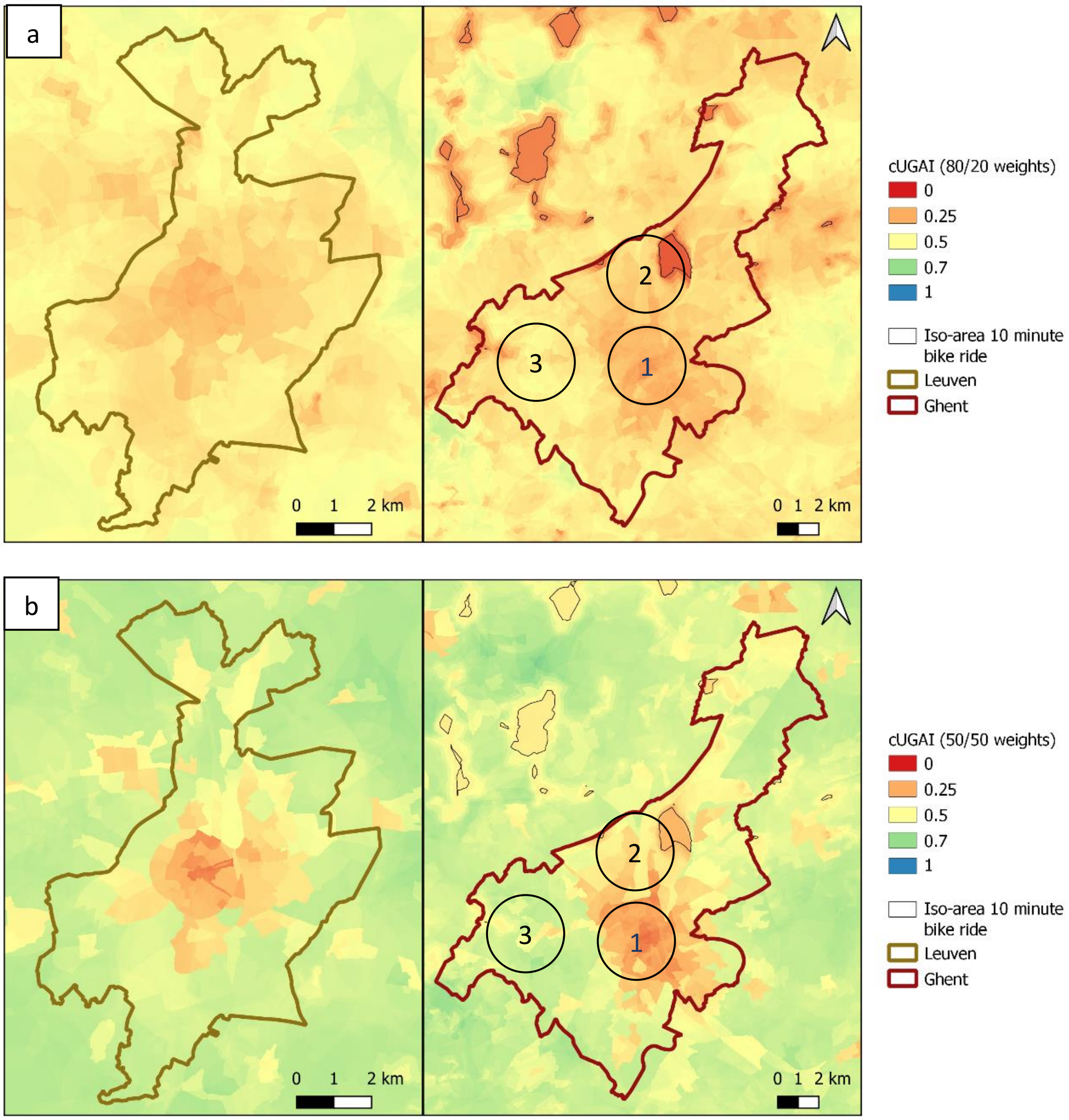

Figure 8.10: Cyclist corrected Urban Green Accessibility Index (cUGAI) for Flanders based on a 0.8 weight for the supply and 0.2 for the demand (a) and a 0.5 weight for the supply and 0.5 for the demand (b), with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017). Three zones are indicated in Ghent: (1) a high context score in the city centre, (2) a medium context score in an industrial area, (3) a low context score in an agricultural area.

8.7 The tri-layered model

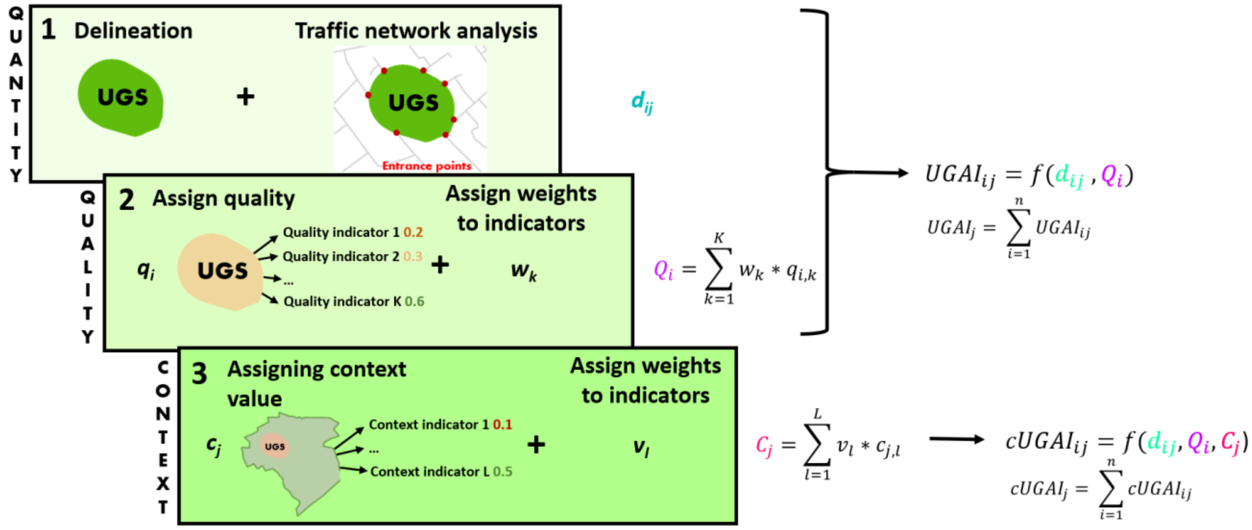

Figure 8.11: The tri-layered model. The first layer represents the quantity of Urban Green Spaces (UGS) by first delineating them and subsequently performing a traffic network analysis on them using their actual entrance points. The second layer introduces the quality of UGS by scoring them on different quality indicators and weighing those indicators. The final layer introduces context by assigning a value to each neighbourhood through scoring context indicators and weighing those indicators. d_{ij} is the shortest distance via the traffic network from pixel j to the entrance point of UGS i. The quality score of UGS i (Q_i) can be computed by the sum of the multiplication of the weights per indicator k (w_k) and the quality indicator score ($q_{i,k}$) for an indicator k and UGS i. The Urban Green Accessibility Index ($UGAI_{ij}$) for a pixel j in function of an UGS i is therefore a function of the distance and quality score. The sum of all $UGAI_{ij}$ for all UGS i in the neighbourhood is the $UGAI_i$. The context score C_j is the sum scores per context indicator of a pixel j ($c_{j,l}$) for an indicator l, multiplied by the weights per indicator l (v_l). The corrected UGAI ($cUGAI_{ij}$) for a pixel j in function of an UGS i is then a function of the distance score, quality and context score and the final $cUGAI_j$ for a pixel j is the sum of the $cUGAI_{ij}$ for all UGS i close by pixel j. Source: author.

8.8 Green Typologies 2019

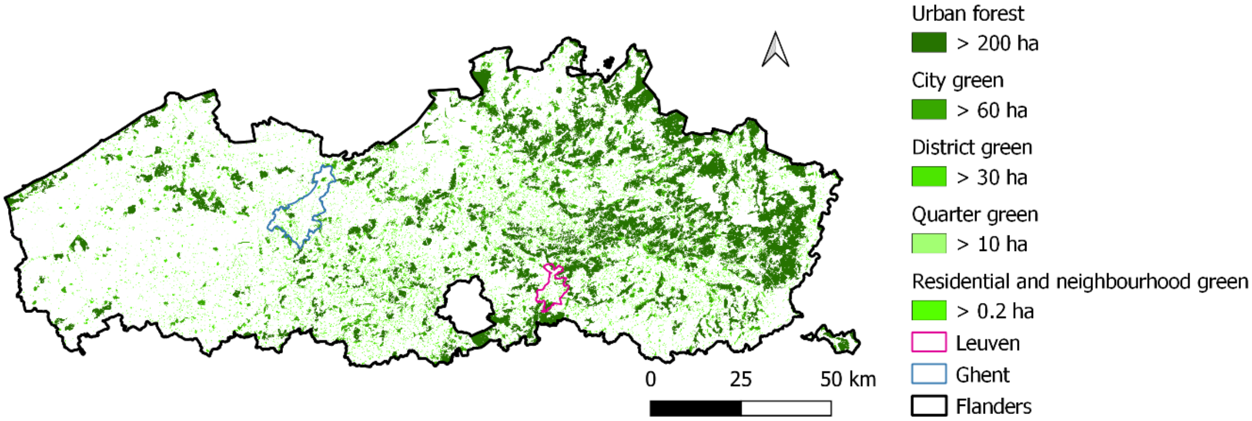

Figure 8.12: Green Typologies 2019 (Verachtert, & Poelmans, 2022) according to 5 functional levels by Aminal (1993); with Flanders, Leuven and Ghent (Agentschap Digitaal Vlaanderen, 2017)

8.9 Comparison OpenStreetMap and reference map Ghent

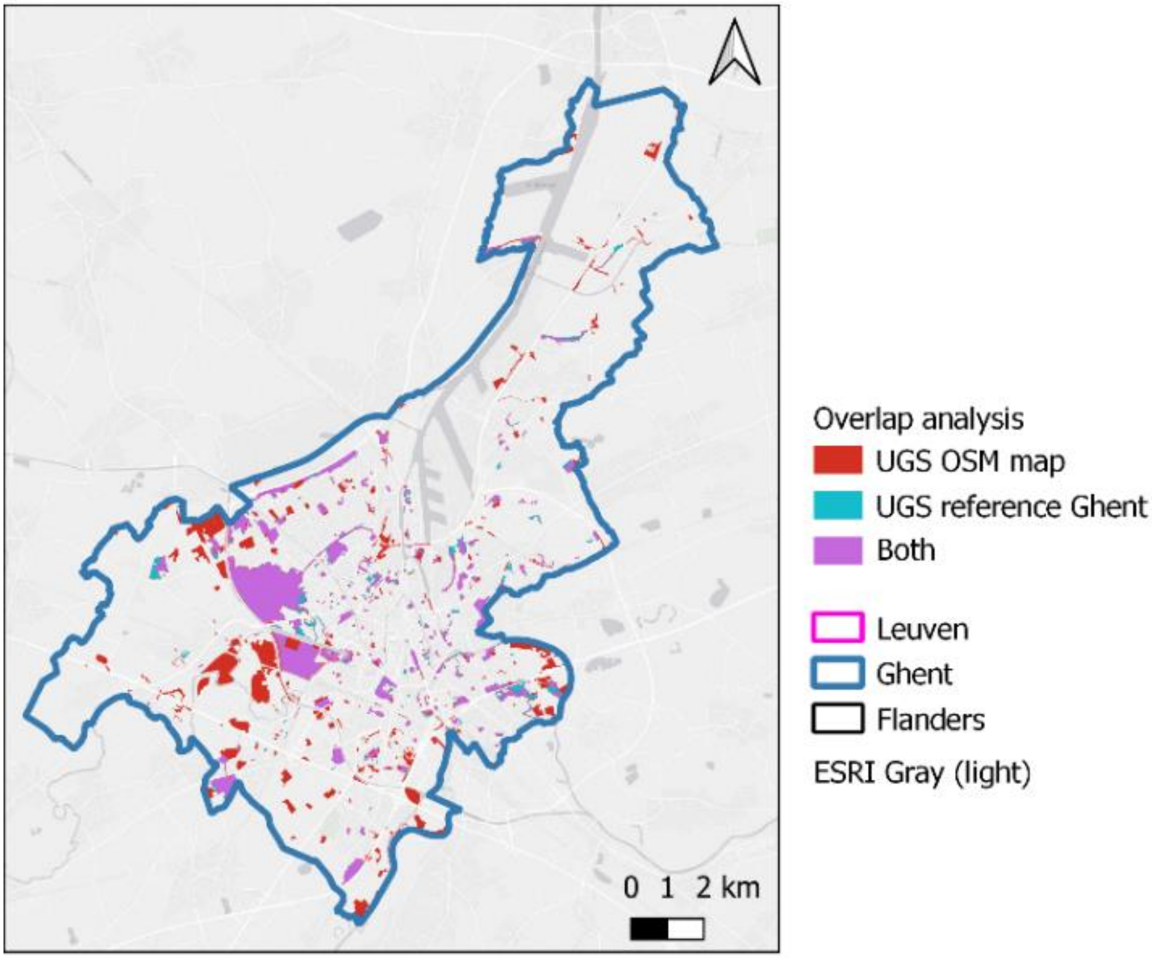

Figure 8.13: Reference map of Urban Green Spaces (UGS) by Ghent based on map parks (Stad Gent, 2022b) and neighbourhood and residential green (Stad Gent, 2022c), with Ghent indicated (Agentschap digital Vlaanderen, 2017) compared to OpenStreetMap (OSM) UGS

8.10 Accessibility to functional levels

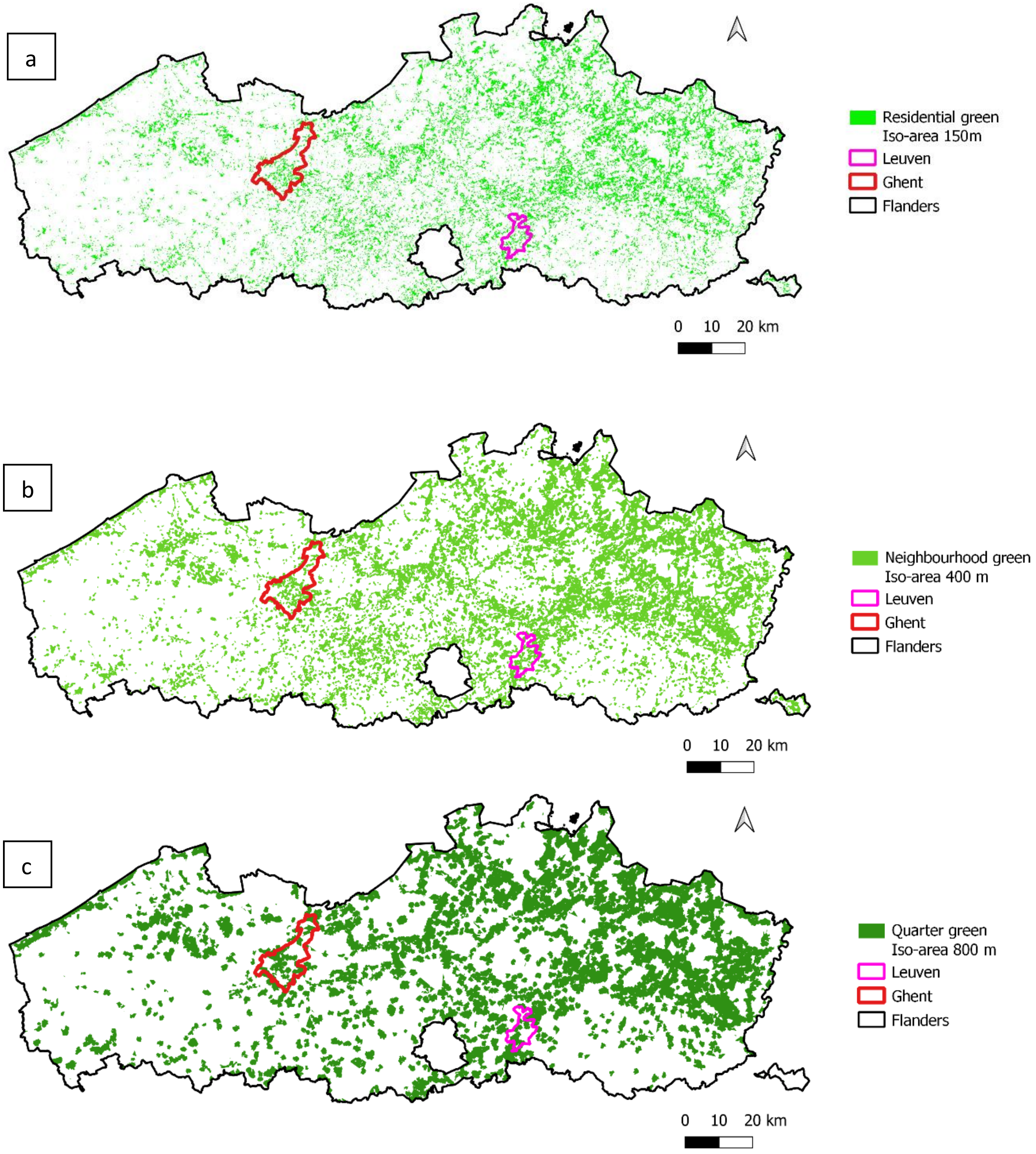

Figure 8.14: Iso-areas of different functional levels by Van Herzele and Wiedemann (2003). For residential green, which is larger than 0.2 ha, the iso-distance is 150 m (a). For neighbourhood green, which is larger than 1 ha, the iso-distance is 400 m (b). For quarter green, which is larger than 10 ha, the iso-distance is 800 m (c). With Flanders, Leuven and Ghent (Agentschap Digitaal Vlaanderen, 2017)

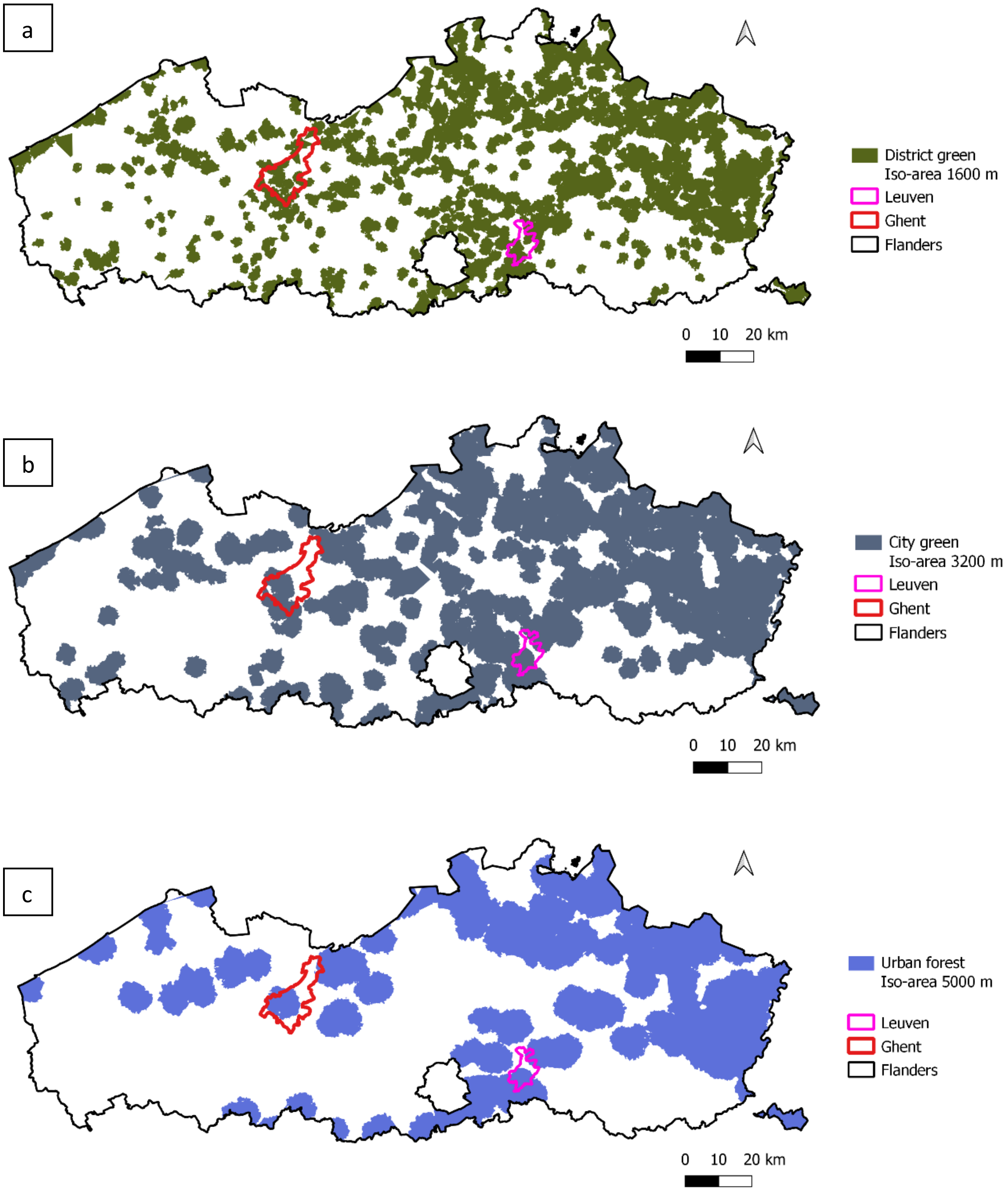

Figure 8.15: Iso-areas of different functional levels by Van Herzele and Wiedemann (2003). For district green, which is larger than 30 ha, the iso-distance is 1600 m (a). For city green, which is larger than 60 ha, the iso-distance is 3200 m (b). For urban forests, which are larger than 200 ha, the iso-distance is 800 m (c). With Flanders, Leuven and Ghent (Agentschap Digitaal Vlaanderen, 2017)

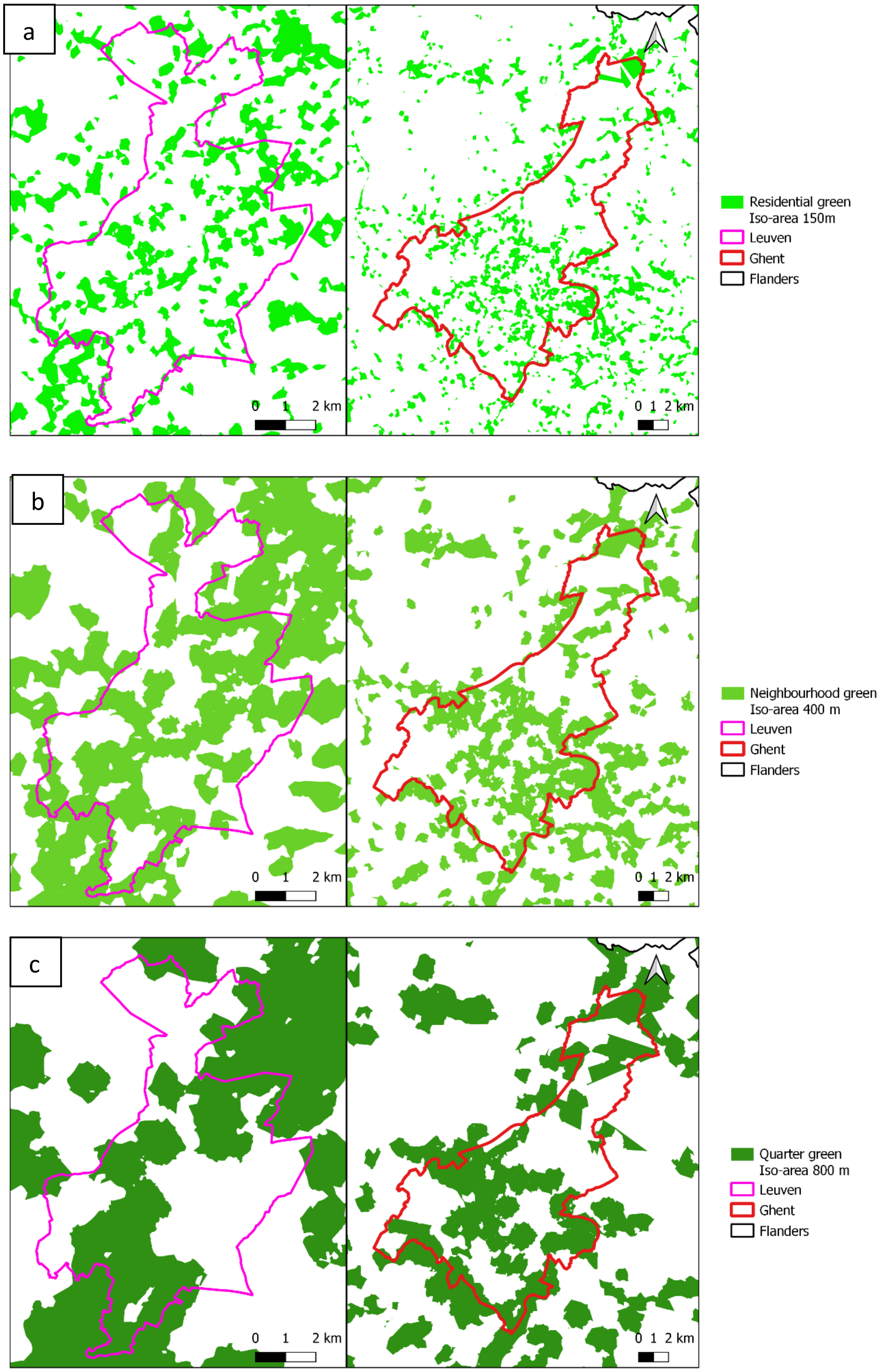

Figure 8.16: Iso-areas of different functional levels by Van Herzele and Wiedemann (2003). For residential green, which is larger than 0.2 ha, the iso-distance is 150 m (a). For neighbourhood green, which is larger than 1 ha, the iso-distance is 400 m (b). For quarter green, which is larger than 10 ha, the iso-distance is 800 m (c). with Leuven and Ghent (Agentschap Digitaal Vlaanderen, 2017)

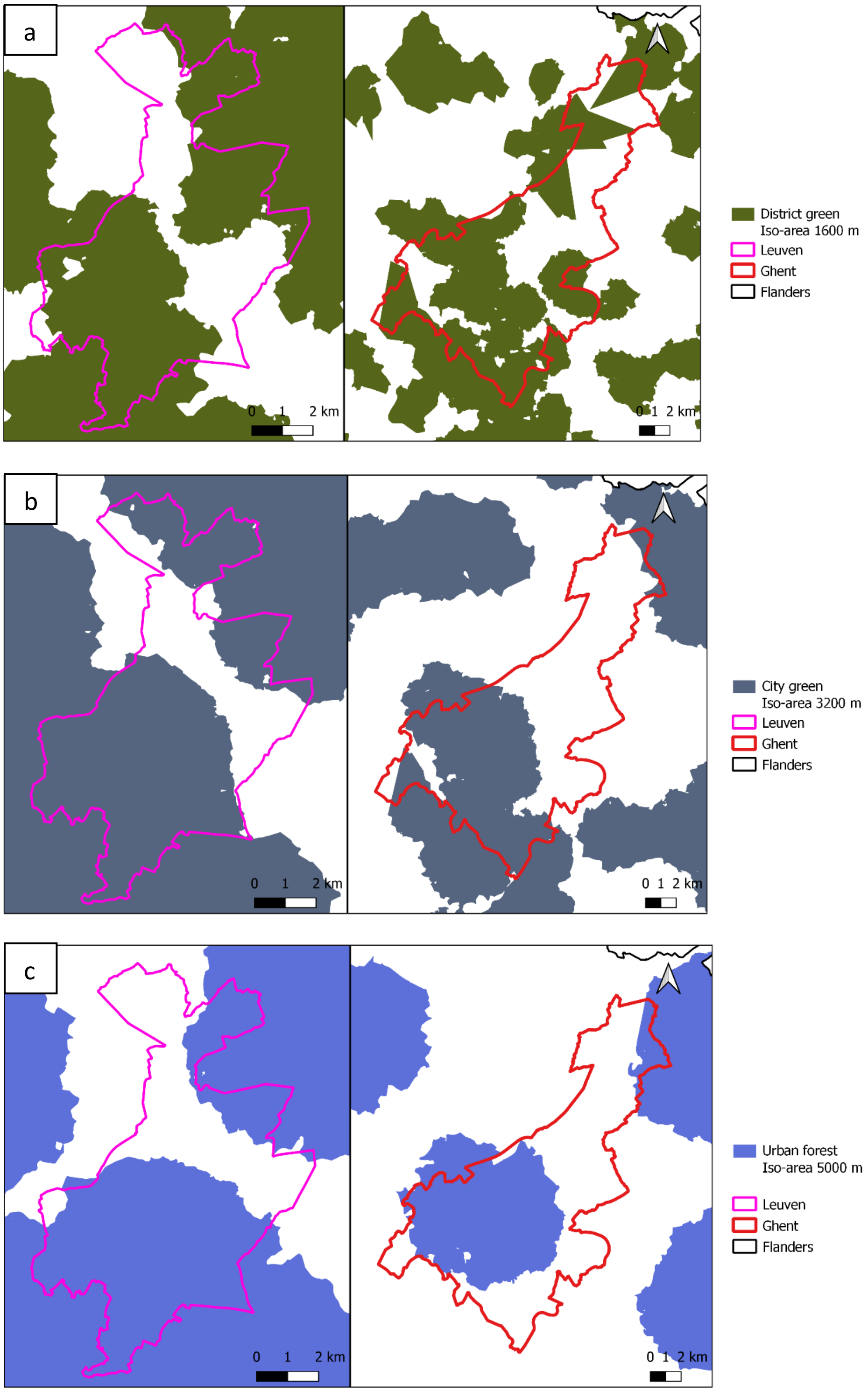

Figure 8.17: Iso-areas of different functional levels by Van Herzele and Wiedemann (2003). For district green, which is larger than 30 ha, the iso-distance is 1600 m (a). For city green, which is larger than 60 ha, the iso-distance is 3200 m (b). For urban forests, which are larger than 200 ha, the iso-distance is 800 m (c). With Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

8.11 Merged iso-area for traffic network analysis

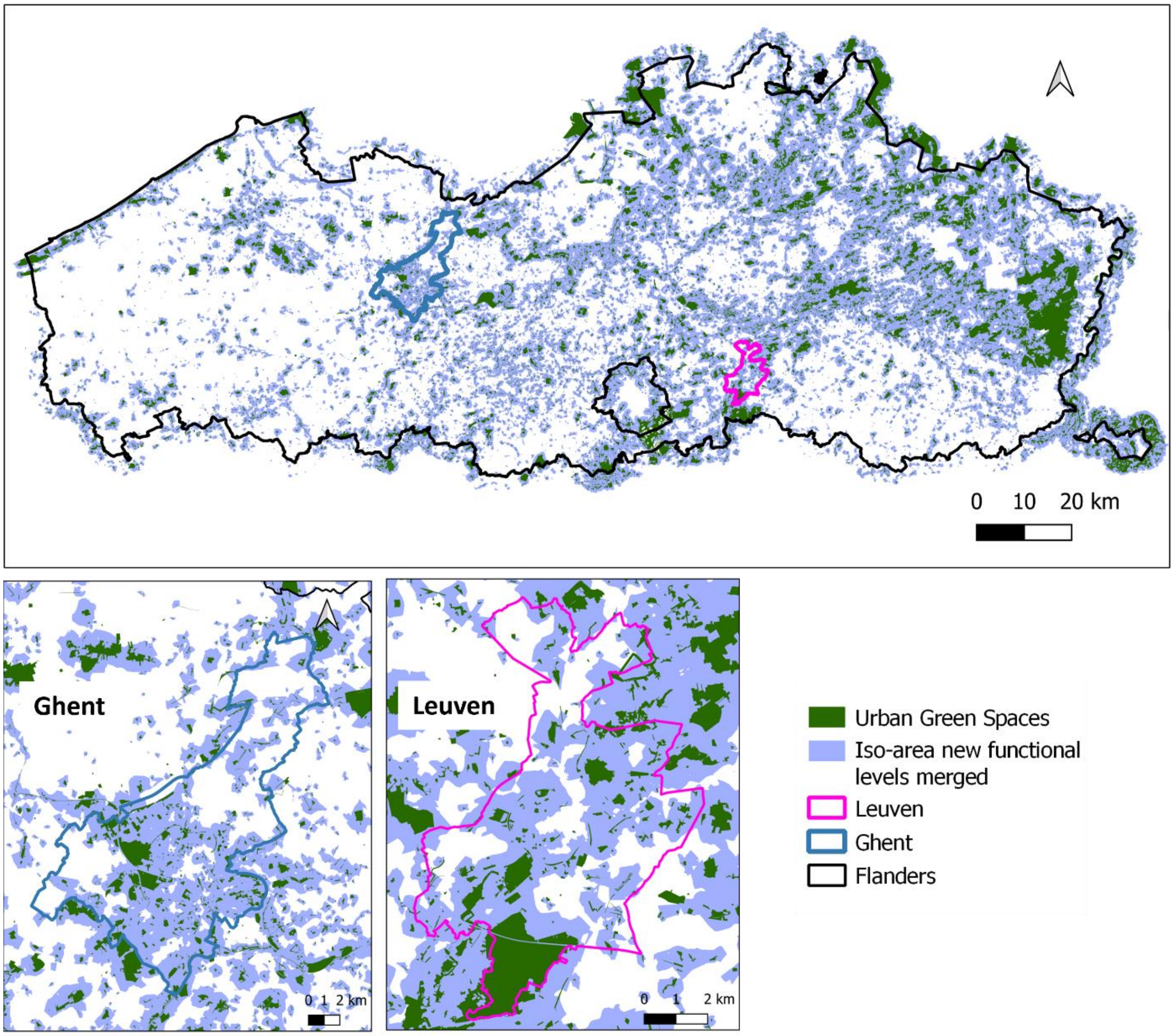

Figure 8.18: Merged iso-areas for three new functional levels: residential green, neighbourhood green and municipal green, according to Table 3.3. With Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

8.12 Quality indicator scores Urban Green Spaces

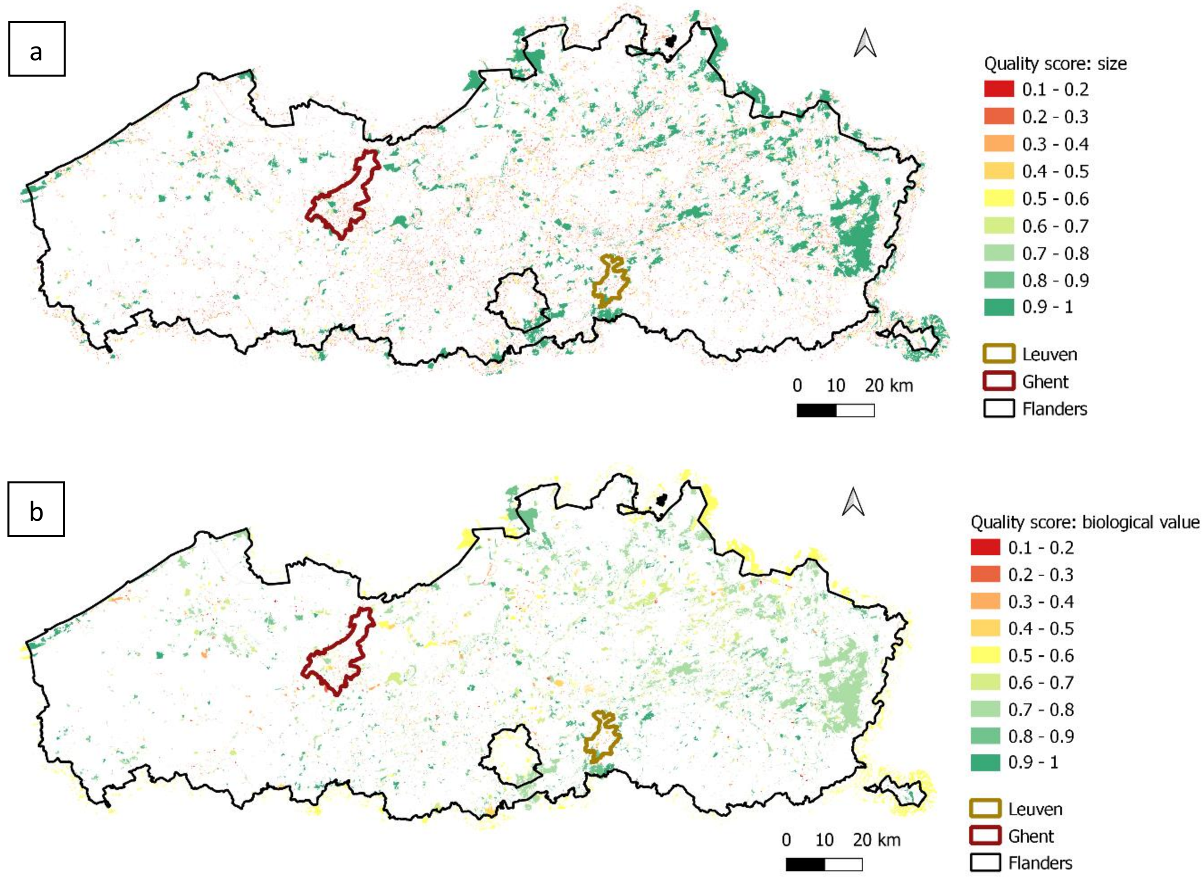

Figure 8.19: Quality scores for size (a) and biological value (b) of urban green spaces, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

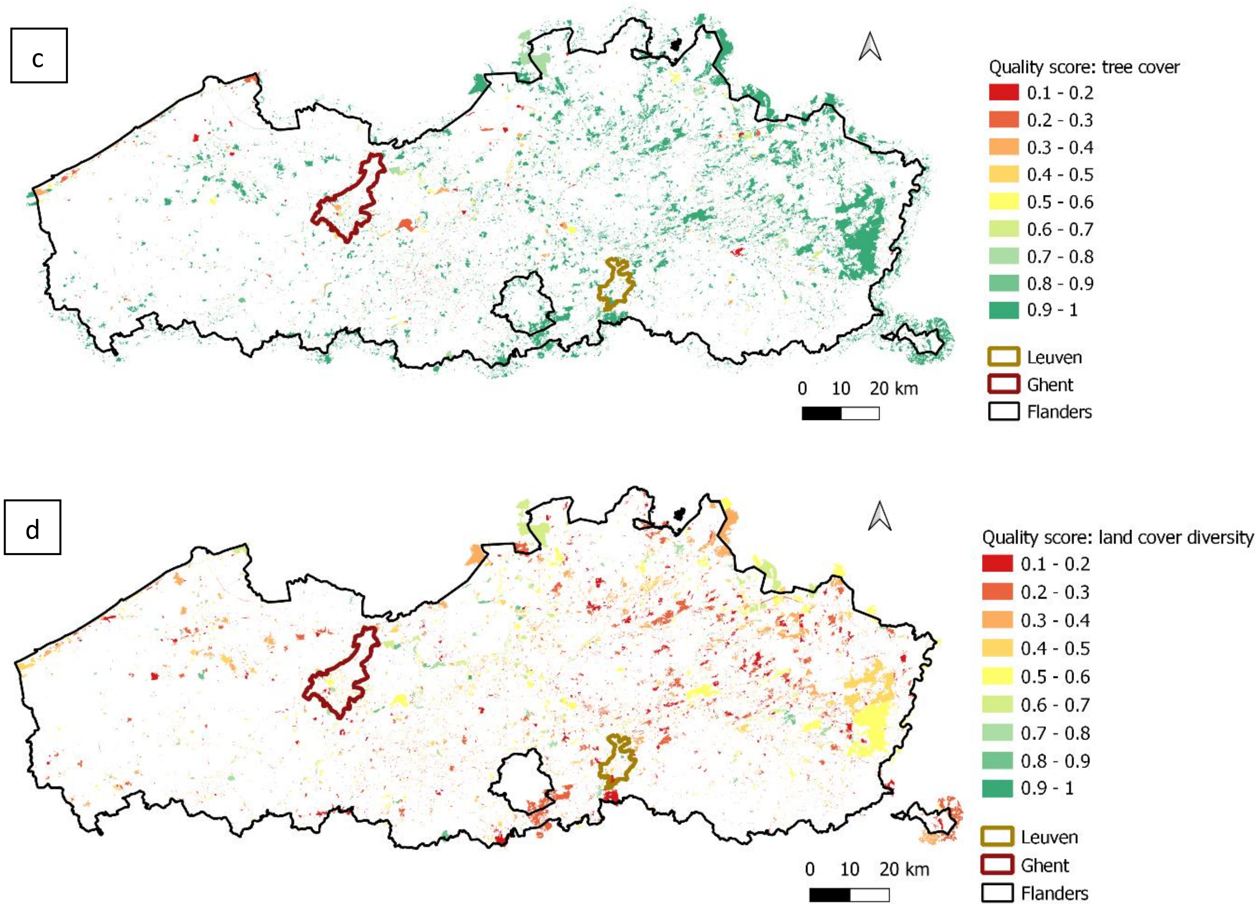

Figure 8.20: Quality scores for tree cover (c) and land cover diversity (d) of urban green spaces, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

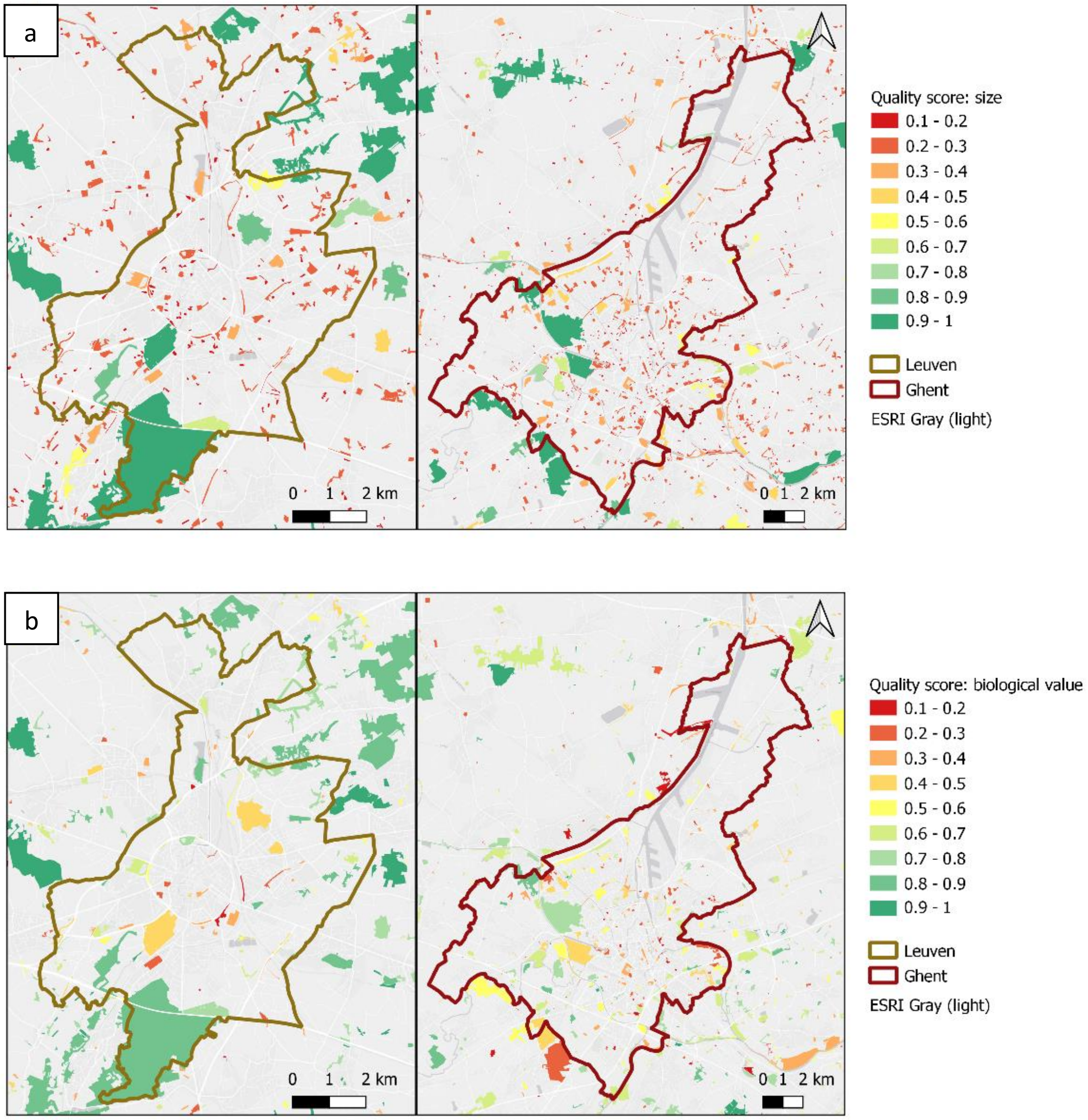

Figure 8.21: Quality scores for size (a) and biological value (b) of urban green spaces, with Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

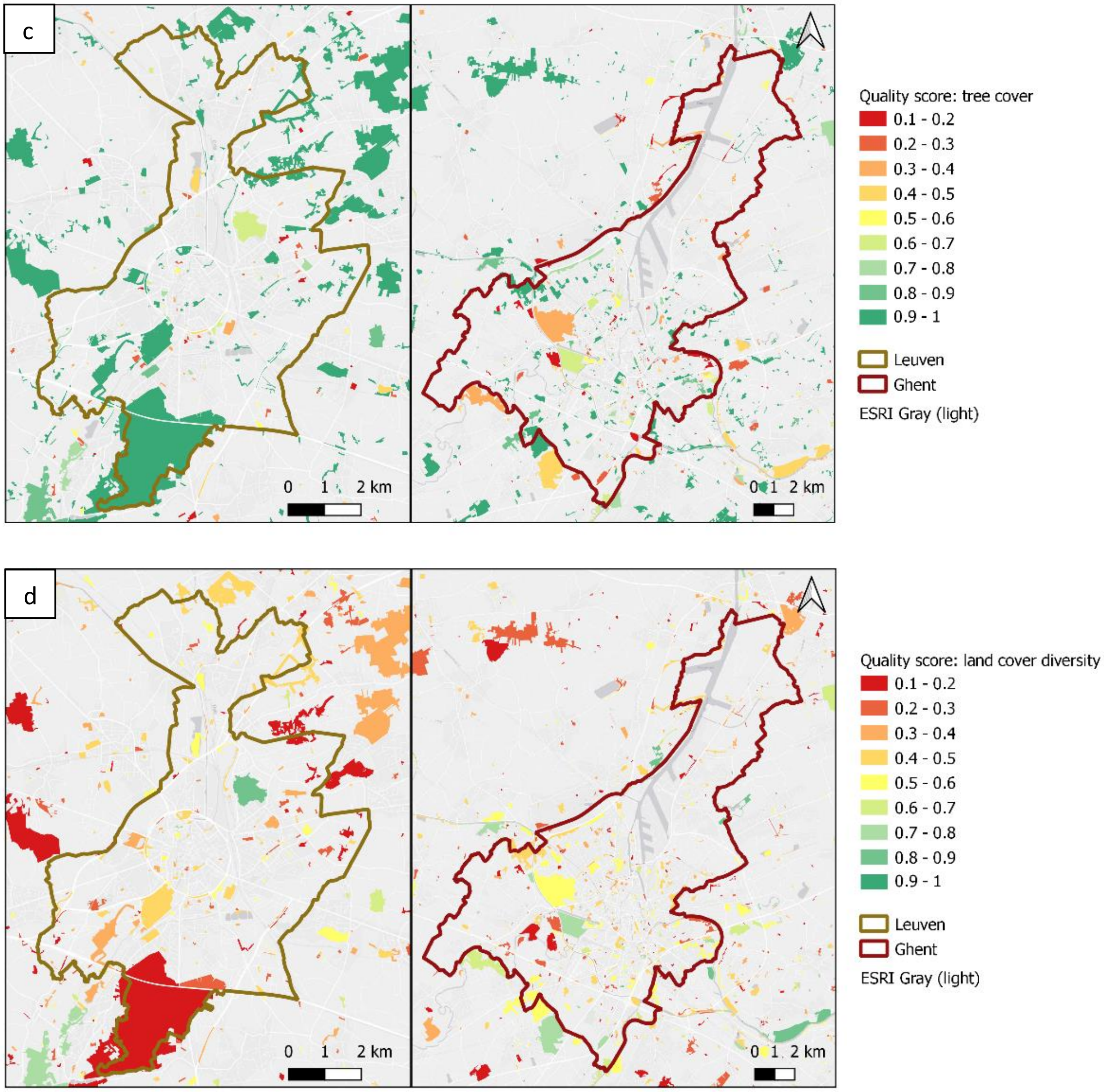

Figure 8.22: Quality scores for tree cover (c) and land cover diversity (d) of urban green spaces, with Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

8.13 Spearman correlation quality and context indicators

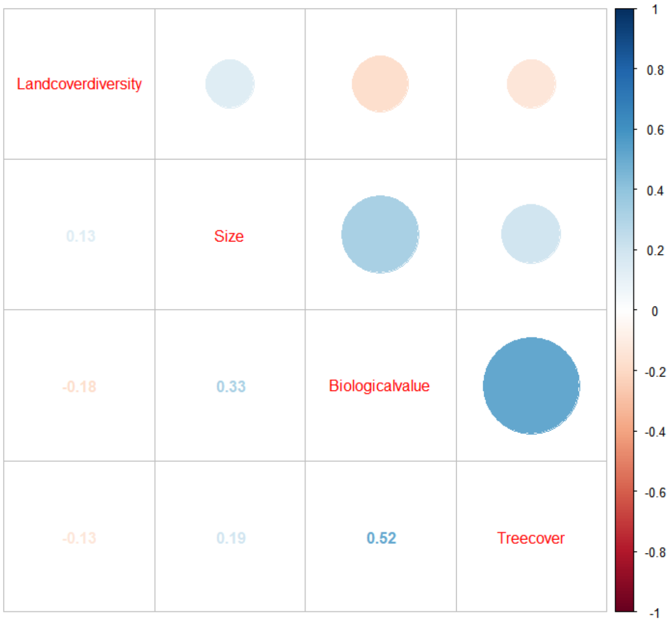

Figure 8.23: Spearman correlation between quality indicators land cover diversity, size, biological value and tree cover. R output from corrplot package R (Wei & Simko, 2021) comparing all indicators. Red signifies a negative correlation and blue a positive correlation. The size represents the absolute magnitude of the correlation.

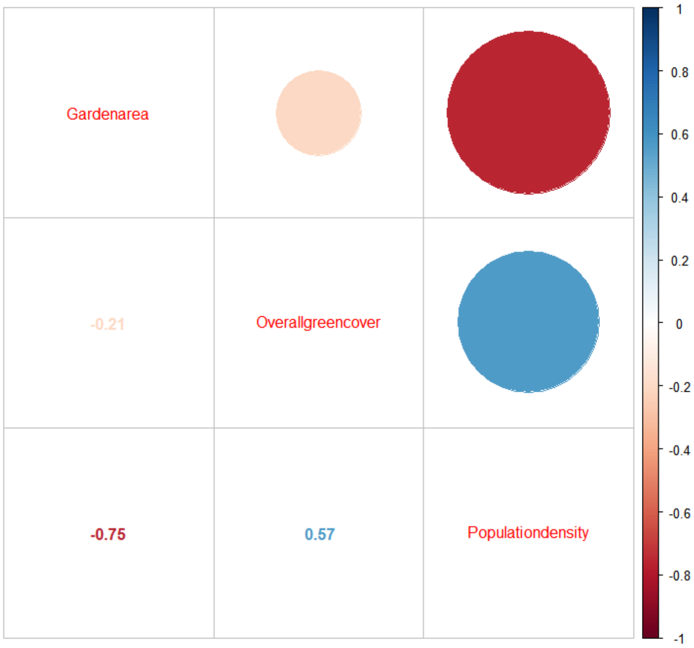

Figure 8.24: Spearman correlation between context indicators garden area, overall green cover and population density. R output from corrplot package R (Wei & Simko, 2021). comparing all indicators. Red signifies a negative correlation and blue a positive correlation. The size represents the absolute magnitude of the correlation.

8.14 Context indicator scores statistical sectors

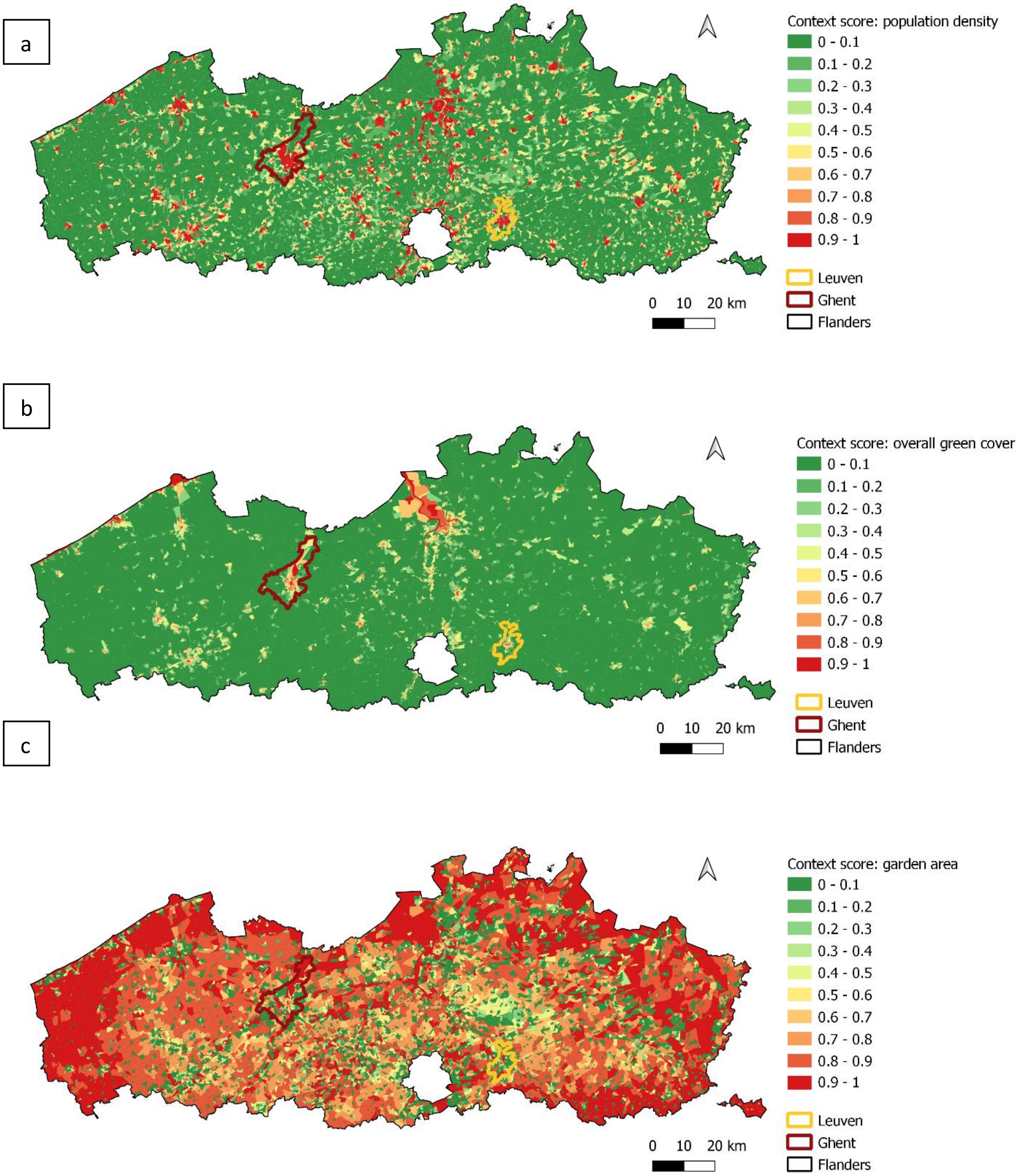

Figure 8.25: Context scores for population density (a), overall green cover (b) and garden area (c), with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

Figure 8.26: Context scores for population density (a), overall green cover (b) and garden area in Leuven and Ghent, with Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017)

8.15 Corrected Urban Green Accessibility Index with 80/20 weights: expanded view

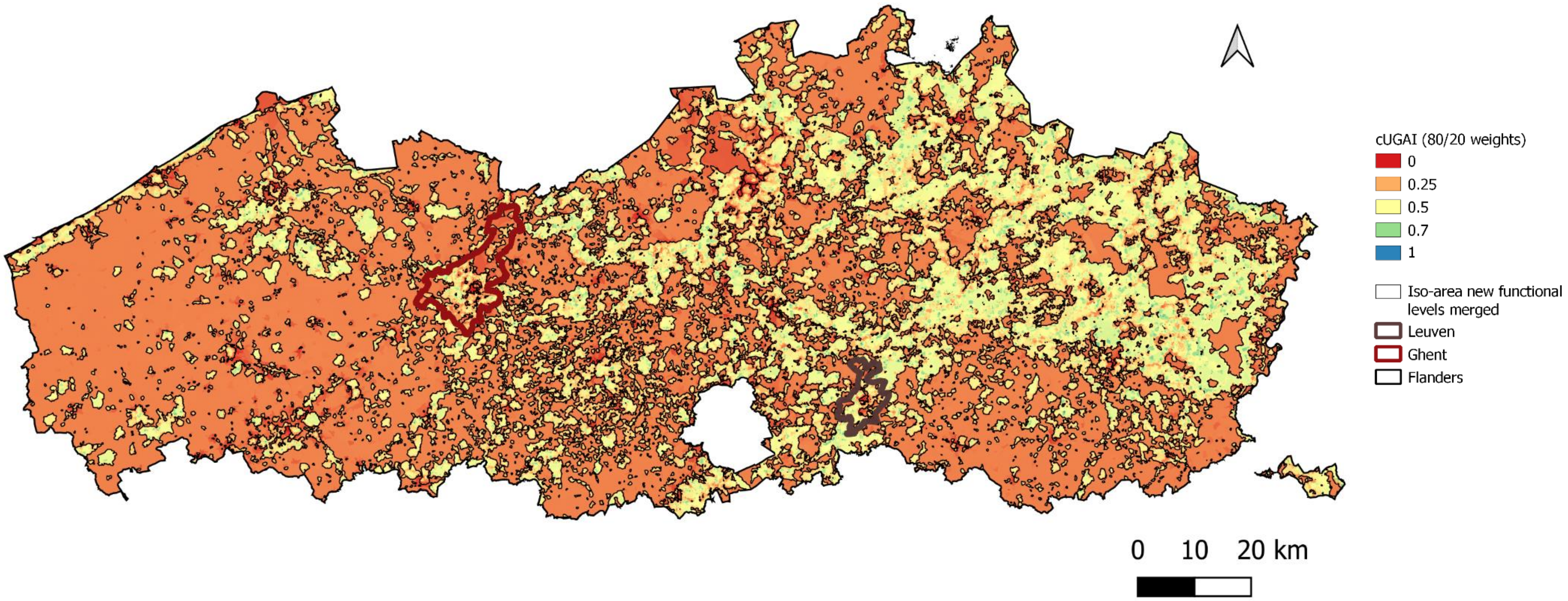

Figure 8.27: Pedestrian corrected Urban Green Accessibility Index (cUGAI) for Flanders, Leuven and Ghent based on a 0.8 weight for the supply and 0.2 for the demand, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen, 2017).

8.16 Corrected Urban Green Accessibility Index with 50/50 weights: expanded view

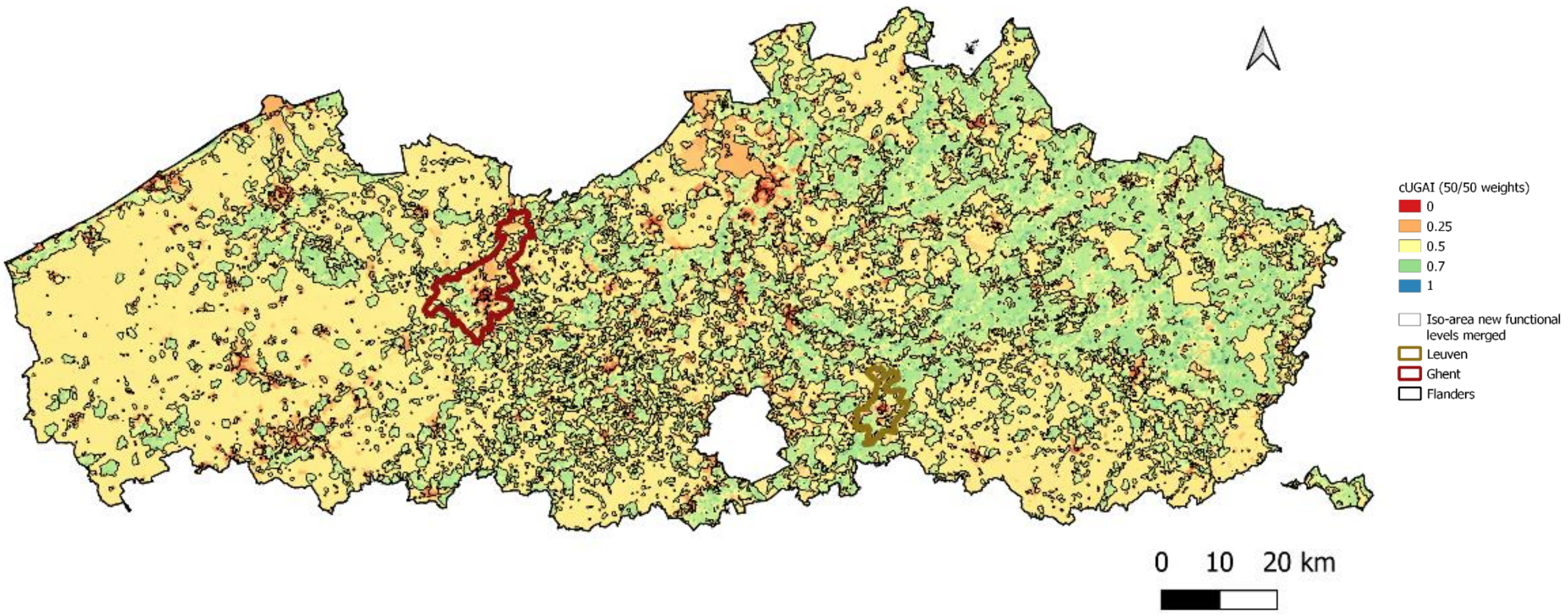

Figure 8.28: Pedestrian corrected Urban Green Accessibility Index (cUGAI) for Flanders, Leuven and Ghent based on a 0.5 weight for the supply and 0.5 for the demand, with Flanders, Leuven and Ghent indicated (Agentschap Digitaal Vlaanderen)

8.17 Use of ChatGPT (or any other AI Writing/ Coding/ Visualisation Assistance) – Form to be completed

Student name: Eline Rega
Student number: r0760890
Please indicate with "X" whether it relates to a course assignment or to the master's thesis:

X This form is related to my master's thesis.
Title master's thesis: Developing an Urban Green Accessibility Index for Flanders: A Comprehensive Analysis of Accessible Urban Green Spaces
Promoter: Ben Somers, Valerie Dewaelheyns

O This form is related to a BIG-project.
Title BIG-project: …
Promoter: …

O This form is related to a course assignment.
Course name: …
Course code: …

Please indicate with "X":

- ○ **I did not use** ChatGPT or any other AI Writing/Coding/Visualisation Assistance.
- X **I did use** AI Writing/Coding/Visualisation Assistance. In this case **specify which one** (e.g. ChatGPT/GPT4/...): ChatGPT (OpenAI)

Please indicate with "X" (possibly multiple times) in which way you were using it:

- X **Assistance purely with the language of the paper** (This use is similar to using a spelling checker)
- ○ **As a search engine to learn on a particular topic (**This use is similar to e.g. a Google search or checking Wikipedia. Be aware that the output of ChatGPT evolves and may change over time)
- ○ **For literature search (**This use is comparable to e.g. a Google Scholar search. However, be aware that ChatGPT may output no or wrong references. As a student you are responsible for further checking and verifying the absence or correctness of references)
- ○ **To let generate programming code (**Correctly mention the use of ChatGPT and cite it)
- ○ **To let generate graphics (**Correctly mention the use of ChatGPT and cite it)
- ○ **To let generate new research ideas (**Further verify in this case whether the idea is novel or not. It is likely that it is related to existing work, which should be referenced then)
- ○ **To let generate blocks of text (**Inserting blocks of text without quotes from ChatGPT to your report or thesis is not allowed. According to Article 84 of the exam regulations in evaluating your work one should be able to correctly judge on your own knowledge. In case it is really needed to insert a block of text from ChatGPT, mention it as a citation by using quotes. But this should be kept to an absolute minimum)
- ○ **Other** (Contact the professor of the course or the promotor of the thesis or BIG-project. Motivate how you comply with article 84 of the exam regulations. Explain the use and the added value of ChatGPT or other AI tool: ….)

Further important guidelines and remarks:

- ChatGPT cannot be used related **to data or subjects under a Non-Disclosure Agreement.**
- ChatGPT cannot be used related **to sensitive or personal data due to privacy issues**.
- **Take a scientific and critical attitude** when interacting with ChatGPT and interpreting its output.
- As a student you are responsible to comply with article 84 of the exam regulations: your report or thesis should reflect your own knowledge. Be aware that plagiarism rules also apply to the use of ChatGPT or any other AI tools.
- **Exam regulations article 84**: "Every conduct individual students display with which they (partially) inhibit or attempt to inhibit a correct judgement of their own knowledge, understanding and/or skills or those of other students, is considered an irregularity which may result in a suitable penalty. A special type of irregularity is plagiarism, i.e. copying the work (ideas, texts, structures, designs, images, plans, codes, ...) of others or prior personal work in an exact or slightly modified way without adequately acknowledging the sources. Every possession of prohibited resources during an examination (see article 65) is considered an irregularity."
- **Information on citing ChatGPT as proposed by ChatGPT itself**: "Citing and referencing ChatGPT output is essential to maintain academic integrity and avoid plagiarism. Here are some guidelines on how to correctly cite and reference ChatGPT in your master's thesis:
    1. Citing ChatGPT: Whenever you use a direct quote or paraphrase from ChatGPT, you should include an in-text citation that indicates the source. For example: (ChatGPT, 2023).
    2. Referencing ChatGPT: In the reference list at the end of your thesis, you should include a full citation for ChatGPT. This should include the title of the AI language model, the year it was published or trained, the name of the institution or organization that developed it, and the URL or DOI (if available). For example: OpenAI. (2021). GPT-3 Language Model. https://openai.com/blog/gpt-3-apps/
    3. Describing the use of ChatGPT: You may also want to describe how you used ChatGPT in your research methodology section. This could include details on how you accessed ChatGPT, the specific parameters you used, and any other relevant information related to your use of the AI language model. Remember, it is important to adhere to your institution's specific guidelines for citing and referencing sources in your master's thesis. If you are unsure about how to correctly cite and reference ChatGPT or any other source, consult with your thesis advisor or a librarian for guidance."

9. Popularised summary

As our cities grow, it is becoming increasingly important to ensure that we have enough green spaces. Urban Green Spaces (UGS) are essential for promoting both mental and physical health and can help tackle the challenges that come with growing cities. This means it is necessary to ensure sufficient and evenly distributed UGS to the population and there should be guidelines based on evidence for urban planners to make decisions on where to add new UGS.

This study wanted to provide such a tool and is specifically based on accessibility of UGS, or on how easy it is to reach, enter and use UGS. The tool that is proposed exists of several components. First, a map of UGS was created based on OpenStreetMap data in Flanders. The correctness of this map was tested by comparing it to a self-created map of UGS in parts of Flanders. Second, an Urban Green Accessibility Index (UGAI), which gives a score for the accessibility of urban green, was proposed and applied for Flanders. The score took the quantity, quality and the context of UGS into account. The first calculation for this score, was the area where people lived closer than a 10-minute walk or bike ride from UGS using the road network. Next, the quality of UGS was calculated based on four factors: size, natural importance, tree cover and landscape variety. With these elements, the first score (UGAI) could be calculated. Following this, the circumstances were determined in a neighbourhood to estimate how much UGS is needed by people in this neighbourhood. The circumstances included the amount of people, the total green space and the amount of gardens in a neighbourhood. All these factors were combined in a corrected score.

It was shown that the UGS map we created was sufficiently accurate to use it in further steps of the process. Furthermore, about half of the people living in Flanders can access UGS within walking distance from their home, while almost all of them find UGS within a 10-minute biking trip. After calculating the score (UGAI) and corrected score, different patterns in Flanders were revealed. The city centres of larger cities, like Leuven and Ghent, had the lowest scores and the highest need for urgent action.

The results of this study can be important and valuable for urban planners and cities and highlight the need to improve UGS accessibility and to invest in cycle paths. The tool can offer insights in the quantity, quality, and circumstances of urban green in Flanders, separately or combined in one score. The tool can also be adapted to what planners need and can be used in other regions.