Ecosystem Services in Urban Green Spaces: Planning and implementation in Vestbyen district

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Goal and scope of the study

This study is conducted by Kíra Lancz, a fourth-semester Master's candidate at Aalborg University's Department of Planning in completion of her thesis work in the Cities and Sustainability study program. The study was conducted in the period between 01.02.2023 – 02.06.2023 under the supervision of Finn Arler.

The main goal of the thesis is to provide knowledge about the potential of using ecosystem services as a framework for planning and implementing urban green spaces in order for these spaces to provide benefits for people and nature alike. The case study of Vestbyen district in Aalborg city was used as a case study to evaluate current planning strategies, the state of urban green spaces, and the advantages, tools, and challenges of ecosystem service-focused planning. A mixed methodology of document reviews and spatial analysis in qGIS was developed to investigate both planning strategy, the implementation, and evaluation of urban green spaces.

Abstract

Cities are both drivers and victims of the climate and biodiversity crises. Urban green spaces (UGS) can be valuable tools for the mitigation and adaptation of these adversities by providing valuable ecosystem services (ES) such as carbon sequestration and storage, improved biodiversity, thermal regulation, environmental resource management, health- and wellbeing, flood protection, food production, recreational, and aesthetic values. The study evaluates how these ES are integrated into the current UGS planning strategies of Aalborg, Denmark by reviewing public planning documents and conducting spatial analysis in qGIS. It compiles relevant data from related peer-reviewed research for the valuation of these services provided by the UGS in Aalborg, as well as their synergic benefits. The study concludes that while Aalborg has an ambitious planning agenda with several goals and targets specifically addressing ES, the state of UGS in Vestbyen district is not yet fulfilling these ambitions. ES are already providing valuable economic, social, and environmental benefits to the district which are hard to accurately measure. Finally, the analysis finds that the fine-scale documentation of the characteristics of existing UGS is of high importance in order to identify benefits and missed opportunities for value creation from ES. The CUGIC method was identified as a suitable classification and documentation tool for this task.

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Abbreviations

CSS	Carbon sequestration and storage
CUGIC	Consolidated Urban Green Infrastructure Classification
ES	Ecosystem services
GDP	Gross Domestic Product
GIS	Geographic Information System
LULC	Land use and land cover
UGS	Urban Green Space

1. Introduction

Urban areas are concentrated hotspots of human activity. Although they only occupy 1% of the total global landmass, they are home to over half of the human population, growing continuously, and are expected to attract over two thirds of worldwide population by 2050 [1]. They provide essential functions to humans: they serve as hotspots of economic, social, and cultural activity, providing their residents with shelter, access to food, work, connections, and consumer goods. They are critical points of contact in global trade and international supply chains, as well as melting pots of cultures and knowledge.

Cities, however, take a heavy toll on the environment both on a local and global scale. Urban living and consumption trends have high environmental burdens and put critical pressure on biodiversity [2]. Climate change is one of the biggest challenges faced by humanity. Urban areas are major contributors of greenhouse gas emissions globally, and drive land use change and consumerist behaviors.

Alongside the climate crisis, the closely related problem of the decline of biodiversity has emerged as a high-priority discourse on the global stage. Biodiversity itself is a precious ecosystem service. Healthy and diverse ecosystems, such as forests, grasslands, and freshwater habitats are significant carbon sinks, improve soil quality, help managing, storing, and cleaning water supplies, regulate floods, and provide food and natural resources.

Among many other factors, the loss of habitats and species drives food and freshwater insecurity, an increase in vulnerability to diseases, the degradation of soils and environmental resources, and an increased risk of flooding and droughts. Additionally, it is a major contributor to climate change, due the mechanisms of disrupted carbon sequestration and storage capacities [3]. The UNEP working paper on the #BecomingGenerationRestoration campaign claims that the world-wide degradation and loss of biodiversity and its related ecosystem services on an annual basis is equal in value to 10% of global GDP [3].

Cities are exceedingly vulnerable to the consequences of climate change and biodiversity loss, such as more frequent natural disasters, warming average temperatures, natural resource and food production shortages, diseases, population pressure, polluted air and water, and even climate-driven inequalities[4]. As the biosphere suffers losses, farmlands lose productivity, land managers lose revenue, non-resilient coastal towns lose their natural protection against climate events, diseases burden the population [5]. As significant as these losses, as well as the costs of alleviating the damage and treating the consequences, most modern economic models do not fully account for the monetary value of biodiversity's ecosystem services [3]. However, healthy urban ecosystems can contribute to adaptation and mitigation efforts to create healthier, more sustainable, and more resilient cities with improved socio—cultural factors [6].

An effective way to advance this agenda is by recruiting the ecosystems existing in cities, such as urban parks, roadside vegetation, trees, gardens, incidental green spaces. These urban green spaces (UGS) have the potential to recruit natural processes and synergies to provide benefits for people and nature. Functions of nature that result in direct or indirect environmental, social and economic values, the so-called ecosystem services (ES), are potent tools to address the previously described adverse effects of unsustainable urbanization [4].

Due to their density and small geographical footprints, cities have limited opportunities to alleviate these climate pressures compared to the rest of the terrestrial environment. There is, however, under-realized potential that may be unlocked with proper planning, policy, and disposition [7]. This is addressed also in the recent Kunming-Montreal Convention, an international agreement expected to serve as a guiding framework, and to provide legitimacy to efforts to preserve, conserve, and restore biodiversity. #12 of its twenty-three main targets specifically calls for action to "significantly increase the area and quality and connectivity of, access to, and benefits from green and blue spaces in urban and densely populated areas [8]".

Urban green spaces (UGS) are a diverse set of elements within the urban landscape containing some form of natural vegetation. UGS exist in both the publicly and privately owned and managed urban spaces, and include types such as urban forests, parks, lawns and gardens, as well as urban wilderness and incidental green spaces. They are popular tools and platforms to promote benefits for people and nature. The scope of this project is limited to UGS that is owned and managed by the municipality, and/or is accessible to and used by the general public. This includes parks and green recreational areas, green buffer zones, but excludes artificial green spaces, such as green roofs and balconies, and private, semi-private, and residential green spaces.

UGS, usually studied within the broader context on urban green infrastructure, have been understood to provide several services in the context of climate change adaptation and mitigation of the city. They can offer various ecosystem services on multiple spatial dimensions, from the residential garden-level to the entire urban area [2], [9], [10]. These services include water management benefits, thermal regulation, air quality and habitat improvement. UGS can also provide social and cultural services to the residents of the city. Places of gathering, recreation, multifunctional areas, and accessible landscapes are vital to the urban community [11], providing benefits such as health and restorative functions, comfort, aesthetic value, and educational opportunities among others [10], [12].

They can also contribute to bringing the urban carbon budget closer to net-zero conditions, a goal pursued by an increasing number of cities – such as Aalborg [13]. For example, the capacity of the global urban carbon pool has been estimated to hold as much as 10% of the terrestrial carbon budget. Although the built environment accounts for a significant portion of this capacity, UGS can play a valuable part in lowering the greenhouse gas emissions of cities [1].

Not all UGS have the same effects and outcomes, and if not planned and managed with ES in mind, their benefits can be drastically reduced. The ubiquitous urban landscape feature, the conventional lawn, for example, is a popular feature of UGS on all scales: private gardens, smaller residential-adjacent spaces, and urban parks. From an ecosystem-services-perspective, they require frequent mowing, the removal of organic material, and are often treated against species diversification to preserve a homogenous aesthetic. Removing organic litter, such as the cut grass and fallen leaves deprives the ecosystem from much needed nutrition, habitat, and insulation. Spaces like this have vastly different ecological dynamics compared to urban wetlands, forests, food-producing areas, wildlife gardens and such [2].

Certain common practices in the implementation and management of UGS are limiting their success in providing environmental benefits. Such practices include the pruning, pesticide and herbicide use in lawn management, the planting of invasive species, and the use of fossil fuels in maintenance activities, especially mowing [2]. Other potential limiting factors include vegetation of low productivity, poor soil quality, excessive fragmentation, not enough structural complexity, and more [1]. These potential shortcomings can bring about significant differences between distinct types of UGS. For example, comparative studies between various scales and vegetations suggest that while bio-diverse, high-productivity urban environments act as carbon sinks, low-productivity lawns that requite high maintenance can become net sources of carbon emissions [14]. Hence, a well-designed and informed strategy is crucial to turn UGS into positive contributors of urban sustainability.

This wide variety of opportunities, functions, and potential fallbacks show that the further study of ES in the context of UGS is necessary for urban planners. Without an evidence-driven understanding of how specific conditions in the UGS influence their overall environmental impact, they can hold back city-level climate action.

Currently still only a small portion of research focusing on the quantification and valuation of ES in the urban context, there is a knowledge gap between ES in rural and natural areas compared to their role in city-scale climate adaptation and mitigation [6].

This study aims to contribute to the growing body of literature on the assessment of the advantages and disadvantages of UGS of different scale, composition, and management strategies by evaluating the ES they provide in an urban setting.

With a specific focus on Aalborg-Vestbyen, the thesis maps an understanding of how UGS are planned and implemented, what kind of ES do they provide, and assesses the extent to which the realized ES live up to planning goals in the district. It explores the contribution of these green spaces to local and global goals related to biodiversity, climate action, and the improved city life. It also considers potential for improvement to maximize and optimize progress in these areas. This urban ecological data can be utilized for improving planning practices, and consequently the health and resilience of urban and urbanizing areas.

Through a procession of reviewing planning strategies, conducting a spatial analysis of existing UGS, and discussing the values, contributions, and challenges of ES-based planning in the Vestbyen district, the thesis aims to answer the following main research question:

How can an ecosystem services-focused framework be utilized in the planning process and valuation of urban green spaces to create more sustainable and climate-resilient cities?

To build a theoretical and logical framework for the investigation, the following three sub-questions were defined:

a. To what extent are ecosystem services integrated and prioritized in the urban green space-related planning strategies in Aalborg city?
b. What kind of ecosystem services are provided by urban green spaces in Vestbyen district?
c. How can urban planners develop ecosystem services-based planning frameworks in their specific geographic, social, and temporal context?

2. Methodology

2.1. Aalborg UGS planning strategies

To paint an accurate picture of where the city stands in terms of ES-related strategic initiatives and the state of biodiversity in the target area, a selection of recent publications by the municipality were reviewed.

Aalborg Municipality has a historic record of including sustainability as a key point in strategic planning. Notable commitments include the city's signing on to the Aalborg Charter in 1994, and then the Aalborg Commitments in 2004 [15]. Currently, several of the city's publicly available strategic planning documents include vision, targets, and actionable items regarding green spaces.

After a brief review of the publicly available planning strategies, guidelines, and commitments on Aalborg Kommune's homepage, the following documents have been identified as the most relevant to discussing UGS planning framework in Aalborg:

- Planning Strategy 2019[1]:
  The most recent municipal urban planning framework[16]
- World Goal Strategy[2]:
  Aalborg's sustainable development framework building on the SDGs [17]
- Rich Nature in Aalborg – a strategy for biodiversity[3] (Rich Nature):
  A biodiversity-focused planning strategy [18]
- Under Open Sky – policy for nature, parks, and outdoor life[4] (Under Open Sky):
  The policy framework for the development of nature, parks, and outdoor life within the Vision 2025 planning package [13]

These four documents were then processed in a more detailed document review, with the primary goal of extracting information about whether or not they explicitly refer to one or more ES; if they contain specific goals or commitments related to these ES; what kind of goals or measurable targets do they establish; and what kind of impact do they aim to achieve.

All four documents contain overarching statements about the importance of nature, hence the analysis was mostly focusing on actual strategies or planning objectives that help translate the nature-friendly language into tangible outcomes.

[1] Original (Danish) title: Planstrategi
[2] Original (Danish) title: Verdensmålsstrategi
[3] Original (Danish) title: Rig Natur i Aalborg Kommune – en strategi for biodiversitet
[4] Original (Danish) title: Under Åben Himmel - Politik for natur, parker og udeliv – Vision 2025

2.2. Mapping the UGS in Vestbyen

The spatial analysis of UGS was conducted in QGIS software, utilizing pre-existing maps and the manual addition of features based on aerial photographs and field visits.

The boundaries of the study area were established based on the borders of Vestbyen district as defined on the KortInfo webGIS platform's Aalborg section. The district borders are available under the 'Planer -> Kommuneplan -> By- og bydele' layer.

The locations, extent, and characteristics of the designated UGS were obtained from a variety of sources. Maps were acquired from OpenStreetMaps and GeoDanmark. As some relevant features were missing from the digitized maps, or were incorrectly represented, manual adjustments were made based on the ortophotomap and personal observations by visiting the sites in question when needed.

Table 1. summarizes the pre-existing base maps and GIS files used in the process.

Description	Source
Basemap: Ortofoto forår	GeoDanmark
Basemap: Skærmkort - dæmpet	GeoDanmark
Planning zones	OpenStreetMap
Designated nature areas: Tema Natur, 1-25.000	GeoDanmark
Specific natural features	OpenStreetMap

Table 1: GIS data sources

Only spaces with green coverage and public access were considered as UGS. Non-public sports fields, gardens, commercial entities and residential areas, and semi-private green areas belonging to apartment blocks were not included in the UGS analysis.

The classification of green infrastructure features was completed by following an adjusted version of the CUGIC methodology developed to include ES data in UGI research. The CUGIC methodology is a double-layer approach to classify GI data based on both Land Use/Land Cover (LULC) and vegetation assessments [19]. The CUGIC classification allows for an assessment of the extent and basic characteristics of the UGS in the target area.

In order to accurately describe the UGS in Aalborg, not all labels of the CUGIC framework were used, and some of the vegetation layer's descriptors were slightly modified. Table 2 and 3 summarize the differences between the CUGIC and the assessment framework used in this study.

LULC data	
CUGIC designation	Notes or explanation
Remnant vegetation	n/a in Vestbyen
Natural land	n/a within the city
Park	
Agriculture	n/a within the city
Botanical garden	n/a within Vestbyen
Cemetery	
Golf course	n/a within Vestbyen
Wetland	n/a within Vestbyen
Rain garden	n/a within Vestbyen
Bioswale	n/a within Vestbyen
Detention basin	n/a within Vestbyen
Infiltration basin	n/a within Vestbyen
Green buffer zones	
Green roof	Not within the scope of the study
Green wall	Not within the scope of the study

Table 2: LULC data classification with notes on application

Vegetation data		
CUGIC	Modified-CUGIC	Notes or explanation
Highest level of vegetation: Grass; Shrub; Wooded	Highest level of vegetation: Grass; Shrub; Wooded	
Dominant tree species: Evergreen forest; Deciduous forest; Mixed forest	Plant diversity: Low; low-medium; medium-high; high	As plant diversity is an essential indicator of biodiversity, and not only urban forests were included in the analysis, this attribute was modified to reflect on vegetation diversity as a whole. The designations were loosely defined as follows: Low: a single species dominating (e.g. lawns, single trees) Low-medium: There are a few species present, but there is still a dominant species (e.g. lawns with sections of flowering plants) Medium-high: There are multiple species present, each accounting for a significant portion of the coverage (e.g. extensive plantation of diverse flowering plants, shrubs or tree groups with undergrowth) High: Several species on multiple levels (e.g. dense urban forest with multiple tree species and undergrowth, shrubs with dense undergrowth and trees)

Vegetation layers: Single-layered; Multi-layered	Vegetation layers: Single-layered; Multi-layered	
Vegetation coverage: Sparse vegetation; Open vegetation; Closed vegetation; Dense vegetation	Excluded	As only designated green spaces are covered in the study, vegetation coverage is close to 100% in every plot; hence including this designation offers no additional information in this context

Table 3: Vegetation data classification with nots on modifications and application

As the product of the spatial analysis, two multipolygon GPKG layers were created: 'LULC Vestbyen' and 'Vegetation Vestbyen', containing a detailed classification of UGS within the Vestbyen district limits.

'LULC Vestbyen' contains (1) the designation of LULC (e.g. park, buffer, cemetery) and (2) the area in meters for each area identified on the map.

'Vegetation Vestbyen' contains the designations for (1) the highest level of vegetation (notated form here as vegetation type), (2) plant diversity, (3) vegetation layers (also notated as level of complexity), and (4) area in meters.

Both layers contain other attribute features too, such as ID designations, however, those are remnants of the working process and carry no meaningful information to the UGS analysis.

After the completion of the two layers the attribute tables were extracted to an aggregated Microsoft Excel file for further analysis and calculations, such as % values of the share of different designations, the prominence of certain classes, and the calculations of quantifiable ecosystem services.

2.3. Evaluating the ecosystem services

Nine ES categories were identified in the document review described in Section 2.1. The following section will describe these ES and the dynamics in which they provide benefits and value. The aim of this component of the research design is to present a way in which a valuation of the provided ES in Aalborg Vestbyen's UGS can be conducted. The actual value of the ES will be discussed in Section 3 and Section 4, according to the methods and practices presented here.

The descriptions are edited after a brief literature review in the Scopus database. Keywords and article selection criteria is described individually for all ES of interest in Table 4. The results for each ES were filtered by "most cited", and after a brief abstract review of the top twenty results, the most relevant papers were identified. This method was complemented by a snowballing approach, where papers outside of the search results were included if they were highly relevant and directly referenced by the most cited documents.

Papers not relevant to the ES present in the reviewed documents, or focusing on a out-of-scope aspects of UGS such as social justice dimension access, and studies focusing on research design and very specific data analysis methods were excluded from the review.

Ecosystem service	**Search query**
Biodiversity	"urban green space" OR "green infrastructure" AND biodiversity AND "ecosystem service" AND "climate change" AND lawn OR turf OR grass PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (LANGUAGE , "English"))
Carbon Sequestration and Storage	"urban green space" OR "urban green infrastructure" AND "carbon sequestration" OR "carbon storage" AND soil AND "ecosystem service" AND "climate change" AND management PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (LANGUAGE , "English"))
Thermal regulation	urban AND "green space" OR "green infrastructure" AND "thermal regulation" OR "heat mitigation" OR "heat island" OR "heat stress" AND "ecosystem service" AND "climate change" AND management AND park PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "EART") OR LIMIT-TO (SUBJAREA , "ECON") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (LANGUAGE , "English"))
Natural resource management	"urban green space" OR "urban green infrastructure" AND environmental resource AND "air quality" OR "water quality" OR pollution AND "ecosystem service" AND "climate change" AND management AND park AND vegetation PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA,"AGRI") OR LIMIT-TO (SUBJAREA,"ENER") OR LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"EART") OR LIMIT-TO (SUBJAREA,"ECON") OR LIMIT-TO (SUBJAREA,"MULT")) AND (LIMIT-TO (LANGUAGE,"English"))
Health and well-being	"urban green space" AND "ecosystem service" AND benefit AND "public health" OR "mental health" AND PUBYEAR > 2017 AND biodiversity AND "climate change" OR sustainability AND (LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-

	TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "EART")) AND (LIMIT-TO (LANGUAGE , "English")).
Flood protection	"urban green space" OR "urban green infrastructure" AND flood AND management OR prevention AND "ecosystem service" AND "climate change" AND park AND vegetation PUBYEAR > 2017 AND (LIMIT-TO (SUBJAREA,"ENVI") OR LIMIT-TO (SUBJAREA,"AGRI") OR LIMIT-TO (SUBJAREA,"ENER") OR LIMIT-TO (SUBJAREA,"ENGI") OR LIMIT-TO (SUBJAREA,"EART") OR LIMIT-TO (SUBJAREA,"ECON") OR LIMIT-TO (SUBJAREA,"MULT")) AND (LIMIT-TO (LANGUAGE,"English"))
Food production	No additional search for documents was conducted
Recreation	No additional search for documents was conducted
Aesthetic values	No additional search for documents was conducted

Table 4: Summary of search queries

Biodiversity

Although biodiversity within the urban landscape has not been extensively studied in relation to the increased anthropogenic impacts, UGS have a potential to boost biodiversity both on a local and regional scale [20]. Studies in parks and gardens have shown that the diversity of the vegetation, as well as the structural complexity of the habitat encourages higher biodiversity in across the ecosystem as a whole [21].

The management practices of UGS are closely associated with their levels of success in improving biodiversity, and inadequate practices can have detrimental effects. For instance, introducing invasive or predatory species may lead to diseases and biodiversity loss [21]. Size and connectedness are also determining factors, the so-called “ecological land-use complementation”, in as much as larger UGS, and those with connections to other UGS, or a wider UGS network generally have a higher diversity of species, and are better able to provide the resources for the present species [21], [22].

Biodiversity within an ecosystem has been suggested to positively correlate to several other ES through intricate synergies.

Carbon sequestration and storage

Urban green spaces sequester and store carbon from the atmosphere both above and under the soil surface. Above ground, carbon is stored in the biomass of the vegetation, for example in the trees of urban parks, as well as bushes, grasses, and other organic matter.

Research in this field concludes that the vast majority of CSS above the ground is associated with trees. The density of sequestered carbon in tree-covered urban spaces have been estimated to be 28.06 kg C $m^{-2,}$ in Leicester, UK [23], and 10.64 kg C m^{-2} in Rotterdam, NL [6].

Urban soils are not to be overlooked in the carbon dynamics of the UGS. Soil organic carbon (SoC) is accumulated primarily through organic matter deposition and the subsequent decomposition processes underground. Since the rate of these processes largely depend on several properties of the system, for example temperature, moisture, nutrient availability, and surface primary productivity, there can be significant differences between different sites, and thus predicting SoC based on management practices is difficult [24].

Carbon can be stored in the urban soil in the long term due to the lack of annual disturbances, such as fires or agricultural use, which makes it an ideal climate change mitigation prospect for city planners. To maximize the storage capacity, multiple factors need to be considered. For instance, disturbances such as landscaping and construction affect the sequestration and storage processes [24]. Several other studies support this notion of carbon storage increasing in urban soils with time since the last significant disturbance [25], [26]

The underground carbon storage capacity of urban soils specifically has not been extensively studied, however, the existing literature suggests a significant contribution to the total urban carbon storage. Churkina et al. estimated that soils hold 64% of the urban carbon store. The soil carbon density of urban vegetation was estimated to have an average of 15.5 kg C m^{-2} in Helsinki [24], and 13.2 kg C m^{-2} in Leicester, UK [26], and 10,64 kg C m^{-2} in Rotterdam [6]. While there are variations depending on the intensity of management practices and the type of the coverage, the average values in Northern European locations like Helsinki or Rotterdam can be considered applicable to Aalborg as well. The Lindén et al. (2020) study in Helsinki study also showed that several times more carbon is stored underground compared to urban forest above-the-ground biomass.

Thermal regulation

Due to the effects of urbanization on the landscape and the surface patterns and materials, cities often experience the “urban heat island” effect, where higher temperatures are observed in the urban areas compared to their surroundings [10], [27]. As global average temperatures are projected to rise, this increases the vulnerability of urban populations to heat stress. There have been many studies investigating urban green and blue infrastructure as a means of mitigating the heat island effect, with various methodologies and outcomes to define the parameters which dictate the efficacy of different urban landscapes in thermal regulation.

The major driving mechanics of thermal regulation by UGS is the vegetation’s ability to selectively alter and the absorption and reflection of incoming radiation, and the exchange of heat in their area by providing shade and by conducting transpiration [27].

The extent and shape of the UGS may also play a significant part in determining the characteristics of the thermal regulation.

The exact measures by which UGS can regulate their immediate climate are site-specific, and thus impossible to generalize. To get likely relevant metrics to Aalborg, results focusing on cities with similar latitude and climate conditions were identified. In Göteborg, a maximum cooling effect of 5.9 ℃ was observed in summer conditions, with a more than 1.1 km cooling distance. A study in Copenhagen indicated an average of 2.47 ℃ cooling in a 150 m cooling distance of urban parks in the summer. The Copenhagen study also found that 0.69 ha is the threshold-size of an UGS, above which the space does not generate significantly more thermal regulation benefits, and that the effect is more significant in the summer than in the winter [28]. The same study also concludes that tree covered green spaces are the optimal choice of UGS to maximize thermal regulation benefits over grass covered green spaces.

Environmental resource management: improved air and water quality

UGS has a beneficial effect on the management of natural resources such as clean air and water. Urban vegetation helps mitigating anthropogenic air pollution by binding and taking up PM pollutants and gases, and by modifying the air circulation and dispersing pollutants[29]. UGS with a higher structural complexity and less intensive management strategies was shown to have higher efficacy to improve air quality, while lawns and non-complex vegetation have less impact on the air quality [30]. Generalized metrics applicable to Aalborg, however, were not identified in the literature.

Water quality is improved by the filtration of groundwater and precipitation by the roots of the vegetation and the soil itself. Urban drainages can be high in pollutants and nutrients that can cause a degradation of groundwater quality and eutrophication, hence ensuring that UGS are optimized for this ES can make a significant impact on the urban habitat [31].

Health and well-being

The proximity and quality of green spaces have been understood to provide important health-related ecosystem services leading to a number of diverse benefits to the citizens. There are several synergies between health and other ecosystem services. Improved air and water quality, for example lead to a reduction of illnesses born of pollution and poor water quality. Thermal regulation, especially in times of extreme heat events reduces heat stress on citizens in the affected areas.

Through encouraging and facilitating social interactions, UGS can be associated with improved social cohesion and a sense of belonging [11]. These benefits, however, don't only depend on factors governing the ecology of the UGS, but also their governance, including access, open designs, and organized activities [11].

UGS enables and fosters more active lifestyles by offering space for recreational activities such as walking, biking, hiking and running. These are activities suitable for most groups within the urban population and were found to lead to increased physical activity, reduced stress, better immune response, and cognitive improvements as well [11].

The social cohesion benefits have been linked to psychological benefits as well, however, these links remain under-studied and not well substantiated [11]. In general, after scraping through the literature, it can be deducted that health-related ecosystem services are especially difficult to quantify, as physical and mental well-being depends on a multitude of factors including but not limited to socio-economic status, geographical context, and age. Hence, controlling all variables is not possible, and further studies are needed to establish clear links between high-diversity UGS and public health benefits.

Flood protection

Impervious surfaces that replace natural surfaces in the process of urbanization have a limited capacity to manage groundwater, runoff from precipitation, the flooding of water bodies, and storm surges. UGS have the capacity to store water in the soil, aided by the underground structure of vegetation that helps the water infiltrate deeper, and to disperse and direct runoffs, thus serving as major drivers of mitigating flood risk [32], [33].

Studies in urban flood risk prevention have shown impressive result, such as UGS equivalent to 1% of the city's runoff area may lead to a prevention of 30-50% of sewer and river floods in an up to 100-year period [34]. However, the applicability of these metrics to Aalborg specifically is uncertain.

Food production

Edible fruits, berries, and other consumable goods in UGS may contribute to food availability and pleasant nature experiences [4].

Recreation

UGS provide space and opportunities for residents to engage in outdoor activities with various activity levels. From running, biking, or engaging in group sports, to walking with friends or pets, to having a picnic, or to just sitting outside and enjoying the environment there are plenty of opportunities for everyone. A combination of feature, vegetation types, and landscape elements increase the possibilities of recreation, thus improve the recreational value of the UGS [6].

Aesthetic values

The aesthetic value of UGS is a socio-cultural value related to the perception of the urban landscape and the attractiveness of its features. As such, it is a highly subjective and dynamically changing ES that depends on geographical, generational, and individual standards and conventions of beauty and unpleasantness. This variety in interpreting what an aesthetically valuable UGS is makes it impossible to quantify or objectively judge. However, when aesthetic values are considered and acted towards by planners and citizens, a higher sense of attachment to and personal responsibility for the local environment can be induced [10].

3. Results and discussion

3.1. Management strategy and goals of the municipality

The reviewed planning documents show an established strategic vision regarding UGS in the context of Aalborg's sustainable development. Aside from general goals and commitments regarding the extent and management of green spaces, the city has also formulated ES-specific objectives.

Planning Strategy

The condensed Planning Strategy does establish blue and green infrastructure as a central planning priority in the ongoing strategic planning cycle, however, it has very few planning objectives or action items that relate specifically to UGS. Even less, that relate specifically to individual ES, other than broad statements about the presence of green infrastructure being beneficial to residents. The explicit references to ES were made to health- and well-being, aesthetic value, and conservation, the latter translated to biodiversity as it is focused on the protection of species. The tangible planning objectives related to these ES were increasing tree coverage in the city; improving the connection between UGS and mobility networks; and creating green corridors.

The Strategy has also outlined privately managed green spaces as platforms and enablers to the 'green goals'. This is an important notice, as the role of residential and commercial green spaces has great potential in maximizing the value provided by ES, if they are intentionally complementing the public green space network.

World Goal Strategy

Among these, the "World Goal Strategy" is a framework set to complement the existing planning strategies in order to cover more of the 17 SDGs in the form of locally applicable objectives. The document has been adopted by the city council in 2021 and is structured into four main focal areas: climate, resources, inequality, and biodiversity. Of the four areas, only the biodiversity-chapter contains explicit references to ES.

Although mostly discussing rural environments in the broader municipality, the chapter stresses the importance of expanding and improving green spaces within the city to provide "benefits of people and nature", but remains vague about what exact benefits there are to be gained from UGS. It mentions health and well-being as direct benefits from improving the accessibility of UGS to citizens. Indirectly, there is also reference to the lack of education regarding the importance of diverse nature within the city and sets a goal of raising awareness.

The implementation of the World Goal Strategy remains somewhat aspirational, as it is not a binding framework of action, but rather a high-level vision that is meant to inform decision making going forward. The strategy established the cross-municipal Climate and Sustainability Group, that is tasked with ensuring the SDGs and the prioritized planning principles become a part of the planning discourse and policymaking process.

Rich Nature in Aalborg

This strategy, adopted in 2017 singles out biodiversity as an urgent problem area, and its nurturing as a planning priority in Aalborg municipality. The scope of the Rich Nature strategy covers a range of geographical areas and a variety of land management schemes. As public urban green spaces are highlighted as one of the focal areas of the strategic vision, this document is highly relevant to the study of ES-based UGS planning in the city.

Although Rich Nature primarily deals with biodiversity, it considers the synergies between related ES, such as food and medicine production, natural resources, protection against flooding and extreme weather events, thermal regulation, air and soil quality management, CSS, as well as health-related and aesthetic benefits.

Beyond justifying the protection of biological diversity from a valuation perspective, Rich Nature takes a step further, and raises a(n unanswered) question about mankind's moral responsibility over the destruction of other species, regardless of whether or not they hold value to people. The awareness and caring of the citizens is identified as an important factor in achieving these goals.

The Rich Nature strategy provides an extensive list of planning objectives. These are categorized, based on their relevance to different types of urban green habitats, into nine areas, including: parks and recreational areas, old trees, residential and commercial properties, incidental green spaces, ports, and various water-based habitats. The strategy also covers waterways, mines, agricultural areas, protected areas, forests, and summer houses in the context of the wider municipality, however, these are not highly relevant to the UGS analysis.

For each designation, the ecological value of the habitat, challenges hindering progress, and a set of proposed goals and objectives is included.

The strategy identifies aesthetic preferences, zoning regulations, lack of awareness, continued urban development, fragmentation, and pollution as major challenges of preserving biodiversity. According to the document, urban and urban-adjacent waterways are polluted by agriculture and industrial activity, roads and infrastructural elements fragment green areas and prevent species from migrating between them, while new developments and construction destroys incidental green spaces. Additionally, the extensive holiday home-zones are encouraging a sprawl of intensively managed plots, taking up space from many plant and animal species.

Under Open Sky

This document outlines the policy guidelines applicable to nature, parks, and outdoor life in the Vision 2025 framework. It is structured into the four main pillars of accessible nature, rich and diverse nature, communication and education, and collaboration to achieve these goals. It has a great focus on the connection between people and nature, both in- and outside of the city limits. It explicitly refers to several ES in the context of UGS, such as recreational benefits, biodiversity, health and well-being, and aesthetic value.

While some of the goals are vague and generic, Under Open Sky contains some specific measurable metric targets regarding UGS accessibility (see in Table X). These are metrics that can be discussed in conjunction to the conducted GSI analysis of Vestbyen's green spaces.

The strategy identifies communication and education as both a challenge and a driver of progress of the vision. The authors acknowledge that they have a responsibility to the citizens and their wishes, and that those wishes sometimes are in conflict with the previously stated goals. For example, citizens may prefer traditionally managed lawns and flower beds instead of diverse green landscapes. The municipality hence considers it crucial to communicate their approach, and to raise awareness of the importance of nature in cities, especially to children.

Collaboration is also noted as an essential tool to achieve progress. By working with multiple stakeholders, volunteers, and citizens, the municipality hopes to build a sense of ownership and sense of community, and to capture the urban residents who are not yet involved with the UGS around them.

The ES-related planning objectives that apply specifically to the urban areas and residents of Aalborg city are collected in Table 5.

Ecosystem service	Planning objective	Specific goals or targets	Planning document
Health and well-being	*Improve the accessibility of nature to citizens living in Aalborg*	*n.s.*	*Rich Nature*
		n.s.	*World Goal Strategy*
		• *Max. 300 m distance to 1 ha UGS* • *Max. 500 m distance to 5 ha UGS*	*Under Open Sky*

		• *Create connectedness within the green spaces and other aspects of city life, such as pedestrian pathways and public transit*	*Planning Strategy*
Biodiversity	*Improve communication*	*n.s.*	*World Goal Strategy*
		• *Convey the importance of biodiversity*	*Rich Nature*
		• *Encourage people to become "crazy about Aalborg"*	*Rich Nature*
		• *Compile a database of "naturinteresser"*	*Planning Strategy*
		• *Publicize information about the UGS management strategies, esp. lighthouse projects*	*Under Open Sky*
		• *High visibility projects, such as bird boxes, bat boxes and insect hotels*	*Rich Nature*
		• *Educate children about the importance of nature*	*Under Open Sky*
	Protecting endangered species	*n.s.*	*Rich Nature*
	Protect and conserve existing green spaces	• *Employ diversity-friendly management strategies, such as less mowing composting, less fertilizers and pesticides*	*Rich Nature*
		• *Preserve old trees and veteran trees*	*Rich Nature*
	Improve and increase high-quality urban habitats	• *Minimize sealed surfaces*	*Rich Nature*
		• *Create a variety of habitats (dry, wet, multi-level), piles for insects and birds, bird boxes*	*Rich Nature*
		• *3% incr. of trees every 5 years* • *Focus on species richness*	*Under Open Sky*
		• *Plant trees with consideration to species diversity, woody mass*	*Rich Nature*
		• *Ensure "a lot of" greenery in new urban development*	*Under Open Sky*

		• *Support waterways with green banks*	*Rich Nature*
	Support native species	• *Cultivate native vegetation*	*Rich Nature*
Food production	*Cultivate urban vegetation that provides food*	• *Plant trees with edible berries and fruits for humans*	*Rich Nature*
Thermal regulation	*n.s.*		*Rich Nature*
Natural resource management	*n.s.*		*Rich Nature*
Flood protection	*Protect the city from flooding*	• *Use roadside vegetation to help with water management*	*Rich Nature*
CSS	*n.s.*		*Rich Nature*
Recreation	*Provide more access to green recreation*	• *Improve and expand urban and rural green recreational network*	*Under Open Sky*
		• *Connect schools and institutions to green recreational areas*	*Under Open Sky*
		• *Collaborate with landowners*	*Under Open Sky*
	Provide more space for green recreation	• *Clean up and open residual green spaces for recreation*	*Rich Nature*
Aesthetic values	*Create a more attractive urban landscape*	• *Plant more trees in the city*	*Planning Strategy*
		• *Less frequent mowing of roadside vegetation; min. height 10 cm*	*Rich Nature*

Table 5: Planning objectives from the analyzed documents categorized by which ES they aspire to benefit from. Only planning objectives directly related to UGS are included.
n.s. (not specified): the ES is explicitly referred to in the document, but no concrete goal, target, or tool has been included

3.2. Green spaces in Aalborg

The GIS analysis focused on one of Aalborg's smaller districts, Vestbyen. Vestbyen lies on the Southern shore of the Limfjord, neighbouring the Midtby, Mølholm, Hasseris, and Hobrovejkvaretert districts, as shown on Figure 1:

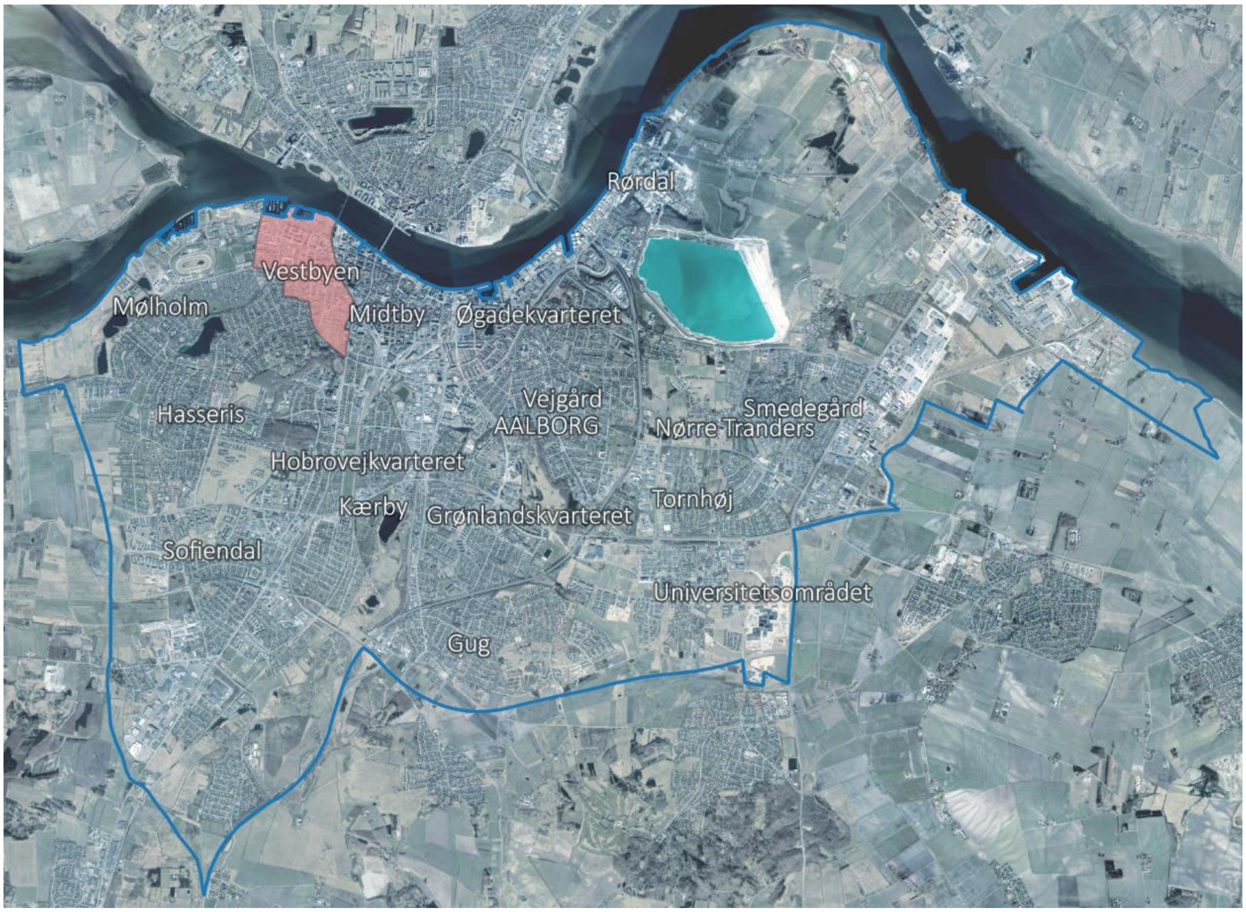


Figure 1: The location of Vestbyen within the city

The CUGIC classification yielded two separate map layers, one containing the LULC designations (Figure 2.1.), one containing the vegetation information (Figure 2.2.).

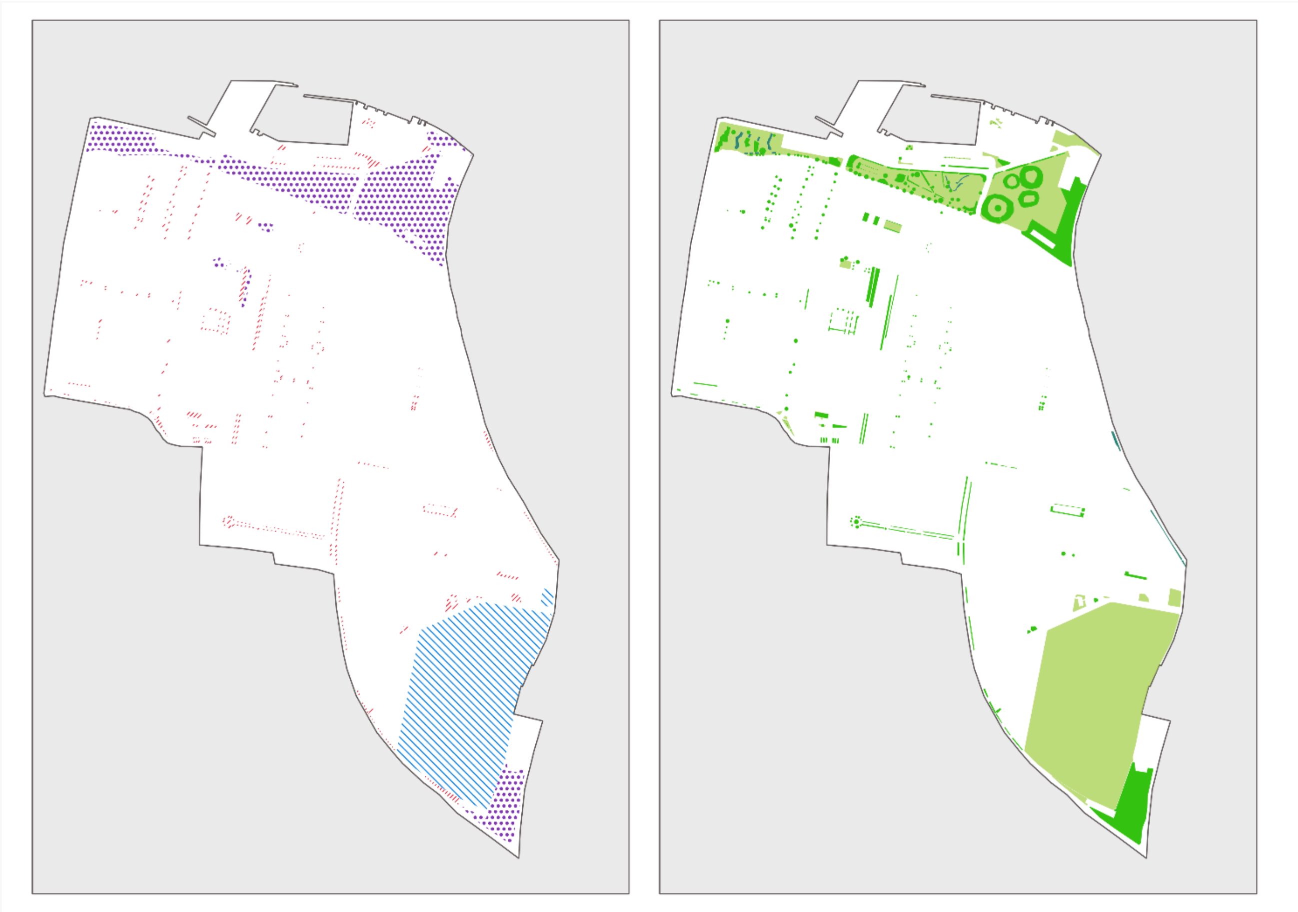


Figure 2.1 (left) LULC Vestbyen
Figure 2.2 (right) Vegetation Vestbyen

The LULC analysis revealed that the three main UGS categories are parks, green buffer zones, and cemeteries. Only the relevant UGS are shown on the maps, excluding other land use designations such as residential spaces, semi-private, commercial and retail spaces, and other non-green infrastructure.

Important to note that there are a number of other green spaces in the district, for example yards and gardens, hedges next to the pavements on privately owned property, sports fields belonging to schools or other institutions, and green spaces between apartment blocs that are primarily serving the residents of those specific blocs. Because these are not universally accessible by the public, they are not considered to fall within the scope of UGS for the purposes of the present study, but their potential ES contributions may be discussed in Section 3.

The Vegetation layer includes a triple classification according to the modified CUGIC methodology: either grass, shrub, and tree coverage as the main vegetation type;

single-layered or multi-layered as a the structural complexity; and low, low-medium, medium-high, or high as the diversity.

Overlapping the LULC and the Vegetation layers create the complete visual CUGIC classification (Figure 3).

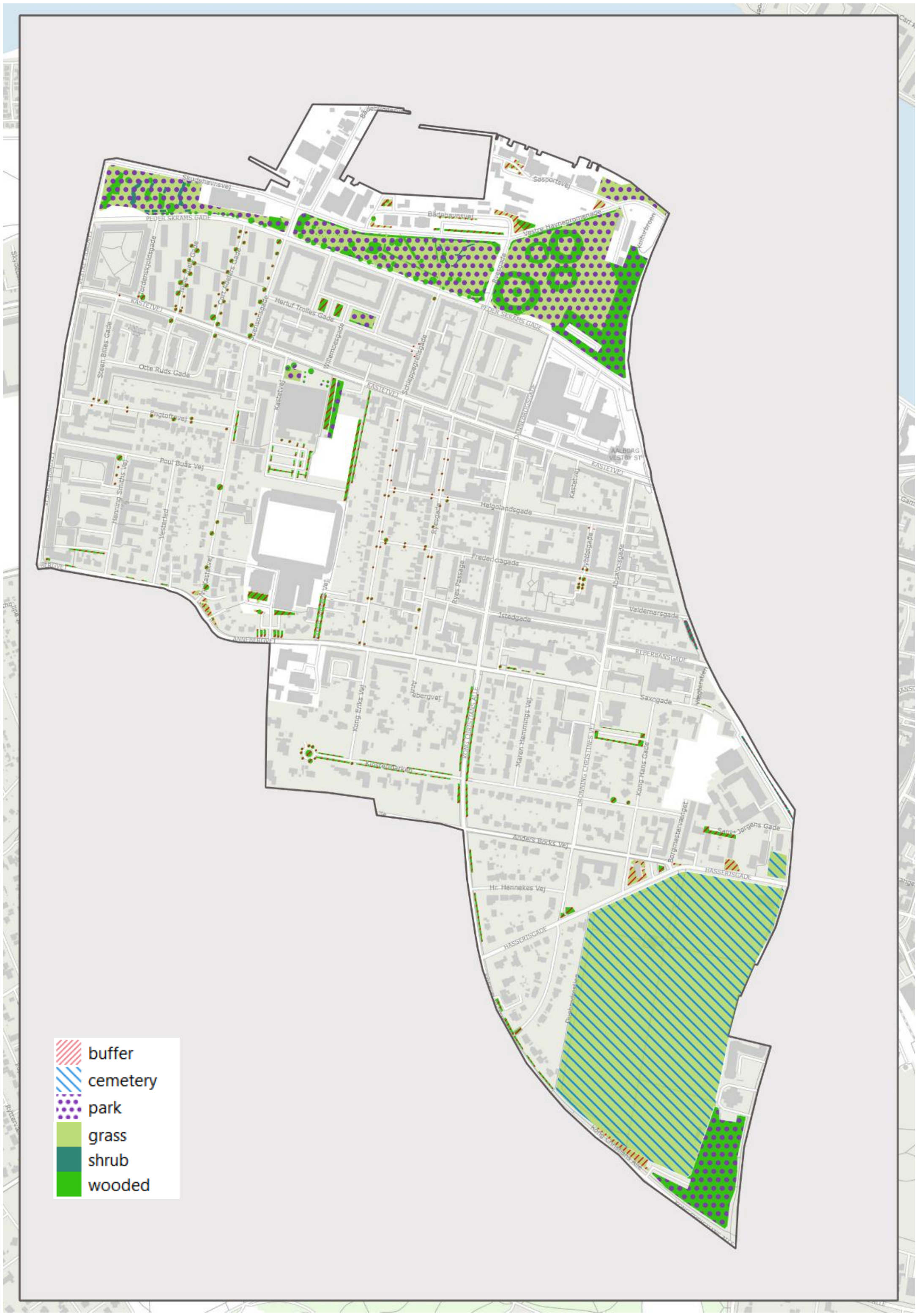


Figure 3: CUGICclassification

The total area of Vestbyen is 1.3 km^2, and it consists mainly of residential and retail zoning areas. The designated UGS, including the large cemetery in the south-eastern corner of the district, take up of the total 18.4 % of the area.

The cemetery is somewhat of an outlier within the collective of all public green spaces. It is by far the largest green area with 12.6 ha. For comparison, the next largest UGS is only 4.1 ha. It can be used as a park or green recreational area, but it has a number of conventional management practice, such as the maintenance of paths, parcels, turfs, and decorative landscape element. This set structure does not necessarily allow ES to be of significant consideration. Since the present study focuses on how ES frameworks can contribute to UGS planning, including the cemetery in the assessments and comparisons does not always make sense, and excluding it yields significant differences to the characteristics of the UGS landscape.

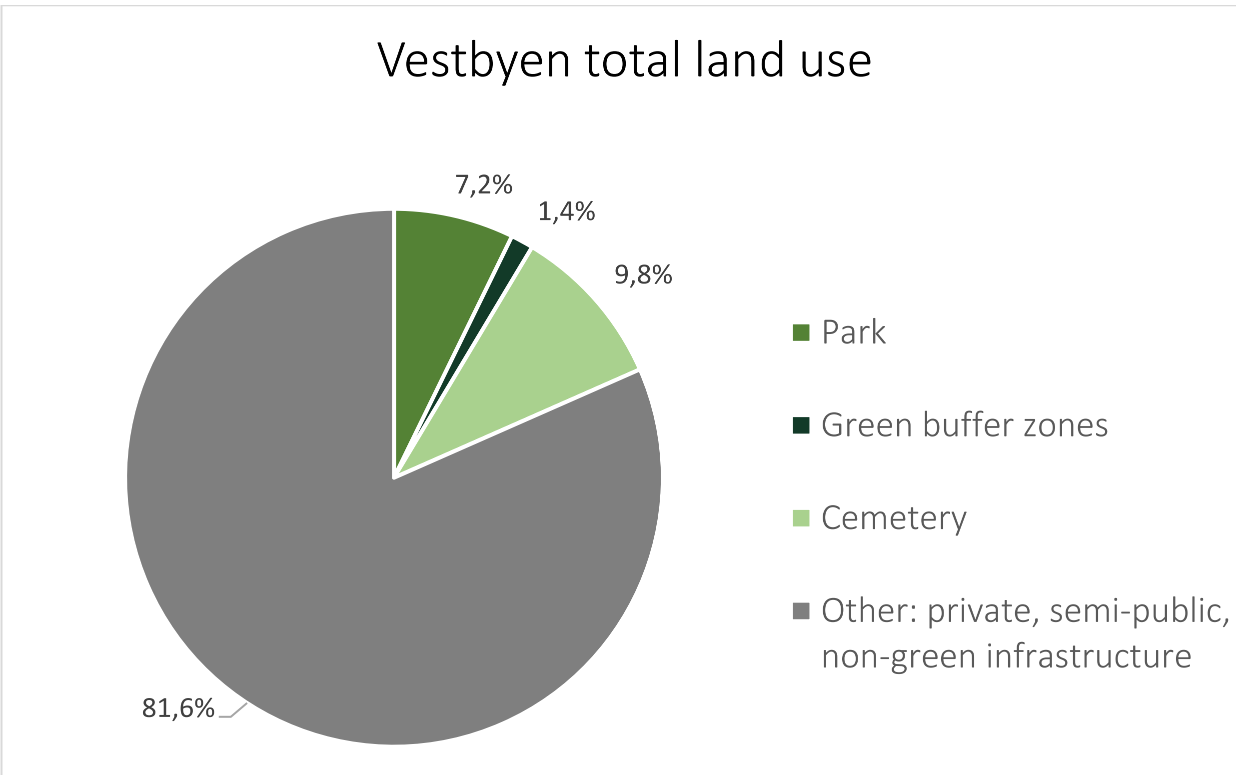
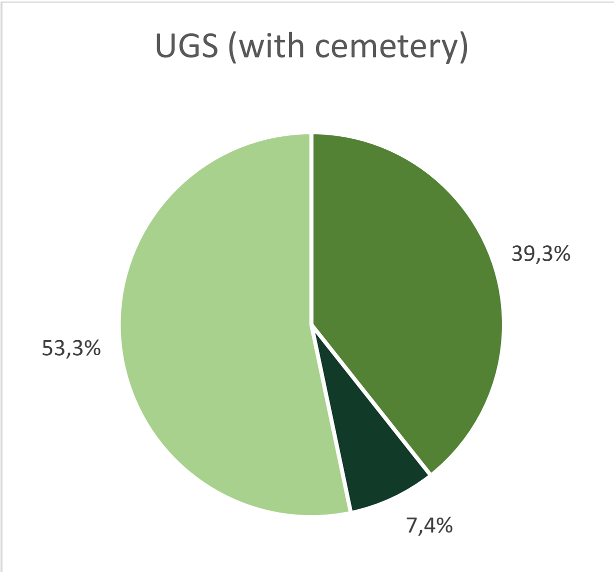


Figure 4.1 (above): Land use designations in Vestbyen
Figure 4.2 (below left): UGS share by designation (w/ cemetery)
Figure 4.3 (below right): UGS share by designation (w/o cemetery)



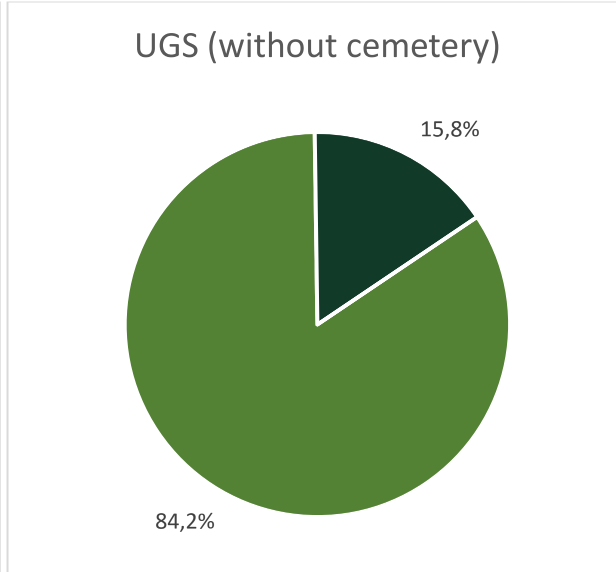


Figure 4.1-4.3. shows that the cemetery accounts for more than half of the UGS. Without it, the share of green spaces drops to just 8.56% of Vestbyen, to a total area of 11.1 ha. The composition of this remaining UGS is dominated by a few parks of various sizes, the largest four ranging from 1.3 ha to 4.1 ha.

One of these larger parks, a forested area is located in the southernmost tip of the district, while the rest of the larger than 1 ha UGS are concentrated in the North, close to the Limfjord. This leaves the middle section of the district without any UGS of a significant extent. This middle region is peppered with small parks, and green buffer zones, which are small patches of vegetation along roads, buildings, and parking lots.

The CUGIC assessment reveals the main characteristics of the existing UGS in the Vestbyen area.

Most, a little more than 70% of the wooded areas are multi-layered, meaning that they are either planted together with bushes, or have significant undergrowth. These multi-layered wooded areas are mainly located in the two forested areas, and in the parks nearby the fjord. The remainder, single-layered wooded areas are found in green buffer areas, where they often are standing alone, with only grass or sealed surfaces on the ground level. There are a few instances of multi-level wooded vegetation in buffer zones as well, as shown on Figure 5 below.

Wooded vegetation occupies all four levels of diversity, with roughly half of the areas falling into the low/low-medium, and half into the medium-high/high diversity ends of the spectrum.

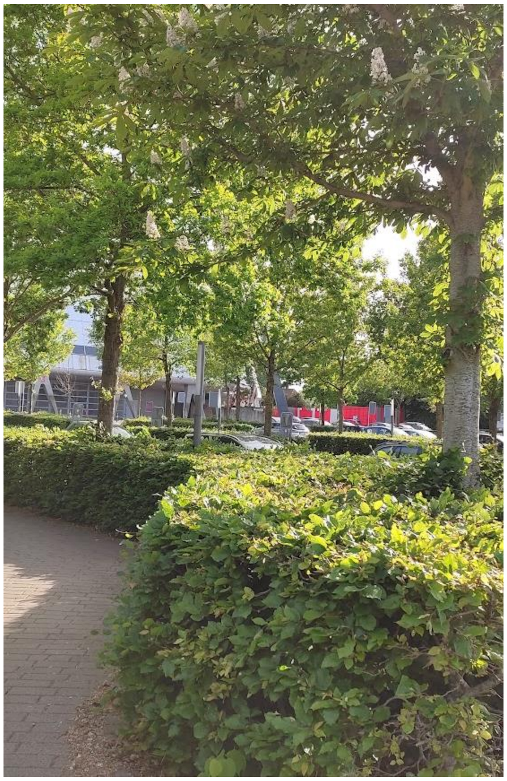


Figure 5 (left): Multi-layered wooded green buffer zone
Figure 6 (right): Single-layered wooded buffer zone

Shrub-covered areas were only observed with significant undergrowth or in conjunction with planted diversity, hence no single-layered shrub coverage was recorded. Shrubs primarily occur at the edges of parks, and in buffer areas. Shrub coverage is the least prominent vegetation type, accounting for less than 2% of the total UGS.

Grass coverage is always single-layered, and almost always on the low/low-medium end of the diversity spectrum, as all grass areas were observed to be mostly uniform, with sometimes flowering plants present, but with signs of regular moving and low growth levels.

Figure 7: Single-layered grass coverage by the fjord

In total, the spatial analysis showed that, not considering the cemetery, grass-covered and wooded vegetation account for 98% of all UGS in almost equal halves, with slightly more grass-covered areas recorded.

The majority, about two-thirds of the non-cemetery UGS are single-layered and low-diversity, and less than 10% of the UGS was categorized as high level of diversity.


Figure 8: Single layered wooded park in the foreground, multi-layered wooded buffer in the background

3.3. Themes, trends and priorities in the strategic vision

Taking a deeper look at the results presented in Section 3.1. about the reviewed municipal planning strategies can reveal a lot of information about how integral – or not – ES are to UGS planning in Aalborg.

Aalborg city is home to over 60% of the municipality's residents. Although the municipality has a number of natural reserves outside of the city limits, supplying the urban residents with high-quality UGS is to the benefit of the majority of the population. This is reflected by the high level of attention to ES in the UGS planning framework.

The compiled list of ES-related planning objectives and goals show that in the overall strategic vision a wide range of ES are represented in some way. Biodiversity dominates the list with fifteen specific goals or targets, and seventeen total items identified. The next two most commonly addressed ES are health- and wellbeing and recreation with three and four goals respectively. Food production, flood protection, and aesthetic values also have been addressed with at least one specific objective. Of course, the process of extracting these items included the categorization and aggregation of content from the documents, so these numbers are only valid in reference to the list in Table X.

These trends show that biodiversity is the most important ES from the perspective of the local government. Biodiversity is the only ES in the list that provides value to the human population in an indirect path, as it serves the natural ecosystem first, which then provides benefits to people through a variety of mechanisms.

This focus on biodiversity is important, because when coupled with the sentiment expressed in the Rich Nature regarding a moral obligation to take care of nature, it demonstrates the municipalities intention to use UGS not only to the benefit of the resident, but also to the non-human components of the urban ecosystem. While residents have social and political frameworks to express their wishes and opinions on their cities, urban nature, animals, trees, and other non-human ingredients do not have a voice in planning and policy unless they are represented by people.

Of course, the main goal of the municipality is still to serve the interests and wishes of their citizens. A common theme in the documents is the objective of improving communication about the values of diverse urban nature. All four documents included at least a clearly stated desire to educate Aalborg residents about native species, urban habitats, and the green space management practices employed in the city, often describing the pathways in which the improvement of nature will eventually lead to an improvement in the quality of life of people.

The planning documents highlight several intentions for these communication-related goals. In Under Open Sky, general awareness about green recreational sites and activities hope to encourage more people to use these places, and the education of children aims to nurture a generation of citizens that understand the value of urban nature [13]. Rich Nature sets communication-related goals in order to challenge people about their perceptions of low-diversity lawns and parks as "tidy" and orderly", and instead show the value in "messy" landscapes, thus fostering love and acceptance towards biodiversity-friendly initiatives [18]. The Planning Strategy's approach is more focused on knowledge creation by compiling data about urban nature and environmental initiatives [16].

The other prominent ES, such as health- and wellbeing, recreation, and aesthetic values benefit people in a more direct manner. Health and wellbeing and recreation are very closely related to each other, and they are both addressed by different strategies to enable and encourage people to experience the UGS available to them. Infrastructure developments such as the connecting of green networks, and improving mobility from transportation and pedestrian pathways to green infrastructure are believed to generate value in terms of these ecosystem services.

The aesthetic values are also closely linked to wellbeing, as both the Planning Strategy and Rich Nature consider an attractive urban landscape a way of improving the overall experience of living in Aalborg. While planting trees seems like a standard practice and have many demonstrated benefits, Rich Nature includes an interesting proposal regarding the roadside vegetation. In brief, it proposes to decrease the frequency of mowing such peripheral habitats, and keeping a minimum length of 10 cm of vegetation to encourage the growth of many species, providing a meadow-y look. This would of course obviously benefit biodiversity and also create value in terms of water runoff management, however, a common perception according to the same document is that citizens might consider these areas messy and unattractive. So in order to really add aesthetic value, perceptions of attractive green spaces must be challenged.

Education and communication are powerful allies to the environmental cause. Encouraging discourse about locally applicable problems and solutions is especially important in fostering collective understanding, a sense of belonging, and a feeling that individuals or communities can make a positive impact [35]. This can likely apply to ES in the urban context as well.

Thermal regulation, natural resource management, and CSS are mentioned, yet not actively pursued in the analyzed strategies. These services, however, are crucial for a city like Aalborg whose location on the waterfront makes it susceptible for future see-level rise and increased storm surge events, and whose high latitude makes it particularly vulnerable to future heat wave damage [28].

The synergies between ES ensure that these specific services will not be completely missing from the UGS landscape, however, the lack of addressing them directly is a serious shortcoming of the planning from the perspective of this study. By excluding them from the actionable objectives, their value is less apparent and less accounted for compared to the other ES. Since the public strategies hope to not only describe the approach, but also inform and educate the audience, there is a missing opportunity in conveying how UGS planning and management can provide values in terms of resilience against projected heatwaves, improving air and water quality, and mitigating the CO2 emissions of Aalborg.

Looking forward, filling these gaps could help to assign more value to UGS, potentially increasing the support and capacity to allocate more resources to related planning projects.

Let us not forget, however, that these plans are just that: plans, without evidence of implementation. This next section, therefore, will discuss whether the spatial analysis of the UGS in Vestbyen city shows an alignment between the aforementioned strategies and the current state of the UGS in the district. While there is a limitation to which certain goals can be assessed on such a small scale, there is still value in discussing the opportunities in how spatial analysis and the detailed classification of UGS can inform urban planning.

3.4. Evaluation of the ecosystem services

The spatial analysis in Section 3.2. allows for a critical analysis of how successful the existing UGS in Vestbyen are when compared to the ambitious ES targets of the reviewed plans. The generated CUGIC data also serves as basis for discussing what kind of ES are dominant in the district, and if there are any ES that are currently underperforming. Some ES, such as flood protection, food production, and aesthetic values were not discussed due to insufficient data.

Biodiversity

The low levels of observed diversity and structural complexity and the high level of fragmentation in the Vestbyen UGS landscape contradicts the ambitious biodiversity targets of the planning documents.

CSS:

Since the literature review for determining the carbon density of above-ground urban vegetation yielded such a wide range of estimates, an average value of those results, 19.35 kg C m^{-2} was used to estimate the carbon stored in the Vestbyen UGS. Since this method is not of high precision, this result should be viewed as a guiding metric to conceptualize the order of magnitude of CSS services provided. To get a more accurate measurement a focused ecological carbon dynamics modelling study would be necessary.

Accordingly, the over 56 thousand m^2 covered by trees and shrubs would account for the removal and storage of 1095 t of carbon from the atmosphere over a 50–100-year outlook. The soils of all UGS (cemetery included) could add up to 3697 t of carbon over the same period. The above and underground CSS of the current UGS configuration of the district is therefore somewhere in the magnitude of 5000 t of carbon.

Taking this estimation a step further, dividing the 5000 t with the total area of Vestbyen yields the carbon density of UGS in the district as 3.7 kg C m^{-2}. If UGS configuration is similar across the city, then Aalborg's UGS would sequester and store some 300000 t of carbon until the late century. In comparison, the average Dane emits 6.65 t of CO_2 (about 1.8t carbon) every year [36].

While these numbers are far from exact measurements, they demonstrate the limitations of CSS in cities.

Thermal regulation

The presence of five UGS features with an area of at least the 0.69 ha efficiency threshold stated in the relevant paragraph of Section 2.3, optimal efficiency of cooling can be expected in the near vicinity of those spaces. However, since the cooling effect is only expected to extend ~150 m from the UGS, the middle section of the district with no large enough areas are not likely to benefit from this ES, even if the tree canopy across the district's buffer zones is likely to provide shade and some level of cooling effects.

Additionally, the thermal regulation effect of the UGS near the Limfjord is possibly compromised by the large body of water, and therefore accurate valuation could only be conducted via site-specific measurements of the intensity and spatial extent of thermal regulation.

Health and well-being

The main target addressing this ES was the access to UGS. Figure 9 depicts a 300-meter-wide buffer zone around the green areas with at least 1 ha area.

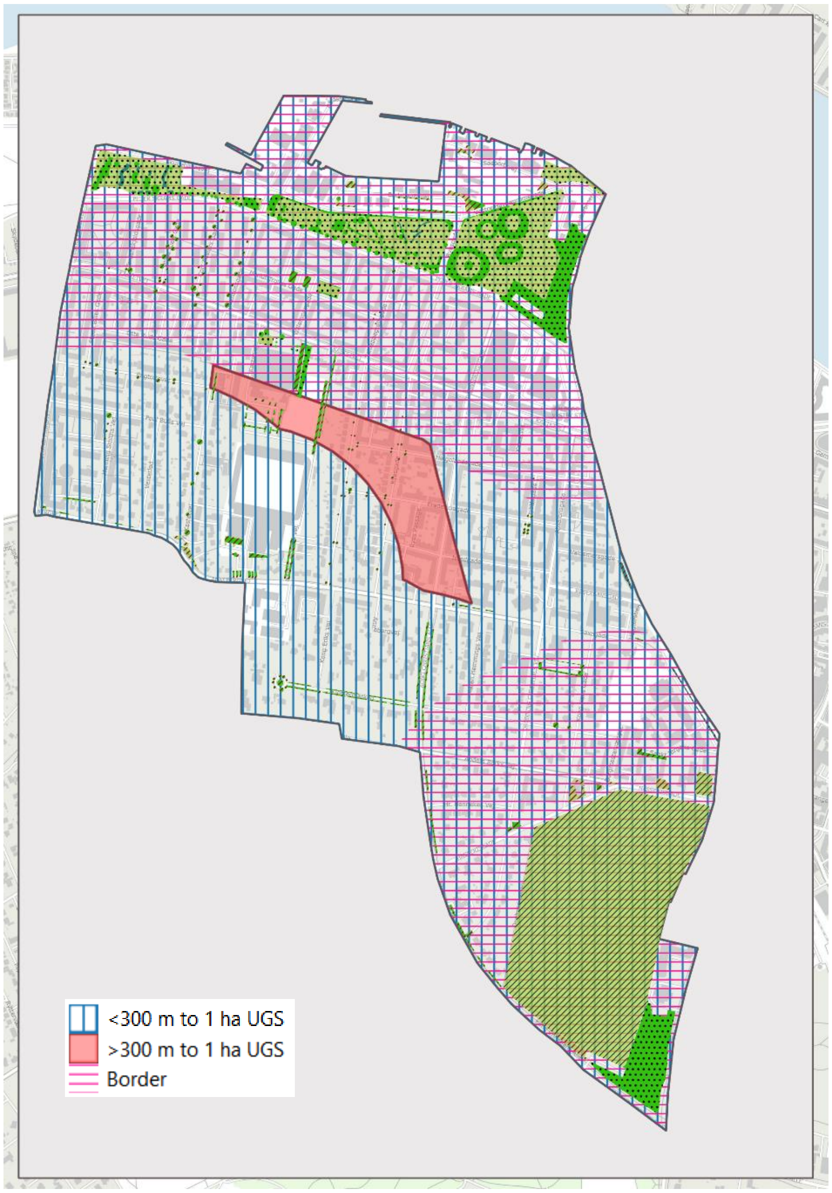


Figure 9: Distance to 1+ ha UGS

As a municipal goal is to have at least one, minimum 1 ha large green space within a distance of 300 meters from residential areas, this map shows the parts of Vestbyen that are sufficiently served by green spaces, as well as the ones that are at the moment underserved by the available UGS. The map also includes a 300-meter-wide zone from the edges of the neighboring municipalities. The areas within this peripheral buffer zone that do not overlap with the areas served by the Vestbyen-UGS are potentially underserved, however, without assessing whether there is a 1 ha UGS within the targeted range outside of the district borders no conclusion can be drawn. Although, even if these peripheral areas are served by UGS in adjacent districts, there is a central part of Vestbyen, colored red on Figure 9, that is underserved by any applicable green space.

For the second similar target, the access of a minimum 5 ha UGS withing 500 meter distance from the residence, similar results can be found. The only applicable UGS is the cemetery, and its 500 meter buffer zone covers less than half of the municipality, leaving a significant portion of Vestbyen underserved by both the smaller and the larger UGS. However, since there is no point of the district that is more than 500 meters away from the district border, this analysis does not produce meaningful results without also analyzing green spaces in the adjacent districts.

Recreation

While the parks in the northern area of the district are close to each other and are connected by pedestrian and bike infrastructure, the are to a significant distance to the larger UGS in the southern half of Vestbyen. The UGS in-between is fragmented and consists mainly of buffer areas not offering any opportunities for recreation, therefore there is no established green recreation network, nor the benefits expected of such a network present.

3.5. Tools and considerations for planners

The in-depth study of how ES are accounted for, performing, and incorporated into the planning strategies revealed a lot of information about how planners can effectively use ES frameworks to plan UGS that provide valuable benefits to people and nature. Based on the analysis we can deduct learnings about the strengths and weaknesses of ES—based planning, some challenges, and important considerations that must be kept in mind when planning UGS.

Temporal and spatial dimensions of change

When thinking about the extent and value of ecosystem services, the specificity of the urban environment must be considered. Depending on a variety of factors, such as location, climate, and temporal changes, the same ecosystem might perform different functions and provide different services in two distinct scenarios. Furthermore, even the same performed function might be of different value in different settings.

For instance, urban vegetation might perform similar functions of thermal regulation in different climates: providing shade and influencing air flow. The benefits, and hence value of these services, however, differ vastly in different localities. Thermal regulation is of high-value in urban communities vulnerable to extended exposure to sunlight and high temperatures. Referred to as heat island mitigation, this thermal regulation can relieve heat-related stress on the urban population and thus the healthcare system, mitigate damage to infrastructure, and save energy and money by reducing the need for cooling.

If we observe the same ES in the specific case of Aalborg, the valuation looks completely different. Located in the Northern part of Denmark, Aalborg is not exposed to as much sunlight year-round, although it is becoming more and more vulnerable to heat stress[5] in the coming decades [37]. Generally, every ray of sunshine is welcomed on the streets, in parks, and through windows, especially in the darker months of the year. Thermal regulation through increased shade, therefore, may even be considered a negative impact. A forward-looking climate resilience agenda and UGS management strategy, however, should account for the future value of ecosystem services such as thermal regulation. Right now, it may not be a pressing issue, but when the urban heat island effects increase in the future, it might be too late to start planting more trees along pathways and parks.

Consequently, it is not only the spatial scale that makes assigning value to these ES, but also the temporal. Urban ecosystems are not at rest, and climate change, as its name suggests, is not a state but a process. Both the human and environmental components of UGS in Aalborg are expected to go through significant changes in the coming decades. For instance, over a 50-year outlook, average temperatures are projected to increase by as much as 2.6 ℃, average daily rainfall by up to 14.3 %, and population is also expected to keep increasing [37].

In these dynamic systems, the value of ES are changing alongside these other factors. At the same time, certain ES, such as biodiversity and CSS need time to mature and reach the ideal or desired effectiveness. It is a mighty challenge to try and solve tomorrow's problems today, but planners must think in these extended time-frames to ensure that the UGS in their cities are addressing the needs of their constituents.

Trade-offs and synergies

ES services do not exist in isolation. As thermal regulation affects health benefits, biodiversity impacts CSS, CSS is interlocked with the climate crisis itself, or aesthetic values influence the way we utilize the recreational functions of UGS, there are many pathways in which ES form synergies. This means that, from a planning perspective, every induces change, modified feature, added function may cause a multitude of consequences, often unexpected.

Synergies and interactions are not always positive. The cooling effect of thermal regulation for example can lead to increased heating demand and thus higher energy use in the winter; high-diversity green spaces can be seen as unsightly and unattractive, and they can accumulate trash; inviting wildlife and insects into the urban ecosystem can

[5] A heat wave is defined as three or more consecutive days with a maximum daily temperature of 28 ℃ or higher. In Aalborg, the median amount of annual heat wave days is predicted to be 15 by the mid century, and 17 by the end of the scenario under RCP4.5. Under RCP85, the median predictions are 17 by the mid-century, and 28 by the end of the century.

lead to nuisance such as loud birds and organic waste around the town[6], aggravate allergies, or spread diseases; and old trees can damage infrastructure with their roots [4].

Similarly to the positive impacts, trade-offs can also be difficult to foresee and mitigate in tie. Hence a level of flexibility and the readiness to react is necessary to keep the changes under control.

Acquiring and analyzing data

Ecosystem-based planning and evaluation requires a high resolution of data regarding the attributes of UGS. Depending on the location and the management practices, generally limited, or no data at all is available about the composition and species diversity of parks or other green spaces. Similarly, municipal maps do not necessarily provide a differentiation between green and other spaces within the residential, commercial, industrial, or similar zoning areas.

Of course, data can be acquired from multiple sources and schemes. Some planning departments may have dedicated in-house teams, while some outsource data generation and mapping tasks to private companies or researchers when in-house expertise or capacity is lacking. In Aalborg for example, only in 2017 were the municipal plans digitized on DKplan, undertook by NIRAS [38]. Non-government affiliated researchers and scholars may also contribute to the expansion of the data pool through research projects and reports, such as the present study. Citizen science is another avenue through which finer-scale data can be generated: interested urban dwellers can mark sports and designations, updating incorrect or outdated information, thus contributing with their experience and taking ownership over their living space[7], [39].

This study suggests that it is beneficial to establish a multi-scale assessment framework specific to the considered location. As demonstrated in the UGS analysis of the previous section, this may be accomplished by taking an existing classification framework, such as the CUGIC, and tailoring it to suit the specific conditions of the site. Although this process might be labor intensive, it leads to a database that describes the UGS in high detail, enabling planners to use it as a guide for decision making.

Residential and commercial green spaces in the city

Residential green spaces should not go underappreciated, as they can also play an important role in the urban ecosystem, especially if they are managed in a complementing manner to the public green spaces. Gardens and yards, while not

[6] Just like in Aalborg, where, anecdotally, the seagulls are undesired co-habitants of many apartment blocks

managed directly by the municipality, can become valuable assets within the city-wide green network and account for a large portion of overall green spaces.

The Rich Nature and the Planning Strategy both include language that show initiative to encourage private and commercial stakeholders to align their green space management practices with the municipality's goals. The references to residential gardens and allotments establishes a desire and willingness from the government's side to collaborate with, and incentivize other stakeholders to improve the overall quality of UGS in Aalborg.

These private or semi-private habitats can create or expand green corridors when in the proximity of UGS, help migration pathways and support a larger population. They can also increase the city-wide capacity to provide habitats and food resources to pollinators and avian populations. Similarly, while the UGS in Vestbyen often does not reach the optimal size for thermal regulation, in conjunction with residential areas this might show a different picture, as larger and more complex green coverage may be achieved. A related research project by Goddard et al. suggests that in order for these benefits to be realized, the individual gardens must have a certain level of heterogeneity on the larger scale [21].

Therefore, a more detailed plan about how exactly these spaces can fit into the larger scheme of the city's green spaces is needed to realize the potential ES benefits.

Challenges of ecosystem-based UGS planning

Urban nature is difficult to compare to nature surrounding the cities. Because of the spatial limitations, the frequency and nature of visitation, the disturbances, and the fragmentation, UGS cannot be assessed with the same criteria as for example parks and natural reserves in the vicinity of the city limits.

The scope of planning must also be considered. Planning on the municipal scale may result in too high a level of strategy, without capacity to address the micro-scale of buffer zones, individual trees, roadside plantations and the variety of vegetation classes within parks. These smaller features can be better understood when approaching the topic from neighborhood- or district-level lenses. This approach has been taken during the present study.

While isolating the Vestbyen-area for analysis allowed to go into fine details regarding the UGSs, it must be acknowledged that narrowing the focus this way limits the researcher's ability to analyze the networks of UGS connected to the ones that fall within the neighborhood's borders. When these intra-municipal borders are established along man-made features, such as roads and railways, they don't account for the cross-border connections of green pathways and adjacent spaces. These larger networks of UGS can significantly increase the provided ES values, even though their study requires more data and hence research capacity.

The availability of data, capacity, and tools has a significant impact on the potential of ES-based planning. If fine-scale data is not available or accessible, the classification and GIS representation of the UGS is time consuming and labor intensive. Marking vegetation based on aerial maps and field surveys are available to planners in most locations, however, without easily selectable data points or GIS features, these processes can require significant amount of monotone work. Not all planning agencies have the resources to undertake this process. Of course, these workflows can be made more efficient by higher expertise in GIS software, programming, or other skills. Furthermore, cross-municipal sharing of resources, such as the case with the DKplan digitized planning platform, can also enable planners to share their expertise.

3.6. Limitations of the study

This thesis work cannot account for the full picture of UGS planning in Aalborg.

For one, the limited time frame of four months for such a study, in addition to the limited capacity and previous experience of the author, and the amount of data points that needed to be collected required the focus of the GIS component of the thesis to narrow down to a single district within the city. Given that the reviewed planning frameworks operate on a municipality, or whole city level, there are probably significant ES benefits that are not assessable on a district-scale, such as the extent of green corridors and the true access to UGS. However, the observations about the types and size of UGS are still providing valuable content for discussion.

Second, the thesis does not include reviews of regional, national, and EU-wide planning strategies that may have ES-related objectives in UGS planning.

Third, the author’s limited knowledge of Danish hindered and prolonged the process of obtaining maps and information. In a continued research project, it is recommended that someone with knowledge of the local language and urban planning frameworks is involved.

Fourth, ES can be defined, categorized, and studied in many different ways and frameworks. The ES considered in the study followed the language in the reviewed planning documents, and the author acknowledges that there are many other ecological benefits and synergies of UGS other than the nine classes discussed in this paper.

Another limitation to consider is the vast complexity and variability of the mechanisms driving the ES. As seen in the CSS-related calculations, for example, a simple review conducted as a sub-task of a four-month research project barely scratches the surface of the complex ecological science of calculating carbon budgets. This applies to all the other ES as well. This thesis does not claim to have exhausted the methods of assessing and valuing ES and their contribution to UGS.

4. Conclusion and further study

Ecosystem services are a key part of the strategic vision of Aalborg's UGS management. The implementation in Vestbyen district does not yet fully achieve all the goals and objectives set by the review planning documents, but a number of features and spaces are present that are in alignment with the plans. As the reviewed documents are recent from an urban planning perspective, all from the last six years, more time can be reasonably expected to achieve the goals set in the latest strategies. Additionally, certain goals and targets cannot be fully evaluated on the base of a single district.

As demonstrated in the case of Aalborg city, the concept of ecosystem services can be a valuable tool for multiple aspects of the UGS planning process from establishing planning priorities to setting goals and measuring progress. They can also provide a framework for the valuation of the benefits that urban nature provides, and a science-based narrative for support and justification.

ES may also assist planners to think ahead and address problems that change over time, such as climate conditions and population growth. Investing in ES within the city can improve the resilience of the community and its adaptation to climate change.

The most significant challenges related to ES as a central focus of planning can be a lack of awareness on both the sides of residents and decision-makers; the lack of technical expertise in the planning agency; the lack of capacity to carry out the additional assessments and analysis; the difficulty of anticipating all the synergies and trade-offs in the systems; and the fragmentation and the limited space available for nature in dense urban areas.

Enablers of ES-based planning include high-resolution data about the existing UGS; the growing literature on ES and their role in urban nature; the accelerating attention to climate change and the biodiversity crisis on the global level; and collaboration between municipal governments and private landowners. Utilizing a wide range of data sources and data processing technologies, such as GIS and the CUGIC classification framework, as well as the knowledge of planning experts and local residents can make the obtaining and processing of information more complete and efficient. Expanding the ES-based strategies to private and semi-private green spaces can multiply the available space, resources, and thus the benefits from ES in the city.

This study offers a starting point for a variety of directions in which further research can branch out. While working on this project, several ideas, necessities, and inspiration popped up that will hopefully one day be pursued, including (but not limited to):

- Expanding the spatial analysis to the whole city
- A comparison of Aalborg and other locations with different specific characteristics and opportunities

- A more in-depth investigation on how to optimize CSS and biodiversity performance
- An investigation of ES benefits and challenges in the kolonihaver
- An interview-based research about the attitudes of municipal planners towards ES in UGS planning

Thank you for taking the time to read my work.

5. Bibliography

[1] M. Ariluoma, J. Ottelin, R. Hautamäki, E. M. Tuhkanen, and M. Mänttäri, "Carbon sequestration and storage potential of urban green in residential yards: A case study from Helsinki," *Urban For Urban Green*, vol. 57, p. 126939, Jan. 2021, doi: 10.1016/J.UFUG.2020.126939.

[2] M. F. J. Aronson *et al.*, "Biodiversity in the city: key challenges for urban green space management," *Front Ecol Environ*, vol. 15, no. 4, pp. 189–196, May 2017, doi: 10.1002/FEE.1480.

[3] United Nations Environment Programme, "Becoming #GenerationRestoration: Ecosystem restoration for people, nature and climate," Nairobi, 2021. Accessed: May 16, 2023. [Online]. Available: http://www.un.org/Depts/Cartographic/

[4] C. Choi, P. Berry, and A. Smith, "The climate benefits, co-benefits, and trade-offs of green infrastructure: A systematic literature review," *J Environ Manage*, vol. 291, Aug. 2021, doi: 10.1016/J.JENVMAN.2021.112583.

[5] P. Dasgupta, "The Economics of Biodiversity: The Dasgupta Review," London, 2021.

[6] M. L. Derkzen, A. J. A. van Teeffelen, and P. H. Verburg, "REVIEW: Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands," *Journal of Applied Ecology*, vol. 52, no. 4, pp. 1020–1032, Aug. 2015, doi: 10.1111/1365-2664.12469.

[7] N. Frantzeskaki *et al.*, "Nature-based solutions for urban climate change adaptation: Linking science, policy, and practice communities for evidence-based decision-making," *Bioscience*, vol. 69, no. 6, pp. 455–466, Jun. 2019, doi: 10.1093/BIOSCI/BIZ042.

[8] UN Convention on Biological Diversity, "Kunming-Montreal Global biodiversity framework," Montreal, Dec. 2022. Accessed: May 17, 2023. [Online]. Available: https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf

[9] R. W. F. Cameron *et al.*, "The domestic garden – Its contribution to urban green infrastructure," *Urban For Urban Green*, vol. 11, no. 2, pp. 129–137, Jan. 2012, doi: 10.1016/J.UFUG.2012.01.002.

[10] M. Demuzere *et al.*, "Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure," *J Environ Manage*, vol. 146, pp. 107–115, Dec. 2014, doi: 10.1016/J.JENVMAN.2014.07.025.

[11] V. Jennings and O. Bamkole, "The relationship between social cohesion and urban green space: An avenue for health promotion," *Int J Environ Res Public Health*, vol. 16, no. 3, Jan. 2019, doi: 10.3390/IJERPH16030452.

[12] J. A. Belaire *et al.*, "Fine-scale monitoring and mapping of biodiversity and ecosystem services reveals multiple synergies and few tradeoffs in urban green

space management," *Science of The Total Environment*, vol. 849, p. 157801, Nov. 2022, doi: 10.1016/J.SCITOTENV.2022.157801.

[13] By- og Landskabsforvaltningen Park & Natur, "Under åben himmel - Politik for natur, parker og udeliv," Aalborg, 2018. Accessed: Mar. 08, 2023. [Online]. Available: https://www.aalborg.dk/politik/strategier-og-politikker/under-%C3%A5ben-himmel-politik-for-natur-parker-og-udeliv-vision-2025

[14] A. Kinnunen, I. Talvitie, J. Ottelin, J. Heinonen, and S. Junnila, "Carbon sequestration and storage potential of urban residential environment – A review," *Sustain Cities Soc*, vol. 84, p. 104027, Sep. 2022, doi: 10.1016/J.SCS.2022.104027.

[15] Department of Health and Sustainable Development, "Local Initiative for Sustainable Development - Sustainability Strategy 2008-11," Aalborg, Jun. 2008. Accessed: Mar. 08, 2023. [Online]. Available: https://www.yumpu.com/en/document/read/4458801/local-initiative-for-sustainable-development-aalborg-kommune

[16] Aalborg Kommune, "Planstrategi 2019," 2019. Accessed: May 27, 2023. [Online]. Available: https://aalborgkommune.viewer.dkplan.niras.dk/plan/18#/91083

[17] Aalborg Kommune, "Verdensmålsstrategi," *Aalborg Kommunes bidrag til en bæredygtig udvikling i det 21. århundrede*, 2021. https://www.aalborg.dk/om-kommunen/baeredygtig-kommune/verdensmaalsstrategi (accessed Jun. 02, 2023).

[18] Park og Natur, COWI for Aalborg Kommune, and By- og Landskabsforvaltningen, "Rig Natur i Aalborg Kommune - en strategi for biodiversitet," Aalborg, 2017.

[19] J. Morpurgo, R. P. Remme, and P. M. Van Bodegom, "CUGIC: The Consolidated Urban Green Infrastructure Classification for assessing ecosystem services and biodiversity," *Landsc Urban Plan*, vol. 234, p. 104726, Jun. 2023, doi: 10.1016/J.LANDURBPLAN.2023.104726.

[20] J. A. Belaire *et al.*, "Fine-scale monitoring and mapping of biodiversity and ecosystem services reveals multiple synergies and few tradeoffs in urban green space management," *Science of The Total Environment*, vol. 849, p. 157801, Nov. 2022, doi: 10.1016/J.SCITOTENV.2022.157801.

[21] M. A. Goddard, A. J. Dougill, and T. G. Benton, "Scaling up from gardens: biodiversity conservation in urban environments," *Trends Ecol Evol*, vol. 25, no. 2, pp. 90–98, Feb. 2010, doi: 10.1016/J.TREE.2009.07.016.

[22] J. Colding, "'Ecological land-use complementation' for building resilience in urban ecosystems," *Landsc Urban Plan*, vol. 81, no. 1–2, pp. 46–55, May 2007, doi: 10.1016/J.LANDURBPLAN.2006.10.016.

[23] Z. G. Davies, J. L. Edmondson, A. Heinemeyer, J. R. Leake, and K. J. Gaston, "Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale," *Journal of Applied Ecology*, vol. 48, no. 5, pp. 1125–1134, Oct. 2011, doi: 10.1111/J.1365-2664.2011.02021.X.

[24] L. Lindén, A. Riikonen, H. Setälä, and V. Yli-Pelkonen, "Quantifying carbon stocks in urban parks under cold climate conditions," *Urban For Urban Green*, vol. 49, p. 126633, Mar. 2020, doi: 10.1016/J.UFUG.2020.126633.
[25] H. M. Setälä, G. Francini, J. A. Allen, N. Hui, A. Jumpponen, and D. J. Kotze, "Vegetation type and age drive changes in soil properties, nitrogen, and carbon sequestration in urban parks under cold climate," *Front Ecol Evol*, vol. 4, no. AUG, p. 93, Aug. 2016, doi: 10.3389/FEVO.2016.00093/BIBTEX.
[26] J. L. Edmondson, Z. G. Davies, N. McHugh, K. J. Gaston, and J. R. Leake, "Organic carbon hidden in urban ecosystems," *Scientific Reports 2012 2:1*, vol. 2, no. 1, pp. 1–7, Dec. 2012, doi: 10.1038/srep00963.
[27] Z. Yu, G. Yang, S. Zuo, G. Jørgensen, M. Koga, and H. Vejre, "Critical review on the cooling effect of urban blue-green space: A threshold-size perspective," *Urban For Urban Green*, vol. 49, p. 126630, Mar. 2020, doi: 10.1016/j.ufug.2020.126630.
[28] G. Yang, Z. Yu, G. Jørgensen, and H. Vejre, "How can urban blue-green space be planned for climate adaption in high-latitude cities? A seasonal perspective," *Sustain Cities Soc*, vol. 53, Feb. 2020, doi: 10.1016/J.SCS.2019.101932.
[29] T. S. Eisenman *et al.*, "Urban trees, air quality, and asthma: An interdisciplinary review," *Landsc Urban Plan*, vol. 187, pp. 47–59, Jul. 2019, doi: 10.1016/J.LANDURBPLAN.2019.02.010.
[30] J. Vieira *et al.*, "Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks," *Environ Res*, vol. 160, pp. 306–313, Jan. 2018, doi: 10.1016/J.ENVRES.2017.10.006.
[31] T. Mexia *et al.*, "Ecosystem services: Urban parks under a magnifying glass," *Environ Res*, vol. 160, pp. 469–478, Jan. 2018, doi: 10.1016/J.ENVRES.2017.10.023.
[32] R. Berndtsson *et al.*, "Drivers of changing urban flood risk: A framework for action," *J Environ Manage*, vol. 240, pp. 47–56, Jun. 2019, doi: 10.1016/J.JENVMAN.2019.03.094.
[33] L. Prudencio and S. E. Null, "Stormwater management and ecosystem services: A review," *Environmental Research Letters*, vol. 13, no. 3, Mar. 2018, doi: 10.1088/1748-9326/AAA81A.
[34] K. Krauze and I. Wagner, "From classical water-ecosystem theories to nature-based solutions — Contextualizing nature-based solutions for sustainable city," *Science of the Total Environment*, vol. 655, pp. 697–706, Mar. 2019, doi: 10.1016/J.SCITOTENV.2018.11.187.
[35] K. Hayhoe, "Saving us: a climate scientist's case for hope and healing in a divided world," p. 307, 2021.
[36] Climate Watch, "CO2 emissions (metric tons per capita) - Denmark | Data," *The World Bank*. https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?locations=DK (accessed Jun. 01, 2023).
[37] DMI, "Klimaatlas Kommuner Aalborg," 2022. https://www.dmi.dk/klima-atlas/data-i-klimaatlas/ (accessed Jun. 02, 2023).

[38] "Digital local plans in Aalborg Municipality." https://www.niras.dk/projekter/digitale-lokalplaner-i-aalborg-kommune/ (accessed May 12, 2023).
[39] J. Sörensen, A. S. Persson, and J. A. Olsson, "A data management framework for strategic urban planning using blue-green infrastructure," *J Environ Manage*, vol. 299, p. 113658, Dec. 2021, doi: 10.1016/J.JENVMAN.2021.113658.